
TAXONOMY IN ENVIRONMENT & BIOLOGY

ZOOLOGICAL SURVEY OF INDIA

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Edited by
Director, Zoological Survey of India



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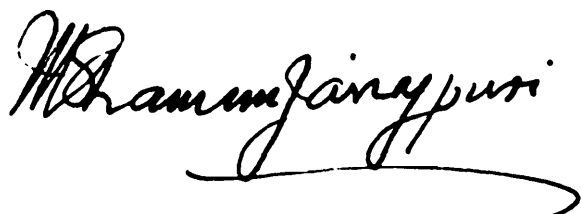
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Preface

Man does not live in isolation on this planet but interacts with other living organisms. It was therefore quite natural to take interest in the animals co-habiting with him. With the dawn of civilization the interest increased considerably, thanks mainly to the philosopher-naturalist, Aristotle and in later years to Linneaus, Darwin and a few others. It was mainly due to their contributions that the study of animal distribution, identification, description and classification came to be recognised as an important branch of biology called taxonomy. During the 18th and 19th century and even up to the early part of the 20th century taxonomic research formed the major chunk of research in Zoology, but the increasing interest in the experimental and applied research in biology in the last 3 or 4 decades has unfortunately and unnecessarily led to a gradual eclipse of taxonomy. The taxonomists are now finding it very difficult to get employment on the basis of their expertise. The universities and research institutes which had excelled in taxonomy in the past have began losing interest in this field of study. This is tragic as knowledge of taxonomy is indispensable for study on biological diversity, environmental management programmes, utilisation, conservation of animal wealth, etc.

The Zoological Survey of India as a premier institute owes special responsibility for promoting taxonomy and setting trends and standards for taxonomic research in this country. The 75th or the Platinum Jubilee year of this Survey has fortunately provided us an opportunity to organise a symposium so as to focus attention on the relevance of taxonomy in environmental management and modern biology. Leading taxonomists of the country including those involved in research on biological diversity, ecology and environment management programmes have been invited to this symposium and given topics, depending upon their expertise, on which they will speak. It has been quite often that outcome of extremely well organised symposia or seminars can go waste if these are not properly documented for posterity. Many a time the organisers do make sincere efforts to publish the proceedings but invariably due to situations beyond their control these get inordinately delayed as much of the enthusiasm and interest is usually lost once the seminar is over. In order to overcome these foreseeable problems we requested the participants to provide us well in advance a write-up of their lecture for the symposium. We record our gratefulness to each one of them for their positive response. This has enabled us to bring out the present book and release it at the time of the symposium.

The main thrust of the symposium is to highlight the importance of taxonomy in environmental and biological research programmes, but some articles on general taxonomy and methodology have also been included. A perusal of the book would undoubtedly reveal that it is one of the best efforts that has been made in recent years to defend taxonomy, bring to the fore its multifaceted and dynamic nature, and to impress upon the modern biologists its value in research programmes. It has not been an easy job to collect, edit and print these papers within the very short time that was at our disposal. In this endeavour, I received tremendous support and assistance from Drs. J. R. B. Alfred, V. C. Agrawal, and N. V. Subba Rao. The help rendered by Drs. A. K. Ghosh, R. K. Varshney, R. P. Mukherjee, G. K. Srivastava, M. Hazfeezeullah, Q. H. Baqri and C. B. Srivastava is also acknowledged with thanks. I greatly appreciate the efforts of our Publication and Production Officer, Shri G. Sivagurunathan who worked very hard to bring out this book. We are very grateful to the Ministry of Environment and Forests and in particular to Shri Mahesh Prasad, Secretary to the Govt. of India, and Shri A. K. Narayanan, Director (CS) for the financial and moral support in organizing this symposium. I sincerely hope that this book with its rich collection of valuable articles by leading biologists of the country will be of immense value to students, teachers and researchers not only for taxonomy but for all related areas of biology.



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Editor

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Taxonomy in Environmental Management and Modern Biology : An Overview

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We are in the last decade of the 20th century and are marching ahead with confidence into the 21st. This situation is largely due to the highly significant advances that have been made in science and technology after the Second World War, but more particularly during the last 2 or 3 decades. Blessed with the superior brain power and intellect we have acquired a dominion over the Earth, have successfully landed on the moon and are now exploring new horizons in space. Our fight to conquer diseases, hunger and death through highly significant advances in the medical, veterinary and agricultural sciences is continuing. This century has seen the phenomenal rise of physical, chemical and mathematical sciences but the next will most likely belong to biological sciences. It is expected that many marvels and mysteries of the animal and plant life will be unravelled during this period. In this fast changing scenario, the genetic engineers are promising to repair and remove all kinds of genetic disorders, develop new crop varieties with in-built pesticide producing mechanisms, while some enthusiastic scientists are even threatening to produce made to order forms of life including possibly the human beings and others are busy in creating life in the laboratories. The expanding horizons of our knowledge are no doubt a joy for the whole of humanity but we should not forget that all these recent advancements have come by gradually rising step by step on the foundations of fundamental or basic sciences. Blinded by the glitter of advancements in science and technology many people feel that the basic sciences have lost their relevance and should better be forgotten or abandoned altogether. *Taxonomy, the science of identification, description and classification of animals*, as well as plants, is one such discipline whose utility in the present-day context has been questioned time and again. The very purpose of this symposium is to provide a befitting answer to such questions or doubts by highlighting its importance so that taxonomy finds its proper place and gets due recognition.

The 17th and 18th century saw many European countries vying with each other to build their empire in different parts of the world. As a consequence, there was an unprecedented spurt in travelling and voyages of discoveries. New areas of the world were explored, their fauna and flora collected and brought

mostly to Europe for study. In addition some naturalists went on explorations themselves. These trends continued well into the early 20th century. During this time Zoological research was, for all practical purposes, synonymous with taxonomic research and new species of animals were collected, named and described at an amazing rate. Things slowly began changing from the early 20th century as interest in the experimental aspects of life sciences began to develop gradually but noticeably.

The Zoological Survey of India has been in the fore-front of taxonomic research since its inception in 1916 as its main task is the assessment and exploration of the faunal wealth of the country. Besides the ZSI, the taxonomic studies also flourished in Indian universities and in research institutes like the Indian Agricultural Research Institute, Forest Research Institute, etc. However, with the break-through taking place in experimental biology, it was quite natural that emphasis gradually shifted from taxonomy to other areas of research such as physiology, ecology, biology, developmental biology, genetics, molecular biology, etc., and now more recently to biotechnology. Perhaps, to a budding biologist the field of taxonomy based on the study of the structure of dead and preserved animals appeared hopelessly old-fashioned, a rather dry and static field of study, offering very little scope and fascination for research and involving considerable waste of time. It was therefore no wonder when Constance (1964) said that organisms are merely *containers* within which interesting physio-chemical processes are taking place, and only the latter are worthy of any serious kind of study. There cannot be two opinions that the progress made in the sphere of modern biology and bio-technology, and the promise that it holds for the future advancement of humanity is a matter of great satisfaction, but in the process many fundamental areas of research including those of taxonomy have unnecessarily and unfortunately been side-tracked and almost abandoned. In universities, not many students now dare to offer taxonomy as a field of specialization, obviously due to lack of job opportunities, but also because of some kind of an inferiority complex which has come to be associated with this branch. Taxonomy is also being deleted or perhaps, has already been deleted from the zoology curricula of many universities. It is unfortunate that this is being done without proper understanding of the relevance of this subject:

It has to be understood and appreciated that the decline of fundamental and basic sciences shall not continue for long as many countries of the world are now not only encouraging these aspects by allowing them to flourish and expand for a more balanced growth and development of scientific research. It appears that taxonomy too may now gradually but surely bounce back into prominence and ironically the experimental sciences that had brought about its downfall may lead to its revival. The concept of *New Systematics* (Huxley, 1940) is at last finding respect and acceptance and is providing a fresh lease of life to taxonomic research, giving a new direction to taxonomists and leading to incorporation of taxonomy as an integral part of many research programmes. The application of new techniques developed in the chemical, physical and mathematical sciences

is likely to make taxonomy an exciting and more challenging field of study with potentials to reach new and unexplored horizons. The use of *new tools*—scanning and transmission electron microscopes, *modern techniques*—histochemical, biochemical and immunological and *new approaches*—ecological, biological and physiological will perhaps give a measure of confidence to taxonomists and will earn respectability for this field of study (Willmott, 1979).

Much like in some other disciplines, the initial break-through in zoology was made by the taxonomists, experimental and applied zoologists came to the scene only later and widened the area of work further. As has happened so often in other fields too, very soon the latter group of scientists began to raise doubts about the utility of taxonomic research. India is no exception to this well-known global tendency that has caused severe discouragement to the taxonomists and it has been responsible for serious set-backs in the growth and expansion of taxonomy (Jairajpuri, 1988). *Neither taxonomy nor taxonomists are redundant.* On the contrary, as will become evident during this symposium, both have a very special role to play in the the overall development of zoology. The knowledge of taxonomy is essential for the study of biological diversity, management of environmental programmes involving both sustainable utilisation and conservation of faunal wealth, pest and parasite management, biological control programmes, pollution management, etc., etc. A few of these aspects will be taken up briefly in the present paper while the remaining aspects, it is hoped, will come up for presentation and discussion by other scientists.

Evolution, Biological Diversity and Taxonomy

In order to understand the relationship between evolution, biological diversity and taxonomy it would be of interest to first take a look at the origin of life itself and the mechanism by which Nature is able to maintain an equilibrium thereby assuring its continuity. It is to be kept in mind that Nature has a *make and break* system, be it an individual or a species. We call this *life and death* when individuals are concerned, and *evolution and extinction* in case of species. Further, the various components of Nature are *counter-balanced* to maintain an equilibrium e.g., predator and prey. This is to ensure *Nature's great recycling process as matter can neither be created nor destroyed, but only changes its form.*

The early forms of life which evolved on this living planet were capable of making their own food and this had to be counter-balanced by organisms which fed on the former as Nature could not sustain only the producers for a very long time. So from the very beginning the dependence of one kind of life on the other or *interaction*, became an essential part of Nature's strategy and it was on this principle that the future organisms gradually evolved and the various ecosystems slowly developed. Plants being the primary producers, had to be sessile, so that they would remain fixed to the ground from which they could derive their nutrition. The animals on the other hand could not manage without

locomotory ability as they had to search for food. In other words, both forms of life could neither be locomotory at the same time nor sessile. If they were, they would not counter-balance each other. The same is true of utilization of carbon dioxide by plants in photosynthesis and the resultant release of oxygen which is used by animals in respiration and the cycle goes on and on. The ability of the plant life to carry out photosynthesis was one of the very important, perhaps the most crucial landmarks in the evolution of life forms as it made free oxygen available to the environment. This paved the way for the development of aerobic organisms. The oxygen, high in the air, got converted into *ozone* by the action of sunlight and formed a layer. This layer began filtering out most of the *ultra-violet rays* in the sunlight thereby making the land and air safe for life to emerge from the sea for living on land. The sea waters had been acting so far as protective shield saving the sea life from destructive ultra-violet rays. The environment, thus has played a decisive role in the evolution and diversification of organisms, be these animals or plants, and it is because of environmental stress that they have changed gradually, generation after generation.

Evolution based on the Darwin's concept of *survival of the fittest* through *Natural Selection* has, slowly but surely, produced myriads of forms (species) of animal and plant life, existing in every nook and corner of this living planet in the varied kinds of ecosystems. These are all adapted structurally, physiologically, biologically, etc., to the habitats in which they are found and interact with the biotic and abiotic environment around them. This is Nature's curious *Web of life* which binds all living beings to one another and proves further that every species which dwells on this planet has got a definite reason or purpose for its existence and each is important in its own ways no matter how small or insignificant its physical appearance may be. We can infer from this that no species should be considered in isolation, since *the extinction of one species may threaten the existence of several others* which are linked with it ecologically and these could also become extinct in due course of time if they fail to adjust themselves physiologically and otherwise.

The principle of dependence, directly or indirectly, of living organisms on one another need not be either elaborated or stressed any further. To know and understand biological diversity, be it for the purposes of their *sustainable utilisation* for the sake of humanity or for their conservation it has to be studied. The very first step in this direction would be to *identify and name* them (inventorisation); *describe* them, if need be, so that others, as and when they come across that species face no difficulty in its identification; and *classify* them so that the information is properly systematized. All these activities are nothing but *taxonomy* as has already been defined earlier.

Only about one million species of animals are presently known to us but it is estimated that the exact number could be as high as ten to twenty millions or even more. Our ignorance therefore in this field is quite evident. For instance, we do not know the actual extent of diversity among the soil micro-organisms as also

in the aquatic habitats. Further, quite a number of the known species are already under the threat of extinction, largely due to human activity, like habitat destruction, pollution, etc. If we do not accomplish the taxonomic studies quickly, we may lose some of these species for ever and no amount of human technology and skill will be able to bring them back, once the valuable genetic diversity is lost. But how are we supposed to accomplish this stupendous task when there are not many taxonomists around and taxonomic research is going down hill ? As has been stressed earlier, the universities in India are gradually backing out from this kind of research and the Zoological Survey of India will find it very difficult to carry out this task single-handedly with the kind of available resources at its command. It may be pointed out here that India is one of the richest areas of the world in animal life. Moreover, the ZSI is a purely research organisation and all its scientists come from the universities which are no longer encouraging taxonomy and are not producing as many taxonomists as in the past. From where will the ZSI or similar organisations get trained persons in place of those retiring or for its various expansion programmes ? It seems we have gone wrong somewhere in fixing our priorities in biological research. While it was natural for any young scientist to be attracted to the newly emerging areas in biology and biotechnology, was there any reason to cold-shoulder research in taxonomy and morphology ? In fact it was a folly and we seem to have followed the Western countries in this trend, but they are already retracing their steps now and giving full encouragement to taxonomy in spite of the fact that animal and plant genetic diversity in their countries is far less than in India. The wrong trend of ignoring taxonomy that has unfortunately developed in our country, is to be arrested and we have to retrace our steps and move in the right direction. We would only then perhaps be in a position to fully understand the tremendous biological diversity that Nature has bestowed upon us and enjoy its fruits. It may not be out of place to mention here that the Committee on Research Priorities in Tropical Biology of the National Academy of Sciences of the U.S.A. has estimated and desired *a five-fold increase in the number of taxonomists* over and above the present 1,500 trained professional taxonomists so as to be able to identify and describe a significant proportion of the diversity still existing, particularly in the tropical forests.

The problems confronting taxonomists may perhaps be judged from the fact that even with a limited number of specialists in the field of taxonomy, some 13,000 new animal species and 1,000 new subspecies are described, about 2,000 new genera and subgenera are proposed, and some 25,000 nomenclatorial changes are made every year (Goto, 1982). Mayr(1969) had estimated that about 99% of all the birds are now known and that nearly 90% of mammals and reptiles are supposed to have been discovered, but only about 5% of nematode species, 10% of marine invertebrates and some 25-30% species of insects are known to the Science. So most of the unknown, undescribed species belong to these groups, though occasionally new species, even of mammals, are found. For instance, in 1973 a new marsupial mouse belonging to the family Dasyuridae was discovered in South

Australia. This year (1990) a new species of lion-tamarin, a squirrel-sized monkey with a lion-like mane has been found to occur on a small, forested island off the coasts of Sao Paulo (Brazil), one of the world's largest and busiest cities. This is considered the most amazing primatological discovery of the century as it comes from an area which is so urbanized and developed. It is predicted that another new species of mammal may not be discovered until 15-20 years are elapsed. Similarly, it may be difficult to get new species of other vertebrate groups also, and for the birds it is almost impossible. The majority of new species will therefore come from invertebrates, particularly those belonging to Insecta, Nematoda, Protozoa, etc. It is a fact that these groups, particularly the last two, are very poorly known and their full potential in relation to man is yet to be understood. It also shows how little we know about our animal life and how much we stand to lose before we even know what is there.

Ecological Balance

No doubt evolution has led to vast biological diversity, as is seen in the world today or as it existed in the past ages. Along with biological diversity there also exists diversity in the ecosystems as evolutionary changes in the living organisms are brought about largely to meet environmental (habitat) requirements. The earth with its arctic, temperate, sub-tropical and tropical climates has many different kinds of ecosystems like the frozen continent of Antarctica, and North Pole, mountains, valleys, lush green forests both in the temperate and tropical zones, deserts, plains, vast oceans, seas, rivers, lakes, lagoons, grasslands, etc., etc. Each of these have a very large number of different species of animals and plants in their most luxuriant forms and shapes. Some habitats which were earlier considered inhospitable (very deep zones of oceans, extremely cold zones of the world, etc.) and rather unsuitable for life forms have now revealed bizarre species living there comfortably. It may not be out of place to mention here that *animal life is more variable than that of plants*. The reasons for this are not very difficult to visualize. Animals have to depend on plants for food directly or indirectly, and this has cost them rather dearly in terms of energy utilization as they need locomotory, nervous, sensory and other supporting mechanisms for food hunting. As such, they have developed greater adaptability leading to tremendous diversity. Plants on the other hand, by remaining rooted and fixed to the ground do not require much of these paraphernalia and are able to produce far more energy than required thereby allowing some species, particularly of higher plants, to grow to huge, often gigantic sizes. Compared to this, the largest present day land-dwelling animal species is that of elephants and the largest aquatic species is that of blue whales. Besides extensive energy requirements of large-sized animals their movement is also a problem.

Observations on the *ecology* (relationship of individuals/species to their environment/habitat) form an integral part of taxonomic studies. It has also been stressed earlier that the *animals are shaped by their environment* (both abiotic and biotic) and the selection processes operate to evolve/develop more and more

adaptability to their habitat. So much so that seasoned taxonomists with their vast experience and knowledge of animal species distribution (zoogeography) may very well be able to predict, to some degree of accuracy, the fauna of any particular kind of habitat or conversely may deduce the habitat from which a particular type of fauna has been collected. This knowledge has sometimes proved useful in identifying certain species as indicators of particular kind and characteristics of a habitat. Such species called *Biological indicators*, help in determining the condition of an ecosystem and are very useful in pollution studies and its management. Adaptability of a species to an ecosystem does not mean that it will fail to survive if the habitat changes. In fact, most ecosystems undergo some kind of changes throughout the year due to seasonal fluctuations and the animal species are adapted to these changes. However, there is always a *tolerance limit* which varies from group to group and species to species of animals. Species with a narrow range of tolerance are unlikely to spread to new areas as they may not survive sudden changes in the environment. But species which can colonise new habitats because of their wider tolerance limit are likely to have a longer evolutionary future. The changes in habitat, if very sudden and vital, falling well beyond the threshold levels of a species (e.g., fish out of water) will cause its imminent death but within limits, the species will survive by making suitable structural and physiological adjustments which may be referred to as *developmental flexibility*. The above also explains why the era of great reptiles, the dinosaurs came to an abrupt end. Most probably it was due to a sharp rise in the atmospheric radiation and temperatures which went beyond the level of tolerance of these creatures. The subsequent evolution of reptiles into birds and mammals, however, provided more adaptability to the latter groups as compared to their ancestors because of their becoming homotherms.

Since habitat is so important for organisms, Nature must maintain an *ecological balance* between its various components. How this can be achieved is a vital question and its various aspects require in-depth consideration? Any imbalance in the environment, natural or artificial, would be disastrous, leading to faunal loss or eventual disappearance. The latter aspects are not only significant from the *biological* point of view but are also very important from *taxonomic* point of view. Species of animals and plants co-exist and interact with other species forming a *community*. Species in such a community are held together by their *feeding interactions*, similar environmental requirements and dependence on one another. A change in the ecology of any community usually effects the entire community as it may lead to the breaking up of the delicately balanced food chain. The single most important factor in maintaining the equilibrium is the *constancy of population* levels of all species. The rise or fall of the population density of species, other than due to natural causes may lead to ecological imbalances possibly affecting other components of the ecosystem as well. Nature takes special care through the reproductive processes of the living beings to replace individuals and thereby maintaining an ecological balance.

At this juncture, it might be interesting to look into the phenomenon of *life and*

death in the context of the ecological balance of an ecosystem. The death of living individuals of a species, sooner or later, depending upon their life span, is inevitable because of ageing, disease, accident, wear and tear of their body organs in performing various life activities, etc. From an ecological and evolutionary point of view, *death is an essential fact of life and is useful for the survival of ecosystem* as it makes available the organic material of the dead body for the recycling process and its subsequent utilisation in the food chain. In other words, our bodies are Nature's *fixed deposit* that will be made available to it at some point of time, to be *spent* for other purposes. *So unless the death takes place life wont blossom.* Nature has indeed taken a very special care in producing life forms and as such the reproductive system happens to be the most important system of an animal's body. If the chain of *life-death-life* does not go on infinitely the evolutionary processes, in particular the Natural Selection, can not operate. *Every succeeding generation ought to be better adapted than the preceding one to the slowly but surely an ever-changing environment.* In other words each generation of a species is suitable only for a particular period (span) at a given point of time (geological time scale) after which it must perish and yield place to a new generation. An inverse relationship between fecundity of a species and its *life span* is also quite evident. *The shorter the life span (age) of individuals of a species the greater is their reproductive rate and vice versa.*

The parasite(s) are so well adapted and physiologically dependent on their host(s) that the two evolve together in *co-evolution*. One of the best examples of this phenomenon is species of body louse, Mallophaga parasitising birds. Some difficult taxonomic problems of relationships of their host species have been solved by studying the mallophagan parasites and vice versa. Though co-evolution may be strikingly evident in the host-parasite system, the geological records, if carefully examined, would reveal that the entire biotic ecosystem and all its component species also evolve together but at varying paces. If during the process of *ecosystem co-evolution*, any species goes into extinction all those which are vitally linked with it will be affected by the loss and shall have to develop some kind of physiological adaptability in order to compensate for this loss. Those species which fail to do so may first become endangered or threatened and then gradually, in course of time, move towards extinction.

The intimate relationship between the animal and plant life with their ecosystem shows that *taxonomy* of life forms is so very vital for all kinds of habitat management, be it Biosphere Reserve, National Park, Sanctuary, Wetland, etc., or any problem concerning Eco-restoration or Eco-regeneration. No Environmental Monitoring Programme can be successfully handled without full knowledge of its animal component.

Parasites and Pests

Parasites occur in all ecosystems and play an important role in the population balance of their host species. Purely from an ecological point of view the

parasites are not harmful to mankind, livestock, wildlife, etc., but they have become so because of our own activities. To a large extent *human beings themselves are responsible for spreading parasitic diseases*. The destruction of natural ecosystems and their transformation into man-made artificial ecosystems coupled with exponential rise in human population is believed to have caused spurt in parasitic diseases and has created many pest problems. The habitat destruction is usually detrimental to many existing species of the biotic community whose populations gradually decline and ultimately disappear yielding their place either to the rising populations of the surviving species or to those species which previously did not occur in that environment but have migrated from other localities to utilise the niche. Naturally some species which thrived in this changed ecosystem may be parasites which will attack other species. A gradual build up of these parasitic species will seriously affect the survival of the host species and if the damage exceeds economic threshold level, these become *pests*.

Management of parasites and pests, which interfere with human welfare, is extremely important be these insects, nematodes, fungi, bacteria, viruses or others. The first step which is of prime importance in all management programmes is the correct identity of the causative organisms. Quite often it so happens that large sums of money and research time and efforts go totally waste if the species of the parasite is incorrectly identified. The identifications serve as focal points around which informations accumulate, and if these gather round an incorrectly identified name then much of the research data become entirely useless and misleading. This knowledge is useful in various control measures against pests and parasites, advisory service, quarantine or biological control programmes pertaining to the fields of entomology, nematology, plant pathology, etc. The taxonomic studies thus provide invaluable data on species of parasites and pests not only for their correct identity but also on their distribution, hosts and interacting organisms.

Species

In taxonomic hierarchy, the *species* occupies the lowest, but most important position. In fact only species actually exist in Nature, the others (Phylum, Class, Order, Family, Genus, etc.) above the species are man-made categories for the purpose of facilitating taxonomic study and classification. Species are therefore rightly regarded by taxonomists as the building blocks of Animal Kingdom and are defined as *groups of interbreeding natural populations with similar genotype and which are reproductively isolated from other such groups*. In practice, however, species are generally characterized for their structural (i.e., *phenetic* or morphological) similarities rather than their biological characteristics or the genetic make-up. It may be stressed here that the *species represent only a temporary phase of a genetic lineage*. How temporary that phase will be, only the adaptability of the species and the stability of its environment can determine. The species has the possibility to either *continue* as the same species

infinitely (e.g., fossil fish, king crab) or *evolve* into another stock (species) at the same level of organisation (e.g., one species of Protozoa evolving into another species of Protozoa), or *evolve* into a species with higher grade or organization, or perish due to the onslaught of environment (*extinction*).

The structure represents only one aspect of the multi-facet, dynamic and ever-evolving characteristic of a species. The latter is, in fact, also unique in its embryology, ecology, ethology, physiology, serology, etc. Though informations on all aspects are desirable to define the species in its totality, the complexity of the techniques involved, number of specimens needed, and above all the amount of time required put obvious difficulties in the way of determining these factors. Further, taxonomists usually have only the possibility of studying dead and preserved specimens and just can not observe the above mentioned characteristics. For all practical purposes structure therefore remains the only aspect that can be taken into the consideration and studied. But the direct and intimate relationship between the structure and genetic constitution is proved beyond doubt by the example of identical twins which possess identical genotype and same looks or appearance (i.e., structure). The conclusions drawn from the study of morphology, if the same is done with care and in-depth, are quite sufficient to define a species properly. To be able to successfully serve our purpose, *taxonomy* in fact, *should be based on simplicity and not complexity* and should be able to provide quick information retrieval with minimum possible material and time (Jairajpuri, 1988).

In applying morphological criteria for species *definition*, one has to be very cautious as *variability* is to be taken into the consideration. Too narrow an approach may lead to *splitting* of species, but its reverse would result into unnecessarily *lumping* together of distinctly separate species. Both these situations would lead to *synonymies* which often create irritation among non-taxonomists because of frequent nomenclatorial changes. Perhaps due to this reason many biologists have remarked that *taxonomy is more of an art than science*. Whether this is right or wrong is another matter, but we taxonomists have to share some blame for the decline of this subject. If taxonomy has to become an integral part of modern biology, a lot of experience, patience, thought, intelligence and hard-work must go into the studies. Otherwise like an endangered or threatened species it will ultimately lose its touch with time and would become extinct.

Artificial Selection

The evolution through Natural Selection progresses generation after generation in a species and is a very slow process. It can only be inferred or presumed to have taken place and can not be observed as taking place in a species during the life time of a biologist who may be interested in such a study. However, a few examples will give some clue to the phenomenon of selection though these are artificial rather than natural. The common species of dog has

many so-called varieties which have been developed through inbreeding generation after generation, from the same stock but for different characters. Inbreeding genetic variable for a number of generations may lead to the production of these varieties which will be structurally and to some extent behaviourally different from one another though still belonging to the same species. The existence of different races in human beings are also good examples of genetic distinctness maintained largely due to inbreeding within these races. Each race is variable from the other but still genetically compatible. The rather rigid inbreeding practised by certain castes, sects, etc., reflects a desire on their part to keep gene pool protected and the identity maintained. But the inbreeding has its own advantages and disadvantages. For instance, in certain tribes practising intensive inbreeding (e.g., Todas) or forced inbreeding due to lack of opportunities (e.g., Sentinels), it may result into their eventual extinction primarily due to a very limited gene flow.

The knowledge and technology arising out of artificial selection is based primarily on the theory and principles of evolution and taxonomy. It has proved very useful and highly successful in developing new varieties or strains of animals and plant species, be it for the purposes of milk or meat production, better quality grain production, breeding for resistance, etc.

Hybridization

Species as defined above are genetically distinct entities which interbreed amongst themselves but are reproductively isolated from others. A reproductive barrier, even between two very closely related species, exists because of an *isolating mechanism* (genetic incompatibility). This mechanism helps in protecting the integrity, distinctiveness and characteristics of species. Interbreeding is only possible among individuals belonging to the opposite sexes of the same species because of the presence of male-female *recognition mechanism* (Lambert *et al.*, 1897). In simple words it may be said that males and females of a species only recognize each other for reproductive purposes either through their visual or non-visual modalities (sex attractants, pheromones, etc.). Cross attraction between taxa at various levels is possible, though extremely rare. It may not necessarily lead to mating, and if it does, the genetic incompatibility (isolating mechanism) would prevent fusion of gametes and formation of an offspring. However, in spite of these protective mechanisms it is sometimes possible to cut across all such barriers and produce, between two closely related species, an offspring (*hybrid*) with characters common to both (e.g., mule, tigon, liger, etc.). Hybridization is extremely rare in Nature but can possibly be induced experimentally/artificially in the laboratory. The hybrids generally fail to produce their own offsprings because of reproductive impotence, and hence are of little value in animals but in plants, as further propagation is possible through vegetative methods, its value and utility may be great. Much like artificial selection, hybridization is also very useful in producing artificial genetic lineage for desired characters in breeding programmes.

Both artificial selection and hybridization are based mainly on evolutionary genetics and the biologists involved in this kind of research programmes should have adequate knowledge of the principles of *taxonomy* and species concept. It would be relevant to mention here that when *varieties, breeds, hybrids*, etc., produced as a result of artificial selection and hybridization, are allowed to compete in Nature, they sometime lose their selected and hybrid characters after a few generations and succumb possibly to the environment-mediate Natural Selection processes.

Genetics and Genetic Engineering

Taxonomy is intimately linked to Genetics, the science of inheritance. The definition of a species itself would be rather incomplete and in fact meaningless without the mention of the genotypic similarity and its identity, which is primarily responsible for interbreeding among the individuals of the same species belonging to opposite sexes and their reproductive isolation with individuals of the other species. Taxonomy which was initiated by Aristotle came to be regarded as a distinct and important branch of biology because of the subsequent outstanding work of Linnaeus which was later strengthened by Darwin's theory of evolution. But even they could not understand the real mechanism of inheritance of characters and it was left to Mendel to provide the answer. *Taxonomy and Genetics are thus complimentary to each other* and a good taxonomist must have an adequate knowledge of the mechanism of inheritance and vice versa.

It would not be stretching the imagination too far to mention here that genetic engineering which is a fast emerging branch of modern biology, to some extent, has its roots in the principles of taxonomy. As mentioned earlier, each species has a similar, but not exactly identical genotype, as every individual differs a little bit in its genetic constitution due to variations. Some of these variable characters may be useful while others could be harmful. Through genetic engineering, the genes for defective characters may be replaced by those having useful ones. The genetic engineering, though still in its infancy, is likely to be of immense value, in times to come, in getting rid of many hereditary diseases and also in introducing genes for desired characters for the correction, improvement and repair of genetic material (genotype). This is a great break-through in the human history, as this technology has potentials to make altogether new genotype leading perhaps to the creation of new kinds of animals and plants. However, *the new technology is fraught with very serious social and environmental problems and could become more devastating for humanity than the nuclear technology, if not handled properly and allowed to go unchecked.* Further, a question-mark shall always be there as to the survival of the laboratory-bred 'made to order' life forms in Nature.

A close look at Nature's mechanism of sexual reproduction reveals that in reality it is itself based on sophisticated genetic engineering right from the time

sex evolved in animals. The genetic material comes from two sources (male and female) and usually the dominant characters make their appearance in the phenotype. Further, the weaker individuals of the population are weeded out through Natural selection under the impact of environment. Continuing improvement in the genetic material is therefore, taking place already in Nature, we have just expanded its scope by introducing artificial manipulation and coined the name, genetic engineering. In human society, the selection of bride/bridegroom, either by the parents or by the couple themselves, consciously or unconsciously, is also based on the basic idea of genome improvement.

In controlling pests and parasites the practice of using resistant varieties in place of susceptible ones is quite common these days. The resistant varieties are artificially bred either by selection, hybridization or genetic engineering. To begin with, the majority of pathogens (pests and parasites) are unable to feed on the new variety of host because of physiological incompatibility. It is, however, frequently been observed that the pathogens are able to break the resistance only after a few successive generations. Within their populations, there are always some individuals (variants) which can overcome this physiological barrier and are able to feed upon the host (resistant variety). It is these variants which multiply in the future generations and others which are physiologically incompatible are gradually eliminated. So, it may be seen that initially *Man outsmarts the pathogens by using resistant variety but ultimately the pathogens are able to outsmart Man by breaking the resistant factor*. This kind of battle will go on and on as Man will attempt to breed yet another resistant variety with a different type of resistant factor and the pathogens will make renewed efforts to overcome this as well. This is an interesting example of *artificial (Man-made) genetic engineering* for the host *vs Nature's genetic engineering* operating upon the pests and parasites.

Conclusion

As would be evident from the above, *taxonomy* contrary to the understanding of some biologist, does not merely deal with the collection and identification of specimens, but it is a dynamic, multifaceted discipline with its roots in almost all areas of modern biology. It has quite inappropriately been regarded as a dry, stereotypic and a routine branch of study which does not offer much to a modern day biologist. Some people even compare taxonomic work with mere stamp collecting and regard taxonomists as stamp collectors. This is obviously not true because taxonomy is highly specialized, thought-provoking and a challenging field of study. It is historical in approach and an unbroken link is to be maintained with the work done in the past and nothing published anywhere in the world, can be ignored. The correct identification of animal species and their placement in the existing system of classification is a *specialist's job* requiring a high level of training, experience, and constant up-dating of knowledge and improvement in methodology. The *taxonomy is complimentary and not contradictory to the experimental or applied biology* (Jairajpuri, 1989). It is quite

a common experience that biologists with basic background of taxonomy can switch-over, with ease, to any type of research on environment or biology, but the reverse of this is extremely rare. Any research programme in biological sciences can not take off successfully unless the taxonomy of the species or group of species involved is properly understood. Be it the study of fauna or animal diversity, their distribution and inter-relationship or any problem related to ecology including pollution control, biology, behaviour, developmental biology, genetics, pest management or exploitation and conservation of biological resources, etc., the knowledge of taxonomy of the animal species involved is a must for the successful implementation of all these programmes. *Taxonomy, therefore, deserves full backing, support and encouragement from all shades of biologists so that it attains its proper place in the biological sciences and blossoms into a discipline to which the students and researchers feel very proud in being associated with.*

References

- Constance, L. 1964. Systematic Botany : an unending synthesis. *Taxon*, 13 : 257-273.
- Goto, H.E. 1982. *Animal taxonomy*. Studies in Biology No. 143. Edward Arnold, U. K.
- Huxley, J.S. 1940. *The new systematics*. Oxford Univ. Press, London, U.K.
- Jairajpuri, M.S. 1988. Taxonomy of Nematodes. In : *Adv. in Plant Nematology*, 101-111. (Eds.) M.A. Maqbool *et al.* Natn. Nematology Res. Centre, Univ. Karachi, Pakistan.
- Jairajpuri, M.S. 1988. Identification of Nematodes in India. In : *Nematode Identification and Expert System Technology*, 237-243. (Ed.) R. Fortuner. Plenum Press, New York and London.
- Jairajpuri, M.S. 1989. Nematode taxonomy in India. In : *Nematode Pest Identification*, 20-25. (Ed.) M.S. Jairajpuri. Deptt. of Zool., AMU, Aligarh, India.
- Lambert, D.M., Michaux, B. & White, C.S. 1987. Are species self-defining ? *Syst. Zool.*, 36: 196-205.
- Mayr, E. 1969. *Principles of Systematic Zoology*. McGraw-Hill Book C., New York & London.
- Willmott, S. 1979. Systematics in Parasitology. *Systematic Parasitology*, 1 : 1-2.

Biological Diversity and Our Biofuture

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Biological diversity is the variety and variability among living organisms and the ecological complexes in which they occur. To assess the extent of genetic diversity occurring in the ecosystem, we will need detailed inventories of species and varieties. The committee on Research Priorities in Tropical Biology of the National Academy of Sciences of the United States has estimated that at least a 5-fold increase in the number of systematists (above the current estimated 1500 trained professional systematists competent to deal with any of the tropical organisms) will be necessary to deal with a significant proportion of the diversity still existing, particularly in tropical forests.

For convenience, many scientists assume that about 10 million species exist, although only about 1.5 million species have been described so far. Some estimate that the number of species on earth may be as high as 30 million. Some have gone even as far as 50 to 60 million. Our ignorance in this field is vast.

Currently, the number of species threatened with extinction has been estimated by the World Conservation Monitoring Centre at Cambridge, U.K., as follows:

	<i>Already extinct</i>	<i>Threatened Taxa</i>
Plants	384	19078
Fish	23	343
Amphibians	2	50
Reptiles	21	170
Invertebrates	98	1355
Birds	113	1037
Mammals	83	497
	-----	-----
Total	724	22530
	=====	=====

Even many animal and plant species not in immediate danger of extinction are suffering from declining populations and declining genetic variability due to a variety of causes.

Biological diversity is often referred to as a "Common human heritage". However, differences between developed and developing countries on methods of utilising this common heritage for common good are growing. Developing countries are rich in biological diversity, while industrialised countries are rich in biological technology essential for converting biological wealth into economic wealth. Unfortunately, informal innovation systems which constitute the very foundations of agricultural evolution and crop and farm animal germplasm resources are not given recognition in discussions on intellectual property rights.

It is in this context that discussion relating to Farmers' Rights (the informal innovation system) and to intellectual property rights at the General Agreement on Tariffs and Trade (GATT) discussions on Trade-related Intellectual Property issues (TRIPs), World Intellectual Property Organisation (WIPO), International Union for the Protection of New Varieties (UPOV), FAO and UNEP assume importance. *Any expansion of the scope of formal patent rights such as gene patenting and non-recognition of informal innovation systems will render the "common heritage" concept of biological diversity meaningless.*

A convention for the protection for informal innovation in plant and animal breeding is necessary to resolve this conflict. International co-operation in saving and sharing plant and animal genetic resources will increase if there is equity in sharing benefits.

The economic and ecological importance of genetic diversity will grow as we face new situations as for example those likely to arise from the accumulation of "greenhouse gases". According to the World Resources Institute, human activities added during 1987 the equivalent of 5.9 billion tonnes of carbon to the atmosphere. Of this 63 per cent was from carbon dioxide, 14 per cent from methane, and 24 per cent from chloroflourocarbons (CFCs).

WRI has standardised a method of determining "*The Greenhouse Index*", based on greenhouse gas net emissions in each country. According to this calculation, the United States with a greenhouse index of 1 billion tonnes of carbon equivalent contributed the largest share (17.6 per cent) in 1987. USSR, Brazil, China, India, Japan, Federal Republic of Germany and the United Kingdom followed in that order. India's contribution was 230 million tonnes of carbon equivalent in 1987.

The loss of every gene, species or ecosystem limits our options for the future. For example, the loss of mangrove species along the coast will render facing the problems likely to arise from ocean warming more difficult.

The full range of ecological processes and the species diversity of tropical forests can be maintained only if large undisturbed areas are established in

perpetuity for conservation. Yet only three per cent of the world's remaining tropical forests is legally protected. It is essential that some areas are maintained in their pristine purity to serve as nature's evolutionary laboratories where evolutionary mechanisms can continue to work uninterrupted. In India, we should maintain a minimum of 5 per cent of the geographical area in its pristine purity. In this context, the initiative of the President of Guyana in earmarking early 4,00,000 ha of Amazonian rain forest, partly for serving as a Wilderness Preserve and partly for developing sustainable management practices, is worthy of emulation.

The search for new genes will be possible only if we conserve biological diversity at the ecosystem, species and intra-specific levels. We cannot face successfully the growing threat to sustained agricultural advance arising from increasing biotic and abiotic stresses and diminishing land and water resources, if we do not protect our biological wealth.

National Strategy for the Conservation of Genetic Resources

Every country should prepare a national strategy for conserving its biological wealth through appropriate *in situ* and *ex situ* and *in vivo* and *in vitro* methods. Highest priority should go to the conservation of ecological and economic key species and to the animals and plants listed in the Red Data Books published by IUCN as well as National Conservation Monitoring Agencies. A priority task is to bring to a halt the further extinction of species and land races. Genetic species and ecosystem diversity needs to be preserved through an integrated action plan involving government and non-governmental organizations and professional institutions and universities. Appropriate bilateral and multilateral support-technical and financial - should be extended to countries needing such help both for developing and implementing an integrated genetic resources conservation strategy.

Establishment of Mechanism for Genetic Enhancement

Such work could be organized at suitable locations in the major centres of origin and diversification of farm animals and crop plants, using the system proposed by N.I. Vavilov for determining the centres of origin. Specially designated centres should help plant and animal breeders in developing countries to get breeding material possessing "candidate genes" for specific characters, particularly those conferring resistance/tolerance to biotic and abiotic stresses. A mechanism could be developed for this purpose by the International Centre for Genetic Engineering and Biotechnology sponsored by UNIDO, in collaboration with appropriate national/international research centres in developed and developing countries. Such an arrangement would help developing countries to derive speedy benefit from advances in recombinant DNA technologies. The collaborative network on Rice Biotechnology developed by the Rockefeller Foundation is a good example of the kind of symbiotic partnership that can be

fostered between scientists working in the forward edge of biotechnology and those engaged in practical rice breeding work. An appropriate blend of Mendelian and molecular genetics can be achieved through such research networks.

Institutional Structures

The Heads of State of government of seven major industrial nations and the President of the Commission of the European Communities in their communique issued on July 16, 1989, stressed, "the increasing complexity of the issues relating to the protection of the atmosphere calls for innovative solutions. New instruments may be contemplated" The participants of the first Keystone Dialogue on Plant Genetic Resources made several suggestions relating to the strengthening of institutional structures at the national, regional and global levels. The time has come for finding agreed formulae for the following purposes.

- a. Promoting the involvement of local communities in the conservation of genetic resources.
 - b. Achieving active cooperation among government agencies, universities, private and public sector industry and non-governmental organizations in tasks relating to the collection, conservation, classification and utilization of animal and plant genetic resources at the national, regional and international levels.
- and
- c. Coordination of measures for the conservation of biological diversity at the global level and implementation of appropriate international conventions. Division of responsibilities among UN organisations and other institutions will have to be worked out.

Looking Ahead : The Need for a Global Germplasm Ethic

We can now develop an integrated conservation strategy ranging from the *in situ* conservation of populations to conservation at the molecular level.

Biosphere reserves and national parks are becoming important instruments for the *in situ* conservation of biodiversity. The establishment of such biosphere reserves is particularly important in the main Vavilovian centres of origin. In November 1972, a convention for the Protection of the World's Cultural and Natural Heritage was adopted by the UNESCO General Conference. This convention provides the framework for international co-operation in conserving the world's outstanding natural gifts. IUCN has published an indicative inventory of natural sites of world heritage quality. The recent book 'Our World's Heritage' published by the National Geographic Society in 1987 provides a glimpse of the glorious natural and equally glorious, but occasionally hideous, man-made heritage we possess.

Plant and animal genetic conservation is unfortunately becoming an area of considerable controversy on the basis of ownership and patenting issues. What is urgently needed is a global germplasm ethic. While professionals and political leaders may quarrel, it is not surprising that in some of the world's less disturbed habitats indigenous tribal people as well as traditional farmers are practising a holistic germplasm ethic. Aldo Leopold, whose birth centenary fell during 1987, proposed a land ethic for the conservation, evaluation, and utilization of genetic resources of economic plants and animals for the purpose of increasing human happiness and welfare everywhere.

A global germplasm ethic should be based on the following foundations :

- (a) Germplasm conservation should start with the inhabitants of each agro-ecological area. For example, tribal societies, indigenous people, and forest dwellers should play a major role in the conservation of the biological endowments of the areas where they live.
- (b) Educational and research institutions in each area should take a leading role in generating public awareness and in developing effective monitoring and early warning systems to prevent the loss of valuable genetic material.
- (c) Every country should develop a national germplasm ethic to provide opportunities for all citizens to participate in the conservation of genetic resources and to share them with people everywhere for the common good. A national germplasm ethic should be backed up by appropriate *in situ* and *ex situ* conservation strategies.

Guidelines for the global germplasm ethic can be developed by UNESCO with the help of IUCN and other appropriate international conservation organizations. This will be a logical extension of the UNESCO Convention for the Protection of the World Cultural and Natural Heritage.

Preserving the Present

Nature (Vol. 345, page 465, 7, June, 1990) carries a report on the establishment of a *Centre for Genetic Resources and Heritage* (CGRH) at the University of Queensland, Australia. CGRH will be a "genetic louvre" and will conserve tissues, cells, isolated DNA and clonal gene libraries. CGRH will collect cells or DNA from Australia's most threatened species, such as the false water rat, one of the country's rarest mammals, and the short-necked swamp tortoise. On the occasion of its Platinum Jubilee, the Zoological Survey of India could consider establishing a *Centre for the Conservation of India's National Heritage in Animals*. This could specialise in developing a DNA Library of the genetic material of species under threat of extinction.

Oceanographic Research in India

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Human race has been depending largely on land resources for its welfare and survival. With intensive exploitation, the land resources are rapidly getting depleted and it is believed that with coming 25 to 30 years, many raw materials that are at present obtained from the land will be in acute short supply. Therefore, attention has been drawn towards the oceans which cover 71% of the earth. The oceans contain almost all the natural resources which the land offers. Since mankind will have to depend on the oceans for its survival, it is very necessary to give a considerable thought to planning and execution of ocean science and technology programme in the country.

For India, the Science of Oceanography is a young Science. It began in an organized fashion during the early sixties and in less than twenty-eight years, it has made spectacular progress. As time passes, our dependence on the sea is rapidly increasing. Since ancient times, sea has been used for two main purposes - fishing and shipping, but the recent discovery of offshore oil and gas, other minerals, chemicals, drugs and energy extraction has convinced every one that some of the biggest treasures of the world lie hidden in the sea. Thus the ocean is called "our last frontier" and mankind is looking towards the sea as our future hope. The old saying that the country which controls the sea rules over the earth, has proved to be true beyond doubt.

It has been estimated that the available land per person in the early part of the next century will be reduced to about half of the area available today for different activities of human beings. In many parts of the world, land is not readily available. Even if it is available, the pressure on land for agriculture, housing, industries and other activities is so enormous that it will go on reducing progressively for each of our needs. Therefore, in our strategy for future planning we will have to consider first what will be the population trend and what the oceans really offer to be called as the future hope of mankind.

There is a general agreement among most demographers that the population of India by the year 2000 A.D. will approach the 1,000 million mark (or one billion). Projections generally range from a low estimate of 875 million to a high of 1,020 million. Thus, it is almost certain that by the year 2000, the population

will be around 998 million. Of this, 508 million will probably be males and 490 million females. These estimates clearly indicate the immensity of the population problem to be tackled in India.

This would also mean that about one-sixth of the world population would become congregated in a 150th part of the world's surface area and this population will have to be sustained from the agricultural land far below than what it is available today.

India has a coastline of about 7,000 kilometres. Assuming that 25 per cent of the present population of 850 million live in the coastal areas (within a few hundred miles from the sea shore), it can be estimated that about 212 million people are directly or indirectly dependent on the sea for their livelihood. Even for those who live in landlocked regions, the influence of the sea on their daily lives is significant. Along the coastline, the many rivers discharge about 1,645 km³ of fresh water into the sea. Of this quantity, nearly 75 per cent is discharged into Bay of Bengal. Fourteen major rivers of India carry about 85 per cent of the total run off, covering 83 per cent of the drainage basins, while about 80 per cent of the population live in these basin areas. The seas around India receive about four times as much rainfall as does the land.

During the next two decades, one of the areas in which the most spectacular advances are expected to be made is the ocean sector. Coastal and offshore activities are rapidly on the increase in India. The establishment of the Department of Ocean Development shows that the Government of India is giving a high priority to the frontier areas of ocean development. During the last 10 years our country has made notable advances in the field of ocean development which have enhanced our prestige considerably among the other nations of the world. Large investments are being planned for the exploration and exploitation of various ocean resources such as food, chemicals, minerals, transportation, recreation and energy to improve the socio-economic conditions of the vast population. The offshore construction and operational activities have been rapidly increasing largely because of the exploration and exploitation of oil and gas.

Ocean and Climate

Largescale oceanic circulations are driven by atmospheric winds and by an exchange of heat with the overlying atmosphere. In addition, there are other transfer mechanisms, such as evaporation, precipitation and river discharge, which couple atmospheric systems with the oceans.

Recent years have witnessed two important developments in the global climate programme, and these are likely to play an important role in the future. The first includes space-based platforms, which have continuous link with weather satellites, and the second is related to large computer capabilities for simulating ocean-atmosphere exchanges. India is using both these very

effectively and the super computer recently obtained from the United States and installed in the Mausam Bhavan, which is the Office of the India Meteorological Department is an important development in this direction in India. Our knowledge of the sea will give us a more accurate weather forecast and our understanding of the monsoon, on which the livelihood of millions of people depends, will become far greater as time passes.

The response time of the ocean is generally much slower than that of the atmosphere, hence the ocean is often referred to as being the memory of the atmosphere. This is an important feature of climatic changes. One of the difficulties that has been encountered is the lack of precise knowledge about how anomalies in the characteristics of the ocean affect the atmosphere.

Numerous experiments are now in progress to determine the atmospheric response to fluctuations in sea-surface temperature, the reflective power of land and the sea (albedo), ground hydrology and many other features. The principal difficulty lies in the lack of understanding of how the momentum of the wind is transferred to the ocean.

In the early years of this century, Sir Gilbert Walker embarked on a search for predictors which could be associated in a statistical sense with the summer monsoon rainfall over India. During his search, he found three important oscillations in the world weather. By far the most important of these was the oscillation located over the Indian Ocean, which is now known as the Southern Oscillation. It refers to a tendency for the accumulation of our (high pressure) over the Indian Ocean to be associated with the removal of air (low pressure) from the Pacific and *vice versa*. The intensity of the Southern Oscillation shows marked changes from one year to the next. The oceanic response to the Southern Oscillation appears to be linked with the El Nino phenomenon off the coast of Peru. This phenomenon is associated with warm current passing along the coast of Latin America.

Very little is yet known of the reverse process, namely the atmospheric response to oceanic anomalies. Clearly there are global, long time-scale atmosphere-ocean systems, our understanding of which is still not clear.

The next two decades will see the most exciting revelations of our knowledge of the ocean and climate, and by the year 2000 our understanding of the monsoons, on which the livelihood of millions of people depends, will become far greater.

Living Resources

Under the living resources we will consider capture fishery, culture fishery, seaweeds, mangroves and coral reefs. The oceans occupy nearly three-fourth of the earth's surface with an average depth of 3,730 metres. The zone of maximum importance to mankind today for the exploitation of natural living resources is the uppermost layer of 100 m. This is the zone where most of the photosynthetic production of organic matter occur. It forms about 1.8 per cent of the world oceans.

From this zone, more than 50 per cent of the world's fish catch is obtained at present. The regions occupying this zone are either fairly close to the coast or are in very fertile areas of the coastal or offshore upwelling regions called 'oases' in the sea. Since such areas constitute only 25 per cent of the total oceanic area, it can be assumed that 75 per cent of the ocean area may be termed as oligotrophic with moderate to low production rates.

In India, marine fish production consists largely of capture fisheries and for these the intensively exploited areas are found in the narrow coastal belt. In 1947, fish production in India was about 0.4 million tonnes. In 1979-80, it had increased to 1.4 million tonnes. In 1970, it passed the million mark and thereafter its increase has been somewhat unsteady. Today our marine fish production is of the order of 1.6 million tonnes. During the last few decades substantial inputs have been provided for marine fisheries in the form of infrastructure, institutional base and manpower. At present India ranks 6th in the list of fish producing countries. Fish constitutes only about 4% of the world's food production but in Asia, it supplies about 45% of the total animal protein to the people. Within the last 27 years, India has also emerged as one of the foremost exporters of seafood in the world. The export of seafood which started in 1962 from India with a modest value of Rs. 4 crores has shown a very high rate of increase and in 1988 it has reached Rs. 600 crores in value.

The estimates of potential fish yield from the Indian Ocean vary from about 7 million to 17 million tonnes. Of this potential, India's contribution is expected to be of the order of 5-9 million tonnes. Thus, a four to sixfold increase over the existing production is envisaged.

From the present state of our knowledge about the potential and sustainable yield, the fish production from the Indian Exclusive Economic Zone (EEZ) is expected to be about 3 million tonnes. The projected fish requirements of India's population by the year 2000 are estimated to be 11.4 million tonnes. Of this, 60-75 per cent is expected to come from the sea and the rest from fresh-water sources. The increase in fish production during the last three decades has been attributed to the increase in mechanized fishing vessels, of which there are now more than 25,000 in the country. However, the operating costs of these vessels have increased so much that unless a substantial quantity of high quality fish is caught with 20 per cent or more of the catch containing prawns, fishing becomes somewhat uneconomical. It is, therefore, very unlikely that the expected targets for the year 2000 will be met from mechanized fishing alone.

Another important and productive sector, namely, mariculture, is not properly organized in India. It is being practised on a small scale in the enclosed backwater and estuarine areas of Andhra, Kerala, Karnataka and West Bengal. The culture is largely based on traditional methods of trapping the juveniles of prawns and fishes brought in by the tidal currents into the enclosed areas provided with sluice gates, where they are allowed to grow from three to nine months before harvesting. The total production of fish and prawns from

aquaculture practices is about 20,000 tonnes. The potential in this sector appears to be most promising and by the year 2000, the annual production of 4 million tonnes (2.5 from coastal and 1.5 from fresh-water areas) appears to be within reach. World aquaculture production is expected to reach 70 million tonnes by the year 2000 and this is supposed to come largely from the developing countries. Intensive efforts are being made in Asian and South-East Asian countries to attain substantial increases in fish production by the year 1990 so as to achieve the targets laid down by the turn of the century. In India also sea farming has started producing significant quantities of seafood.

Seaweeds are one of the important living resources exploited by man for food, animal feed, fertilizers and for chemicals and pharmaceutical products. The total marine algal yield of the world has been estimated as 172,000 tonnes per year. Of this, India contributes only about two per cent of the total. The demand for agar-producing seaweeds (agarophytes) and alginm-producing seaweeds (alginophytes) by industry in India and abroad is increasing very rapidly. Unfortunately, India has not yet fully utilized its seaweed resources. Seaweed-based industries in India came into existence only during the last twenty five years and, because of the shortage of natural resources, many industries are confronted with serious problems. Before the advent of an indigenous seaweed industry, about 200 tonnes of dried seaweed used to be exported from India annually. Shortage of seaweed is faced by most of the industries because of the depletion of natural seaweed resources after harvesting. The natural regeneration in the beds is not fast enough to meet the demand, so that the only way to generate extra resources is by cultivation of seaweed on ropes and wooden frames. Production by cultivation is likely to increase substantially during the next two decades, but intensive efforts combined with research and development are required to achieve the targets.

In India, mangrove ecosystems, as in several other countries, have been severely depleted during the last two decades. In the past they have been treated as unwanted plants and were largely used as a source of timber and charcoal. It is only in recent years that they have been recognized as ecologically vital areas. Mangroves play a very important role in protecting the shoreline from the major erosion damage. The ecosystem forms an ideal nursery for juvenile forms of many economically important species such as mullets, sea trout and shrimps. A large percentage of detrital food that supports a variety of young fishes and shrimps is generated from mangroves.

Awareness of conservation issues and the need of protection for mangroves have been developing rapidly in most of the tropical and subtropical regions and by the year 2000, while mangroves will be denuded from most of the shorelines of India because of the population pressure on land, some mangrove forests will be protected as biosphere reserves. It is only in these areas that future studies on the mangrove ecosystem will be undertaken. We have two very famous mangrove forests in our country - the Sunderbans forest in West Bengal which is the home of

the Bengal tiger and the lush mangrove forest of the Andaman and Nicobar Islands. Both these require conservation.

Coral reefs are among the most biologically productive, taxonomically diverse and aesthetically important living communities. While their massive occurrence provides much needed protection for the coastline from waves, their biological productivity yields a multitude of fauna and flora dependent on the coral-reef ecosystem. The communities also form the main attraction for skin diving, underwater photography, sport fishing and shell collecting. They thus provide a vital stimulus to the tourist industry.

Due to population pressure, most of the coral reefs have become extremely vulnerable to pollution and industrial development along the coastline. Hence, unless protection is offered to coral reefs in the future, most of them will shrink in size and will ultimately die. The forecast is that out of most of the fringing reefs in India along the main coastline only a few will survive by the year 2000, unless extensive protection is offered to them in the form of coastal marine parks. The reefs that would probably flourish would be on the atolls of Laccadives and on some of the islands of Andaman and Nicobar. Some states such as Tamilnadu and Gujarat have declared certain areas of coral reefs as protected.

Non-living Resources

In terms of population growth, the world supply of freshwater is dwindling very rapidly every year, and therefore, measures are being undertaken to obtain drinking water at least from all possible sources. There are many areas in India where potable water is in short supply and thus people even resort to drinking saline water, very often containing objectionable chemicals. For example, the presence of flourine in drinking water causes what is commonly known as fluorosis - a disease leading to painful symptoms of bone deformity. Several desalination technologies are being employed to generate freshwater from sea-water.

The first method is by solar stills. These are well suited for small and isolated communities where water is limited and where power is either not available or is in short supply and the transport of large quantities of water from neighbouring places is not practicable. The solar stills consists of a glass chamber in which the sea water is heated by sun rays and made to boil. The steam vapours are condensed as fresh water. Solar stills are ideal for small coastal villages as they run on a non-expendable energy source. They are simple to construct and their operating and maintenance costs are minimal. A solar still of 5,000 litres per day capacity has been installed in Avnia village in Gujarat where 500 families obtain their drinking water from this source.

The other method of obtaining freshwater from sea-water is by flash distillation. In this process, heated saline water is allowed to flow through a series of chambers which are maintained at different pressures below atmospheric, and progressively decrease towards the end of the series. Saline

water thus evaporates in each section of the chamber, the vapour is released and then condensed over a bundle of tubes cooled by circulating sea-water inside them. The distillate of freshwater thus produced at each stage is gathered either separately or collectively to be used as freshwater.

The third method is by electrodialysis. This technique employs iron-selective membranes for the desalination of brackish water. Electrodialysis is more economical for salinities below 5,000 p.p.m. The energy cost of the process is directly proportional to the salinity, thus beyond 5,000 p.p.m., the process is no longer economical.

The fourth method is by reverse osmosis. This is the most widely used desalination technique. In this process, suitable osmotic membranes are used which reject salts and allow the water to pass through when the seawater is put under high pressure. Several plants with capacities of 50,000 to 100,000 litres have been set up in Indian villages to supply potable water to the villagers. The Institution which has contributed very richly to this field is the Central Salt and Marine Chemical Research Institute, Bhavnagar in Gujarat. This institution has refined and updated the technology of reverse osmosis and has passed it on to Bharat Heavy Electrical Ltd which is now supplying plants of different sizes in the country.

In the future, desalination technology of different types will play a distinct role particularly in India's rural development programme for the supply of potable water. However, it is not certain that desalination technology can produce enough water to meet the demand of growing population. It can only supplement other technologies but will not provide a substitute.

Drugs from the Sea

In India the utilization of marine plants and animals as raw material for effective and safe drugs and pharmaceuticals is of recent origin. Of the 200 or more organisms that have been screened so far, many have given promising results. The most remarkable feature is the antifertility properties of several marine organisms. Recently prostaglandins, which play a major role in controlling biological reproduction, have been isolated from the seaweed *Gracilaria* sp. Studies in India indicate that all those species of marine algae that exhibit antifertility properties may also contain prostaglandins. For this work, the scientists of the National Institute of Oceanography are to be congratulated because they took the initiative to establish a team of scientists capable of handling this project successfully. Researches in this field and also on the cultures of marine bacteria, fungi, yeast, etc., will advance considerably during the next two decades for the production of bioactive substances.

Marine Chemicals

Of the sixty elements present in sea-water, only six are recovered

commercially. These are sodium and chlorine in the form of common salt, magnesium in the form of its compound, bromine, calcium and sulphur in the form of calcium sulphate (gypsum). Owing to its low concentration, the recovery of potassium directly from sea-water is not considered economical. However, it is possible to recover potassium from bitterns (the mother liquor from salt extraction). Efforts are being made to recover many useful elements commercially, namely iodine, uranium and gold from sea-water. So far, owing to the availability of cheaper extraction methods from land deposits, the technology of obtaining some of these valuable elements either from sea-water, sea-brine or seaweed is not economical. Recently, a commercial process for the recovery of uranium from sea-water has been reported. It is almost certain that research in this field will accelerate considerably and a very large number of elements will be recovered from sea-water in commercial quantities by the year 2000.

Placer Deposits

These are mineral deposits found along the coastline and are seen on the exposed beaches. Chemically stable minerals are not decomposed by weathering processes, and as the rocks surrounding such minerals become dissolved and disintegrate, the heavy particles settle to the bottom in layers and become continuously enriched as heavy, chemically stable minerals. All such concentrates are called placers. Mineral placers along the seashores, usually known as black sand, occur in many localities along the Indian coast. Deposits on the west coast are largely concentrated as high-grade beach and low-grade dune deposits, extending from Kanyakumari to the Maharashtra coast with interruptions in between. These deposits mainly contain ilmenite, rutile, zircon and monazite with varying proportions of magnetite and garnet. As time passes, their importance and value will go on increasing and by the turn of the century they will probably be exploited extensively.

Offshore Mining

Major minerals available from the sea are minerals on the sea floor and in the sea bed and minerals from the sea-water. From the ocean floor, coal, gold, diamond, tin, iron, phosphorite, potash, sulphur and rare earth metals are being mined by several countries. India exploits only a few of these. Mining from the sea is either done by tunnelling, pumping or dredging. Mining companies are extracting coal from the sea beneath the shelf in several countries by tunnelling under the sea for more than five kilometres. Iron ore is also extracted by tunnelling. However, undersea tunnelling for minerals is expensive and sometimes hazardous. Special engineering problems of undersea tunnelling add to the extraction costs, making competition with land producers totally uneconomical. Pumping of many minerals from the sea bed is also an increasing activity, as in the case of sulphur and potash in many countries. Thus, many offshore and placer deposits are exploited by pumping the material from the sea bed to the shore.

Dredging in the sea is becoming increasingly important for mining of heavy minerals such as aragonite and biogenic material (corals, shells, etc.).

By the turn of the century, the demand for almost all minerals will increase two or threefold. Thus their production from land sources alone will be difficult to meet the rising demand. In India, efforts are underway to collect all possible information on the nature of marine mineral resources to work out the most efficient extraction method of both placer and offshore deposits so that the withdrawal of minerals from the sea bed can become economical. It is to be hoped that environmental protection will not be ignored in the search for profitability.

Deep-sea Mining

The past two decades have witnessed the development of technology to mine polymetallic nodules from a depth range of 4,000-5,000 metres and to extract the economically important metals from them. They have also witnessed the development in the Third United Nations Conference on the Law of the Sea, of the legal and institutional framework in which the exploitation of the nodules will take place. Who will exploit these resources, how will this be done and who will benefit from the exploitation are some of the questions which can be answered now. The crucial factor in the development of resources such as polymetallic nodules is the economics of their recovery. Due to uncertainties in the scientific explanation regarding the nature of the resources, their relative inaccessibility and the lack of adequate technologies, even the most basic questions about the magnitude and distribution of polymetallic nodules are still imperfectly answered.

It was only in the early 1960s that the nodules were recognized as the largest resource on the deep-sea bed. They exhibit varied physical and chemical properties and occur in different sizes (from 0.5 to 10 centimetres in diameter, though most of them are in the size range 3-4 centimetres), and they are essentially porous. Generally they have been described as dark, potato-shaped lumps. Their chemical composition also varies widely. In the field of placer deposits, offshore mining and deep sea mining the contribution made by the National Institute of Oceanography, Goa remains unparalleled and the scientists of this institution deserve the highest appreciation of the country. It is entirely because of the work of NIO, Goa that our country has received admiration in the international circle.

India's Efforts in Nodules Programme

The first successful cruise for polymetallic nodules was undertaken in 1981 in the Indian Ocean. The cruise was undertaken in the Indian built research vessel "Gaveshani" of NIO, Goa and I had the privilege of leading this cruise as Chief Scientist on board the vessel. We worked for nearly fifteen days with no results, but on the 16th day, the day being 26th January the Republic day when we lifted the first nodule sample from a depth of about 6 kilometres. The success of this

cruise generated a great deal of interest within the scientific community of India. The Government of India set up in July 1981, a new Department of Ocean Development to act as a nodal agency in the country for policy-coordination, promotion of research and to give a new thrust to the overall development in the ocean sector. The Department identified the programme for exploration of polymetallic nodules as one of the major thrust areas. India was the first among the developing countries to successfully carry out an oceanographic programme dedicated to manganese nodule exploration. Based on the result of the exploration carried out by the National Institute of Oceanography (NIO), Goa, a prime area of 4 million square kilometres was initially demarcated in which extensive survey work had to be conducted to identify the most promising mine site. These efforts led to the demarcation of a total application area of 300,000 sq. km., which was divided into two regions of 150,000 sq. km., each of equal estimated commercial values. The Indian claim for a mine site in the Central Indian Ocean was thus filed with the Preparatory Commission of the International Seabed Authority in January 1984. However, after prolonged negotiations among the first group of pioneer investors (India, France, Japan and the USSR) and with the PREPCOM on the resolution of overlapping claims in the Pacific and other related issues, the Indian application was revised and resubmitted in 1987 which was registered by PREPCOM and an area of 150,000 sq. km. was allotted to India. Thus India became the first country in the world to have the registration of a mine site. This event was regarded as an important landmark in the history of Indian Oceanography. The Prime Minister of India was pleased to give the news to both houses of Parliament where it was received with considerable applause.

Besides the survey and exploration, the R & D work on the extractive metallurgy in respect of polymetallic nodules is also in progress at four national laboratories, namely, the Regional Laboratory (Bhubaneswar), the National Metallurgical Laboratory (Jamshedpur), the Hindustan Zinc Limited (Udaipur) and the Hindustan Copper Limited (Khetri). A number of process routes are under investigation in these laboratories.

Ocean Engineering

Engineering tasks associated with the ocean are many times more expensive than similar activities on land. Moreover, the hazards of work are greater and the management of operations more demanding. The farther a structure lies from the shore or the greater the distance from the sources of supply, the more prodigious will be the cost of any marine operation. Special problems pertaining to ocean engineering include designs and constructions to withstand very high pressure and hydro-elastic forces due to flow and wave action especially on slender structures, estimation of wave and current forces in a particular location, transport of polyphase mixtures via submarine pipes, design and analysis of submarine pipelines and offshore structures, pipe-laying techniques under different sea conditions, control of underwater machinery, underwater surveying,

oceanographic measurements, analysis of data, etc. The problems can broadly be divided into five sub-headings namely coastal zone management, control of coastal erosion, control of coastal pollution, production of offshore oil and gas and extraction of energy from the sea.

Coastal Zone Management

The vast coastal zone of India is being utilized for the development of ports and harbours, fisheries, beach resorts, land reclamation, location of shorebased industrial complexes, human settlement, agriculture, disposal of wastes, etc. The coastal states of India are presently confronted with the problems of coastal erosion. Pollution in estuaries and nearshore waters is becoming a serious problem requiring scientific solution. Due to the increase in population and industrialization and steadily increasing tourist traffic, there is an ever growing demand for more and more recreational beaches, tourist resorts and scenic spots along India's shoreline.

Moreover, the increase in offshore activities for oil and gas extraction, fisheries, mining of sea-bed minerals, extraction of renewable energy from the sea, shipping and marine transportation, etc., pose special problems in the coastal zone since it would be necessary to provide special onshore facilities in harmony with the natural environment in order to cope with the new demands on the coastal zone.

Thus the coastal zone is subjected to multiple use leading thereby to conflicting demands for the exploitation of various coastal resources by different interest groups and user agencies. It has, therefore, become very vulnerable to the destructive forces caused by pollution and several other man-made changes. There is consequently a need for a comprehensive national policy and guidelines with requisite enforcing powers for managing the various coastal developmental activities in India.

Increase in the volume of seaborne traffic in petroleum and petroleum products, mineral ore, coal, fertilizers, food grain, etc., has necessitated the development of new harbours and the expansion of the existing harbour and port facilities in the country. Sea trade has become very competitive in the world. It is, therefore, necessary for India to reduce the unit cost of transportation by introducing large ships, cargo containerization and adopting new methods of handling cargo at high speed and in large bulk. In almost all harbours there is a need for regular dredging to maintain required depths at navigable approaches. Congestion is becoming a serious problem in India, particularly in large ports. It has, therefore, become necessary to divert ships to uncongested ports and develop others to receive the increased traffic.

Control of Coastal Erosion

Various parts of the east and west coasts of India are confronted with severe

erosion problems. Erosion is caused by the interaction of natural forces, which, very often, are aggravated by man-made changes along the shoreline.

The most important factors affecting the stability of a beach or a shoreline are waves, tides, currents, beach-material characteristics, geomorphology and man-made changes. Engineering measures designed to control erosion and stabilize the eroding shore can be put under two general categories. First, the construction of structures such as seawalls, revetments, groynes, breakwaters and jetties to reduce or prevent the wave energy from reaching the erodible material on the shore. Second, the artificial nourishment of an eroding shoreline to make up the deficiency in the supply of sand with or without structures like groynes, etc., to reduce the rate of the loss of entrapped material.

Control of Coastal Pollution

Due to the increase in population and industrial activities, the estuaries and nearshore waters are being polluted because of the disposal of waste materials. Problems of thermal and oil pollution are also becoming very common in many parts of India.

To develop suitable solutions to pollution problems, investigations are to be undertaken to study the diffusion and dispersion characteristics of coastal waters in which waste disposal is planned. To deal with the oil-pollution problems, research and development on chemicals and oil-cleaning equipment will have to be intensified. Suitable oil booms and skimmers are to be developed or obtained.

Production of Offshore Oil and Gas

The present production of offshore oil and natural gas is approximately 38% of the world production and this figure is likely to go up substantially by the turn of this century. India has mounted a major effort to increase its oil exploration and development capabilities. Over the next few years, this effort is likely to increase rapidly. Though the present activities related to offshore production of oil and gas are confined to Bombay High areas, the exploration activities are intensively going on both on the east and west coasts of India. To support the efforts in offshore exploration, it would be necessary for India to develop various related services indigenously. A large number of supply vessels and other multi-purpose support and inspection vessels, helicopters, crew boats, etc., are required. A large number of drilling and process platforms, including submarine pipelines, have already been installed and more of them will be constructed in the future. There are substantial reserves of oil and gas in the ocean. However, quite a large part of our continental shelf is still unexplored. Further technological progress in the method of drilling at depths beyond the shelf edge will enhance the potential of oil production from the offshore areas substantially. The production of oil and gas from the Bombay High Oilfields has gone up many times during the last 10 years. Continued oceanographic support is most essential for safe and optimum exploitation of offshore oil and gas.

Extraction of Energy from the Sea

It is well known that the vast seas around India have great potential for renewable sources of energy available in the form of ocean thermal energy, waves, tides and salinity gradients. The time is not far off when the extraction of energy from these sources will become economical because of the increasing cost of power generation from the depletable sources of energy such as coal, oil and natural gas.

A major research and developmental effort is being undertaken in the country to develop the necessary capabilities in this frontier area. More research and developmental efforts are required in connection with the data collection, analysis, environmental modelling, selection of materials, design of various components, fabrication, sea trials, environmental impact studies, etc. India has been carrying out intensive studies on the extraction of energy from waves at the Indian Institute of Technology, Madras and I would take this opportunity to give my highest appreciation to the scientists and engineers of the Ocean Engineering Centre of IIT, Madras for providing a major break-through in this field. Within a short span of 7 years, the young team at Madras has developed a design of 150 kilowatt wave energy plant to be built in India. Based on the principles of Oscillating Water Column (OWC), this plant is under construction at Vizingham in Kerala and will be commissioned soon. Once in operation, this would be first plant of its kind in the world, completely designed, built and managed by Indian scientists and engineers.

Taxonomic Research in India

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The beginning : Taxonomy in India is inevitably linked with the establishment of British rule in the middle of the 18th century. As a result, army officers who had the time and inclination, started collecting Indian animals and sending them to the British Museum (Natural History), London, for storage and identification. Thus, this institution, already well established, played a major role in the growth of taxonomy in India.

The following institutions successively played a major role :

British Museum (Natural History), London,

The Asiatic Society, Calcutta (founded 1784),

The Indian Museum, Calcutta (founded 1866),

The Commonwealth Institute of Entomology, London,

The Commonwealth Institute of Helminthology, St. Albans,

The Zoological Survey of India, Calcutta (founded 1916).

Acquired zoological collections of the Indian Museum.

Edward Blyth, the Curator of the Asiatic Society, Calcutta, made large collections of birds and mammals, discovering many new species. These Collections were acquired by the Indian Museum (Natural History Section), Calcutta, in 1866. Finally, they were acquired by the Zoological Survey of India in 1916. They have been designated as the National Zoological Collections of India, and run into millions of specimens, preserved either as dry examples, or stuffed, or in spirit. They are housed in two separate buildings. Those in spirit are kept in a special (Fire Proof) Spirit Building in the premises of the Indian Museum, and the rest in the multistoried building of the Zoological Survey of India, New Alipur, about 5 km away.

Other centres of taxonomic research were started in the early part of the twentieth century. Entomological taxonomy began in the Imperial Forest Research Institute, Dehra Dun, about 1906, and at the Imperial Agricultural Research Institute at Bihar, about 1903, later shifted to New Delhi. The

taxonomy of animal parasites (helminths, Protozoa, etc.) began at the Institute of Veterinary Research at Makteswar (later shifted to Izatnagar near Barielly) early in this century.

In addition to these, many universities carried out taxonomic work, especially in entomology, and the process was accelerated with the formation of the Agricultural Universities. The Imperial Council of Agricultural Research sponsored schemes of taxonomic research in insects, etc. in the early part of this century.

Thus, taxonomic research flourished and much valuable work was done. Research on the marine fauna of India began by the HMS *Investigator* in the later part of the 19th century, and continued today through the Marine Biological Station of the Zoological Survey of India (Madras), the Indian Oceanographic Institute, Panaji (Goa), and the Freshwater and Marine Fisheries Research Institutes at Barrackpur (West Bengal) and Cochin respectively.

The object of all this taxonomic study is to understand the faunistic composition of a country, a smaller region or of the world. The knowledge so acquired could be used for environmental studies, pest control, etc. Thus, we have comprehensive account of the Indian fauna by Rao (1937) and by Roonwal and Ali (1965), and the fauna of the Great Indian Desert by Roonwal (1982). Roonwal and Mohnot (1977) have dealt with the primates of South Asia. On a world basis and on broad aspects of modern biology, evolution, etc., we have the work of Simpson (1949 and 1972).

In these institutions, the types (of new species) and uniques and collections in general are maintained, especially in central institutions like the Zoological Survey of India. Great care is taken for the preservation of "types" (Roonwal, 1963).

Identification and Publication : It is important that the material collected is identified quickly, up to the species level, and this work is done, more or less promptly in the institutions mentioned above.

Following identification, the quick publication of results is important, so that new species, genera, etc. are recognised. For this purpose, most of the institutions mentioned above have their own publications (some regular, others less so).

The Zoological Survey of India, runs the following publications :

Records of the Zoological Survey of India (formerly, the *Records of the Indian Museum*). Quarterly.

Memoirs of the Zoological Survey of India (formerly the *Memoirs of the Indian Museum*). Irregular.

Fauna of India series of books. A continuation of the former *Fauna of British India* series, started by the British Government in London, in 1833, the first volume (on *Mammalia*, by W. T. Blanford), appearing in 1888-1891. Subsequently, a large number of *Fauna* volumes have appeared on many groups of Indian animals; some even as second editions. The latest edition to the *Fauna* is the volumes on termites (*Isoptera*) by Roonwal and Chhotani (1989).

In addition to the above, many institutions run their own regular publications, variously called *Records*, *Bulletins*, etc. Also, there is a large number of journals run by various scientific societies, such as the science academics, and other professional bodies, such as the Zoological Society of India, (*Journal of the Zoological Society of India*). In Entomology, there are no less than six journals (one, the *Hexapoda*, started in Madras as recently as 1989).

Thus, there is a liberal supply of publications, and taxonomic work in India has not suffered due to want of such facilities.

References

- Rao, H. S. 1937. An outline of the fauna of India. In : *An Outline of the Field Sciences of India*. 91-124. 3 pls., 1 col. map. Calcutta.
- Roonwal, M. L. 1963. The deposit, care, preservation and scientific importance of type-specimens and other zoological collections in India. - *Recent Adv. Zool. in India* (Proc. 1st Summer School Zool., Simla, 1951), 111-121. Manager of Pubs., Govt. of India, Delhi.
- Roonwal, M. L. 1982. Fauna of the Great Indian Desert. (Past and present composition, zoogeography, ecology, biology, physiology and conservation.) In : *Desert Resources and Technology*. Vol. 1: 1-86 (Ed.) Alam Singh, Vol. 1, pp. 1-86 (8 pls.). Scientific Publishers, Jodhpur.
- Roonwal, M. L. & Ali, S. 1965. Fauna. In the *Gazetteer of India. Indian Union*. 1. *Country and People*, 231-287. Publication Division, Ministry of Information and Broadcasting, Govt. of India, New Delhi.
- Roonwal, M. L. & Mohnot, S. M. 1977. *Primates of South Asia. Ecology, Sociobiology and Behavior*. Cambridge, Mass. and Harvard University Press, London.
- Roonwal, M. L. & Chhotani, O. B. 1989. *The Fauna of India and the Adjacent Countries. Isoptera (Termites)*. Volume 1 (*Introduction and Families Termopsidae, Hodotermitidae, Kalotermitidae, Rhinotermitidae, Stylotermitidae and Indotermitidae*). Director, Zoological Survey of India, Calcutta.
- Simpson, G. G. 1949. The principles of classification and a classification of mammals. *Bull. Amer. Mus. nat. Hist.*, 85: xvi + 350
- Simpson, G. G. 1972. The evolutionary concept of man. In : *Sexual Selection and the Descent of man 1871-1971*. 17-39 (Ed.) B. Campbell, Aldine Publ. Co., Chicago.

Coevolutionary Implications in Insect - Plant Interactions

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A change in two or more species in which one species acts as a selective force on the other, contributes to the phenomenon of 'coevolution', a term primarily intended to refer to the nature of the chemical and physical defences of plants against herbivory and of the adaptation of insects to these factors. The large scale diversification of modern plants and phytophagous insects is presumed to be due to the coevolutionary process, which implies a step-wise evolution within populations of both plants and insects, the defenses of plants providing the selective process for counter adaptation by phytophagous insects, which in turn select for modified defenses in plants (Ehrlich & Raven, 1964). The insect which stimulates the plant itself responds to the evolutionary change and a change may continue for a long time scale. In other words the diversity of plants would tend to increase insect diversity and the diversity of phytophagous insects would tend to augment the diversity of plants (Ananthakrishnan, 1986). Such diversities led to the formulation of the adaptive zone hypothesis, wherein a highly successful species proliferates into many habitats and speciates into multiple forms (Smiley, 1985). This generated quite some interest in coevolutionary interactions between species.

Coevolution between insects and plants provides substantial biochemical evidence from several points of view. Many insect species discriminate between their host plants and non-host plants by differential behavioural responses to varying secondary plant substances which have mosaic distribution throughout the plant kingdom. Many of the secondary plant substances are known to exert a toxic or antibiotic effect on utilising herbivore and the host plants of a particular insect species tend to share similar secondary plant substances, though they differ in several other respects. Feeding specialisation of phytophagous insects (monophagy, polyphagy and oligophagy) allows close adaptation to the microhabitat and phenology of a particular species of plant, though this advantage is likely to be reduced to the extent that closely related plants within the insect host range differ in their phenology. The importance of the biochemical component in coevolution was stressed by Feeny (1976) on the basis of discrimination of insects between host plants and non-host plants through differential behaviour responses to several secondary substances, many of which

are toxic to insects. The occurrence of almost similar secondary substances in various food plants of a particular insect species, genus or family is therefore of interest. It is postulated that herbivores tend to lead to decreased abundance of host plants allowing greater number of coexisting species. Conversely, as a result of insects gaining protection from the secondary substances of plants, increased selection of plants with noxious chemicals resulted due to pressure from herbivorous insects.

The ability of herbivores to utilise specialised tissues in plants such as fruits, seeds, flowers, leaves, buds, etc., offers excellent examples of coevolution viewed from the biochemical angle. For example, the antibiotic activity of phenolic substances within cotton plant tend to vary within different tissues and offer differential susceptibility to the colonizing species (Ananthakrishnan *et. al.*, 1990). Moreover the differential impact of the antibiotic plant allelochemicals to co-existing pests reflect the fact that the action of resistant principles in plants such as tannic acid and pyrogallol is not common to all the herbivores utilising the host plant, but offers differential susceptibility to even closely related species. This has been highlighted in the cotton - *Spodoptera* - *Heliothis* system (Ananthakrishnan *et. al.*, 1990a). Diversification in host breadth and host niche specialization is also another line of coevolution. The development of newer resistant crop varieties leads to the development of newer biotypes with increased host range by complicating the detoxifying mechanisms. Individuals of many species are known to become more polyphagous when their normal host becomes scarce or exhausted (Dethier, 1970).

The evolutionary trend in host plant range of phytophagous insects is towards increasing specialisation. Plants develop newer and newer chemicals in response to many selective pressures of the environment. Insect populations are also capable of developing newer counter measures by means of modified enzyme machinery extending their diet breadth, specialising by developing newer strains, utilising the repellents as kairomones or by sequestration. There can be no better examples than the *Leptinotarsa* - Solanaceae, *Pieris rapae* - Cruciferae, *Papilio polyxenes* - Umbelliferae, *Papilio glaucus* complex/host complexes, and *Passiflora* - *Heliconius* systems, to mention a few to exemplify the above aspects (Feeny, 1976; Gilbert, 1975; Scriber, 1988; Spencer, 1988; Berenbaum, 1983).

Acridids offer an excellent example of biochemical coevolution. Food selection aims at a balance between the need for nutritive substances and the need to avoid antibiotic chemicals. Avoidance may be direct by a virtually complete failure to feed on plants containing certain chemicals as in the case of locusts or it may be indirect with the insect sequestering or eliminating the toxicants. The *Poekilocerus* - Asclepidaceae system is very relevant in this connection. Antibiotic compounds are widely distributed in all plant taxa except Gramineae and a few other isolated families (Gibbs, 1974). Hence, insects adopting the strategy of avoiding antibiotics will tend to be graminivorous. The alternate strategy will lead to polyphagy if the insect develops a tolerance for a wide

range of antibiotics, but if the tolerance is restricted to specific chemicals it may lead to oligophagy or even monophagy among dicotyledons. There has been two major lines in the evolution of acridids associated with plant evolution, the first being the extensive radiation following the development of angiosperms and the second followed the evolution of grasses. The evolution of angiosperms seems to have been associated with the reduction in the occurrence of condensed tannin and an extension in the variety of secondary plant chemicals. The evolution of grasses being associated with the loss of most secondary plant substances which are active against insects, do not promote the development of insect forms which are not required to spend energy for detoxification.

Another important area where plants become adapted to the attack by insects relate to the biology of gall formation. Plant galls are adaptations of plants to attack by gall insects, endowing them with more favourable conditions of microclimate, providing an optimal environment for rapid reproduction and abundant food for the duration of the season. Initiation and exploitation of plant tissues leading to the formation of plant galls by insects is considered as a highly developed form of phytophagy. The evolution of the gall forming capacity also depends on the habits and behaviour of the cecidozoans and this is very obvious among chalcids, gall midges, some gall wasps and tephritids living in higher plants where not only sufficient nutritive substances are available, but also undifferentiated meristematic tissues, ideal for the development of a gall (Zwölfer, 1978). Gall insect-host plant association seems to exemplify an advanced/specialised level of 'trophic strategy' This is evident from the organisation of a nutritive zone in galls, an adaptation of the insect life cycle in relation to the phenology of the host plant also appears to be a decisive factor in phytophagous insects with specialised life cycles. (Ananthakrishnan, 1984).

Selective pressures are provided by plant defenses for counter-adaptation by insects which in turn select for modified defenses in plants. It is the radiation of angiosperms in the Mesozoic and Coenozoic that created opportunities for flower infesting insects to diversify. This led to a broad interdependence between angiosperms and pollinating insects. The coevolution of plants and pollination is based on the 'most effective pollinator principle' (Stebbins, 1975), in which different flower visitors exert different selective forces due to the relative effectiveness with which they transfer pollen. There is always a mutualistic relationship between the flower and the pollinating insect. The orchid-euglossine bee association is a typical example of mutual interaction, orchids generally being dependent on male bees for pollination, the male euglossines collecting scent from the flowers, utilising them as sex pheromones. Further, the calorific and amino acid rewards are synchronized and as a result of co-evolution, one or more amino acids which were lacking in primitive angiosperms, become available to the pollinators. In many cases, the evolution of the flower tends to restrict visits by certain categories of pollinators to flowers of a single species, so that insects needing more energy will not visit flowers with low nectar production.

In recent years diverse opinions have been expressed as to the implication of coevolution and whether it really occurs. While each species affects the fitness of the other to enable detection of coevolution traits, instances occur wherein coevolutionary trends do not exist in conditions wherein each species in an interaction is evolving in response to numerous species. Coevolutionary traits should be a dominant selection force and coevolution would be opposed if stronger selection forces occur in the interactions. There is an opinion that coevolution in the real sense is rather rare between insects and plants.

Janzen (1973) postulated that "the more predictably available specific food item, the more a herbivore can afford to specialise in the face of interspecific 'competition'. Atsaat and Dowd (1976) take into consideration that members of the plant community form a 'plant guild' by which is meant ecologically unified, functional groups of organisms i.e., individuals that are functionally dependent or interdependent with regard to herbivores. Accordingly these guilds function an antiherbivore resources by aiding harbouring their natural enemies, by acting as repellent plants and as "attractant decoy plants" detracting or luring away the insects, giving advantage to the plant guild as a whole. Step-wise coevolution is most likely to occur when the number of interacting species is small and diffuse coevolution will be increasingly evident as the number of species increase. The evolution of furanocoumarins favouring specialisation on Umbelliferae plants is one of the finest examples of the 'adaptive zone hypothesis, which in turn created a 'competitor free adaptive zone' in which members of the papilionid butterflies could speciate. As such chemical defense systems involving detoxification mechanisms appear to be the primary causes of reciprocal adaptive radiation in insects and plants (Berenbaum, 1983). Futuyma (1983) opines that the observed coevolutionary traits may have resulted from coevolution, 'rather than from a process which produce coevolutionary traits'. Jermy (1984) argues that evolutionary interaction between insects and plants are 'asymmetric' and that insects do not affect plant evolution. He emphasises the lack of definite evidence for specific impact of phytophagous insects on the resistance traits of naturally growing plants. Berenbaum (1985) proposed that one of the reasons for the tremendous chemical diversity within individual plants is that plants rely on additive and synergistic interactions as a form of 'multichemical defenses' against insects. While Spencer (1988) lays stress on the biochemical aspects of coevolution, Bernays and Graham (1988) indicate that behavioural specialities set the stage for physiological adaptation. Feeny (1990) argues that while many papilionids form only a minor part of the insect faunal complexes, they do not tend to show coevolution with their hosts, except for the Troidine swallowtails colonizing *Aristolochia* species wherein the possibilities of specific coevolution exist. As such much can be said in favour of and against coevolutionary aspects of phytophagous insects. We have nibbled only at the fringes of a subject that has a vast potential which calls for indepth investigations on several groups of phytophagous insects.

References

- Ananthakrishnan, T. N. 1984. Adaptive Strategies in Cecidogenous Thrips. In : *Biology of Gall Insects*, 1-9. (Ed.) T. N. Ananthakrishnan. Oxford & IBH : New Delhi.
- Ananthakrishnan, T. N. 1986. *Dynamics of Insect Plant Interaction*. Viswanathan Printers & Publishers Pvt. Ltd., Madras.
- Ananthakrishnan, T. N., Senrayan, R., Annadurai R. S. & Murugesan, S. 1990. Antibiotic effects of resorcinol, gallic acid and phaloroglucinol on *Heliothis armigera* (Hubner) (Insecta : Noctuidae). *Proc. Indian Acad. Sci. (Anim. Sci.)*, 99(1) : 39 - 52.
- Ananthakrishnan, T. N., Annadurai, R. S., Senrayan R. & Murugesan S. 1990a. Differential impact of tannic acid and pyrogallol on nutrition and reproduction of two co-existing pests *Heliothis armigera* (Hubner) and *Spodoptera litura* Fab. (Lepidoptera : Noctuidae). *Phytophaga* (in press).
- Atsaat, P. R. & Dowd, D. J. O. 1976. Plant defenses guilds. *Science*, 193: 24 - 29.
- Berenbaum, M. 1983. Coumarin and caterpillars : a case for coevolution. *Evolution*, 39: 163 - 179.
- Berenbaum, M. 1985. Brementown revisited : interactions among allelochemicals in plants. *Recent Advances in phytophagous Insects*, 19: 139 - 169.
- Bernays, E. & Graham, M. 1988. On the evolution of host specificity in phytophagous arthropods. *Ecology*, 69: 886 - 892.
- Dethier, V. G. 1970. Chemical Interactions between plants and insects. In : *Chemical ecology*. 83-102. (Eds.) E. Sondheimer and J. B. Simeone, Academic press, London and New York.
- Ehrlich, P. R. & Raven, P. H. 1964. Butterflies and Plants : a Study in Evolution. *Evolution*, 18: 586 - 608.
- Feeny, P. 1976. Plant apparencies and chemical defenses. In : *Biochemical interaction between plants and insects*, Vol. 10, 1-40 (Eds.) J. H. Wallace and R. L. Mansell. Plenum press, New York.
- Feeny, P. 1990. Chemical constraints on the evolution of swallowtail butterflies. In : *Herbivore : Tropical and temperate perspectives*, (Eds.) P. W. Price, T. Lewins, John and E. W. Fernand. John Wiley & Sons, New York.
- Futuyma, D. J. 1983. Selective factors in the evolution of host choice by phytophagous insects. In : *Herbivorous insects host seeking behaviour and mechanisms* : 227-241. (Ed.) S. Ahamed, Academic press, New York.
- Gibbs, R. D. 1974. *The chemotaxonomy of flowering plants*. McGill Queen's University press, London.
- Gilbert, S. E. 1975. Ecological sequences of a coevolved mutualism between butterflies and plants. In : *Coevolution of Animals and Plants*. 210-240. (Eds.) S. E. Gilbert and P. H. Raven. University of Texas Press, Austin.
- Janzen, D. 1973. Community Structures and Secondary Components in Plants. *Pure. Appl. Chem.*, 34: 529 - 538.
- Jermey, T. 1984. Evolution of Insect Host Plant Relationships. *Amer. Nat.*, 124: 609 - 630.
- Scriber, M. 1988. *Papilio* biogeography and food plant choice In : *Chemical mediation of Coevolution*, 241-301. (Ed.) K. Spencer, Academic press, New York.
- Smiley, J. T. 1985. Are chemical barriers necessary for evolution of butterfly - plant association? *Oecologia (Berlin)*, 65: 580 - 583.
- Spencer, K. 1988. *Chemical mediation of Coevolution*. Academic press, New York.
- Stebbins, G. L. 1975. Adaptive radiation in angiosperms pollination mechanisms; *Ann. Rev. Ecol. Syst.*, 1: 307 -326.
- Zwölfer, H. 1978. Mechanismen and Ergebnisse der Co-evolution von phytophagen und entomophagen Insekten und höheren pflanzen, 20, Phylogenetisches Symposium (Hamburg), *Sonderband des Naturwissenschaftlichen Vereins*, Hamburg, 27-50.

Taxonomy in Pest Management

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India exhibits a spectacular diversity of living forms in various ecosystems varying from the Alpine meadows to deserts and evergreen rain forest. In each of the ecosystem, every species of plants as well as animals occupy a special niche. For correctly understanding the functional ecology of a taxon it is extremely essential that we know that animal by its exact name. The exact name of a species in a way is known as taxonomy.

Pest management is a highly specialised discipline since pests occur everywhere, on land, in water, in air and inside bodies of animals; the latter being called parasites. An integral inter-relationship occurs between predators and pests and between pest and the ecosystem. This delicate inter-balance can be made use of only if we understand them to the species-level. It is essential for any sound pest management to understand the pest in its over-all taxonomic and ecologic perspective.

Surveys

Especially in tropical country, a single habitat is inhabited by a number of species. It is, therefore, logical to conduct a survey to register their relative numbers and predominance. The next sequence would be to study the pest status of one or all species. Unless we know the taxonomy of all the species, it will not be possible to do full justice for evolving a control programme. For example it has been worked out that about 14 species of rodent-pest occur in various habitats in the Thar desert (Table 1). Most of the species are important because they destroy vegetation and are impediment to various antidesertification attempts. After identifying them up to sub-specific level we studied their food in nature to establish their pest status (Table 2). In another attempt, damage inflicted by *Meriones hurrianae* was estimated in a grassland. The population of this gerbil was worked out to be 477 per ha. The annual forage feed requirement of gerbils at this density is about 1,040 kg/ha compared with an annual forage production of this rangeland of 1,210 kg/ha. At this rate it was revealed, that the gerbils leave very little forage for the grazing livestock. Thus the desert gerbil *Meriones hurrianae* is a serious competitor of livestock. The economy of the desert dwellers is based on pastoral produce which is directly proportional to the quality and

quantity of fodder. Gerbils not only feed upon it but also destroy large quantities of grasses thus depriving the livestock animals. Therefore this species is a serious competitor of livestock as far as feed and fodder are concerned. From the above it is very clear that unless we knew the taxonomy of various rodent species it would have not been possible to single out *Meriones hurrianae* as the major foe of grasses, thereby an agent of adversely affecting the livestock production. For achieving the excellence in pest control it is necessary, therefore, to study the species in a great detail.

Table 1. Percentage Distribution of Rodents in Different Habitats in the Indian Desert

Species	Habitats			
	Sandy	Gravel	Rocky	Ruderal
<i>Funambulus pennanti</i>	14.2	—	35.8	50.0
<i>Gerbillus nanus indus</i>	100.0	—	—	—
<i>Gerbillus gleadowi</i>	56.0	—	—	44.0
<i>Tatera indica indica</i>	28.8	10.0	3.6	57.6
<i>Meriones hurrianae</i>	60.0	17.0	—	23.0
<i>Rattus cutchicus cutchicus</i>	—	—	100.0	—
<i>Millardia meltada pallidior</i>	37.0	1.6	5.1	56.0
<i>Millardia gleadowi</i>	66.6	33.3	—	—
<i>Mus musculus bactrianus</i>	—	—	—	100.0
<i>Mus booduga booduga</i>	—	—	—	100.0
<i>Mus cervicolor</i>	—	—	100.0	—
<i>Mus phillipsi</i>	—	—	100.0	—
<i>Mus platythrix sadhu</i>	28.0	13.5	53.3	13.3
<i>Golunda ellioti gujerati</i>	25.0	12.5	—	62.5

After Prakash, 1975

Table 2. Showing the Percentages of Stomach Contents of *Meriones hurrianae*

Months	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
No. of Stomachs	(17)	(14)	(19)	(9)	(9)	(4)	(11)	(17)	(25)	(13)	(18)	(16)
Stomach contents												
Seeds	60	50	40	30	20	10	20	20	20	30	50	60
Stems and rhizomes	10	15	25	35	40	45	30	20	25	20	15	10
Leaves and rhizomes	25	25	15	10	5	15	25	35	30	40	30	30
Insects	0	0	0	5	15	15	15	10	10	0	0	0
Miscellaneous	5	10	10	20	20	15	10	15	10	10	5	0

After Prakash, 1962

Sometimes poor knowledge of a species creates problems in controlling a disease or a pest. The famous case of the epidemiology of malaria is a good example. The supposed vector in Europe, the mosquito (*Anopheles maculipennis*) was reported from throughout the continent and yet malaria was restricted to local districts. Large amount of money was wasted because no one understood the connection between the distribution of malaria and the mosquito. Careful taxonomic studies, summarised by Hackett (1937) and Bates (1940), finally provided the key to the situation. The *maculipennis* complex was found to consist of several sibling (sub) species with different habitat preferences and breeding habits. Only some of which were responsible for the transmission of malaria in a given area. This new information enabled control measures at the exact spots where they would be most effective.

Behaviour

The taxonomical studies in the study of intraspecific and interspecific behaviour assume sufficient importance. While undertaking rodent control operations in the crop fields it was revealed that *Meriones hurrianae* is quickly eliminated after poison baiting but *Tatera indica*, another predominant rodent, does not die and continues to menace the crops and grasslands. After studying their circadian rhythm, it was found that their feeding period occurs at the time of dusk. This was a reason that poison bait placed in the morning were consumed by *Meriones hurrianae* because it was their feeding time. When we poison baited the fields before dusk, good success in control of *Tatera indica* was also achieved. Likewise a number of examples can be cited where the studies on behaviour in relation to various taxa help in improving the control success.

Host Pest Specificity

A number of microbes and virus are specific to certain species. Unless we know the details of the taxonomy of host and the pest, successful biological control programme cannot be properly formulated. When a large number of domestic rabbits started dying in Uruguay, the cause was assigned to a pathogen, a virus. This virus naturally occurs in native species of rabbits, *Sylvilagus brasiliensis* and *S. floridanus*. Both the species of rabbits are almost immune to the virus (*Leporivirus*). It was thought that this disease is easily transferred through contact to healthy animals. Working on this assumption, the virus was cultured in large quantity and was taken to Australia where introduced wild rabbits *Oryctolagus cuniculus* were a big menace to agriculture and rangelands. A large number of rabbits were inoculated and released in nature. The epidemic spread in a very limited area. The reasons for the failure were investigated and it was found that *Anopheles annulipes*, living in rabbit burrows is the vector of this virus. Mosquitoes play the part of mechanical carriers of the *Myxoma*. This virus does not reproduce in an arthropod organism. When these mosquitoes feed on the tumours caused due to *myxomatosis*, they transfer the disease to healthy rabbits. The disease spread widely and a fairly good control of rabbits was achieved. The

taxonomic study of the South African rabbits, *Sylvilagus*, of the European rabbits *Oryctolagus* and the mosquito, *Anopheles* was taken up, and it resulted into an excellent biological control programme. However, the strain of *Myxoma* virus has lost its virulence and the rabbits have developed resistance to it and, therefore, there is a search for a more virulent strain.

From these examples it is evident that taxonomy is an integral necessity of pest management.

References

- Bates, M. 1940. The nomenclature and taxonomic status of the mosquitoes of the *Anopheles maculipennis* complex. *Ann. Ent. Soc. Amer.*, 33: 343-356.
- Hackett, L. W. 1937. *Malaria in Europe*. Oxford University Press, London.
- Prakash, I. 1962. Ecology of gerbils of the Rajasthan desert, India. *Mammalia*, 26 : 311-331.
- Prakash, I. 1975. The ecology of vertebrates of the Indian desert. In : "*Ecology and Biogeography in India*" 369-420 (Ed.) M. S. Mani, W. Junk, The Hague.

Taxonomy in Biomedical Resources of the Exclusive Economic Zone of India

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Marine organisms as a group, possess considerably modified biosynthesis pathways to produce novel and dynamic metabolites, than do their terrestrial and limnetic counterparts (Attaway, 1978). Interest in marine biomedical research, as a lead for drugs, pharmaceuticals and other industrial materials, has been widespread, especially in the last three decades. The pioneering work aimed at tapping the biomedical potentials of marine organisms, was confined to the Pacific and the Atlantic Ocean as also, on a lesser scale, to the Caribbean and the Mediterranean Sea. However, no information about the biomedical potentials of Indian Ocean, was available, till the recent past.

Marine biomedical research is multidisciplinary and involves taxonomy, ecology, nutrition, physiology, pathology, ethnobiology, microbiology, medicine, pharmacology, chemistry of natural products, toxicology and biochemistry (Halstead, 1970). The taxonomic studies have an unique place, as the marine biomedical potential is species specific and unless the correct systematic position upto species level is known, the scope of resources for exploitation and utilization, will greatly be restricted.

Research in Marine Taxonomy in India

India is one of the few countries, having long and glorious traditions of more than a century, in marine biological research. A review of relevant literature reveals that from the year 1875 to almost 1950, taxonomy, especially faunal, formed an important component of marine science research in India.

A large number of research contributions, pertaining to distribution and taxonomy of algae, phytoplankton, macrophytes, sponges, sea anemones, corals, polychaetes, crustaceans, molluscs, echinoderms, minor phyla, fishes and marine mammals from diverse ecosystems, like Okhamandal, Bombay, Karwar, Malabar and Travancore Coast, Gulf of Mannar, Madras, Pulicat Lake, Visakhapatnam, Chilka Lake, Port Canning, Hooghly estuary, Andaman Sea

and the Laccadive Archipelago, are on record. Though main emphasis of these studies was on the biota of easily accessible intertidal and shallow brackish water ecosystems, a few investigations on the open sea habitat, were also undertaken.

In the post-independence years, the emphasis on marine taxonomic research decreased considerably. During 1961-1965, thanks to International Indian Ocean Expedition (IIOE) programme, the taxonomy of plankton, mainly zooplankton, besides a few groups of nektonic and benthic organisms, received the most stimulating impetus, resulting in the generation of voluminous data, documented through several research papers, atlases and technical reports. During the last four decades or so, emphasis on the quantitative and/or applied aspects of marine biology and biological oceanography, with specific objective of assessment and evaluation of the potential and sustainable living resources, of the EEZ, assumed importance. Consequently, the marine taxonomic research got side-tracked and relegated to less importance.

With long traditions of marine taxonomic research, a number of research institutions and maritime universities have developed large holdings of marine biota, besides capabilities and expertise in identification of certain taxa of flora and fauna. Excluding planktonic and some of the interstitial taxa, bryozoans, insects, myriapods, birds and mammals, the marine survey division of the Zoological Survey of India, have estimated the total number of marine faunal species from seas around India, to be 12,000 (Table 1).

Table 1. Estimated Number of Marine Faunal Species of India

Taxa/Phyla	Number
Protozoa	2,000
Porifera	550
Coelenterata	480
Annelida	500
Echiura	28
Sipuncula	30
Pycnogonida	10
Mollusca	2,750
Echinodermata	700
Crustacea	3,000
Arachnida	2
Pisces	2,000
Others	14

Not included are planktonic and interstitial forms. Due to lack of authentic information, many marine faunal taxa have not been included. Thus the compilation is far from complete.

Source : Zoological Survey of India (1989)

Similarly, the number of species of marine algae, recorded from the Indian Coastline, is estimated to be 624 (Table 2).

Table 2. Marine Algal Species of The Indian Coasts

Taxa	Species	Genera	Family	Order
Chlorophyta	159	45	15	4
Phaeophyta	141	39	12	5
Rhodophyta	307	120	31	6
Cyanophyta	17	11	6	2

Source : List of Marine Algae From India, NIO Tech. Publ. 1983.

Recently, Bakus (1986), based on recommendations from active marine taxonomists from India and also on international opinion from the British Museum, London, Museum National D'Histoire Naturelle, Paris and the National Museum of Natural History of the Smithsonian Institution, Washington D.C., has critically assessed the capabilities and expertise in marine taxonomy in India. The search revealed that for some of the taxa, like, soft corals (alcyocea), zoantharia, gorgonians, sea pens, priapulids, pycnogonids and tanaids, no expertise is available in India. For some of the other groups, like sponges, actiniarians, stony corals, brachiopods, bryozoans, sipunculids, opisthobranch (including nudibranch) molluscs, isopods, nebaliceans, mysids, echinoderms, marine reptiles, sea birds and marine mammals, the expertise is limited to single individual. In the majority of marine taxa, the researcher works single handedly for two to three decades, and no induction of fresh manpower in the area of speciality, occurs. In other words, existing expertise, centres around a person rather than a team or group of specialists, and consequently, in the absence of fresh input of manpower, the expertise, developed over a long period of time, just dies off.

Further, a number of studies on taxonomy and biotic survey, remain unpublished, either in the form of thesis or technical reports, with restricted distribution. With relatively low prospects of employment for marine taxonomists, fresh graduates and post-graduates are reluctant to pursue research career in marine systematics.

Taxonomy of Marine Biomedical Resources

Studies on the systematics of marine biota of India, with specific reference to biomedical resources, are of recent origin. In the year 1978, a R&D project on "Drugs From The Sea", as a collaborative venture between two CSIR Laboratories, namely the National Institute of Oceanography (NIO), Goa and the Central Drug Research Institute (CDRI), Lucknow, was initiated. One of the

critical objective of this project was to explore, investigate and taxonomically characterize the flora and fauna of exclusive economic zone (EEZ) of India, for bioactivity potential. Subsequently, in the year 1985, the project was expanded and diversified, under INDO-US collaboration programme, with financial assistance under PL-480 rupee funds. The redesigned bilateral project "Bioactive Substances From The Indian Ocean" gave tremendous impetus to marine biomedical research in India.

From 1978 to 1984, the exploration and taxonomic survey was confined to estuarine and intertidal marine biotopes along a small stretch of the central west coast of India, between Lat. (N) 18-13 and Long. (E) 72-75. However, since the year 1985 and thereafter, new dimensions in the form of : subtidal collections by SCUBA diving upto 30 meter depth; wider coverage of coastal ecosystems and intensive studies on taxonomy and chemical ecology of biomedically potential species, besides pharmacology and natural product chemistry, became effective.

Through 650 field days and 410 hours of SCUBA diving, a wide range of ecosystems — estuaries, lagoons, mangroves, seagrass meadows, coral atolls and reefs; submerged banks; continental islands, neritic and oceanic waters — along the northwest coast (Gulf of Kutch & Kathiawar); central west coast (Maharashtra, Goa & Karnataka); southwest coast (Kerala and west coast of Tamil Nadu); Lakshadweep Sea (Kavaratti, Minicoy, Agatti, Kiltun, Pitti,

Table 3. Exploration of Biomedical Resources of India – Species from Intertidal and Subtidal Ecosystems

Region & Geographical position	Number of sampling sites	Intertidal species (n)		Subtidal species (n)	
		Flora	Fauna	Flora	Fauna
Northwest coast (23-21 N ; 68-70 E)	6	24	39	–	–
Central west coast (18-13 N ; 72-75 E)	10	34	56	2	19
Southwest coast (11-8 N ; 74-77 E)	4	4	6	–	–
Lakshadweep Sea (12-7 N ; 72-74 E)	9	4	13	3	59
Southeast coast (11-8 N ; 78-80 E)	5	15	58	–	–
Northeast coast (22-19 N ; 85-88 E)	4	9	17	–	–
Andaman Sea (13-11 N ; 92-94 E)	5	11	30	–	3

Suheli, Bangaram & Kadamat); southeast coast (Tamilnadu); northeast coast (Orissa & West Bengal) and the Andaman Sea (South Andaman group of islands) have been explored, through repeated surveys (Table 3).

The exploration, so far carried out, is extensive, but, of course, not much intensive. However, it represents a systematic approach, to a new and highly potential area for the exploration, exploitation and utilization of marine living resources of the EEZ of India. Further, though certain areas, like, central east coast, the Andaman and Nicobar group of islands south of 11°N as well as the distant waters of EEZ have still not been explored, but it is for the first time in India, that full-fledged capabilities to explore and study the potential marine biomedical resources, have been developed.

So far, 283 species of marine flora and fauna have been collected, taxonomically confirmed and screened for biological evaluation (Table 4).

Table 4. Flora and Faunal Species, Identified and Screened for Biomedical Potentials of The EEZ of India.

Taxa	Species Identified & Screened (n)	Species With Biomedical Potential /Activity (n)
Chlorophyta	24	8
Phaeophyta	13	7
Rhodophyta	30	7
Cyanophyta	3	1
Mangroves	2	1
Seagrasses	5	—
Porifera	69	13
Coelenterata	78	24
Bryozoa	1	—
Mollusca	25	5
Arthropoda	7	—
Echinodermata	21	8
Urochordata	5	—

Out of 77 species of flora, identified and screened, so far, only 5 species were subtidal as against 73 out of 206 faunal species. One algal species (Untawale, Jagtap and Dhargalkar, 1980); nine species of soft corals (Alderslade, Sirvoiker and Parulekar, 1990 a) and six species of sponges (Alderslade, Sirvoiker and Parulekar, 1990 b) are new to science. Further, 6 floral species (Untawale, 1985; Deshmukhe and Untawale, 1985; Bhat and Untawale, 1987; Ambiyé, 1987;

Ambiye, Chaugule and Untawale, 1989; Ambiye and Untawale, 1990, and 8 faunal species (Parulekar, 1981, 1990; Sirvoiker and Parulekar, 1987), have been reported, for the first time from India and/or new area records. A number of publications on the taxonomy, ecology and the regional inventory of macrophytes, sea anemones, corals, gastropods and distribution of floral and faunal taxa from the Gulf of Kutch, central west coast, Angria Bank (Arabian Sea), Orissa and the coral atolls in the Lakshadweep sea have been published (Parulekar, 1981, 1988, 1990; Untawale and Jagtap, 1984; Jagtap, 1987; Sirvoiker and Parulekar, 1988; Untawale and Ambiye, 1988; Untawale, Ambiye and Reddy, 1989).

The biological screening (carried out by CDRI, Lucknow) of 283 species of marine biota, explored through repeat samples in different seasons, revealed 13 major (Table 5) and 8 minor type of bioactivity potential.

Table 5 Type and Incidence of Major Bioactivity Types in Biota of the EEZ of India

Type	Species (n)	
	Flora	Fauna
Antiviral	2	7
Antimicrobial	–	1
Antifertility/Anti-implantation	4	11
Antihistamine	–	1
Analgesic	1	–
CNS-Depressant	1	–
CNS-Stimulant	5	9
Diuretic	6	10
Hypoglycemic	–	3
Hypotensive	1	6
Spasmogenic	1	1
Spasmolytic	2	1
Toxic	1	8

Some of the interesting findings of the screening for biomedical potential, were :

- i. 100% antifertility/anti-implantation activity displayed by 4 species of seaweeds, 6 species of sponges and 5 species of soft and hard corals.
- ii. Characterization of other bioactivity potentials were, diuretic (16 spp.), CNS-stimulant (14 spp.), toxic & antiviral (9 spp. each), hypotensive

(7 spp.), spasmolytic and hypoglycemic (3 spp. each) and spasmogenic (2 spp.).

- iii. Antimicrobial, antihistamine, analgesic and CNS – depressant activity was displayed by one species each.
- iv. 3 floral and faunal species, each, possess more than one type of bioactivity.

Another interesting finding was the important role of ecological and biological events (life cycle stages; feeding; breeding) in the type, quality and magnitude of biomedical potential in a species (Ambiye and Untawale, 1990; Parulekar and Sirvoiker, 1990). One of the major constraint in studies on the taxonomy of biomedically potential marine living resources, is in the inadequacy and, at times, total lack of expertise in identification. As seen from Table 6, out of 13 major taxa/phyla/groups studied, the lower invertebrate phyla, mainly Porifera and Coelenterata, posed maximum difficulties in confirming the species level identification.

Table 6. Status of Identification

Taxa	Species Explored (n)	Identification To Be Confirmed (n)
Chlorophyta	24	1
Phaeophyta	13	–
Rhodophyta	30	–
Cyanophyta	3	–
Mangroves	2	–
Seagrasses	5	–
Porifera	69	11
Coelenterata	78	29
Bryozoa	1	–
Mollusca	25	–
Arthropoda	7	–
Echinodermata	21	2
Urochordata	5	–

Rather difficult groups are soft corals, gorgonians, and zoantharians, wherein the worldwide expertise, in relevant speciality, is scarce. In case of sponges and hard corals, only limited capabilities exist within the country and, hence,

identification gets delayed. Further, as pointed by Boronjevic *et al.* (1967), the taxonomy of lower invertebrates, like sponges, is quite complex and often new terminologies are proposed. Coincidental, the lower invertebrate phyla, like Porifera and Colenterata, hold high biomedical potentials (Table 4).

As reported by Marderosian (1970), out of 150 thousand faunal species in the marine environment, at least 10% species, by the law of averages, promise biomedical potential. Further, there are numerous species of marine flora, including microbes, who have promising bioactivity, so also, a multitude of minor phyla and chordates which still remain to be explored for "drugs from the sea".

The importance and relevance of taxonomy in the application oriented marine biological research, has offered new challenges to biologists, in the recent times. In the sphere of new vistas, encompassing the vast potentials of marine living resources in biotechnology, mariculture, drugs and pharmaceuticals, containment of pollution and biocontrol of deterioration, the taxonomic and ecological studies, have an important place, as the biomedical resources are species specific as also site specific and therefore, unless the correct systematic position upto species level is known, the scope for exploitation and economic use, will drastically be reduced.

It is, therefore, imperative to revive and strengthen the marine taxonomic research in India, as elsewhere. Though the overall scene is far from optimistic, hopefully in the next few years, the revitalization and sustained pursuit of this important line of marine biological research, would be taken up, vigorously. Coupled with taxonomic work, other complimentary studies to be pursued will be chemical ecology, rearing of organisms, and conservation of germplasm.

The classical taxonomy based on external morphology and anatomical features, when appropriately blended with modern and reliable techniques of DNA and amino acid manifestation; gene frequency data; the computer aided database and archival procedures, shall be an important component of future marine taxonomic research in India.

References

- Alderslade, Phil, Sirvoiker, P. & Parulekar, A. H. 1990 a. On some new species of soft corals from Lakshadweep atolls, India. *J. nat. Hist. (In Press)*.
- Alderslade, Phil, Sirvoiker, P. & Parulekar, A. H. 1990 b. An account of some new species of sponges from India. *Bull. nat. Hist. Mus. Darwin (Australia) (In Press)*
- Ambiye, Vijaya 1987. *Spridia fasiformis* - New record along the West Coast of India. *Mahasagar - Bull. Natl. Inst. Oceanogr.* 20: 267-268
- Ambiye, Vijaya, Chaugule, B. B. & Untawale, A. G. 1989. *Neomeris Van-Bosseae*, Howe - A new record along the Indian Coast. *Curr. Sci.*, 58(24) : 1363.
- Ambiye, Vijaya & Untawale, A. G. 1990. *Galaxaura rugosa* (Ellis et Sol) Lam. from India. *Seaweed Res Utiln. (In Press)*
- Ambiye, Vijaya & Untawale, A. G. 1990b. Bio-ecology of an articulated coralline alga, *Amphiroa fragilisima*, along Anjuna, Goa (Central West Coast of India) In : *Bioactive Compounds In Marine Organisms*. (Ed) Mary-Francis Thompson. Oxford & IBH Publ., New Delhi. (In Press).

- Anon 1983. List of Marine Algae from India. NIO Tech. Paper; pp : 42 (Mimeo).
- Attaway, David H. 1978. Food and drugs from the sea : A perspective from the National Sea Grant Programme. In : *Drugs And Food From The Sea - Myth or Reality ?* (Eds.) P. N. Kaul & C. J. Sindermann : 78-81 (The University of Oklahoma, Norman, Oklahoma).
- Bakus, G. J. 1986. Survey of Indian Taxonomists (Marine Biology) : pp. 28 (Mimeo)
- Bhat, S. R. & Untawale, A. G. 1987. *Bruguiera cylindrica* (L) BL (Rhizophoraceae) : A new locality record from the West Coast of India. *Curr. Sci.*, 56(12) : 604-605.
- Boronjevic, R., Fry, W. G., Jones, W. G., Levi, C., Rasmont, C., Sara, M & Vacelet, J. 1967. A reassessment of the terminology for sponges. *Bull. Mus. Nat. Hist.*, 39: 1224-1235
- Deshmukhe, G & Untawale, A. G. 1985. *Coeloseira compressa*. Hollenb (Champraceae-Rhodophyta). A new marine algal species from Goa, India, *Indian J. mar. Sci.*, 15(1) : 37-41
- Halstead, Bruce W. 1970. Recommendations to the President's Commission on marine science, engineering and resources for a national program in marine biomedicine. In : *Foods - Drugs From The Sea, Proceedings 1969*. 11-21, (Ed.) H. W Youngken Jr.
- Jagtap, T. J. 1987. Distribution of algae, seagrasses & coral communities from Lakshadweep Islands, Eastern Arabian Sea. *Indian J. mar. Sci.*, 16(4) : 256-260.
- Marderosian, A. H. der. 1970. Drugs from the sea - An Overview. In : *Food Drug From The Sea, Proceedings 1969*, 211-253, (Ed.) H. W. Youngken Jr.
- Parulekar, A. H. 1981. Marine fauna of Malvan - Central West Coast of India. *Mahasagar Bull. natl. Inst. Oceanogr.*, 14(1) : 33-44.
- Parulekar, A. H. 1988. Bioecology of the Gulf of Kutch. In : *Marine Archaeology Of The Indian Ocean Countries*, 127-132, (Ed.) S. R. Rao.
- Parulekar, A. H. 1990. Actinarian Sea Anemone Fauna of India. In : *Marine Biofouling And Power Plants*, (Eds.) : K.V.K. Nair and V.P. Venugopalan : 218-228. Bhabha Atomic Research Centre, Bombay.
- Parulekar, A.H. & Sirvoiker, P. 1990. Bioactivity and chemical ecology of some intertidal animals. In : *Bioactive Compounds In Marine Organisms*, (Ed.) Mary-Francis Thompson. Oxford & IBH Publ., New Delhi. (In Press)
- Sirvoiker, P. & Parulekar, A.H. 1987. A new distributional record for the sea cucumber, *Holothuria* (*Semperothuria*) *cinerascens* (Brandt) from Goa. *Mahasagar - Bull natl. Inst. Oceanogr.*, 19(4) : 279-281.
- Sirvoiker, P. & Parulekar, A.H. 1988. Gastropod fauna off Dwarka Beyt in the Gulf of Kutch. In : *Marine Archaeology of The Indian Ocean Countries*, 136-140, (Ed.) S.R. Rao.
- Untawale, A.G. 1985. The occurrence of red alga, *Bangia fuscopurpurea* (Dillwyn) Lungbye (Bangiales, Rhodophyta) from the Malvan coast (Maharashtra), India. In : *Marine Plants Symp. Proc. SRUA. Goa* : 99-102
- Untawale, A.G. & Jagtap, T.G. 1984. Marine macrophytes of Minicoy (Lakshadweep) coral atoll of the Arabian Sea. *Aqua. Bot.*, 19:97-103
- Untawale, A.G. & Ambiye, Vijaya 1988. Flora of Shankhodhar in the Gulf of Kutch. In *Marine Archaeology of the Indian Ocean Countries*. 139-142, (Ed.) S.R. Rao.
- Untawale, A.G., Jagtap, T.G. & Dhargalkar, V.K. 1980. *Dichotomosiphora salina* sp. nov. - A new marine algal form from Goa estuary, India. *Mahasagar - Bull. natl. Inst. Oceanogr.*, 13(1) : 73-76
- Untawale, A.G., Ambiye, Vijaya & Reddy, C.R.K. 1989. Marine algal flora of submerged Angria Bank (Arabian Sea). *Indian J. mar. Sci.*, 18(3) : 207-209

Zoogeography of India

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The dependence of zoogeography on taxonomy is obvious, for without a thorough knowledge of the taxa concerned, any attempt to map or explain distribution is worthless. The dependence of taxonomy on zoogeography was not realised until geographical isolation was claimed as a primary necessity for evolution and speciation. This is expressed through the widely accepted definition of a sub species as an intraspecific unit geographically separated from other subspecies. Geographical isolation, thus, is now regarded as the primary causative agent in speciation. So, taxonomy and zoogeography are closely allied and interdependent fields of study.

Zoogeography is dependent not only on taxonomy but on many other fields, both within and beyond the realms of biology-phylogeny, genetics, evolution, ecology, geography, both past and present, climatology, both past and present, palaeontology and geology. The zoogeographer must, therefore, have a sound knowledge of these different disciplines to facilitate interpretation of the distributional pattern of animals, both living and extinct. Above all he must have an appreciation of the principles of logic and must examine the whole of the available evidence if he is to avoid falling into wrong conclusions.

Mayr (1969) subdivided taxonomy into 'alpha', 'beta' and 'gamma' taxonomy. 'Alpha' taxonomy is the description of taxa, especially new ones, 'beta' taxonomy is the study of the relationships of taxa, and 'gamma' taxonomy is the study of intraspecific variations, evolutionary studies and zoogeography. Some taxonomists argue that a taxonomist should restrict his attention to 'alpha' taxonomy because so many species are yet to be discovered. Probably they argue this way because their specialisation in certain taxon allows them to make their valuable contributions to biology by describing and classifying unknown species. Mayr (1971) questions this attitude, noting that no one is better equipped to derive generalisations from taxonomic data than the specialist "indeed in 99 cases out of 100, if he does not do it, no one else will do it either". Let us remember that almost all of the major questions of evolutionary biology discussed during the past 50 years were either raised by taxonomists or were the products of taxonomic finding" (Mayr, 1971). Taxonomists do the ground work for all zoogeography. It will be their loss, as well as biologist's if they do not take the

trouble to determine what their findings mean in a zoogeographic sense. Zoogeography is a taxonomist's responsibility, and it is a pity that many a fine revisional work, complete with elaborate distributional data has no zoogeographical discussion of the group.

The value of zoogeography is limited by the soundness of the taxonomy on which it is based. So, there is a great responsibility on the taxonomist to produce proper and sound taxonomies.

Our knowledge of zoogeography is undergoing a profound revolution at the moment. The earlier concept that the continents have always been roughly where they are now has been modified in recent years based on Plate Tectonics (Hays *et al*, 1969). It is now believed that the Southern Continents (Gondwanaland) moved 9000 km in 250 million years. The configuration of the Super Continent Gondwanaland is well established on the evidence of fossils both plants (*Glossopteris*) and animals (*Lystosaurus*) both in Antarctica and India (Colbert, 1970). Oceanographers plotted the movement of ocean floor taking into consideration the ocean ridges present along the continents. These are in consonance with the modern theory of Plate Tectonics. As part of the Plate Tectonics activity, the Peninsular India abutted to Eurasia in the Eocene and the consequent buckling and folding produced the east-west chain of mountains, the Alpine-Himalayan range stretching from Western Europe to East Indies. Zoogeography of India is discussed in terms of the uplift of the Himalayas and the climatic changes that had occurred during the glacial periods of the Pleistocene.

Zoogeographical Divisions of India

Faunistically, the Indian region belongs to the Oriental Realm of Wallace's (1876) classification of which it is considered as a subregion. Oriental realm embraces Indian subcontinent, Indo-China, Malaya and Westerly islands of Malay Archipelago, in fact covering most of south, southeast and farcast Asia.

Blanford (1870, 1901) appears to be the first to have studied the vertebrate fauna of India intensively from a zoogeographical point of view. He divided the "Indian Empire" into 19 tracts on the basis of physical features and tabulated all the vertebrate genera known at his time in these tracts, compared and contrasted the fauna of one tract with the other, and finally divided the Indian Empire into the following subregions.

1. *Part of the Eremian Subregion of the Holarctic Region* : Punjab, Sind, Western Rajputana and Baluchistan, should be considered the S.E. extremity of the Eremian Mediterranean subregion of the Holarctic Region.* (Blanford, 1870).

* A zoogeographical Region is a geographical subdivision of the world that possesses a unique fauna.

2. *The Tibetan Subregion of the Holarctic Region* : This subregion consists of Himalayas above forest range and fauna of this division is entirely that of Central Asia, and thus, Holarctic and not Oriental.
3. *The Cis-gangetic Subregion* : This subregion extends from the base of the Himalayas to Cape Comorin and from the Arabian sea and the eastern boundary of the Punjab area to the Bay of Bengal and the hills forming the eastern limit of the Gangetic alluvium and also including Ceylon.
(Blanford did not separate the Western Ghat and the Malabar coast as also Ceylon into a separate subregion).
4. *Trans-Gangetic Subregion* : This consists of the forest area of Himalayas, Assam, Burma (except South Tenasserim), Southern China, Tonquin, Siam and Cambodia.
5. *The Malayan Subregion* : South Tenasserim agrees best with the Malay Peninsula and should be included in the Malayan subregion of the Oriental Region.

After Blanford (1901), the only comprehensive attempt to divide the Indian subcontinent into zoogeographical subdivisions was that of Smith (1931-43) in his *Fauna of British India* on reptiles and amphibians. The limits of British India dealt with earlier by others (Gunther, 1858, 1864; Elwes, 1873; Wallace, 1876 and Blanford, 1901) were confined to the main landmass of the Peninsula of India as far east as Bengal at about longitude 90° and south of the Himalayas. Smith's volumes on reptiles cover a much larger geographical area, and include the whole of the Indo-Chinese Peninsula as well. In support of his departure from the usual practice, Smith (1931-43) observed that "The fauna of Siam, French-Indo-China and Southern China is so closely allied to that of Burma and Assam that it would be scientifically incorrect to separate them from one another. Together with Assam and eastern Himalayas they form a natural subregion and it is only right that they should be considered as a whole" This is true of other groups of animals also. Not only is the fauna of Burma closely allied to that of Siam, French-Indo-China and Southern China but the same can be said with regard to the fauna of the Eastern Himalayas and the Malabar tract of the Western Ghats.

Thus, Smith's zoogeographical area of the Indian subcontinent included the Indo-Chinese subregion. The Indian subregion includes the Peninsula of India as far as latitude 90° east and south of the Himalayas and it has been divided into seven geographical areas as follows:

1. *The Desert area of North-West India* : This includes Baluchistan, the North-West Frontier Province, the Punjab,* Western Rajasthan as far as

* The Punjab of earlier times was split in 1947 into W.Pakistan and Punjab (India).

the Aravalli range and Sind. The area is desert or semi-desert except near the rivers.

2. *Kashmir and the Western Himalayas upto Nepal* : Most of the country is mountainous and elevated.
3. *The Gangetic Plain* : The great Gangetic Plain of northern India, through which flows the Ganges, extends from the valley of the Indus in Sind to the right bank of the Brahmaputra in Bengal. Geologically, it separates the Himalayas from the lands of the Peninsula. Its fertile alluvial soil is for the most part cleared, cultivated and thickly populated.
4. *Central India* : This comprises the tract lying between the Gangetic Plain and the Deccan, and bounded on the west by the Aravalli range and on the east by the Chota Nagpur plateau.
5. *The Deccan* : The greater part of the Peninsula of India between 12° and 21° north latitude is formed by the central table-land of the Deccan. It is bordered on the west by the Western Ghats, sloping more gradually eastwards on the side of the Peninsula.
6. *The Mountains of the Malabar tract and Sri Lanka* : Although geographically a part of the Western Ghats, the hills south of latitude 12° differ markedly from those north of it, both in geological structure and general physiography. Together with the mountains of Sri Lanka they constitute a distinct faunal region.
7. *The Chota Nagpur Area* : This includes Bihar south of the Gangetic plain, the northern part of Orissa, and the eastern part of the Central Province. The area is mountainous and except the neighbourhood of Chaibasa, where industrial occupations have sprung up in recent years, is highly forested and sparsely populated.

Indo-Chinese Subregion

1. *The Eastern Himalayas* : These extend from the western frontier of Nepal to the termination of the range at the bend of the Brahmaputra. The area is more tropical and more heavily forested than the Western Himalayas, conditions which have no doubt influenced the faunal distribution.
2. *The Trans-Himalayan Mountainous Area* : This includes the hills of Assam east of the Brahmaputra, the whole of Burma except the lowlands in the south, and the northern part of Siam.
3. *Annam*.
4. *The Peninsula of Indo-China* : This area includes the lowlands of Burma south of Prome and Toungoo and at the mouth of the Salween and the great river valleys of Siam, Combodia and Cochin China.

5. *The Tenasserim and Peninsular Siam* : This area corresponds to the Tenasserim and South Tenasserim tract of Blanford and includes the mountain chain which extends down the Peninsula.

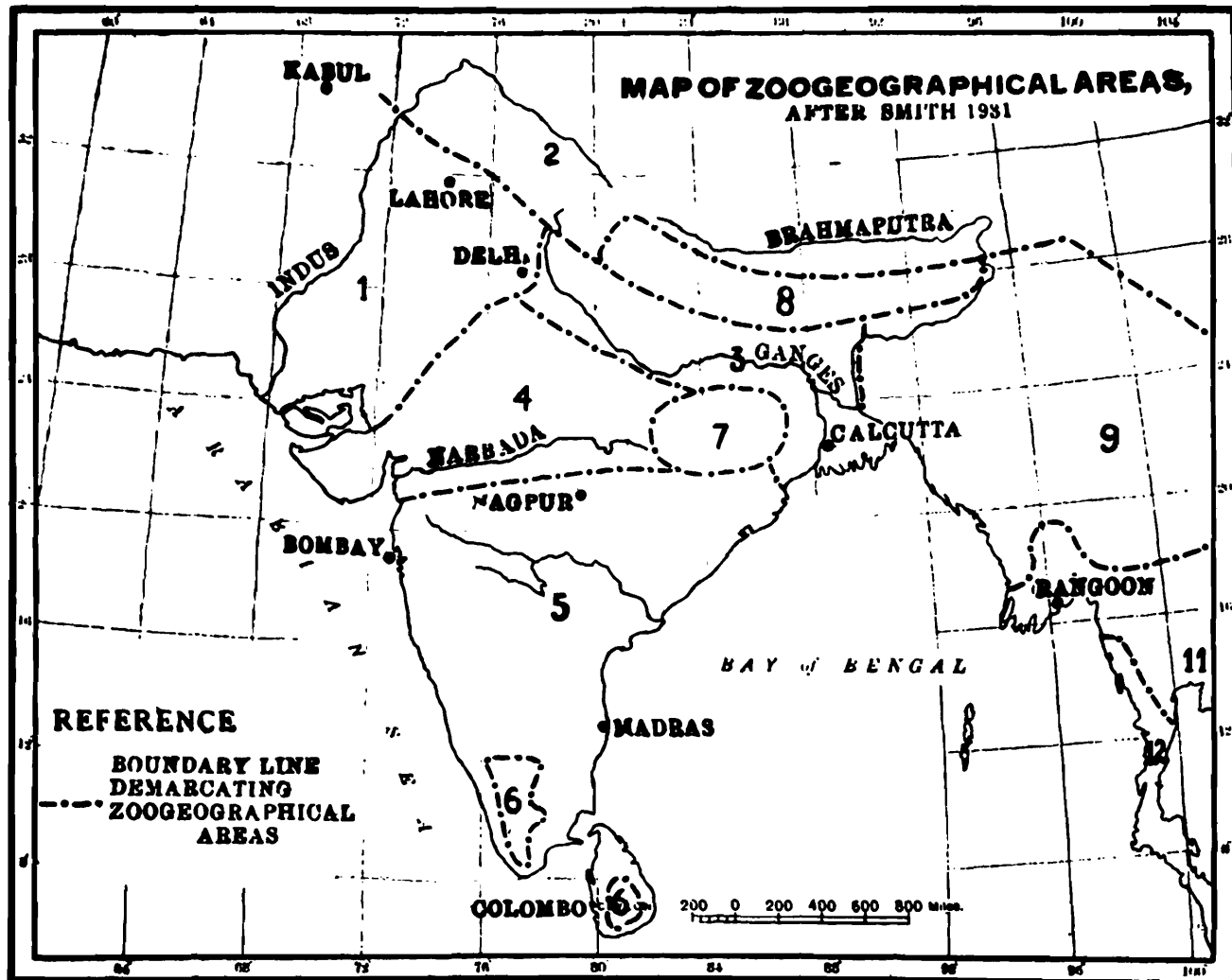


Fig. 1 Malcolm A. Smith's Zoogeographical areas of the Indian subcontinent, including the Indo-Chinese subregion.

After Smith, Mahendra (1939, 1984) on the basis of the distribution of amphibian and reptilian species recognised the following 10 zoogeographical subregions within the limits of the Indian subcontinent:-

1. *The Arid or Semi Arid Province of Northwest India* : This comprises Baluchistan, the Northwest Province, the Punjab, Western Rajasthan as far as or slightly further than the Aravalli range, the Peninsula of Cutch and Sind.
2. *The Western Himalayas* : Consists of Kashmir, Simla, Kumaon and Garhwal districts, adjacent mountainous regions of Western Tibet, alpine Punjab etc.
3. *The Trans Gangetic Province* : This consists of northern parts of Bihar and Bengal, the whole of Assam, Burma approximately north of 20° latitude, Nepal, the Himalayas east of Nepal and the country further eastward.

This province includes two areas of Smith, *viz.*, the Eastern Himalayas and the Trans-Himalayan Mountainous area.

4. *The Southern Burmese Province* : This includes Burma south of 20° latitude.
5. *The Gangetic plain and adjacent country as far south as 20° latitude* : This includes an area of the Gangetic plain and a part of the plateau adjoining it, up to a line drawn from Bombay to Puri. According to Mahendra, the importance of this upland area is in delimiting the poor northern fauna from the rich characteristic Peninsular fauna.
6. *South India below 20° latitude excluding Travancore Province* : The country roughly south of 20° latitude is faunistically distinct from that to its north.
7. *The Travancore Province* : Consisting of the hilly country south of latitude 12° or 13° on the west, and south of the Coleroon river in the east. The distinctness of this division is well recognised, the fauna being extremely rich in endemic forms. The number of characteristic genera and species is extremely large. The province, although differentiated adequately by many forms absent from Ceylon, has much in common with Ceylonese area.
8. *Ceylon* : Ceylon forms a distinct zoogeographical province, with clear affinities to Travancore subregion.
9. *The Andaman Island* : Besides having a few endemic forms which differentiate this fauna as separate from others, the Andamans are faunistically allied to Burmese subregion on the one hand and to the Nicobars on the other. There are hardly any endemic genera.
10. *The Nicobar Island* : The fauna of Nicobar has been derived rather recently from the Andamans. The fauna of the Nicobar is not allied to the Sumatran types.

Comparing the above three zoogeographical divisions of the Indian subregion it will be seen that there is considerable general agreement between them. However, judging from the present day distribution of freshwater fishes, Smith's classification would seem to be a better arrangement of the zoological areas into which India west of the Brahmaputra can be divided. The present day zoogeographical divisions of India reflect the changes which the country has undergone in the past. Ecologically the Indo-Chinese subregion is closely allied to the Malabar Tract and Ceylon and also resemble the Western Ghats and the Chota Nagpur plateau. It is quite reasonable, therefore, to conclude that in the migration of the fauna and development of the present day features of India's physical geography, areas are formed where similar or identical species could survive undisturbed under environmental conditions more or less similar to those under which they have lived over a much wider area (Hora, 1948a). The present day distribution of the fauna and the biological peculiarities of the fauna give us abundant material for restoring the palaeogeographical conditions, mostly of the

Tertiary and Quaternary periods. This point shall be illustrated when dealing with certain aspects of the palaeogeography of India which enabled the development of the present day zoogeography of India.

Origin and Spread of Fauna of India

Peninsular Fauna

One of the most remarkable feature of the zoogeography of India is the occurrence of the Malayan element in the fauna of Peninsular India. This element is rich in species and genera of practically all groups of animals which are found in the hills of Peninsular India and Sri Lanka on the one hand and in the Eastern Himalayan hills of Assam and Burma and further east on the other. The absence of the Malayan fauna from the rest of India and this present day discontinuous distribution of a large assemblage of genera and species of Malayan affinities have long attracted the attention of naturalists (Medlicott and Blanford, 1876; Sarasin, 1910; Stephenson, 1921, 1923) and efforts have been made to explain the causes of these similarities (Hora, 1949a). One of the important explanations proposed is the well known Satpura Hypothesis by Hora (1937).

To understand the origin and evolution of this Peninsular fauna one should have an adequate knowledge of the palaeogeography and palaeontology of the earth in general and of India in particular. An overview of these aspects is therefore presented here.

Geography of the Past

At the close of the Palaeozoic (225 millions years ago) all the continents were united in a supercontinent called Pangaea, encompassing the entire crust of the earth (Wegener, 1929). By the late Triassic, about 180 million years ago, Pangaea began to break into two land masses: the northern Laurasia (Angara) and a southern Gondwanaland, separated by the Tethys sea. Another important rift was aligned north south and caused South America and Africa to split from the remainder of the Gondwanaland. India by then severed from Antarctica. At the close of Jurassic, about 135 million years ago, Laurasia was still one unit, with North America and Europe joined at the northern end, so that a widening North Atlantic ocean occupied what are today its southern reaches. A land connection existed in the area of Spain and Morocco, while South America and Africa had an expanding South Atlantic ocean between them. Antarctica to which Australia was joined had separated from Africa. During the early Cretaceous, sea floor spreading further opened the North Atlantic and Indian oceans. The Tethys sea narrowed at its eastern end, the plate convergence here creating active Alpine-Himalayan uplift movements. At the same time South America finally separated from Africa but had remained connected with Antarctica and thence to Australia till the end of Cretaceous.

In the Middle Eocene, about 45 million years ago, Australia separated from Antarctica and India butted into Eurasia. The consequent buckling and folding produced the West-east chain of the Alpine-Himalayan mountain systems stretching from West Europe to East Indies. Final elevation of this system took place in the Pliocene and Pleistocene and the process is continuing. The rising Himalayas have effectively separated India from Eurasia.

In the Quaternary period, about 1.6 million years ago, Eurasia and North America were connected via the Bering land bridge. North and South America were joined by the Panamenian Isthmus. Africa and Europe were linked through the Middle East, while Antarctica and Australia became separate continents.

Extent of Gondwana Element to Tropical Southeast Asia

Peninsular India, separated from the Gondwanaland in the late Jurassic or Liassic times, before advanced mammals had evolved, does not seem to have contributed its distinctive fauna to the tropical biota of Eurasia when it joined that continent in the Eocene, about 45 million years ago. On fossil evidence it is concluded that the rich Gondwana fauna flourished, before India joined Eurasia, died out through the intensive desiccation during the upper Triassic-Jurassic periods and partly by the lava-flows of the Deccan during the Cretaceous. Only certain micromammals and certain groups of teleostean fishes, remnants of the rich Gondwana fauna had, however, lingered along with dinosaurs in the estuarine marshy regions of the Pranahita-Godavari Valley of the Andhra Pradesh which also ultimately perished there for want of suitable environmental conditions for their survival (Yadgiri and Prasad, 1977).

However, while the dinosaurs, micromammals and fishes of the Gondwana died out in the Peninsula, several invertebrate groups of animals including insects (Mani, 1974 : 614) seem to have survived in the Peninsular India. They seem to have escaped the effects of lava-flows by retreating to areas south of the Deccan trap. In the south in Madhya Pradesh and Andhra as far as Sri Lanka a number of valleys interspersed with forests, lagoons, marshes, remnants of the earlier Mesozoic period, must have most probably presented environmental conditions suitable for their survival. Subsequently in the Quaternary or the Holocene they seem to have recolonised the entire Peninsula. The Holocene conditions were probably most ideal with the river systems being fully established as at present. There were no marked orogenic movements either.

India had a varied angiosperm flora in the early Eocene (Lachanpal, 1970), soon after it became united with Asia. Apart from the presence of the Proteaceae there is little evidence of Gondwana angiosperms (Chlorophyceae) in the early Eocene flora, and it seems more likely that it dispersed to India from Asia. The Indian flora to-day is dominated by flowering plants found also in South-east Asia, and it contains no endemic families (Mani, *loc.cit.*, p.159).

The fauna of the Peninsular India especially the isolated plateaus in the southern India and the mountains of Sri Lanka is closely allied, as has been pointed out earlier to the fauna of South-east Asia especially South China. The spread of this fauna is explained in terms of the Himalayan uplift and the changes in the climatic conditions of the Pleistocene in a succeeding section.

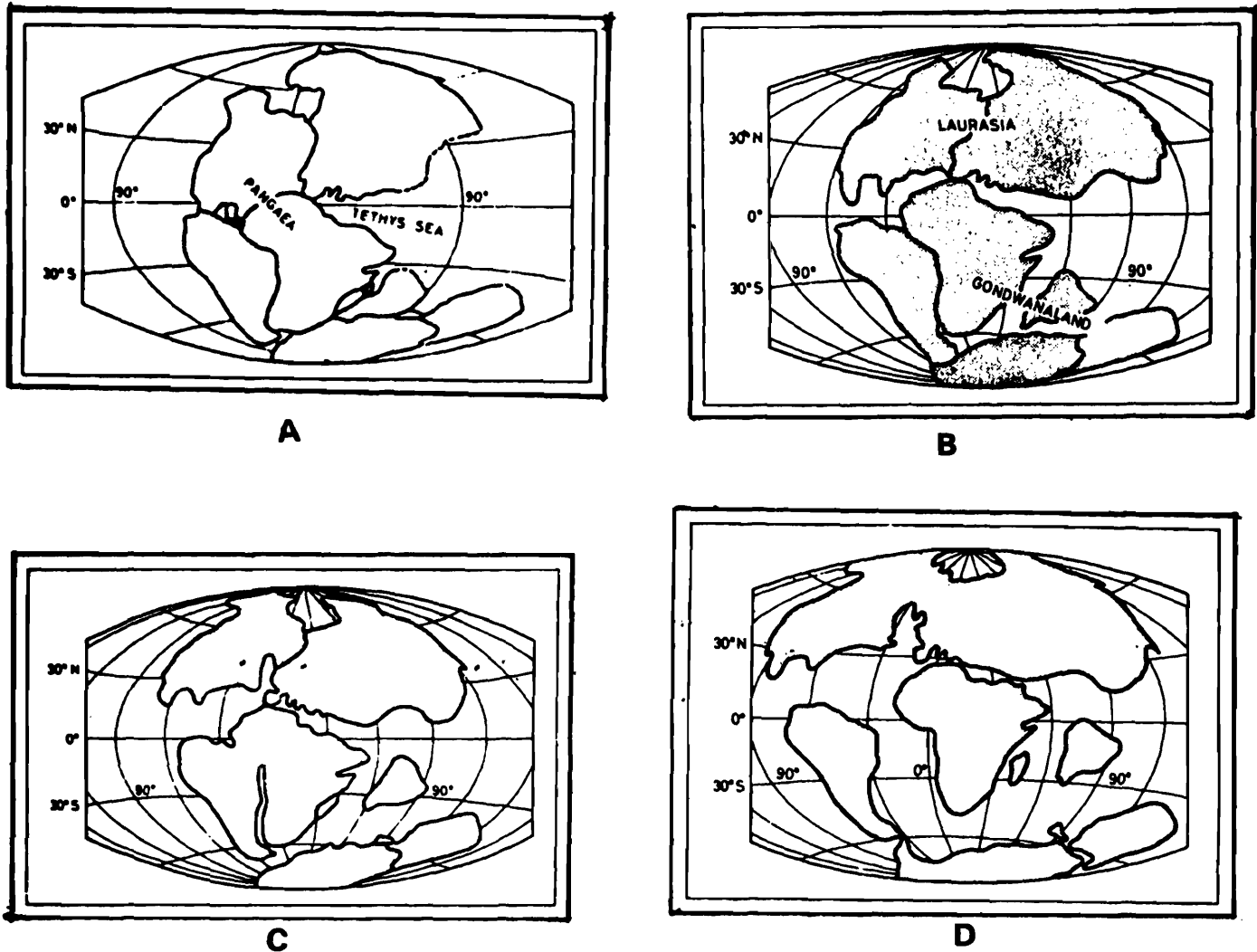


Fig. 2 Continental drift and configuration and oceans from Late Permian to the present day.

(After Dietz and Holden, 1970)

A. Late Permian, 225 million years ago., B. Late Triassic, 180 million years ago.,
C. Late Jurassic, 135 million years ago., D. Late Cretaceous, 65 million years ago.

Extent of Ethiopian Element to Peninsular India

A vast tropical area extended from North Africa to Southeast Asia during the Oligocene-Pliocene periods. Three land masses contributed to this vast tropical areas of Africa, India and Southeast Asia. Of these, as has been shown, only Southeast Asia was part of Asia for both India and Africa were originally part of the Gondwanaland. After 100 million years and a movement involving 9000 km northward, India collided with Southern Asia in the Eocene, about 45 m years ago, the collision raising the great Himalayan mountain chains. Africa, though formed part of the Gondwanaland had, however, never lain far from southern

Eurasia, shallow seas separating the two continents until they dried up some time in the Miocene, 17 million years ago, creating a vast single intercontinental series of tropical areas stretching from Western Africa to Southeast Asia. Many elements of the tropical biota became widespread throughout this region and even northwards to higher latitudes of Eurasia, before the late cenozoic cooling of the Northern Hemisphere started.

Most of the early placental mammals evolved in the Northern Hemisphere in the beginning of Cenozoic and spread southwards into Africa as and when that became possible in the Palaeocene or Eocene. Though the shallow seas separated Africa from Eurasia certain placental mammals seem to have managed to enter Africa from the north and by late Eocene or early Oligocene two different faunal groups had already evolved there (Coryndon and Savage, 1973). One group consists of the elephants, hyracoids, aquatic sirenians and the extinct embriothopods, all differentiated from an early ungulate stock that had entered Africa in early Eocene. The other group included artiodactyls, creodonts, insectivores, rodents and early members of the anthropoid primates.

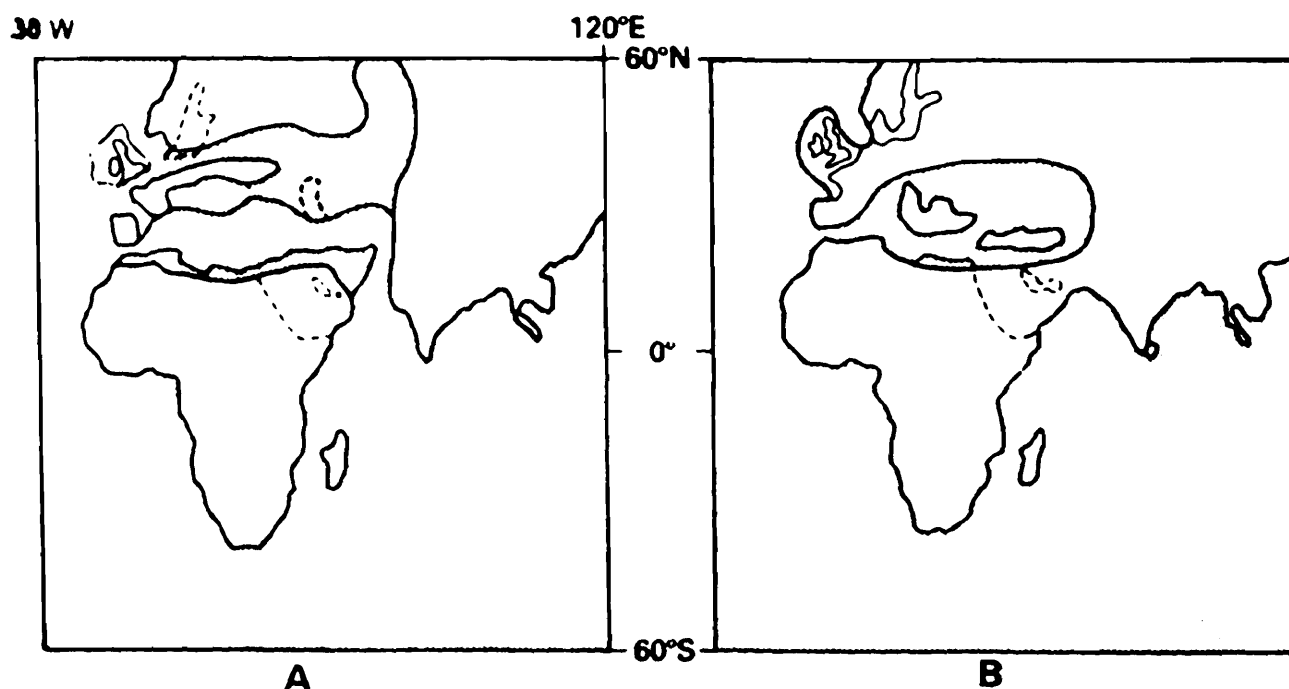


Fig. 3. Evolution of tropical belt of Africa, India and Southeast Asia.

A. Early Oligocene, 30 million years ago, after India had joined Eurasia but before Africa also had become connected. B. Mid-Miocene, 15 million years ago, after Africa had become connected but before the development of the Red Sea and Persian Gulf (After Smith and Briden, 1977).

In the early Miocene the shallow seas that had isolated Africa and tropical Eurasia withdrew, and there was a great increase in the biotic exchange between

the two areas, along the forested route that ran directly from the northeastern Africa along the southern margin of Arabia to Western India (*Vide* Prashad, 1942).

Primitive primates such as lemurs and lorises as well as old world monkeys and porcupines, apes, rhinoceroses, elephants and pangolin all seem to have migrated to India and further diversified in the Siwalik region as evidenced by the Siwalik fossils (Osborn, 1936).^{*} Each group, however, is represented by different genera in the two areas. For example, African rhino, elephant and porcupine all belong to genera different from those found in the Oriental region. Similarly, the lemurs of Madagascar and Chimpanzees and gorillas of Africa are not found in the Oriental region. These groups are represented by orangutan and gibbon in the Oriental region.

The direct route between Africa and India was, however, interrupted by the formation of the Red Sea in the Pliocene and by the extension of deserts in the Middle East. The uplift of East Africa in the Late Miocene and the consequent dryness of the area reduced the eastern extension of the great belt of African rain forest. This dryness of the regions had caused the isolation of the original forest fauna of Africa and that of the Indian. Since late Cenozoic the spread of African biota to India ceased. There is no evidence of any African element having spread to the Indian subcontinent since then.^{**}

No such climatic changes affected the tropical forests of Southeast Asia and the Indo-Chinese subregion, especially the South China, is considered as the Centre of Origin of the fauna that spread to India.

Pliocene Geology and Spread of Fauna

The earlier Gondwana fauna of Peninsular India becoming extinct, the chances of further invasion of fauna from S. E. Asia to India was relatively less till the glacial periods of the Pleistocene (Menon, 1987). Geologists have shown that transgression of the Bay of Bengal during the Mid-Miocene cut off the land route between India and Burma and it lasted the whole of Miocene. During this period no faunal exchanges took place between Southeast Asia and India (Hora and Menon, 1953). It is known (Menon, 1951a) that during the Pliocene wet tropical

^{*} The interchange of mammal fauna between the Siwaliks of India and E. Africa is a well known fact. The migration of some mammals took place from India to Africa during the Miocene-Pliocene period. Of these the most characteristic family is the Bovidae which spread to Europe and Africa during the Pliocene. Certain tragulids like *Hyaemoschus* also interchanged from the Siwaliks to E. Africa. Certain forms of the group Suidae, Giraffidae also appeared to have migrated from India to Africa. *Okapia* a giraffe derived from earlier form of giraffes in India is living today in Africa (Colbert, 1935).

^{**} The Peninsular forms of lower of animals with pronounced Madagascan African affinities (Mani, *loc. cit.* : 628 and Prashad, *loc. cit.*, p. 426) are probably Gondwana element. There is no Ethiopian element in the fish fauna of Peninsular India. The Cichlids present in the Peninsula are remnants of the Gondwanan fauna.

conditions prevailed along the southern face of the Himalayas, extending to China in the east and beyond Baluchistan towards the west, facilitating migration of the fauna. Siwalik ecological conditions became established along the base of the Himalayas and dispersal of fauna was entirely along the Himalayas.

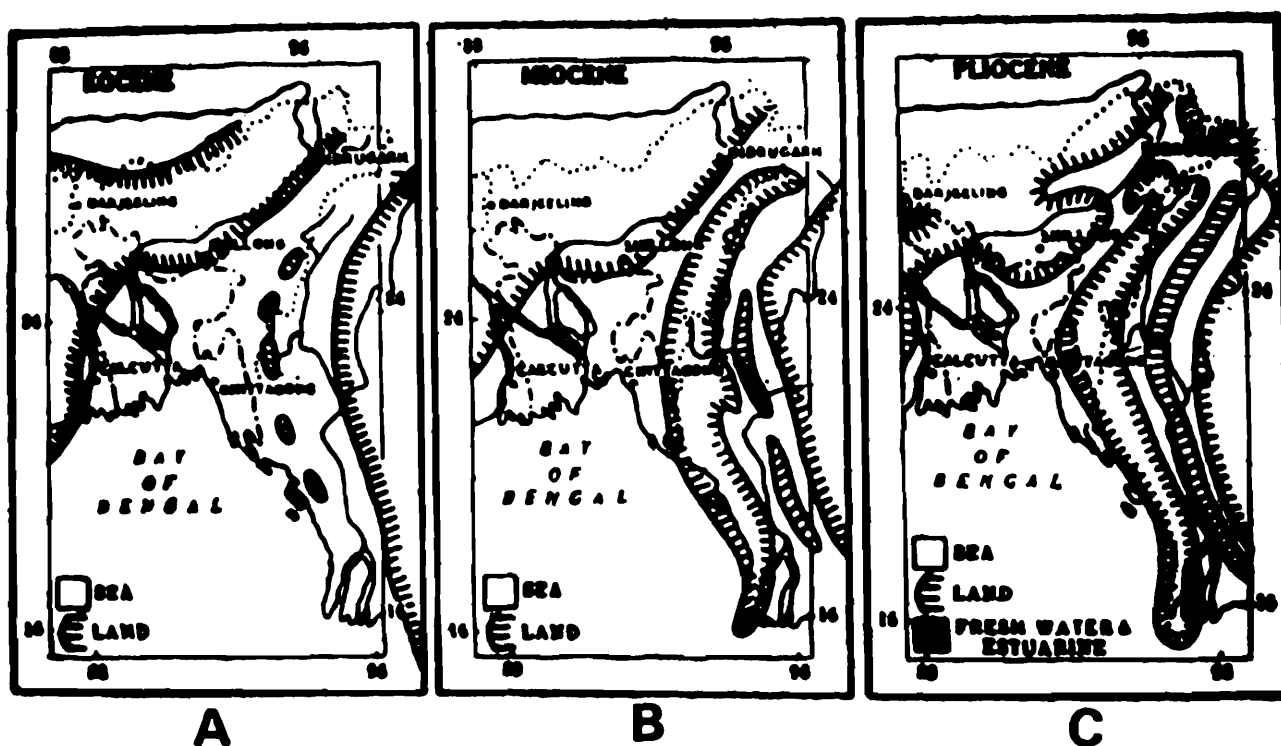


Fig. 4. Transgression of the Bay of Bengal during the A. Eocene, B. Miocene and C. Pliocene periods (After Krishan) (*Bull. nat. Inst. Sci. India*, 1 :26-28, 1952).

Pleistocene Ice-Age and Spread of Fauna

Geologists Medlicott and Blanford (*op. cit.*), have used faunal and floral evidence and the presence of Malayan elements in the Peninsula as collateral evidence of a cold period having affected India in the late Tertiary or Post-Tertiary times.

In India, the glaciers of the Kashmir valley descended to the present elevations of 1676 metres (5500 feet) during the first and second glacial periods (Hora, 1949 b). In the central and eastern Himalayas there are definite signs of glaciation down to present-day elevations of 2133 to 2590 metres (7000 to 8500 feet). But these elevations were clearly not those that obtained during the Ice Age, because the Himalayas are known to have risen very considerably in the late Pleistocene and recent times. The uplift of the Karewas in Kashmir during the late Pleistocene indicates vividly the recent uplift of the Himalayas.

It is likely that the landmass in Northern India may have been from 304 to 914 metres (1000 to 3000 feet) lower in the early Pleistocene than it is now, and

that the glaciers must have descended to levels which were then much nearer sea-level. While the present glaciers of Karakoram and Himalayas have little effect on the climate of the Peninsula, it is reasonable to assume that with a snow line and glacial line probably 1828 to 2438 (6000 to 8000 feet) lower than what now prevails (allowing for glacial recession and isostatic rise) the temperature and humidity in northern India must have been markedly different. It is these climatic factors which had probably facilitated the migration of the Malayan fauna and flora to Peninsular India.

Distribution of Terrestrial Fauna

During the Pleistocene while the glaciers had come down to some 1828 to 2438 metres (6000 to 8000 feet) lower than at the present time, conditions in the montane and bordering zone of northern India must have resulted in a diminution of the temperature in the Peninsular India which had undoubtedly facilitated the spread of terrestrial fauna southwards as far as the Western Ghats and further south the hills of Sri Lanka (Prasad, 1968). But the glacial theory does not explain the distribution of the hillstream or torrential fishes of India whose distribution is influenced by certain dynamic ecological conditions. The factors affecting the distribution of freshwater fishes are quite different from those governing the distribution of terrestrial plants and animals. The former are generally restricted, according to their mode of life, to specific water channels or drainage systems and they remain restricted unless their habitats are by orogenic movements or stream captures. The latter are relatively so easily spread that the whole of India must have become ecologically fit, under pluvial conditions to support their uniform distribution and after the retreat of glaciers they had colonised the hill tops of the Peninsula where favourable ecological conditions prevails up to the present-day.

Distribution of Torrential Fauna

The earlier stock of present day freshwater fishes of India and other aquatic organisms seem to have invaded southeast Asia during the Eocene period but India began to receive the Malayan forms only during the Pliocene Siwalik period (Menon, 1973). The highly specialised torrential fauna developed much later, probably in the Pleistocene. The origin and distribution of this fauna is associated with late Himalayan orogenic movements (Hora, 1948a, 1952; Silas, 1952a, 1952b; Menon, 1987). There are 89 genera of primary freshwater fishes of which excepting 23 endemic genera, 66 can be traced to centres of dispersal in southwest China or Yunnan region. The migration of the fish fauna along the Himalayas took place between India and further east in the Pliocene. The Garo-Rajmahal Gap was still under the sea and did not permit the Pliocene fish fauna to migrate to the Peninsula. However, it has been found (Hora, 1951) that during the glacial periods the level of the gap became several hundred feet higher due to the lowering of the sea level, as a result of the formation of icesheets on the continents and the expansion of the Antarctic icecap. Owing to the increased

precipitations, less evaporation and greater runoff in the warmer latitudes during the glacial periods favourable ecological conditions prevailed for the dispersal of torrential fishes across the gap. There were 5 invasions of fishes to Peninsular India corresponding to the 5 glacial periods of the Pleistocene (Silas, 1952a) and it is quite possible that the route of migration of torrential or other aquatic animals lay along the Narbada-Tapti drainage of the Vindhya-Satpura mountains (Menon, 1951b).

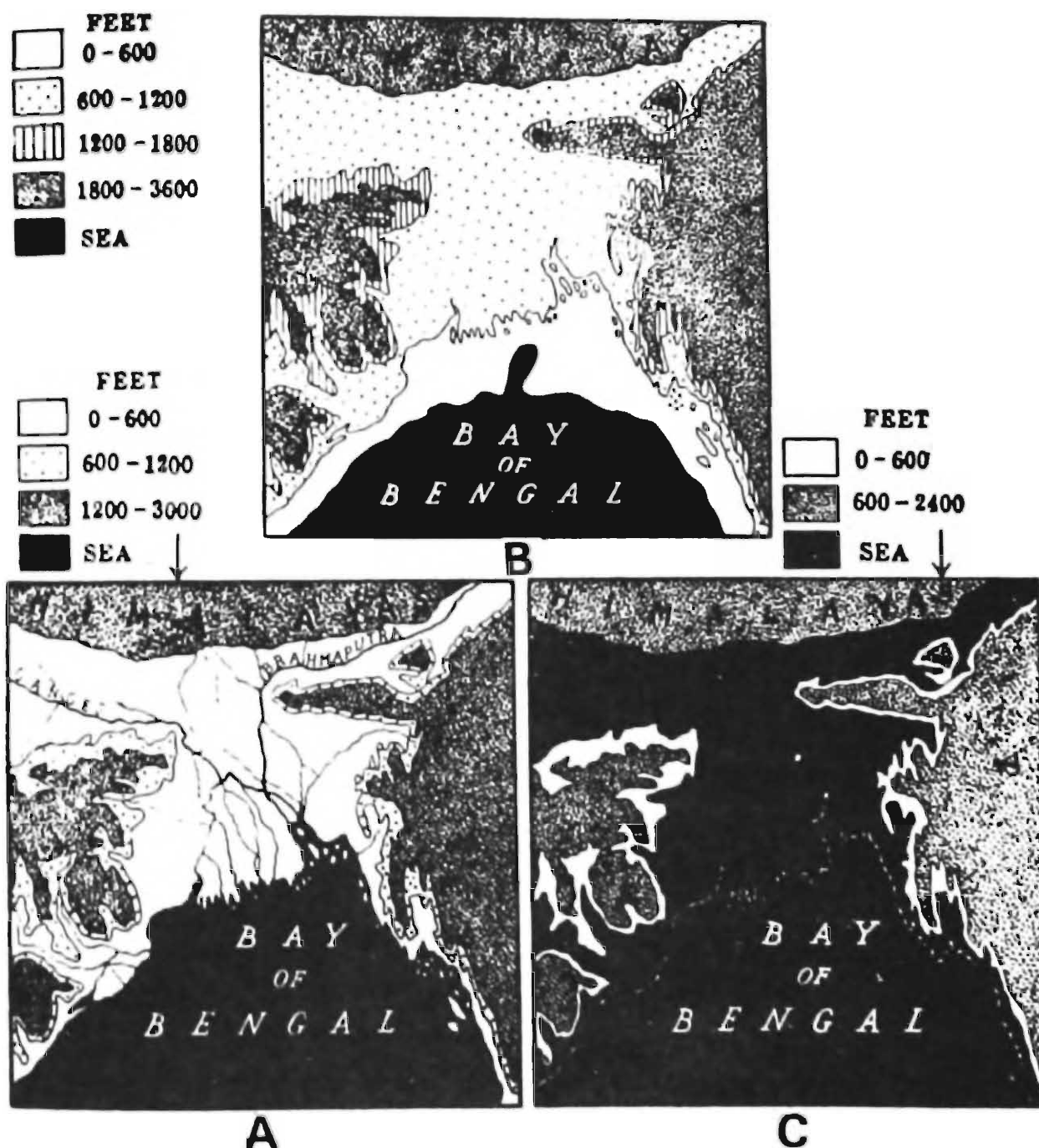


Fig. 5. The physiography of the Garo-Rajmal Gap.

A. Present day conditions. B Conditions during a glacial period. C. Conditions during an interglacial period (After Flora, 1951).

Conclusion

During the late Triassic, Pangaea began to break and India became separated from Africa in the late Jurassic. On the evidence of fossils, it can be stated that a rich Gondwana fauna flourished in India before the Indian subcontinent joined Eurasia, the fauna becoming extinct through intensive desiccation during upper Triassic-Jurassic periods, and partly by the lava-flows of the Deccan during the Cretaceous period. However, the micromammalian and dinosaurian fauna of the Pranahita-Godavari Valley represent the last remnants of the Mesozoic, since they do not persist into the Cretaceous except in the Coramandel coast of Tamil Nadu, where Cretaceous beds have been found to contain dinosaurs. The volcanic activity apparently did not affect the dinosaurian fauna in the Ariyalur-Tiruchirapalli area of Tamil Nadu, though they became extinct at the end of the Cretaceous.

The shallow sea that separated Africa and Eurasia dried up during Miocene and a vast intercontinental tropical area stretched from West Africa to Southeast Asia. The spread of deserts and semi-arid conditions prevailing in the late Cenozoic, however, divided this vast tropical area into a Western African and an Eastern Oriental Section made up of India and S. E. Asia resulting in the stoppage of Ethiopian fauna moving into India. The present day terrestrial and aquatic fauna of India appears to be Indo-Chinese. The spread of this fauna probably took place during the glacial periods of the Pleistocene which gave India Pluvial conditions and converted its plains into plateaus owing to the Eustatic movement of the sea.

References

- Banareseu, P. 1970. *Principles and problems of zoogeography*. Rumania: Science Academy Rumanian Socialist Republic, (in Rumanian), English translation for US. National Foundation by Nolit Publishing House, Yugoslavia.
- Blanford, W. T. 1870. Zoogeographical divisions of India, based to a great extent on a study of the distribution of land mollusca. *Journ. Asiat. Soc. Bengal*, 39, (2):336.
- Blanford, W. T. 1901. Distribution of vertebrate animals in India, Ceylon and Burma. *Phil. Trans. Roy. Soc. London*, (B) 194: 335-436.
- Colbert, E. H. 1935. Siwalik Mammals in the American Museum of Natural History. *Trans. Amer. Phil. Soc.* 26:1-397.
- Colbert, E. H. 1970. The fossil Tetrapods of Coalsack Bluff. *Antarctica Journal*, 5, No. 3. pp. ?
- Coryndon, S. C. & Savage, R. J. C. 1973. The origin and affinities of African mammal fauna. *Spec. Pap. Palaeontology*, 12: 121-1350.
- Elwes, H. J. 1873. On the geographical distribution of Asiatic birds. *Proc. zool. Soc. London*, p:p. 645-682
- Gunther, A. C. L. 1858. On the geographical distribution of reptiles. *Proc. zool. Soc. London*, p:p. 373-398
- Gunther, A. C. L. 1864. *The Reptiles of British India*. London.

- Hays, J. D., Salto, T., Opdyke, N. D. & Burckle, L. H. 1969. Pliocene - Pleistocene sediments of the 'equatorial pacific', their palaeo-magnetic biostratigraphic and climatic record. *Geol. Soc. Amer. Bull.*, 80: 1481-1514.
- Hora, S. L. 1937. Distribution of Himalayan fishes and its bearing on certain palaeogeographical problems. *Rec. Indian Mus.*, 39: 251-259.
- Hora, S. L. 1948a. The Distribution of Crocodiles and Chelonians in Ceylon, India, Burma and Further East. *Proc. Nat. Inst. Sci. Ind.*, 14, (6) : 285-310
- Hora, S. L. 1948b. Fundamental conceptions of zoogeography of India. *Bull. Nat. geog. Soc. Ind.*, 9: 1-19
- Hora, S. L. 1949a. Satpura hypothesis of distribution of the Malayan fauna and flora to Peninsular India. *Proc. natn. Inst. Sci. India*, 15(8) : 309-422.
- Hora, S. L. 1949b. Himalayan Glaciation and its effects on terrestrial and freshwater animal life in Peninsular India. *Bijdragen Dierkunde*, 28: 193-204.
- Hora, S. L. 1951. Some observations on the palaeogeography of the Garo-Rajmahal Gap as evidenced by the distribution of the Malayan fauna and flora to Peninsular India. *Proc. natn. Inst. Sci. India*, 17: 437-444
- Hora, S. L. 1952. Recent advances in the Geography of India. *J. Bombay nat. Hist. Soc.*, 51, (1) : 170-188.
- Hora, S. L. & Menon, A. G. K. 1953. Distribution of Indian Fishes of the past and their bearing on the Geography of India. 2. The extinct Freshwater Teleostean fishes of India. *Everyday Science*, 1: 105-113
- Lachanpal, R.N. 1970. Tertiary floras of India and their bearing on the historical geology of the region. *Taxon*, 19: 675-694.
- Mahendra, B. C. 1939. The Zoogeography of India in the light of herpetological studies. *Sci. Cult.*, 4(7) : 1-11
- Mahendra, B. C. 1984. Handbook of snakes of India, Ceylon, Burma, Bangladesh and Pakistan. *Ann. Zool.*, 22: 16-24.
- Mani, M. S. 1974. *Ecology and Biogeography of India*. W. Junk Publication, The Hague.
- Medlicott, H. B. & Blanford, W. T. 1876. *A Manual of Geology of India*, 2 parts. Calcutta.
- Mayr, E. 1969. *Principles of Systematic Zoology*. Mc Graw-Hills, New York.
- Mayr, E. 1971. Methods and strategies in taxonomic research. *Syst. Zool.*, 20(4) : 426-433.
- Menon, A. G. K. 1951a. Age of the transgression of the Bay of Bengal and its significance in the evolution of the freshwater fish fauna of India. *Bull. natn. Inst. Sci. India*, 1: 240-247.
- Menon, A. G. K. 1951b. Further studies regarding Hora's Satpura Hypothesis. 1. The role of the Eastern Ghats in the distribution of the Malayan Fauna and Flora to Peninsular India. *Proc. natn. Inst. Sci. India*, 17(6) : 75-97.
- Menon, A. G. K. 1973. Origin of freshwater fish-fauna of India. *Curr. Sci.* 42(16) : 563-556.
- Menon, A. G. K. 1987. *Fauna of India and adjacent countries : Pisces : Teleostei : Cobitoidea Vol. 1, Homaloptelidae (Noemacheilinae & Homalopterinae)*. Director, Zoological Survey of India, Calcutta.
- Osborn, H. F. 1936 (1942). Proboscidae. A monograph of the discovery, evolution, migration and extinction of the mastodonts and elephants of the world. *Am. Mus. Nat. Hist.*, New York, 2 Vols.
- Prashad, B. 1942. Zoogeography of India. *Sci. Cult.*, 7, (9) : 421-427.
- Prashad, K. N. 1968. The occurrence of *Hypselephas hysudricus* in the pleistocene deposits of Tinnevely, Madras State. *Cur. Sci.*, 32(18) 516-517.

- Sarasin, F. 1910. Über die Geschichte der Tierwelt Ceylon. *Z. Jahrb.*, 12: 1-190.
- Sclater, P. L. 1858. On the General Geographical Distribution of the Members of the Class Aves. *J. Proc. Linn. Soc. London (Zoology)*, 2: 130-145.
- Silas, E. G. 1952a. Further studies regarding Hora's Satpura Hypothesis. 2. Taxonomic assessment and levels of Evolutionary Divergences of fishes with the so called Malayan affinities in Peninsular India. *Proc. natn. Inst. Sci. India*, 18: 223-248.
- Silas, E. G. 1952b. Classification, Zoogeography and Evolution of the Fishes of the Cyprinoid families Homalopteridae and Gastromyzonidae. *Rec. Indian Mus.*, 50(2) : 173-264.
- Smith, A. C. & Briden, J. C. 1977. *Mesozoic and Cenozoic Paleaeontological Maps*. Cambridge Univ. Press, Cambridge.
- Smith, M. A. 1931-43. *The Fauna of British India*. Reptilia and Amphibia. Vols. I-III., London.
- Stephenson, J. 1921. Contributions to the morphology, classification and zoogeography of Indian Oligochaeta. 1. Affinities and systematic position of the genus *Eudichogaster* Michs and some related questions. 2. On polyphyly in the Oligochaeta. 3. Some general consideration on the geographical distribution of Indian Oligochaeta. *Proc. Zool. Soc. London*. 22 : 745-768, pl. XXVIII.
- Stephenson, J. 1923. *The Fauna of British India*. Oligochaeta. Taylor & Francis, London.
- Wallace, A. R. 1876. *Geographical Distribution of Animals*. 2 Vols. Hafner Publishing Co., London N. York.
- Wegener, A. 1929. *The Origin of Continents and Oceans*. 4th Edn. (1966 English translation), Methuen & Co., London.
- Yadgiri, P. & Prasad, K. N. 1977. On the discovery of new Pholidophorus fishes from the Kota Formation, Adilabad district, A. P. *Geol. Soc. Ind.*, 18(8) : 436-444.

Taxonomy in Agricultural Research

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The real aim of the present discussion is to delineate the exact role played by taxonomy in agricultural research, precisely speaking the agricultural entomology. To begin with, it is better to define and briefly discuss the origin and development of taxonomy upto its present status, because this would provide an opportunity for a better justification of the topic.

In the most simple words, taxonomy is the science that deals with naming and classifying organisms. This Greek term which means arrangement and law was first proposed by Decandolle (1813) for plant classification. The Latin term Systematics referring to classification was utilized by Linnaeus (1735) and was interchangeably used both for plant and animal classification. Later in 1961, Simpson restricted the term taxonomy to the theory and practice of classification while defined Systematics as the study of the kinds and diversity of organisms, including all relationship between them (Mayr, 1969).

While tracing the history of taxonomy it may be said that it is as old as man himself. As a matter of fact it is an inborn inherent characteristic of man. The genes responsible for the ability of naming and differentiating things must have been the first to be implanted on the chromosomes of Adam, the first man. The statement gets its confirmation in the Holy Quran. In the very first chapter (Surah Al-Baqr : Aayah 30-33), while explaining reason for the creation of human beings, it is said: "And when your God said to angels that he intends to create his viceroy on earth, the angels said, Will thou create one who will spread evil, fight and shed blood of each other. We are already here to obey and praise your greatness". The God said, 'I know and you do not know' Then he created Adam and taught him the names of all things. He then presented him before angels and asked them to tell the names of all things if they were true in their statement. The angels said, 'Thou are supreme, we do not know except what you have told us'. God then asked Adam to do the same which was done by him. After this God said, "did not I say that only I know what is there on earth and in the skies and also I know what you express and what you hide"

In these Aayah the most important phrase being, "the teaching of all names" Instead, the phrase, "all knowledge" could have been easily used. But this was

not done by the supreme, clearly indicating that naming of everything being the first essential step towards acquisition of knowledge. The latter will eventually be obtained over the ages and will get accumulated, obviously adhering to the same name. Nomenclature thus plays a pivotal role or is the foundation stone, over which, the library of knowledge is built up. It is from this library that the future workers retrieve knowledge as well as add whenever new informations are obtained.

The earliest scholars notably Hippocrates (460-377 B.C.) and Democritus (405-307 B.C.) had animals in their study and used to differentiate them by their body parts. However, Aristotle, as mentioned by Mayr (1968) was the first great classifier and was also father of logic. According to him, his thinking which is referred as essentialism, dominated till the period of Linnaeus. Several of the higher group-names like Diptera and Coleoptera proposed by Aristotle are in use even today. When we look at the history of taxonomy with respect to our country, we find that it has started about two centuries earlier than anywhere else in the world. Charak (600 B.C.) who is supposed to be the father of oriental medicine and biology, laid the foundation of biological sciences and provided the earliest classification of animals by differentiating them on the basis of their mode of birth. Prasastapada (500 B.C.) followed Charak's classification but he also introduced two additional categories of sexual and asexual animals. It is quite obvious that these systems of classifications must have been the result of considerable amount of initial taxonomic progress, *viz.* recognising and describing of various kinds of organisms. However, a more detailed classification was developed during 500 A.D. by a Jain lady biologist who divided animals on the basis of senses possessed by them. Incidentally insects appeared within those groups which were characterised by having two to four senses. (Sinha and Shankararayanan, 1955).

By the middle of nineteenth century there had been considerable amount of progress at the alpha level of taxonomy and at this stage the student of diversity namely Darwin could put forward the theory of evolution. Obviously it was the outcome of comparative anatomy, which could be rightly considered as an offshoot of taxonomy. The end of nineteenth and beginning of twentieth century witnessed the technological revolution with the introduction of sophisticated microscopes. This led to the study of micromorphological characters and also instigated workers to go deeper in the study of function, behaviour, biology and life histories. Further, efforts were made to explain the biological functions on the basis of physical and chemical characteristics. At the genetic level the segregation was first done on the basis of chromosomal configuration, but involvement of biochemistry led to the study of even DNA structure. Looking very impartially at all these developments till date, it will not be an exaggeration to say that all these modern branches of biology which constitute essential aspects of today's agriculture also, were the outcome of classical taxonomy alone. Had there been no taxonomy, there would have been no comparative morphology, anatomy, physiology, ecology, ethology, genetics and

the molecular biology. The history of taxonomy clearly indicates that the more deeper a taxonomist has gone in the study of diversity of organisms, a more sophisticated branch of biology has come into existence. But the most unfortunate fact remains that whereas the offshoots of taxonomy flourished and were given more recognition, the mother branch was forced to limit itself only for naming and classifying organisms and was never accorded its due place.

Keeping in view the ever growing needs of our population, all agricultural researches were directed to boost up food production. Branches like Agronomy, Soil Chemistry, Botany and Genetics together with Microbiology and Biotechnology are directly concerned with production programmes, whereas Entomology, Mycology and Plant Pathology and Nematology try to achieve this through protection researches. However, for both approaches varying degree of taxonomy is inevitable. Each specialized branch of agriculture is employing techniques through various research projects to achieve the common target of enhancing the food production but always with respect to a particular crop or a group of organisms including insects and other arthropods, pathogens and nematodes. For instance agricultural scientists are always dealing with questions like which fertilizers for which crops? Which type of soil is more suitable for any given crop? Which crop varieties can be recommended for a particular geographical region to obtain maximum yield? Which favourable genes to improve a crop? Which effective insecticides for which pests? What all kinds of insects or other organisms are associated with any crop? Which pathogens are spread through which vectors and which nematodes are found on which crops? It is quite obvious that certain amount of taxonomy is a must in solving all such questions and unless we acquire that, results are not going to be favourable.

With the advancements made in various branches of agriculture, the needed degree of taxonomy has also proportionately increased. Recently during May, 1990, while delivering Dr. Paul's memorial lecture at IARI, the well known agricultural scientist Dr. M.S. Swaminathan very categorically asserted that the need to have expert systematics was never so great as it is today. He made this remark with reference to conservation of biological diversity. He said that today when we have the expertise to transfer favourable genes from wild varieties of crops to cultivated ones, with a view to make improvements, we badly need the services of trained and experienced taxonomists who could help in identifying and maintaining a gene pool for future researches. If this is not done, we are likely to lose many of our natural resources.

A more stronger statement could be made with respect to insects, keeping in view the vastness of the group and its proportion in the animal kingdom. The relative size of the major groups of organisms excluding bacteria, fungi, and algae as given by T.R.E. Southwood (1978) shows that where there are 0.3 million species of plants, the number of known species of insects exceeds 0.8 million. Naming and describing of such a huge number of plants and insects and putting them into a system of classification is itself an extraordinary achievement of taxonomy.

An applied field entomologist is certainly not interested in faunistic attainments with respect to a particular group of insects. But surely, he would like to know the accurate identification of the insect species he is currently dealing with. It is not too long when applied workers would not attach any importance to identification because they were sure to control insect pests with potential pesticides. Thanks to the continued efforts of several devoted spokesmen of Systematics including Essig (1942), Schmitt (1953), Mayr (1968), Sabrosky (1970), Ross (1971), Rosen and De Bach (1973), Kosztarab (1975) and several others who could create an awareness among applied workers and made them to realize the significance of taxonomy. The most frequently asked question: what good are identifications? is no more asked. Because now they know that it is only through taxonomy that they know what is good or bad, it is only taxonomy which enables them to distinguish between a harmful sawfly and a useful honey bee and it is only taxonomy that tells them the difference between a phytophagous and parasitic chalcid.

In agricultural research especially pest management, an identification means much more than just providing a name. As soon as a name is provided to the concerned insect species, we are automatically provided with a ready access to the desired informations already available in the literature with respect to nomenclature, its synonymies, biology, bionomics, host range, distribution, natural enemies and even control measures. In the absence of an accurate identification one is bound to be misguided. He will be led to wrong informations or he may have to spend lot of his time and energy in carrying out researches which may prove to be just repetitions and finally when knowledge is obtained, it is likely to be associated with a wrong name. Rosen and De Bach (1973) very rightly stated, "the time and efforts of biological control workers have often been uselessly wasted due to inadequate systematics of the pest species. Unfortunately popular judgement in such cases is likely to be that biological control has been tried and failed". In biological control programme the misidentification of an exotic pest species will send workers to a wrong place in search of its natural enemies; likewise the misidentification of an introduced enemy against a serious pest will also result in a total failure.

While identifying hymenopterous insects for various correspondents at IARI, on several occasions, the status of the concerned species had to be changed after identification. For instance in one of the consignments when insects were received from the concerned scientist, they were reported to be destroying the seeds of red clover but when identified, they proved as parasites on another phytophagous hymenoptera which somehow could not be noticed during the survey. A similar situation is faced with a variety of Pteromalids which are parasites of storage pests but so often they are mistaken as harmful to grains. Various species of the genus *Eurytoma* (Eurytomidae: Chalcidoidea) are both parasitic as well as phytophagous and hence an accurate identification alone can decide their exact status with respect to a crop. There are many instances within microhymenoptera where species under the same genus might be acting as primary, secondary or even

territory parasites and unless these are correctly identified their exact role with respect to any host can not be ascertained.

Entomologists engaged in pest management programmes will be greatly handicapped if they do not have the services of expert taxonomists. We know that every species behaves in its own peculiar way in a ecosystem and hence a control schedule evolved for 'A' may prove to be a total failure for another closely allied species 'B'. Associated with a crop there may not be just few serious pests but a large community living in total harmony including many which are not allowed to become serious due to a natural balance amongst them. It was pointed out by Kosztarab (1975) that for systematics the most important feature in the concept of pest management is the emphasis on knowing the entire ecosystem before adversely affecting the populations of different species. Since pest management deals with the populations and communities, the accurate identification of pests and their parasite-predator complex is critical. Such a situation was very nicely illustrated by Wiers and Chiang (1973) who prepared a food web for the cabbage crop, showing as many as 210 inhabitants living in a community. There were 125 species of insects including 10 plant sappers, 11 leaf feeders, 4 root feeders, 12 saprobes and 79 saccharophiles. These 125 species were predated or parasitized by 75 species and the latter again had 10 species as secondary parasites. It is quite obvious that under such a situation how important it is to have accurate identification of all the biological units in order to establish their exact status, finally leading to a successful control of any pest species at one time. If this is not done, there is every possibility of disturbing the natural balance and consequently this will result in resurgence of additional pests.

The recent pest management strategies include the use of hormones, pheromones, manipulation of ethological characteristics such as using sound at a desired decibel to cause inhibition in mating behaviour, use of male sterile technique and use of resistant crop varieties. It is quite obvious that all these methods are species specific or species dependent and only an accurate identification of the species in hand can help us to evolve a successful control programme. A slightest error will mean a total failure with loss of time, energy and money.

As already mentioned, the most extraordinary job done by taxonomists is the naming, describing and ordering of about a million species of insects. A system evolved for their classification not only facilitates identification but also provides certain degree of predictability. Many of the groups are well known for their habits such as members of the families Trichogrammatidae and Mymaridae are exclusively egg parasites. Eurytomid genera like *Bruchophagus*, *Tetramesa* and *Systole* contain species which are all phytophagous. Similarly, all the described species of an encyrtid genus *Acerophaga* are parasites of mealy bugs. It will, therefore, be easy to make predictions that as such undiscovered species of these groups will also be behaving like the known ones. General

maintenance of insect collections including regular augmentations, incorporation of nomenclatural changes and time to time revision is another great contribution by the museum taxonomists.

Taxonomists working on various groups of insects write monographs or prepare identification keys, catalogues, checklists and illustrated manuals as a result of their studies which are of great significance in the work of identification. On an international level, bulk of the identifications are done by the Commonwealth Institute of Entomology, London; British Museum Natural History, London; and U.S. National Museum, Washington. Within India such a service is performed on a regular basis by the Division of Entomology, Indian Agricultural Research Institute, New Delhi; Zoological Survey of India, Calcutta and Forest Research Institute, Dehra Dun. Most of the requests received at IARI are from Agricultural Institutes and Universities of the country and that way the identifiers are making great contribution in an applied sense since their identifications are utilized by agricultural workers to direct their researches along most positive lines.

A perusal of taxonomic literature produced especially in hymenoptera, to which the present author is directly concerned, shows that workers are mostly interested in the faunistics of various groups. Undoubtly such works are essential in attaining accuracy and increasing efficiency in our identifications but since these require considerably long periods, the agricultural workers so often suffer on this account. Agriculturists normally require immediate identification as soon as they spot an insect species doing some harm in the field. In case an immediate service is not available they take quick measures, possibly use insecticides, which invariably result in disturbing the balance of nature, thus creating newer problems. Therefore, it may be desirable to evolve short-cut methods where priorities should be made to collate taxonomic informations on all the biological units irrespective of their groups. Another method could be, as suggested by Viraktamath (1983), to revise genera on priority basis. He emphasized the need to prepare keys and illustrations of economic species and also proposed to deposit voucher specimens in recognised institutions.

In parasitic Chalcidoidea, the excellent faunistic work produced by Prof. M.S. Mani (1989) deserves all appreciations. This comprehensive work has tremendously increased the accuracy and efficiency of chalcid identification in the country but from the view point of agricultural entomologists, one of his earlier contributions entitled, "Biological notes on Indian parasitic Chalcidoidea" (1940) is considered more useful. This short booklet not only contains extremely valuable biological informations on important species of parasites but also provides excellent illustrations, enabling even a less experienced worker to draw conclusions rather quickly. Illustrated work of this nature produced by Chu, He and Wu (1978) entitled, "Atlas of Natural enemies of economic insects of China" and "An illustrated guide of some natural enemies of rice insect pests in Thailand (1982) compiled by K.Yasumatsu *et al.* are highly appreciated.

A similar attempt was made by Subba Rao (1983) who in his "Catalogue of enemies of some important planthoppers and leaf hoppers" has provided a key to the important species of *Anagyrus*, *Paracentrobia*, and *Oligosita*, accompanied by good illustrations and notes on distribution and hosts. Pigeonpea and Chickpea insects identification handbook by Reed *et. al.* (1989) is another useful contribution of applied value.

It is felt that a few more recommendations, if adopted, may result in more purposeful utilisation of taxonomy by agricultural scientists, e.g.,

1. Associated with each coordinated crop projects, there should be entomologists who will be responsible for the following jobs:
 - a. Survey and collection of all insects and mites associated with a crop.
 - b. Identification of the material through agencies like C.I.E., London, U.S. natl. Mus., Washington or through inland services like IARI, N.Delhi, Z.S.I., Calcutta and F.R.I., Dehra Dun.
 - c. Maintenance of voucher specimens for future reference as well as their distribution to various centres where taxonomists can carry out in depth study and help in the preparation of manuals or handbooks for speedy identification.
2. Efforts should be made to establish a strong Centre of identification in the country. The staff should comprise (i) Identifiers responsible for providing the identification service and (ii) Researchers to carryout elaborate revisionary taxonomic works on groups of agricultural importance. They should also solve problems of sibling species or biotypes wherever necessary.
3. Short term training programmes should be organized at Centres of taxonomy to extend basic taxonomic knowledge to applied entomologists associated with various agricultural projects.
4. Teaching of taxonomy should be made compulsory for all students of agricultural entomology so as to be utilised by them during their profession, resulting in maximum returns.

The present discussion will remain incomplete if appeal is not made for a greater cooperation and coordination among field entomologists and museum taxonomists. They should not think themselves to be independent as they are almost indispensable for each other. Informations provided by agricultural field entomologists help taxonomists to strengthen the taxonomy and facilitate quick and accurate identifications, whereas the latter are extremely helpful to the applied workers in carrying out the field researches along most purposeful lines.

References

- Chu, He and Wu, 1978. *Atlas of natural enemies of economic insects of China*.
- Essig, E.O.J., 1942. The significance of taxonomy in the general field of economic entomology. *J.Econ.Entomol.*, 35(5): 739-742.
- Kosztarab, M., 1975. Role of systematics collections in pest management. *Bull. Entomol. Soc. Am.*, 21(2): 95-98.
- Mani, M.S., 1989. *Fauna of India. Chalcidoidea : Hymenoptera*. Director, Zoological Survey of India, Calcutta.
- Mayr, E., 1968. The role of systematics in biology. *Science*, 159: 595-99.
- Mayr, E., 1969. *Principles of Systematic Zoology*. Tata McGraw Hill Pub.
- Pruthi, H.S. & Mani, M.S., 1940. Biological notes on Indian Chalcidoidea. *Misc. Bull. ICAR*, 30.
- Rosen, D & DeBach, P., 1973. Systematics, morphology and biological control. *Entomophaga*, 18: 215-22.
- Ross, H.H., 1971. Systematics and scientific understanding. *Bull. Entomol. Soc. Am.*, 17: 15-17.
- Sabrosky, C.W., 1970. Quo vadis, Taxonomy? *Bull. Entomol. Soc. Am.*, 16: 3-7.
- Simpson, G.C., 1961. *Principles of animal taxonomy*. Columbia Univ. Press, New York.
- Sinha, R.N. & Shankarnarayan, D., 1955. Concept of Insect taxonomy in ancient India. *Ent. News*, 16: 243-247.
- Schmitt, W.L., 1953. Applied Systematics. *Proc. Nat. Acad. Sci. Nat. Res. Council.*, : 4-12.
- Subba Rao, B.R., 1983. A catalogue of some important planthoppers and leafhoppers. *1st International workshop on leafhoppers and planthoppers of economic importance.*, CAB. : 385-403.
- Viraktamath, 1983. Genera to be revised on priority basis. The need for keys and illustrations of economic species of leafhoppers and preservation of voucher specimens in recognized institutions. *1st International workshop on leafhoppers and planthoppers of economic importance*, CAB.: 471-484.
- Wiers, R.W. & Chiang, H.C., 1973. Integrated control prospects of major cabbage insect pests in Minnesota- based on faunistics, host varietal and trophic relationship. *Tech. Bull. Univ. Minnesota, Agric. Exp. Sta.*, 291.

Taxonomy and Evolution

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Diversity in the organic world is easily discernible and on a larger scale, plants and animals are distinguished. There are myriads of living organisms of various sizes, symmetry, living styles, etc., and a comprehension of this seemingly complicated biological diversity reveals an underlying order. Primitive man's concept of this diversity was very much restricted. However, he could identify some of the common animals and plants and convey the same through common names. Man, through his inherent quest of knowledge, accumulated more details and applied descriptive names to differentiate living organisms. As the knowledge of biological diversity enhanced, it became complicated and cumbersome to discriminate organisms based on descriptive terms, which often run into a few sentences. A critical approach to distinguish animals was made by Aristotle in the 4th Century B.C. He described about 520 animals, which mostly included marine animals such as crustaceans, molluscs and fishes. He distinguished major animal groups and some of the names proposed by him like Cetacea, Cephalopoda, etc., are accepted even today. But it took another two thousand years for the development of a rational and systematic approach to understand animals and plants. Linnaeus, in his *Systema Naturae* introduced a more scientific method to identify animals and plants, and recorded 4162 species of animals. Linnaeus' work had stimulated further research in taxonomy, and a large number of species were added to those already recorded by him. Thus, Mobius in 1898 recorded about 415,600 species of animals. Present estimates put the total number of animal species at 1.2 million. If we include the microscopic protozoans and nematodes the total number would run into a few millions.

This large aggregation of animals can be organised into an easily comprehensible system by adopting a scientific and systematic approach. It is provided by applying methods and principles of Taxonomy, which is defined as "the theory and practice of classifying organisms" Some consider taxonomy as a biological jargon for the term systematics, which has taken its origin from the *Systema Naturae* of Linnaeus. Although certain experts give different definitions for each one of them, in general practice the two are used as synonyms. Taxonomy is perhaps one of the oldest branch of biology which was born out of

man's natural philosophy. It primarily involves ordering and classifying organisms, and the impact of other branches of biology has widened its scope.

The primary objective of taxonomy is to bring out the underlying order in the biological diversity by identifying, naming and arranging all organisms. It analyses their relationships and lays the foundation for an evolutionary interpretation of their origins and development. The theoretical part of taxonomy involves a number of concepts which has been defined and redefined by different authors at various times. According to his own concept a taxonomist identifies the collections and communicates the same by applying certain nomenclature for which there is an International Code.

Systema Naturae and the Linnaean Concept

Linnaeus is considered as the father of taxonomy. Prior to him scientific names of organisms had been short descriptions in Latin. For example one species of buttercup, which has the lowest part of its stem enlarged into bulb, was known by a long sentence, namely *Ranunculus calycibus retrofleris, pedunculus fulcatis caule erecto, folius compositis*. Linnaeus designated this species as *Ranunculus bulbosus*. Experience has shown that the Linnaean system is more convenient and easy to use. By this method millions of species can be described and organised without much difficulty. Linnaeus' greatest contribution was the use of two names to designate a species which has come to be known as the 'binomial nomenclature'. This idea appears first in the *Systema Naturae*, 1753, that is eighteen years after its first printing. The book had become so popular that sixteen editions have appeared during the life time of its author and the 10th edition published in 1758 is taken as the starting point for zoological nomenclature.

Linnaeus' system of 'natural classification' was based on the common similarities. He developed the power of acute observation and analysis by his early love of flowers and the training in his father's garden. He recognised six categories as one subordinate to the other namely, kingdom, class, order, genus, species and variety. The terms, phylum and family were later interpolated in the post Darwinian era by Ernest Haeckel. The term phylum has been influenced by the theory of evolution and etymologically it means a line of descent. It was introduced to include all the classes. The family was introduced as a category between genus and order.

Impact of the Theory of Evolution on Taxonomy

Linnaeus had brought an order to the large array of organisms and his system has gradually found acceptance. But by the end of the eighteenth century several biologists seriously began to question the concept that species were unchangeable. Domestication of plants and animals had clearly shown that species are not immutable and they had evolved, but not specially created.

The universe is composed of matter and energy, which are dynamic and interchangeable. Their very nature makes evolution an inevitable process. Biological evolution is one aspect of the overall evolution of the cosmos. The concept of organic evolution is based on the premises that plants and animals of the present day and those of the past are related to each other and have arisen from some common ancestor by relatively slow changes.

The idea of evolution has come up at various stages during the development of human thought. Aristotle hinted that "Nature advances by small steps from inanimate things to animate" By the end of eighteenth century, biologists developed doubts regarding Linnaeus' static type concept and that the species wont change. The theory of evolution had its first proponent in Jean Lamarck, who suggested that species and varieties were subject to change, and the simpler organisms had given rise to complex ones. Lamarck reasoned that evolution occurred by acquired characters of an organism by use or disuse during its life time. He believed that such acquired characters were handed down to the offspring, in which the new characters became fixed. These changes were transmitted from generation to generation and slowly a new species came into existence.

The modern concept of the theory of evolution, which has revolutionised the entire human thought has been propounded by Charles Darwin. But before arriving at this epoch-making decision, Darwin amassed a great amount of taxonomical data and field observations. From his various observations, he was convinced that species did change, diverging into different species and different lines of descent in the course of time.

Plants and animals reproduce at a very prolific rate more than what actually survive. If all the offsprings of one generation survive and again reproduce, soon the number would increase to impossibly large proportions. But it is not the situation in nature. It shows that there must be struggle for existence, with a number of participants losing in the process. The living organism is under constant struggle against environmental conditions, against predators and against other organisms sharing the same habitat and food. Darwin has also observed variations among living things. He explained that all living organisms live under constant pressure of competition and selection should work automatically. Variations that favoured organisms survival would be advantageous and such successful individuals would be able to produce fertile offsprings which inherit those variations. Disadvantageous variations would be eliminated sooner or later. An automatic natural selection hence, remains constantly in operation promoting the perpetuation of any variations that conferred advantage in terms of survival and procreation of its kind. Darwin compiled and collected evidence to show that species have changed and are changing. He gave a simple and logical explanation for these changes by the mechanism of natural selection.

Evolution represents a gradual change in the hereditary make up of a segment of population as it slowly gets differentiated from the original population. It is

seen as a two part process, one involving the origin of variation and the other enhancement of variation by natural selection.

The central idea of evolution is change, and it opposes the static type concept of Linnaeus. It proposes that new species arise through adaptive modifications in the existing ones, and each species is a product of a succession of populations. Since species are made up of natural populations, taxonomists are required to study populations. Systematics, which provided the raw materials for the formulation of theory of evolution was in its turn influenced very much by the latter. It has widened the scope of taxonomy and brought a change in its concept. It led to the development of New Systematics, in which organisms are studied by the methods of population genetics, ecology, physiology, behaviour and by every other possible approach in addition to classical morphological approach. New Systematics is a blend of taxonomy and evolution and it tries to understand the dynamics of origin of species. Species has thus become an integral concept of taxonomy and evolutionary theory.

Species Concept

Species is the basic unit for any biological study. Linnaeus conceived species as immutable and each one a specially created unit. He accounted for this the theory of 'archetypes' in which each and every species had an idealized type. A class would correspond to a major archetype and the orders within it to lesser archetypes. The similarity between species of a genus is due to the fact that they are more or less imperfect copies of smaller archetypes. It never occurred to him that similar species might have had a common ancestor.

In the light of evolutionary theory it is known today that species have slowly changed, or evolved, through the ages. In later years, Linnaeus, however, observed small differences of variations within a species and he even produced mixed species in his garden. In the last edition of *Systema Naturae* he preferred not to include the statement that no new species can arise. Even today we give the description of species in such a detail, with the hope that they will be identified on the basis of our description for all time to come. Although Linnaeus had a static type concept, he has successfully achieved a "natural system" of classification.

From Carl Linnaeus' "*Systema Naturae*" to Julian Huxley's New Systematics there is a change in the species concept. Species is no more a stereotyped form, but it is a population affected by ecological and genetic factors. Population has become the taxonomic unit of study, and its characteristics rather than of individuals were taken into consideration. Today a widely accepted definition of species is a genetic one; it is a group of actually or potentially interbreeding populations that are reproductively isolated from other such groups. This concept based upon gene flow between related populations is called the biological species concept, in which the members of a species form a reproductive community, an ecological unit and a genetic unit. But how many species that are described as new

to science and added to the already large number will stand to this definition ? From our experience it is known that the vast majority of the species are not so defined. It is seen that approximately 1/10000 of the known species are definable as genetic species (Hanson, 1963). The rest are defined on the basis of certain morphological characters. Thus it is seen that the concept can be applied to only a few of the known species and its adequate application in all other cases needs a large volume of experimental study. It cannot be applied to several species of Protozoa and lower Metazoa which reproduce asexually or parthenogenetically. Because of these objections many biologists are of the opinion that the species is an arbitrary unit. Nevertheless, there are many supporters to the view that the species is a valid and natural unit.

As a compromise between the morphological concept and genetic concept, some biologists prefer to retain the term species for the former and propose *syngen* for the latter. In certain cases the morphologist's species may not correspond to geneticist's species. For examples, *Paramecium aurelia*, a morphologist's species is found to include at least sixteen genetic species or syngens (Hanson, 1963).

The morphological species, *Lymnaea peregra*, a common British pond snail has four geographically isolated and biochemically distinct races. Laboratory experiments were conducted to test the reproductive compatibility of these four races, say A, B, C and D. The race 'C' hybridized successfully with race A, B and D but members of 'D' did not yield any offspring when crossed with A and B. It shows that race D should be treated as a distinct and reproductively isolated species (Wright, 1973).

On the other hand the genus *Bulinus* of eastern Africa includes polyploid 'cytospecies' which are difficult to be identified on the basis of morphological characters. Many widely distributed freshwater pulmonates could consist of two or more 'cytospecies' having different biogeographical and ecological characteristics (Brown and Wright, 1972).

Sokal (1973) reconsidered the species problem, both its definition and genesis. He recognised four common definitions of species namely, classic phenetic, numerical taxonomic, biological and evolutionary. Hitherto emphasis was given to reproductive isolation to the exclusion of all other factors. Sokal tried to redress the balance by drawing attention to environmental factors and the importance of geographic variation. The two commonly used concepts of species are evolutionary and taxonomic (phenetic). An evolutionary species is a single lineage that maintains its identity from other such lineages and which has its own evolutionary tendencies and historical fate (Wiley, 1981, 1988 as quoted in Funk and Brooks, 1990). A taxonomic species is usually a group of phenetically distinct individuals but, actually it can be anything a taxonomist says it is (Funk and Brooks, 1990).

The species is defined and redefined according to the perception and approach of a concerned biologist. Thus there are palaeospecies, evolutionary species,

morphospecies, genetic species and biological species. Application of so many names to one particular taxonomic category shows its complexity and multifaceted existence. The species has been recognised as a three dimensional one - reproductively isolated, geographic unit and ecological unit. A fourth dimension can be added to this, that is a biochemical unit. Modern taxonomist has been investigating into more details of species and in the process he has progressed from the level of organism to cellular and to molecular levels. At molecular level several species have shown distinctive characteristics.

Magnitude of Difference

The species is separated from all other species by some characteristic differences. But even within the species, individuals may differ from each other. But the definitions of species do not provide enough tools to a practising taxonomist to decide whether the material before him belong to a distinct species or only subspecies. According to classical taxonomy, it is not possible to present a quantitative expression of a species. However, it is possible to quantify the data on the basis of numerical taxonomic methods. The degree of difference between species or its delimitation varies with the group. For example two distinctly good species of *Drosophila*, namely *D. pseudoobscura* and *D. persimilis* exhibit very little morphological difference, whereas different races of a single species, such as *Homo sapiens* show marked differences. It shows that the constancy of difference is more important rather than the degree of difference.

Discontinuity and Interspecific Sterility

Boundaries of species can often be recognised by discontinuous differences. The discontinuity is due to the inability of related species to interbreed. Many of the definitions stress the sterility barrier between species. But it cannot be tested since most of the taxonomists work with preserved specimens or with skeletons, skins or shells. There may be various factors preventing the interbreeding of populations and sterility barrier is one among them. When these barriers are removed by some means interbreeding may take place. There are several instances, in plants and animals, in which crosses were made between well recognized species. Hybridization among natural populations has also been reported. All these point the (fallacy of using) inadequacy of sterility barrier as a criterion of species differentiation. Nonetheless, most of the accepted definitions of species stress on interspecific sterility.

Dobzhansky (1951), one of the foremost among the proponents of Neo-Darwinian theory considered species as a stage in the evolutionary process "at which the once actually or potentially interbreeding array forms become segregated into two or more separate arrays which are physiologically incapable of interbreeding". Goldschmidt stated that groups which can be successfully crossed should be treated as a single species for evolutionary studies, while acknowledging that taxonomists may be justified on other grounds in

separating them into distinct species for purposes of formal classification. Dobzhansky considered species as a natural unit and comments that "some biologists, lacking familiarity with the subject, have in fact, fallen into this error (that species are arbitrarily determined units). In reality, no category is arbitrary so long as its limits are made to coincide with those of the discontinuously varying arrays of living forms. Furthermore, the category of species has certain attributes peculiar to itself that restrict the freedom of its usage and consequently make it methodologically more valuable than the rest."

A species is absolute, but genus and family are arbitrary. It is purely subjective that which characters will define a genus or family. A species is a biological reality, whereas a genus or for that manner other higher taxa are matters of convenience. "A good taxonomic category is what a good expert taxonomist says it". But recent interpretations are convincing that not only species but also higher taxonomic categories are biological realities (Shvarts, 1977).

Problem of a Practising Taxonomist

Majority of the species were described before the formulation of species definitions and concepts and hence they may not fall within the accepted definitions. A number of species were based on a few characters and occasionally on a few individual variants without taking into account the populations. When a practising taxonomist takes up the study of a particular material he has to be guided by his predecessors in identifying his collections and has to operate within the ambit of the recent definitions. The first task of taxonomist is to sort out the collections on the basis of their "similarities" or "dissimilarities". Specimens or for that matter even forms are compared with reference to homologous structures and those with maximum number of homologous correspondences are grouped together. Morphologic description of a taxon has to depend on the concept of homologous structures. Remane (1952), a German morphologist outlined three different types: i) parts which are similarly located on or within an organism ii) parts having same number and form with regard to their sub-parts and iii) parts forming a continuous series, the extremes of which can be joined by intermediate forms eg. human arm, whale's flipper, the wing of a bat or bird, the foreleg of a crocodile or frog, etc.

Species is a group of essentially similar living forms sharing the largest number of homologous structures. The degree of homologous correspondence gets lesser as we proceed from lower to higher categories or taxa. The extent of common shared characters for a genus or family are decided by the taxonomist concerned.

The concept of the use of homologous structures in grouping populations is essentially a morphological one. But what are the factors that govern the distribution of such structures? An explanation to this has to be based on the evolutionary history. Evolution is a cumulative product of many generations of offsprings produced by populations. Changes affected by the evolutionary process

are accumulated in natural populations. The degree of difference or similarity between two distinct but somewhat related populations is a measure of their change or divergence from a common ancestor. Smaller differences indicate only a little change and larger differences mean much change after their origin from a common ancestor. The homologous structures indicate evolutionary relationships among taxa. Thus from homologies it is possible to construct phylogeny.

Application of morphological species concept has its own inherent problems in several groups. Some of the molluscs develop convergent characters in the course of evolution influenced by ecological characteristics. Convergence of shell shapes is seen among a number of families in the phylum Mollusca, such as Rissoacea, Pomatiopsidae, Cerithiacea and Neritidae.

Subspecies

A species may have a wide geographical range. Within its geographical range some of the populations may attempt a 'break-away' from the typical form. Should such a population become geographically isolated from the main stock of individuals, it may gradually evolve its own distinct morphological features. When the isolating barriers are removed interbreeding takes place resulting in a common gene pool and different races become a single race or population. If the isolating barriers continue, the break-away population may gradually become different from the original population and differences may be so striking that it warrants creation of a new subspecies. Thus natural selection first leads to the formation of races or subspecies, which by further alteration of geno type lead to the formation of new species, genera, family and so on.

Subspecies and geographic races are often used as interchangeable terms. However, some prefer to apply the term 'race' to local populations within subspecies. Mayr (1963) defines subspecies as an aggregate of phenotypically similar populations of a species, inhabiting a geographic subdivision of the range of a species, and differing taxonomically from other such populations of that species.

Species include the largest possible population. Its population may be distributed over a large area and include a great variety of phenotypes. A local population is called a deme, which embrace individuals who share a common habitat and select mates from their own members. Group of deme occupying similar, adjoining habitats and having gene flow between them are often called as races or subspecies (ex. *Homo sapiens*).

Thus demes, subspecies and species represent integradation of populational units that differ in size and amount of gene flow between them. A cluster of related demes may be called a race or subspecies, a group of related races a species and several related species make up a genus. The studies on freshwater Triculinae (molluscs) of Mekong river in China revealed that demes diverged

Darwin considered subspecies as “incipient species ... (which) ... become ultimately converted into good and distinct species... by natural selection”

Speciation

Due to historical reasons and fluctuations in environmental condition many groups of animals have evolved a considerable degree of intraspecific variation. It is particularly noticeable in some freshwater molluscs, especially planorbid snails. *Bulinus nyassanus*, which lives in unstable littoral regions in Lake Malawi, is normally an algal feeder, but some have moved into greater depths and taken to detritus feeding. It has resulted in the physiological diversity of the species. Thus when a population invades a new habitat it develops new characteristics and a new species arises differing from its nearest relatives. *Rana canerivora* is a unique species of frog occurring in the mangrove ecosystem. Outwardly it is quite similar to freshwater tiger frog, *Rana tigrina*. The crab-eating mangrove frog could inhabit waters which are inaccessible to other species of frogs. Thus the ancestral species and the evolved species are both seen during the present age.

I. Phyletic speciation (Transformation of species)	i) Autogenous (mutation, selection, etc.) ii) Allogenuous (hybridization, fusion with other species)

- II. True speciation
(Multiplication of species)
 - i) Instantaneous speciation
(individuals)
 - a) Chromosomal rearrangement
 - b) Polyploidy
 - ii) Gradual speciation
 - a) Sympatric speciation
 - b) Allopatric speciation
(Geographic speciation)

New Methods of Taxonomy

Although classical taxonomy brings out the relationships of organisms, often it becomes necessary to take recourse to other branches to establish true affinities. This is in conformity with the idea that natural species do not differ from one another by single, striking characters, but rather they differ quantitatively in a large number of characters. Too much dependence on one particular character may often be misleading. As competent a zoologist as Cuvier was misled by the shell of Cirripedia to treat it as a class of Mollusca. Besides its many typical crustacean characters, the study of its larvae had shown the group's unmistakable position in the class Crustacea. There is another crustacean, which defied classification till its larvae were studied. The adult *Sacculina*, which parasites crabs, have undergone a degenerative development and do not exhibit any character of Crustacea. Their taxonomic position is cleared on the basis of larval characters. Parasitic mollusca belonging to enteroxenoid snails, occurring in echinoderms are worm-like externally, with a reduced gut and hermaphroditic reproductive system. The adult characteristics do not give any clue to their identity, but the typical larvae indicate their identity.

Comparative serology or biochemical techniques provide additional tools for the taxonomist, who bases his findings on morphological characters. The whole exercise of biochemical technique is based on the premise that antigen-antibody reactions are highly specific.

Vertebrates have been extensively studied for their comparative serology. Serological taxonomy of Crustacea, Insecta and Mollusca have also attracted attention of several investigators. The results of serological tests have supported the theories of relationship based upon comparative morphology. At times serological data have been decisive in resolving certain taxonomic problems. The King crab, *Limulus*, superficially resembles a crustacean and was regarded so for a long time. But serological tests have revealed its strong affinity with spiders.

Serum proteins also show varying degrees of homology just as the morphological characters. Serological tests also support Darwin's theory that similar species have been formed by descent with modification from a common ancestor. Serological similarity may become gradually less when pursued from species level to higher taxonomic category.

Contemporary Studies

Application of modern techniques have developed more insights and strengthened taxonomic investigations. During the last two and a half centuries taxonomy has become an important branch of study. With the addition of more data classical theory of taxonomy has to yield place to new theories. As a result there are three contemporary schools of taxonomy, each having its own adherents. These are phylogenetic systematics as proposed by Hennig, evolutionary systematics advocated by Simpson and Mayr and numerical or phenetic taxonomy expounded by Sokal and Sneath. The merits and demerits of these three schools of thought have been explained by Griffiths (1973).

Like taxonomy, evolutionary theory also progressed in its interpretation from the level of organism to molecular level. The latter is, however, termed chemical evolution in contrast to the former which is known as organic evolution. The theory of natural selection proposed by Darwin was synthesised with modern genetics and developed as the theory of Neo-Darwinism. It has four important postulates: i) population is the basic unit of evolutionary process, ii) a change in the genetic structure of population is the first stage in microevolution, iii) population characteristics determine the rate of microevolutionary modifications but not only natural selection and iv) random changes in population structure supported by the strength of selection determine the direction.

One of the important foundations of population genetics is that almost every fresh mutation is deleterious and is eliminated by the natural selection. But Kimura's theory proposes three types of mutations, deleterious, neutral and advantageous. Darwin's theory of natural selection favours advantageous mutations and eliminates the harmful ones. The supporters of natural selection came to be known as 'selectionists' as opposed to 'neutralists' who apply the concept of neutral mutation at molecular level. It came to be known as non-Darwinian theory of evolution. Neutralists, however, have accepted Darwin's theory at the morphological, functional and behavioural levels.

Many evolutionists are of the opinion that mutation pressure may be responsible for variations in populations, but it does not play any major role in the process of speciation. The existence of neutral mutation has been doubted by many. Selection pressures have been demonstrated to be considerably higher and more variable than had been assumed during the earlier period of population genetics. Natural selection has a balancing role and it produces balanced genotypes and a balanced gene pool. It is also not indifferent to neutral mutations and maintains the gene arrangement at an optimal level (Shvarts, 1977).

Classification

A taxonomist's first job is identification of the material at his disposal and arrange it into species and subspecies, if needed. The act or system of arranging the material in classes is a corollary to identification. Theoretically the

taxonomical hierarchy starting from phylum to the species is followed, but in practice it is the other way round. The keys that are adopted are generally "artificial". Classification involves two steps - one classifying organisms into their taxonomical hierarchy and the second to rearrange this into a form of a tree or a diagram to bring out their evolutionary or phylogenetic relationships.

In the beginning animals were classified as a matter of convenience. Linnaeus concept of "natural classification" was based on the recognition of common similarities of form. But after the acceptance of the theory of evolution, attempts are made to base the classification on the concept of homology and its evolutionary explanation. Animals which are believed to have a common ancestor are classified together. Although the present day classification is broadly not much different from that of Linnaeus, the concept of natural classification is different. Cain (1968) discusses what is a natural classification. A classification which is based on the actual course of evolution or evolutionary relationships is known as phylogenetic or phyletic classification. Cain and Harrison (1960) introduced the term phenetic classification or arrangement for natural classification, which uses any sort of available character in the material, without weighting their importance.

The improvement of classical taxonomic techniques and the introduction of new techniques have provided more data to work out the relationships among organisms. The present day classification is based on the evolutionary relatedness among various organisms. All the living organisms are divided into three kingdoms, namely Monera (Prokaryotes), Plantae and Animalia. All the three share common molecular structures and enzymic sequences. The differences get progressively narrowed down with the descending order of taxonomic hierarchy from kingdom to species or to subspecies and races. Bock (1973) enumerates three approaches to biological classification. These approaches are Phenetics, Cladistics and Classical Evolutionary. Phenetic classification is based on degree of similarity between organisms and it excludes phyletic information. Cladistics refers to branching and is based upon common sharing of derived features. It completely excludes evaluation of similarity. It is actually derived from phylogenetic systematics of Hennig. The third one, classical evolutionary, combines the important elements from phenetics and cladistics, *i.e.* the evolution of phenotypical similarity and building up common ancestry on the basis of derived features. According to Bock classical evolutionary classification is the best approach and provides inputs for all comparative biological studies. On the other hand there are strong advocates of cladistics (phylogenetic systematics) who consider it as the appropriate basis for all among-lineage studies (macroevolution) in comparative biology. Macroevolutionary patterns can be documented with the help of phylogenetic systematics (Funk and Brooks, 1990). There are certain biologists who would prefer to call all classifications as "natural", which means either evolutionary, phylogenetic or phenetic (Heywood, 1973).

Conclusion

Taxonomy is not merely identification and inventorization of species. It is a synthetic science, since it has to take into account all the components that influence a living matter. It has to include in its sphere of investigations inputs from other branches such as genetics, evolution, biogeography, etc., which influence the making of a species and which have roles in the composition and evolution of biological diversity. In the process of deciphering the graded order in the biological diversity taxonomy relays information to other areas of investigations concerning the biological world. This interdependence of all branches of science has been steadily growing and this has led to the birth of hybrid sciences like biochemistry, biophysics, etc. Taxonomy and evolution together lay the foundation for an understanding of the biosphere.

Taxonomist is not any more a 'biological filing clerk' He is a 'manager' who oversees the functions and placement of various biological components. Through his 'systematic skills' he draws attention to 'the unity in biological diversity' and exposes the 'dangers' in disrupting this diversity. Variety is the spice of life; it has also the ingredients for taxonomy and evolution.

References

- Brown, D. S. & Wright, C. A. 1972. On a polyploid complex of freshwater snails (Planorbidae : *Bulinus*) in Ethiopia, *J. Zool. Lond.*, 167: 97 - 132.
- Bock, W. J. 1973. Philosophical foundations of classical evolutionary classification. *Syst. Zool.*, 22: 375-392.
- Cain, A. J. 1968. The assessment of new types of character in Taxonomy. In : *Chemotaxonomy and Serotaxonomy*, Special Vol. 2: 229-234 (Ed.) J.G. Hawkes, System. Association.
- Cain, A. J. & Harrison, G. A. 1960. Phyletic weighting. *Proc. zool. Soc. Lond.*, 135: 1 - 31.
- Davis, G.M. 1982. Historical and ecological factors in the evolution, adaptive radiation and biogeography of freshwater mollusks. *Amer. Zool.*, 22: 375-395.
- Dobzhansky, T. 1951. *Genetics and the origin of species*. Columbia University Press, New York.
- Funk, V.A. & Brooks, D.R., 1990. Phylogenetic systematics as the basis of comparative biology. *Smithsonian Contr. Botany*, 73: iii + 45 pp.
- Griffiths, C. D. G. 1973. Some fundamental problems in biological classification. *Syst. Zool.*, 22: 338 - 343.
- Hanson, E. D. 1963. *Animal Diversity*. Prentice Hall of India (Private) Limited, New Delhi.
- Heywood, V. 1973. In : Discussion of Symposium Papers on Contemporary Systematic Philosophies. *Syst. Zool.*, 22: 393.
- Mayr, E. 1969. *Principles of Systematic Zoology*. Tata Mc Graw Hill Pub. Co., New Delhi.
- Remane, A. 1952. *Gründlagen des natürlichen Systems der Vergleichenden Anatomie und der Phylogenetik*. Akad. Verlagsges, Leipzig.
- Shvarts, S. S. 1977. *The Evolutionary Ecology of Animals*. Consultants Bureau (English translation by A. E. Gill).
- Sokal, R. R. 1973. The species problem reconsidered. *Syst. Zool.*, 22: 360 - 374.
- Wright, C. A. 1971. *Flukes and Snails*. George Allen & Unwin, London.

Co-Evolution of Lice and Their Hosts

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The process of descent with modification or variation from a simpler form to a complex one both structurally and functionally is defined as evolution (*L. evolvo*, unrolling, or unfolding). The evolutionary phenomenon follows some principles in the evolution of our galaxy with in the cosmic evolution. The same principle holds good in the evolution of the inorganic and organic matter on our planet Earth. The entire process of evolution in short, may be said as the reaction of the pre-existing matter to the changing surrounding, or its immediate environment caused by different forces. This action-reaction mechanism is responsible for the present day biological diversity and evolution of higher forms from the lesser evolved forms, in their effort to perpetuate the race in the changing environment. Thus, biological evolution is considered as an integral part of the cosmic evolution, and the micro-environment within the immediate vicinity of an organism, as an integral part of the macro-environment. Therefore, the smaller changes in the form, function, and transmission of characters to the offspring, or micro-evolution of parasites in the micro-environment of its host body forms an integrated part of the macro-evolution in the macro-environment or nature.

The biological evolution though well recognized by ancient Indians, it has been first interpreted in the West, by Lamarck in 1809. The development of taxonomy and classification of the species, etc. during the post-Linnaean times, the similarity, dissimilarity and individual variations, in the fauna and flora both living and fossil forms enabled Charles Darwin to propound his theory of Origin of Species and the theory of Natural Selection in 1859. In fact, Alfred Russell Wallace also independently came to the same conclusions as Darwin did, and is considered as the co-author of the modern theory of evolution. The later researchers like Mendel, Morgan, De Vries, Thomas and Julian Huxley, Goldschmidt, Fischer, Dobzhansky, etc., have contributed further to the theory of evolution and in understanding its mechanics. While the studies on the taxonomy and classification give us the clue for the variation of the characters of transformation from one to the other, the evidences of the evolution can be deduced by the study of comparative morphology, physiology, genetics, embryology, biochemistry, biogeography and fossils by direct observation of the existing forms or in extinct forms. An indirect method of the study of evolution

and relationship of the modern host species was first propounded by Kellogg and Harrison independently by their taxonomic studies of the chewing-lice (Phthiraptera) which are external parasites on birds and mammals. Since then several entomologists, acarologists and helminthologists extended not only to the interpretation of host relationship evolution, zoogeography and migration, but also the prediction of climates, by the taxonomic and distributional studies of the extant parasitic species.

Classification of the Suborders of Lice

The Order Phthiraptera as is now understood is broadly divided into three suborders : the chewing-lice (the suborders Amblycerophthirina, and Ischnocerophthirina); the genus *Haematomyzus* (suborder Rhynchophthirina) ; and the sucking-lice (Siphunculophthirina). The Amblycerophthirina and Ischnocerophthirina are parasitic on both birds and mammals, the Rhynchophthirina on elephants, warthog, and bush pig, while the Siphunculophthirina are exclusively parasitic on mammals. The chewing-lice have typical mandibulate biting mouthparts except in the families Ricinidae and the closely related Trochiliphagidae (Trochilicoetidae) where they are also variously modified for piercing. Species of the genus *Haematomyzus* have outwardly 180° rotated mandibles so that their dentated edges face away from each other, and probably best used for anchoring to the host, and Siphunculophthirina have typical sucking type mouthparts and mandibles modified for piercing.

The suborders underwent several permutations and combination within the order. The chewing-lice and sucking-lice were treated as independent orders, and so was the case with Rhynchophthirina, associated with either of them. A detailed discussion is available on the classification and nomenclature in Lakshminarayana (1976).

Evolution and Antiquity of Lice

On the basis of the comparative anatomy and morphology, it is now believed that all these lice have evolved from free living saprophagous Psocopteran ancestors polyphyletically in the bygone. The freeliving Psocopterans living in the burrows and nests have taken to parasitic habit on the evolving birds and mammals, and perhaps, their reptilian ancestors also. Fossil lice have not so far been reported, except for one report of eggs preserved in the baltic amber (Voigt, 1952). The lice being external parasites living amongst the feathers and hairs of the birds and mammals respectively are not likely to be preserved in the fossil state because the feathers (except as impressions), and hides which are perishable. Therefore, the chronology and the antiquity of lice cannot be stated except in arbitrary terms. On the basis of the morphology, distribution, and radiation of the extant species on the bird and mammal hosts, they can be very well conjectured. Hopkins (1949) vividly discussed the probable chronology and

antiquity of lice in general. Hopkins (*op. cit.*) concluded that the ancestors of Amblycerophthirina (the most primitive member of the extant chewing-lice) possibly began their life as ecto-parasites of the Vertebrates during the Triassic Period (225-190 million years ago) and parasitized the early birds and mammals and possibly their reptilian ancestors also. The true Amblycerophthirina possibly evolved at least in the Jurassic (190-135 m. y. ago), the Ischnocerophthirina might have been in existence since early Cretaceous (135-65 m.y. ago), or even in the late Jurassic, and the Siphunculophthirina cannot be later than the middle of Cretaceous. The evidence of Rhynchophthirina is too scanty, but it must have evolved earlier than Eocene Epoch (54-38 m.y. ago), and possibly could have existed even in Cretaceous Period.

The occurrence of a common genus *Struthiolipeurus* on the African ostrich, and the American Rhea and Nandu could not have been possible, but for the evolution of the genus before the separation of the Gondwana block, because these flightless birds have no chance of meeting after the lands were separated. Same is true with the genus *Microthoracicus* with three species on *Llama* in South America and one species on *Camelus dromedarius* in North Africa and both these genera are included in the family Camelidae. *Haematomyzus elephantis* occurs on both African and Indian elephant even in wild state and it is possible that their hosts *Elephas* and *Loxodonta** could have co-existed, or even derived from a common ancestor! In the Rodentia two genera of sucking-lice viz., *Enderleinellus* and *Neohaematopinus* are found on Sciuridae all over the world and therefore as Hopkins (1957) puts it should go back to the origin of the family. The sucking-louse *Pediculus* occurs on man and chimpanzee and it is widely distinct from louse found on non-primates; its occurrence on the Primates must be quite ancient and according to Hopkins (*op. cit.*) possibly of Miocene Epoch. The more recent explanation given by an anthropologist that the Caucasians have possibly evolved from the Chimpanzee, the Mongoloids from Orangutan, the Australoids from Gibbons and the Negroids from the Gorilla type ancestors is interesting in this regard.

Clay (1949, 1950, 1957, 1976) and Hopkins (1942) discussed the avian phylogenetic relationships, while Hopkins (1949, 1957), and Patterson (1957) discussed the mammalian phylogenetic relationships on the basis of lice.

Principles involved in the Lice Parasitization

The lice are obligatory external parasites of birds and mammals. Their food may be either feathers, hairs, mucus, sebum, and blood depending on the group and host involved. They seldom live outside the body of the host, for about a week or ten days at the most. They have no intermediate host and therefore, transmission from one host to the other member of the same species or to another species is direct, i.e., 1) by contact during feeding, roosting, mating, breeding

* the anatomical differences can be of habit & habitat, adaptation.

either between the two sexes; 2) from parent to the offspring; 3) between the prey and predator; 4) by sharing common dust baths, and 5) by phoresy. Yet experience has amply revealed that they do not occur on unrelated host species and even if an accidental transmission takes place do not thrive on the unrelated host. Lakshminarayana (1970b) extended the Markkula's classification of hosts to the chewing-lice into true hosts (*Brutwirte*), pseudohosts (*Scheinwirte*), or non-hosts (*Nichtwirte*). When a species infects a new host and completes its life-cycle, and the host maintains subsequent generations it is considered as a true host, when the species is able to thrive temporarily for one or two generations it is considered as a pseudohost, and when the species is unable to feed and thrive on the new host the latter is considered as a non-host. Sometimes due to natural relationship, or identical feather structure or hair structure, or host physiology, a species if accidentally taken to a new host species may secondarily get established. Evaluation of secondary infestations is given in Lakshminarayana (1970b).

Harrison (1914, 1915, 1916 a,b) stated that when a genus occurs on a number of related host species the relative sizes of the parasite species of that genus is more or less proportional to the relative sizes of the host. This rule christened as *Harrison's Rule* has been well explained by Clay (1949) in the light of Wetmore's observations that larger birds have lower body temperatures, and *Bergmann's Law* that larger species are found in colder climates, and therefore, larger hosts with lower body temperatures harbour larger parasite species, and this was christened as *Clay's hypothesis* in Lakshminarayana (1986).

Fahrenholz's Rule christened by Eichler (1940, 1948, 1949), states that ancestors of the extant parasites must have been the parasites of the ancestors of the extant hosts, therefore the present parasite species indicate the relationship of the present day hosts.

Szidat Rule originally proposed for helminths was extended to lice also by Eichler (1948, 1949) in that primitive host groups harbour primitive parasites and advanced hosts harbour advanced parasite species.

Eichler (1940, 1948, 1949) proposed that isolated group of hosts do not harbour many kinds of parasites, whilst in comparable groups of hosts with many species or near affinities to other groups not only many species (each host with its distinct species), but also many genera could be met with. This rule was christened by Hopkins (Eichler, 1949) as *Eichler's Divergence Rule*. The exception to this rule can be found in relic host species, or isolated group like the Tinamiformes, or when the feather structure as in the case of ostrich do not provide many ecological niches.

Hopkins (1942, 1949) stated that a single correspondance of lice species between two host species hypothetically believed to be related to each other means very little, two such cases on them means the relationship is probably genuine, and three comes very close to certainty. It is named as *Hopkins'*

Principle in Lakshminarayana (1970a). The non-establishment of a louse on an unusual host may be due to different coat or feather structure, competition from the already existing louse populations, unlikely transfer of both sexes, or at least the fertilized female, incapacity of feeding, or laying the eggs, or if laid, the eggs are not viable, or the nymphs unable to feed on the new host due to difference in the food composition. The absence of the specific lice of the foster parents on the brood parasites like cuckoo indicates an inherent host-specificity. This host-specificity, therefore, provides ample evidence for interpreting the natural host relationships.

Host specificity is indeed forced on lice during the evolution or speciation (Lakshminarayana, 1977a). Therefore, the factors involved in speciation are the same involved in host specificity. A purview of the present day lice specially those on birds suggest that certain genera and species are specific to certain host orders, genera, and species. As a rule, the same or closely related parasite species occur on related host species. The feather or hair cover offers a more or less uniform temperature, shelter, and food to the parasite, i.e., the microclimate being almost constant as compared to the micro-and macroclimate of the host. While the host reacting to its own environmental fluctuations, speciates (or speciated) at a faster rate, the parasites naturally evolved at a slower rate because of little microclimatic fluctuations. The rapidly evolving hosts also provided empty ecological niches for the parasite species to diverge in a rapid way also. This difference in the rate of evolutions are described as '*Retarded evolution*' and '*Accelerated evolution*' respectively (Keler, 1958). '*Retarded evolution*' produced generic and specific complexes, while '*Accelerated evolution*' produced number of genera and species. The rapid evolution of the host, however, resulted in certain modifications in the host body which indirectly offered new ecological niches to its ancestral louse populations by creating a tendency or stimulated for further speciation at a faster rate due to adaptation in the new ecological niches. For example, in case of bird infesting lice, the ecological niches recognized are head and neck, wing and abdomen, the larger quills, and the gular pouches of Pelecaniformes. Clay (1949) showed two classic cases of speciation due to changed ecological niches. Normally the head and neck niche lice are broad with dorsal or dorso-posterior genital opening, since they are not exposed for preening, while the lice of the wing and abdomen are exposed for preening, and therefore, developed slender bodies, and ventral genital opening and the copulation is effected by bending the male abdomen. *Sturnidoecus* invading the head niche, and *Columbicola* invading the wing and abdominal niche secondarily modified according to the new niche, but their genital openings indicate that they originally belong to a different ecological niche. Isolation plays an important part in speciation. Since individuals belonging to a single host species normally flock or herd in the same area, they are infested with the same species of the parasite acquired from generation to generation from the remote past. Since natural mixing between two groups of hosts or species of hosts (due to territoriality) is very rare the host itself isolates the lice of each getting

mixed, i.e., in other words it acts as a 'biological island' as Clay (1949) names it. Allopatric and sympatric speciation occurs much in the same way as in other communities in lice also, and where such mixing or speciation takes place, the lice of the combined populations develop sexual incompatibility like asymmetry in genitalia (Lakshminarayana, 1977b) as in *Goniodes parviceps* and *Goniodes mayuri* during the process of sympatric speciation.

Morphological changes (probably genetic also) in the abdomen, position of the genital opening, structure of the male genitalia etc., produce strong sexual isolation and prevents interbreeding even if two closely allied species accidentally are found or have arisen sympatrically on the same host, as in any other group.

In spite of the fact that closely related parasite species occur on closely related host species, genera, and orders, there are certain cases where the current distribution offers no explanation for the occurrence of species on unusual host orders. This discontinuous distribution may be due to i) the present day host orders, genera, and species have acquired the species from a common ancestor in the bygone, and diverged to such an extent that the original host relationships are obliterated, ii) parasite genera and species might have developed on parallel lines, iii) they might have been at one time wide spread on many related host orders genera and species, and might have subsequently disappeared on the connecting or intervening host species, iv) they might have secondarily established which is a rare phenomenon, v) straggling in nature, vi) usage of common dust baths, and lastly vii) human error while handling the species. The lack of specificity in primitive species and genera was primarily responsible for the spread of closely related genera and species on a wide range of host orders, but the development of specificity in their descendants probably prevented back transfer resulting in the formation of new species, complexes and genera. This might have attained not only by the physical isolation of the host, its coat texture, but also on the physiology of feeding of the parasites, altered morphology, physiology, and breeding behaviour.

When a parasite species is more widely distributed on a host than another closely related host species, then we can infer that the former may be phylogenetically older, unless the latter belongs to a dwindling order, or represented by relic species, or the parasites secondarily disappeared as in the case of waders in the highly alkaline waters of Lake Magadi in Kenya (Meinertzhagen, 1950), or as in the case of lice of Ratite birds, where the host body does not provide many ecological niches.

The speciation of the lice amply indicate their co-evolution with their hosts, and therefore, the study of their taxonomy and morphological evolution reflects the natural relationship and in a way the evolution of the host itself. Fossils are not always available for the study of the evolution of the host because of lack of chances of preservation or non-discovery. Therefore, only the taxonomy, comparative anatomy and serology of the extant hosts give us the

information on the probable evolution, but yet there are cases in birds and mammals considerable gaps and in some cases super imposed by other characters due to adaptive radiation. In all such cases, the study of the lice indicate the host relationships a way. It is applicable at species level of the parasites while handling species of hosts with in the family, and at generic level while dealing between families with in host order or between host orders. In fact, this principle helped in drawing conclusions on the host relationships in a number of cases.

Literature on hosts and the lice parasite relationship is listed in Eichler (1963), Eichler *et al.*, (1969a, b), Keler (1960), and Lakshminarayana (1972a, 1975, 1986) and most of the recent revisionary papers discuss in a way the subject. It is not possible to deal with all the cases here.

Conclusion

It is evident from the above account, that lice in general, specially those of birds could be useful tools in our attempts to understand the natural relationships of the host groups, which cannot be explained at the present state of our knowledge. However, one should keep certain basic facts in mind using this tool in a proper and intelligent manner, as follows:

- 1) The eminent parasitologist, Mr Hopkins once said *give me a louse, I shall tell you from where it has come from*, (perhaps both the host and geographical region). His knowledge and understanding of the group was superb. He was so confident because of the inherent host-specificity of the lice in general.
- 2) Mayr (1957) in his inaugural address to the *Host Specificity symposium* stated *Parasitologists have discovered the exceedingly interesting fact that many parasites are strictly host specific and that a group of related species or genera is often restricted to related host species. The evident interpretation is that the association between the parasite and host goes far back in to geological history, the evolution of the parasite being as closely connected with that of the host as if it were an organ of the host.*
- 3) Mayr (*op. cit.*), however, cautions, *It is unrewarding to pursue the problem of host specificity unless one's conclusions are based on sound systematics and reliable host records.* Therefore, it is imperative for any novice to study the taxonomy and morphological evolution amongst the closely related parasite species, first, before attempting their application on one hand, and second, also base their observations on other consistent records available in literature.
- 4) It is also preferable to study fresh material from the wild hosts and not from zoo garden hosts.
- 5) One should be careful about stragglers in the field or lab.

- 6) One should be careful while discussing the relationship of relic or dwindling group of hosts. However, constant reports from these hosts can be used safely.
- 7) For a taxonomist, the study of co-evolution or comparison with host taxonomy would not only be a counter check for his observations on parasite taxonomy, but also a good game and relief from the usual drudgery or monotony of the profession.
- 8) One should keep in mind the statement of Mayr (1957, p. 155), *I want to emphasize this point we should not, because some things have been carried a little too far perhaps (in the interpretation of host relationship), in the least deprecate and devalue the evidence from Mallophaga (chewing-lice).*

References

- Clay, T. 1949. Some problems in the evolution of a group of ectoparasites, *Evolution*, 3(4) : 279-299.
- Clay, T. 1950. A preliminary survey of the distribution of the Mallophaga ('feather lice') on the class Aves (birds). *J. Bombay nat. Hist. Soc.*, 49: 430-433.
- Clay, T. 1957. The mallophaga of birds. *Proc. First Symp. Host specificity among parasites of Vertebrates*, - /Imprimerie Paul Attinger, S. A./Neuchatel : 120-158.
- Clay, T. 1976. Geographical distribution of the Avian lice (Phthiraptera). A Review. *J. Bombay nat. Hist. Soc.*, 71(3) : 536-547.
- Eichler, Wd. 1940. Korrelation in der Stammesentwicklung von Wirten und Parasiten. *Parasitenk. Berl.*, 21(1) : 94.
- Eichler, Wd. 1948. Evolutionsfragen der Wirtsspezifitaet. *Biol. Zbl.*, 67: 373-406.
- Eichler, Wd. 1949. Some rules in ectoparasitism. *Ann. Mag. nat. Hist.*, (12) 1 : 588-596.
- Eichler, Wd. 1963. "Phthiraptera 1. Mallophaga". In : *Bronn's Klassen und Ordnungen des Tierreichs*. 5(3) : 7b. viii + 290. Akad. Verlagsgesellschaft Geost & Portig, K. G./Leipzig.
- Eichler, Wd., & Zotorzycka, J. 1969 a. Zeitgencoessiche Mallophagen Literature (I). *Angew. Parasit.*, 10(1) : 53-60.
- Eichler, Wd., Ribbeck, R. & Zlotorzycka, J. 1969 b. Zeitgeossiche Mallophagen Literatur (II). *Mitt.zool.Mus.Berl.*, 49: 423-461.
- Harrison, L. 1914. The Mallophaga as a possible clue to bird phylogeny. *Austr. Zool.*, 1(1) : 7-11.
- Harrison, L. 1915. Mallophaga from the *Apteryx*, and their significance, with a note on the genus *Rallicola*. *Parasitology*, 8(1): 88-100.
- Harrison, L. 1916 a. Bird-parasites and bird-phylogeny. *Ibis* (10) 4 : 254-263.
- Harrison, L. 1916 b. The relation of the phylogeny of the parasite to that of the host. *Rep. Brit. Ass. Adv. Sci.* : 476-477.
- Hopkins, G. H. E. 1942. The Mallophaga as an aid to classification of birds. *Ibis.*, 14(6) : 94-106.
- Hopkins, G. H. E. 1949. The host-associations of the lice of mammals. *Proc. zool. Soc. Lond.*, 119: 387-604.
- Hopkins, G. H. E. 1957. The distribution of Phthiraptera on mammals. *Proc. First Symp. Host-specificity among parasites of Vertebrates*. /Imprimerie Paul Attinger, S. A. / Neuchatel : 88-119.

- Keler, S. 1958. The genus *Oxylipeurus* Mjoeberg and *Splendoroffula* Clay and Meinertzhagen. *Dt. Ent. Z.*, (n. F), 5(3/4) : 299-362.
- Keler, S. 1960. Bibliographie der Mallophagen. *Mitt. zool. Mus., Berl.*, 36(2) : 146-403.
- Lakshminarayana, K. V. 1970a. Mallophaga Indica IV. Trends in Evolution in the *Laemobothrion*. - complex (Phthiraptera : Mallophaga) with description of a new genus. *Orient. Insects*, 4(2) : 131-142.
- Lakshminarayana, K. V. 1970b. Evaluation of secondary infestation in Mallophaga. *Angew. Parasit.*, 13(1) : 52-53.
- Lakshminarayana, K. V. 1972a. Mallophaga Indica VII. Historical Resume and bibliography of Mallophaga indica. *Angew. Parasit.*, 13(3) : 169-178.
- Lakshminarayana, K. V. 1975. Bibliography of Mallophaga Indica : Supplement I and Errata. *Angew. Parasit.*, 16(1) : 28-30.
- Lakshminarayana, K. V. 1976. Nomenclatural changes in Phthiraptera-some suggestions. *Angew. Parasit.*, 17(5) : 160-167.
- Lakshminarayana, K. V. 1977 a. Factors involved in the host-specificity in Mallophaga *sens. lat.* (Phthiraptera : Insecta) infesting birds. In : *Insects and Host-specificity*. 101-109 (Ed.) T. N. Ananthakrishnan The Macmillan Co. Ltd. , New Delhi.
- Lakshminarayana, K. V. 1977 b. Role of asymmetry in the speciation of certain-lice (Phthiraptera : Insecta)., *Bull.zool. Surv. India*, 2(1) : 29-34.
- Lakshminarayana, K. V. 1986. Data book for the study of the Chewing-lice (Phthiraptera : insecta) in India and adjacent countries. *Misc. publ. Occ. pap. Rec. zool. Surv. India*, 81: 63.
- Mayr, E. 1951. Evolutionary aspects of Host Specificity among parasites of Vertebrates. *First Symp. on host specificity among parasites of Vertebrates*. /Imprimerie Paul Attinger, S. A./Neuchatel : 7-14.
- Meinertzhagen, R. 1950. A visit to Magadi, in Kenya in March, 1949. - *Ibis*, 92: 148-149.
- Patterson, B. 1957. Mammalian phylogeny. *Proc. First Symp. Host-specificity among parasites of Vertebrates*. /Imprimerie Paul Attinger S. A./, Newchatel : 15-49.
- Voigt, E. 1952. Ein Haareinschluss mit Phthirapteren - Eiern im Bernstein. *Mitt. geol. Staatsinst. Hamburg*, 21: 59-74.

Taxonomy and Coevolution of Symbiotic Protozoa

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The lower termites belonging to the families Mastotermitidae, Kalotermitidae, Hodotermitidae and Rhinotermitidae, and the wingless roaches *Cryptocercus* of the family Cryptocercidae compulsorily harbour innumerable flagellates of the diversified groups in their gut bearing systematic similarity. Among protozoa, these flagellates are very convenient material for evolutionary studies because they bear true symbiotic relationship with their hosts. Their transmission from one host species to another follows phylatic lines as will be discussed later and circumstances in this host-symbiote association are very much favourable for consideration of their concomitant phylogeny.

There are three species of *Cryptocercus* and about 525 species of lower termites known so far from the globe out of which 208 species of lower termites and two species of roaches have been studied for their intestinal flagellates which constitute 437 species belonging to three orders Oxymonadida, Trichomonadida and Hypermastigida. Although a large number of hosts still remain unexplored for their symbiotes still whatever taxonomic information on these protozoa is available to date enlightens symbiote-host coevolution to a great extent and corroborated many palaeontological findings on the phylogeny of their hosts.

For the better understanding of host-symbiote coevolution in termites and roaches, a few aspects of their relationship as stated below need little elaboration.

Symbiotic Relationship

Both *Cryptocercus* and lower termites live on a restricted diet of cellulose (wood) and could not adapt to various food niches. These insects lack cellulose splitting enzyme in their gut and, therefore, can not digest their food (cellulose) on their own. Consequently, for nutrition they have to solely depend on their intestinal flagellates which contain the enzyme cellulase that converts cellulose to cellubiose and subsequently to glucose. It has been experimentally shown that lower termites and wood roach *Cryptocercus* can not survive without these symbiotes even when sufficient wood or other form of cellulose is available to them (Cleveland, 1923, 1924, 1926 and Cleveland *et. al*, 1934). These flagellates

in turn get their required sheltered anaerobic environment from the hosts, with abundant supply of food material.

Transmission of Symbiotes

The mode of transmission of symbiotes in *Cryptocercus* is different from that in lower termites. At the time of moult, *Cryptocercus* releases the hormone ecdysone which initiates sexual reproduction of their flagellate symbiotes. During the process of sexual reproduction these flagellates produce cysts and pseudocysts which are discharged into the external medium at the time of molting of their hosts (Cleveland *et. al*, 1934). The young roaches hatched from eggs become infected with these flagellates by devouring cysts with wood particles. But, flagellates of lower termites have lost this ancestral ability to reproduce sexually and to form resistant cysts. Their transmission from host to host in the same termite colony is effected only by proctodeal or anal feeding of termites. Young termites and nymphs of various age lick off anal excreta containing flagellates and get them in their gut. However, at the time of each moult excepting at the time of last one all or most of their gut flagellates die and are eliminated together with the old intima of their gut. As soon as the moult is completed nymphs regain their flagellates by proctodeal feeding from non-moulting nymphs. During the final moult resulting in the release of imago the situation is different (Grassé and Noirot, 1959). The population of flagellates becomes greatly reduced in number in the final nymph about to moult, retaining a representative sample of whole set of flagellates species within the sac like intima. These flagellates are subsequently released into the gut of the imago on rupture of this intima. These observations reveal that in *Cryptocercus* transmission of flagellates usually occurs at the time of moulting whereas in termites it may occur by means of anal droplets between moults and after the final moult.

Uniform Assemblage of Symbiotes in Host Species

Taxonomic data accumulated so far from the study of flagellates of 208 species of lower termites reveals that all termite flagellates are not host specific. But each species of lower termites possesses an uniform assemblage of symbiotic flagellates irrespective of their geographical isolation and zoogeographical associations (Kirby, 1937; Honigberg, 1970 and Das, 1983). In some cases, however, members of a particular colony of termites may lack one or two species of flagellates (Kirby, 1947) due to the reason that the parental pair of termites which formed that colony had missed this/these species at the time of their final moult and could not get the time of regaining that/those flagellates through proctodeal feeding from other non-moulting nymphs as they had left that colony immediately after their release as winged imago. This phenomenon is very important for explaining the evolutionary pathways of symbiotes in termites.

In *Cryptocercus*, however, the situation is different. It is known from the paleontological evidence that recent relict roaches *Cryptocercus punctulatus* and *Cryptocercus relictus* have been developing independently since Tertiary time in complete geographical isolation, the former in North America (in Appalachian area in east and Pacific area in west) and the latter in Soviet Far East (Primorye region). This condition makes possible to follow the formation of their respective fauna (see Table 1).

Is Cross Transmission of Flagellates possible between Interhost Species ?

It has been observed that under experimental conditions the flagellates can be transferred from one host species to another provided those hosts are systematically related (Dropkin 1941,1946). But it is quite improbable that such cross infection has taken place in nature both because of the distribution pattern and of the mechanism of transfer among the termites within a colony and from one colony to another. Further, if such cross infection occurs at all it should occur during the last nymphal stage so that the flagellates such acquired will be of significance in the faunal assemblage in a new colony, since flagellates present in earlier stages are lost at the moult.

The possibility of infection of flagellate from one host species to another in final nymph and their survival through the winged imago is very remote. If it occurs, the chances are further remote that the infected imago would be one which established a new colony and transmitted those flagellates to the offspring of the pair. Even then, if such cross infection between nearly related termites takes place after crossing all the aforesaid barriers it will not disturb the phylogenetic pattern. Under the circumstances, it is quite probable that the lower termites could acquire flagellates from other termites only in the line of descent. For this reason the symbiotes are favourably used as indicators of the phylogeny of termites. Moreover, concomitant studies of symbiotes and their hosts provide a sound basis for studying their phylogeny.

Analysis of Evolutionary Pathways of Flagellates of Termites and Roaches

Based on taxonomic information Cleveland *et. al*, (1934) proposed a hypothesis that systematic similarity between the flagellate symbiotes of lower termites and roaches *Cryptocercus* is a mere reflection of phylogenetic relation of their hosts. Subsequent taxonomic work strengthens this hypothesis which is now universally accepted by investigators on the subject.

Most entomologists maintain that the Isoptera (termites) descended directly from the stem of Blattellidae in the late Paleozoic or early Mesozoic (Emerson 1955,1971). A detailed comparison of the morphology of most primitive representatives of orders Isoptera and Blattellidae—*Mastotermes darwiniensis* and *Cryptocercus punctulatus* respectively reveal that they are similar in organisation (Mc Kittrick,1965 and Krishna,1970) and possess similar symbiotic bacteria in their gut (Grassé and Noirot,1959). Immunological analysis of

intestinal contents of the roach, *Cryptocercus punctulatus* and termite *Zootermopsis nevadensis* also shows a number of similar antigens (Albin and Ritter, 1976). All these findings permit to assume that contemporary relict roaches *Cryptocercus* are the surviving representatives of the stem of Blattodea from which termites diverged. Again, as both lower termites and *Cryptocercus* possess symbiotic flagellates with systematic closeness, it can safely be concluded that their common ancestors, the blattoids are the primary host of these flagellates so also their direct descendant *Cryptocercus*. On the other hand, lower termites acquired these flagellates only secondarily. Under the circumstances the systematic resemblance between the flagellates of *Cryptocercus* and lower termites may be regarded as a consequence of parallel evolution of the hosts and their symbiotes. It is also to be noted that termites diverged from the Paleozoic blattoids along with their flagellates. It is, therefore, of great interest to trace whether parallel evolution between the hosts and symbiotes are retained in the course of subsequent separate evolution of flagellates in lower termites as well as in *Cryptocercus*.

The flagellate genus *Trichonympha* belonging to the family Trichonymphidae and order Hypermastigida would perhaps be the best example to illustrate the evolutionary pathways of flagellates in both roaches and lower termites and to seek satisfactory answer to the queries just raised. The genus *Trichonympha* is chosen in view of the fact that :

- i. This genus is common to symbiotic fauna of both termites and roaches and is widespread among its hosts.
- ii. This genus includes 34 species (excluding the doubtful record of *Trichonympha* by Uttangi, 1959 from the genus *Heterotermes*) of which 10 species inhabit all the living species of the genus *Cryptocercus* studied so far, and 24 species occur in three of the four families of lower termites. The exception is Mastotermitidae which has only one living species *Mastotermes darwiniensis* with very restricted distribution (in Australia). Absence of *Trichonympha* in Mastotermitidae can very well be explained by considering that this protozoan genus might have been present in the extinct genera of the above mentioned termite family but became accidentally absent from the parental pair of the ancestral form of the only surviving genus *Mastotermes* during the course of evolution.
- iii. The difference between the *Trichonympha* species is very distinct.

Now, if we look into the phylogenetic scheme of the hosts and distribution of different species of *Trichonympha* along different branches of that scheme we may be able to trace the pathways of divergence of both hosts and their symbiotes. From Table 1 it is quite clear that *Trichonympha* is strictly host specific in both the living species of wood roaches. This indicates that these symbiotes which occurred in the gut of Tertiary *Cryptocercus* diverged strictly in

parallel to the speciation of their hosts. In other words a distinct parallel evolution of Tertiary *Cryptocercus* and their *Trichonympha* species has taken place.

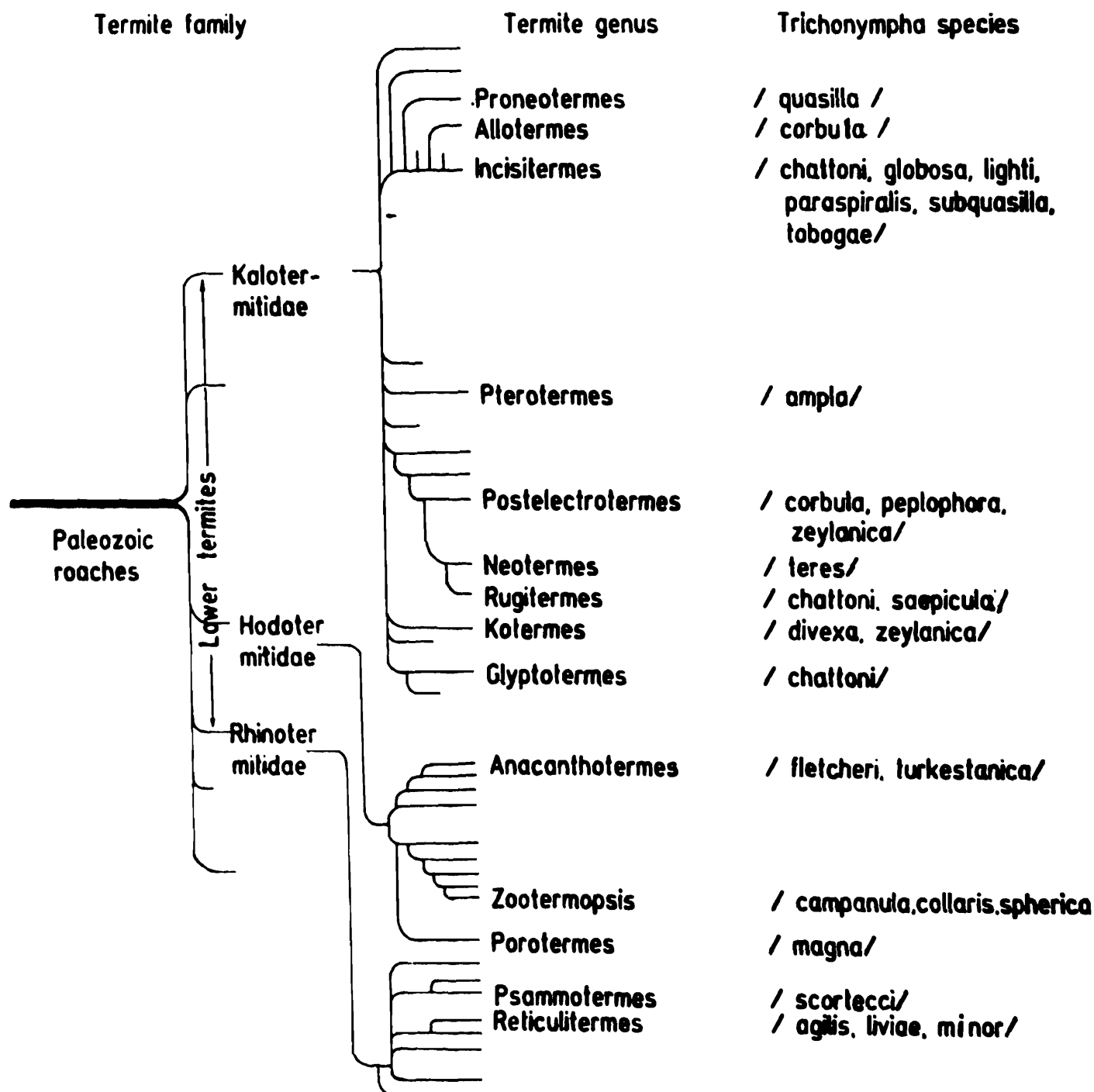
Table 1. Comparison of the Flagellate Fauna of the Orders Hypermastigida and Oxymonadida from the Roaches *Cryptocercus* spp

<i>Cr. punctualtus</i> (in North America)		<i>Cr. relictus</i> (in Soviet Far East)
Appalachian area	Pacific area	
Order Hypermastigida		
<i>Barbulanympha clevelandi</i>	<i>Barbulanympha estaboga</i>	<i>Barbulanympha cryptocerci</i>
<i>B. estaboga</i> , <i>B. ufalua</i> , <i>B. laurabuda</i>	<i>B. laurabuda</i> , <i>B. ufuala</i> , <i>B. wenyoni</i>	
		<i>Bispironympha unica</i>
<i>Euconympha imla</i>	<i>Euconympha imla</i>	<i>Euconympha nana</i>
<i>Idionympha perissa</i>		
<i>Leptospironympha eupora</i>	<i>Leptospironympha rudis</i>	<i>Leptospironympha lepida</i>
<i>L. wachula</i>		<i>L. popularis</i> , <i>L. variabilis</i>
	<i>Macrospironympha xylopletha</i>	
<i>Prolophomonas tocopola</i>	<i>Prolophomonas tocopola</i>	
	<i>Rhynconympha tarda</i>	
<i>Trichonympha acuta</i>	<i>Trichonympha acuta</i>	<i>Trichonympha lutea</i>
<i>T. algoa</i> , <i>T. chula</i> , <i>T. lata</i> , <i>T. okolona</i> , <i>T. parva</i>	<i>T. algoa</i> , <i>T. chula</i> , <i>T.</i> <i>T. grandis</i> , <i>T. lata</i> , <i>T. okolona</i> , <i>T. parva</i>	<i>T. major</i> , <i>T. ussuriensis</i>
<i>Urinympha talea</i>	<i>Urinympha talea</i>	<i>Urinympha cirrata</i>
Order Oxymonadida		
<i>Notila proteus</i>	<i>Notila proteus</i>	<i>Notila proteus ussuriensis</i>
<i>Oxymonas doroaxostylus</i> , <i>O. nana</i>	<i>Oxymonas nana</i>	<i>Oxymonas nana ussuriensis</i>
<i>Paranotila lata</i>	<i>Paranotila lata</i>	
<i>Saccinobaculus ambloaxostylus</i>	<i>Saccinobaculus ambloaxostylus</i>	<i>Saccinobaculus gloriosus</i>
<i>S. lata</i>	<i>S. lata</i>	<i>S. scabiosus</i> , <i>S. spatiatius</i>

On the other hand, after analysing the distribution of *Trichonympha* species in accordance with the phylogram of termites drawn by the Krishna (1970) (Fig.1) two stages of their combined evolution can clearly be demarcated. During the first stage when termite differentiated from Paleozoic roaches and diverged into families in early Mesozoic, parallel evolution of termites and their *Trichonympha* species occurred. Interestingly, this evolutionary parallelism

was discontinued at the second stage of their evolution when phylogenetic differentiation of termites into subfamilies and genera took place in late Cretaceous (Emerson, 1955, 1971 and Krishna, 1970).

Fig. 1. Phylogram of lower termites (as per Krishna, 1970) containing only the families and genera inhabited by Trichonympha species



This view can be further substantiated by analysing the distribution of 24 species of *Trichonympha* in lower termites (Yamin, 1979). Such distribution data

clearly reveals that *Trichonympha* are specific to the host genera but not to the host species excepting three, namely, *T. chattoni*, *T. corbula* and *T. zeylanica* which are found to inhabit more than one host genera. From this data it may also be inferred that when a single species of *Trichonympha* inhabits a number of related genera of termites (e.g., *T. chattoni* occurs in the host genera *Glyptotermes*, *Incisitermes* and *Rugitermes*) it must have been present in the gut of common ancestors of those genera. But, when a *Trichonympha* species is apparently specific to one host genus (see Fig.1) it must have been present in the ancestral form of that genus before it is differentiated to various host species. Besides *Trichonympha* several other genera of hypermastigids also, e.g., *Holomastigotoides*, *Leptospironympha*, *Pseudotrichonympha* and *Spirotrichonympha* provide examples of reciprocal flagellate-host phylogeny in roaches and lower termites.

The flagellate of the Order Oxymonadida comprise two families, namely, Oxymonadidae and Pyrsonymphidae. The former occurs in the host families Cryptocercidae and Kalotermitidae and the latter only in one genus, namely, *Reticulitermes* of the family Rhinotermitidae. The absence of Oxymonadida from the Hodotermitidae and other genera of the family Rhinotermitidae may perhaps be the result of extinction of the species and genera of both flagellates and ancestral termites as opined by Emerson (1971). The Order Trichomonadida, more particularly one of its family Devescovichidae, which inhabits the only living genus of Mastotermitidae and all the genera of Kalotermitidae, and 4 out of 6 genera of Hodotermitidae studied so far, also exhibit reciprocal phylogeny in the genera of the aforesaid families of lower termites. But these flagellates are not found in Rhinotermitidae and Cryptocercidae. It is, therefore, quite probable that these flagellates occurred in ancestral termites which diverged from roaches and subsequently became extinct in Rhinotermitidae in the course of their long evolutionary history.

Sexual Reproduction in the Evolution of Termite Flagellates

It is well known that sexual recombination is more effective as a cause of speciation than is asexual reproduction due to the reason that it is the source of genetic variation. Hence, loss of sexual process in the life cycle of termite flagellates is treated as an important factor for their restricted evolutionary change as traced in the genus *Trichonympha*. But in view of the fact that 395 species of flagellates reported so far from the gut of 208 species of termites and many more species of flagellates are expected to be collected from the remaining host species we can perhaps safely infer that loss of sexuality in termite flagellates has a limited effect on their systematic differentiation *vis-a-vis* evolution.

It has been observed that in asexually reproducing termite flagellates polymerisation (Kirby, 1949) and in limited case polyploidy (Cleveland and Day, 1958) are related to systematic differentiation. In trichomonadid flagellates

systematic differentiation upto family level appears to have occurred through polymerisation of mastigont structure. To be more specific, the flagellate family Calonymphidae in which such polymerisation is exemplified appears clearly to have evolved from the family Devescovichidae. Polymerisation of mastigont system is also found in oxymonadid flagellates. For example, within the family Oxymonadidae, the genus *Oxymonas* is monomonad whereas genera *Microtrichopolodina* and *Barroella* are polymonad.

Polymerisation has also occurred in termite-inhabiting hypermastigids but not in the same manner as found in the families Calonymphidae and Oxymonadidae. In both the above mentioned families, mastigonts, each of which comprises 2 to 4 flagella, an axostyle and a parabasal body associated with a nucleus, have been duplicated as unit. On the other hand in hypermastigids number of nucleus remains normally single even after polymerisation but there has been an increase in the number of individual organelles associated with the spindle pole at division (Kirby, 1949). In one genus of hypermastigids, namely, *Spirotrichosoma*, inhabiting the gut of the termite *Stolotermes ruficeps* polyploid series of species have been reported by Cleveland and Day (1958).

Question now arises whether there is any adaptational significance in the taxonomic characteristics of termite flagellates. Excepting the hold-fast rostellum of some oxymonadids that adhere to the intestinal intima of termites no exoadaptive significance can be recognised in the morphological characteristics which serve for differentiation of their genera and species. However, endo-adaptation within their cell organisation may probably occur in order to enhance multiplication potential, to withstand unfavourable condition of transmission and to achieve more efficiency in the process of contributing to the nutrition of the termite host. The spirochaete and bacteria attached to the surface or within the cytoplasm of the symbiotes also show some adaptive role (Emerson, 1971). But such area of research in symbiotic flagellates is in a preliminary stage. Therefore, exact role of such endo-adaptation in the species differentiation of these flagellates can not be ascertained at this stage.

Conclusion

From the foregoing discussion supported by ample evidence from flagellate taxonomy coupled with phylogenetic studies of their hosts it is quite evident that distinct parallelism in the evolution of hosts and symbiotes occurred throughout the evolutionary period of the roach *Cryptocercus*. Such parallelism was followed by termites also only upto their differentiation in family level. But this was gradually discontinued when they started differentiating into subfamilies and genera. The prime factor responsible for this 'evolutionary inertness' may be that these flagellates have been living in an extremely uniform, sheltered, anaerobic intestinal environment for an estimated 200 million years or more without the necessity to search for food or face predators. Over and above, their hosts (termites) have also evolved buffer against environmental

change through social behaviour that controls the homeostatic physical and biotic factors of their nests. Under this situation these flagellates have not been able to radiate adaptively and, therefore, their genera and species have remained stable for a very long period.

References

- Albin, R.J. & Ritter, H. Jr. 1976. Immunological characterisation of protozoa symbiotic to roach and termite. *Arch. Protistenk.*, 110 : 58-76.
- Cleveland, L.R. 1923. Symbiosis between termites and their intestinal protozoa. *Proc.nat. Acad. Sci.*, 9: 924-928.
- Cleveland, L.R. 1924. The physiological and symbiotic relationships between intestinal protozoa of termites and their host with special reference to *Reticulitermes flavipes* Kollar. *Biol. Bull.*, 46 : 178-201 & 203-227.
- Cleveland, L.R. 1926. Symbiosis among animals with special reference to termites and their intestinal flagellates. *Quart. Rev. Biol.*, 1 : 51-60.
- Cleveland, L.R. & Day, M. 1958. Spirotrichonymphidae of *Stolotermes*. *Arch. Protistenk.*, 103 : 1-53.
- Cleveland, L.R., Hall, S.R., Sanders, E.P. & Collier, J. 1934. The wood feeding roach *Cryptocercus*, its protozoa and the symbiosis between protozoa and roach. *Mem. Acad. Arts Sci.*, 17: 185-342.
- Das, A.K. 1983. A critique to the study of termite flagellates from India in relation to their hosts. *Proc. Symp. Host Environ. zool. Surv. India* : 39-53.
- Dropkin, V.H. 1941. Host specificity relations of termite protozoa. *Ecology*, 22: 200-202.
- Dropkin, V.H. 1946. The use of mixed colonies of termites in the study of host symbiont relations. *J. Parasitol.*, 32: 247-251.
- Emerson, A.E. 1955. Geographical origin and dispersal of termite genera. *Field. Zool.*, 37: 465-522.
- Emerson, A.E. 1971. Tertiary fossil species of the Rhinotermitidae (Isoptera), phylogeny of genera, and reciprocal phylogeny of associated flagellates (Protozoa) and Staphylinidae (Coleoptera). *Bull. Amer. Mus. nat. Hist.*, 146: 243-304.
- Grassé, P.P. & Noirot, C. 1959. L'evolution de la symbiose chez les Isoptera. *Experimensia*, 15: 365-372.
- Honigberg, B.M. 1970. Protozoa associated with termites and their role in digestion. In : *Biology of termites II* : 1-36 (Ed.) K. Krishna and M. Weesner, Academic Press, New York and London.
- Kirby, H. 1937. Host parasite relations in the distribution of protozoa in termites. *Univ. Calif. Publ. Zoology*, 41: 189-212.
- Kirby, H. 1947. Flagellate and host relationships of trichomonad flagellates. *J. Parasitol.*, 33: 214-228.
- Kirby, H. 1949. Systematic differentiation and evolution of flagellates in termites. *Rev. Soc. Mexic. Hist. Nat.*, 10: 57-79.
- Krishna, K. 1970. Taxonomy, phylogeny and distribution of termites. In : *Biology of termites II* : 127-152 (Ed) K. Krishna and M. Weesner, Academic Press, New York and London.
- Mc Kittrick, F.A. 1965. A contribution to the understanding of cockroach - termite affinities. *Ann. ent. Soc., America*, 58: 18-22.
- Uttangi, J.C. 1959. Occurrence of a hypermastigote flagellate, *Trichonympha gujarathensis* n. sp. in Indian termite *Heterotermes indicola* Wasmann from North Gujarat. *J. Karnatak Univ. Sci.*, 4: 101-107.
- Yamin, M.A. 1979. Flagellata with lower termites. *Sociobiology*, 4: 1-119.

Classification and Phylogeny of Clavicornia (Coleoptera)

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The words classification, systematics and taxonomy are now commonly treated as synonyms, because these are carelessly used in modern scientific writings. Originally, classification was the activity of placing things in classificatory groups, whereas, systematics was the general theory underlying this activity. The word taxonomy was proposed long ago and has come into general use comparatively recently. Phylogeny interprets the lines of evolution and is the basis of natural classification.

In order to elucidate natural classification, one should try to collect as much information as possible on the group under consideration and related taxa which usually include both adult and larval, morphological and anatomical characters and non-structural characters too. At the same time one should try to understand the functional aspects of different characters, especially of the modified ones, for which habitat study is absolutely essential. Once the informations are gathered, comparative assessment is required for which one can do matrixes to evaluate relationships of both adult and larval characters as well as non-structural ones. To study phylogenetic relationship one should try to recognise primitive and derived characters. The recognition of primitive characters is of immense importance, which are usually obtained from fossil history and study of earlier work.

Once primitive characters, habits and habitats of a group are distinguished from the derived ones, then Dollo's law can be applied - the principle of irreversibility of evolution : an ancient or primitive character once lost in the course of evolution, is not usually regained in the same form.

In Coleoptera, Crowson(1955 and 1960) neatly enumerated primitive habits, habitat and characters of ancestral Coleoptera. He mentioned that the habitat of ancestral Coleoptera might be under bark, and initial adaptive radiation of beetles gave rise to three stocks e.g. one carnivorous(Adephaga), second wood boring (Archostemata), and the third which may at first have retained the original habitat (under bark) and food (moulds) but soon underwent various reductive changes. The early ancestor of Polyphaga were probably small and obscure looking beetles, but in course of evolution they have adapted to almost all

possible modes of life. The primitive mouth parts of Coleoptera were associated with mould eating habits. There appear to be two basically different ways in which adult beetles have adapted to spend most of their life under bark of trees - together with various intermediate adaptive types. The characters and mode of life (habitat) of first ancestral clavicornia may be considered to be frugivorous, and were associated with lignicolous Ascomycetes fungi, the fungi probably Pyrenomycetes growing in dead or on injured trees. The adult may well have had dorsal mandibular cavity (Sengupta and Crowson, 1966) of the Hymaenotype, which implies a more or less ectosymbiotic relationship with some specific type of fungus. The females of ancestral form probably had a well developed ovipositor of the basic Coleopteran-type, which suggests oviposition in some kind of holes or crevices. The larvae probably lived under bark but they were not likely to be specialized borers (as indicated by the mouth parts and head structure). They probably had 6 well developed ocelli and mouth parts suited for feeding on surface of the bark (probably at night) on spores.

Crowson's notable work on the 'Natural Classification of Coleoptera' in 1955 may be referred to as the starting point of natural classificatory work on Clavicornia. He recognised 26 families. Later Sen Gupta and Crowson (1966, 1968 and 1969) established four new families viz., Boganiidae, Cavognathidae, Phloeostichidae and Lamingtonidae under Clavicornia. They also revised the classification of the families Languriidae, Cerylonidae and Sphindidae (1971, 1973 and 1977). Sen Gupta in 1969 and 1988 reviewed the classification of the family Erotylidae and Rhizophagidae. Crowson (1973) have made some addition and alternation to the family Phloeostichidae and Cavognathidae. During 1966-1988, Sen Gupta and Crowson made several changes in classificatory system of Clavicornia and used several new adult and larval structural and non-structural characters in their work.

The Clavicornia as it stands now includes 29 families and is thought to be a dumping ground of small, flat and pubescent beetles. To reconstruct the phylogeny, the procedure to be followed is to work backwards, step by step, from the modern form, but paying due attention to any fossil evidence. There are certain fossils of distinctive clavicorn-type known from late Jurassic and early Cretaceous sediments (*Parandrexix* Martynov), so that an ancestral species of the group could have been traced back to the Jurassic period, probably lower Jurassic. The approach of classificatory system of Clavicornia should preferably be based on a number of considerations, for instance, fossil history, geographical distribution, fundamental characters, origin and original habits and habitats, morphological characters of larvae and adults e.g. head structures including tentorium, mouth parts, eyes and ocelli, antennae, front, meso and meta coxal characters, meta endosternites, abdominal ventrites and tergites, spiracles, male and female genitalia, legs along with trochanters, tibiae, tarsi and claws, wing venation, etc., and other available biological informations on the group in question and allied groups. Sen Gupta and Crowson have been working on the higher classification of Clavicornia since 1966. The detail findings, with several

changes in classificatory system of the group along with relationship will appear shortly in the form of a book elsewhere. We expect that this would be an important contribution as a number of families of Heteromera, Lymexyloide, Cleroidea, Chrysomeloidea and Curculionoidea have evolved from clavicorn beetles.

References

- Crowson R.A. 1955. *The natural classification of the families of Coleoptera*, London.
- Crowson R.A. 1960. The phylogeny of Coleoptera. *Ann. rev. ent.*, 5 : 111-134.
- Crowson R.A. 1973. Further observations on Phloeostichidae and Cavognathidae with definitions of new genera from Australia and New Zealand. *Col.bull.*, 27(2) : 54-62.
- Sen Gupta T. 1968. *Review of the genera of the tribe Loberini (Coleoptera: Languriidae)*. Breviora Museum of Comparative Zoology, Harvard University, 303 : 1-27.
- Sen Gupta T. 1969. On the taxonomy of Erotylidae (Insecta: Coleoptera), with descriptions of two new larvae. *Proc. zool. Soc.*, Calcutta, 22 : 97-107.
- Sen Gupta T. 1988. Review of the genera of the family Rhizophagidae (Clavicornia: Coleoptera) of the World. *Mem. zool. Surv. India*, 17(1) : 1-58.
- Sen Gupta T. & Crowson R.A. 1966. A new family of Cucujoid beetles, based on six Australian and one New Zealand genera. *Ann. Mag. nat. Hist.*, (13) 9 : 61-65.
- Sen Gupta T. & Crowson R.A. 1968. A new family of Clavicornia (Coleoptera) and a new genus of Languriidae. *Proc. R. ent. Soc.*, London, B, 38 (9-10) : 125-131.
- Sen Gupta T. & Crowson R.A. 1969. Further observations on the family Boganiidae, with definition of two new families Cavognathidae and Phloeostichidae. *J. nat. Hist.*, 3 : 571-590.
- Sen Gupta T. & Crowson R.A. 1971. A review of classification of the family Languriidae (Coleoptera: Clavicornia) and the place of Languriidae in the natural classification of Clavicornia. *Mem. zool. Surv. India*, 15 (2) : 1-42.
- Sen Gupta T. & Crowson R.A. 1973. A review of the classification of Cerylonidae (Coleoptera: Clavicornia). *Trans. R. ent. Soc.*, London, 124 (4) : 365-446.
- Sen Gupta T. & Crowson R.A. 1977. The Coleopteran family Sphindidae. *Ent. month. mag.*, 113 : 117-191.

Trends in Taxonomy

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Since the time immemorial it has been the tendency of mankind to differentiate and assign names to various kinds of animals for their easy recognition. As the time passed, more and more categories and names came into existence, which could not be memorised by any single individual. Thus with advancement of science a need was felt to standardise these taxonomic units and their names on scientific basis and arrange them in some order to avoid confusion.

From this process of arranging the animals and plants arose the branch of study termed as *Systematics* derived from the latinised greek word *Systema*, referred to by earlier naturalists, especially, Linnaeus as evidenced by the title of his famous book '*Systema Naturae*' 1st. ed., 1735. The term *taxonomy* has its origin from the greek words *taxis*, arrangement and *nomos*, law and was first used by Candolle (1831) for the plant classification. According to Mayr (1966) it is correctly coined and is analogous to agronomy, astronomy and economy etc. Both these words, *Taxonomy* and *Systematics* are considered as more or less synonymous. The exploration of vast areas of globe and the increased knowledge of fauna had lead to the better understanding of the subject. Thus, *Taxonomy* denotes the theoretical exercise of putting all known animal species in some order according to their natural relationships. The term *Systematics* refers to study of diversity in organisms, providing basis for stable taxa and all their biological and evolutionary relationships.

Origin and History of Animal Classification

There is a long history before the present system of animal classification was established. Mayr (1969) divides it, for the sake of convenience, into arbitrarily five periods, which overlap to some extent.

It is well known that there exist some common names for animals coined by natives in all parts of the globe. These refer mostly to curious and prominent types only. Most of these names are in vernaculars and may be composed of uninominal, binominal or occasionally trinominals.

The greek philosopher and scientist, Aristotle (384-322 B.C) classified animals according to their structural similarities. He not only tried to name the

taxa but studied the behaviour of some and attempted to correlate these with their structural peculiarities. Some of the names used by him such as Coleoptra and Diptera are in use even to-day. He may thus be considered as father of biological classification. Aristotle was a great philosopher, founder of logic and had profound influence on the taxonomic concept of the period. Contemporary naturalists attempted to arrange animals in a single grade, *Scala Naturae* on the suggestion of Aristotle, who believed that there was an inherent tendency among the organisms in nature to attain greater and greater perfection with corresponding changes in environment which ultimately resulted in perfect gradation from lower to higher categories of animals. This gave rise to the idea of evolutionary thinking.

The typological concept, i.e., all members of a taxon represent exact replica of the 'Type' prevailing at that time had its profound effect on the taxonomy as well. Subsequently, as a result of worldwide explorations, leading to descriptions of new species, the typological concept gradually gave way to population concept. It was realised that species were represented by individuals which have morphological similarities yet exhibited certain amount of variations amongst themselves.

It was, however, the genius of Carolus Linneaus (1708-1778) who adopted consistently a system of binominal nomenclature, in the 10th ed. of his classical book '*Systema Naturae*' published in 1758. As per the 'International Code of Zoological Nomenclature', it is considered as the starting point for zoological nomenclature. The said book passed through sixteen editions during the life time of its author. Most of the classifications proposed during this period were no more than identification schemes resulting into close groupings of organisms of very different nature. Subsequently, the typological concept was criticized by scientists with empirical or nominalist approach.

During the period, i.e. between the publication of '*Systema Naturae*', 10th ed in 1758 and '*Origin of Species*' by Charles Darwin in 1859, the idea of species as a fixable and disparate natural unit was gradually replaced by the more broad based thinking taking into account the totality of characters. More and more material brought through voyages and collection trips to far flung areas of the world provided an opportunity to scientists to evaluate various characters. It gave better understanding of taxa as units of natural system which was very different from that of Linnaen thought embodying Aristotle's logic of inherent nature of organisms. Many of the existing methods and principles were established for the delimitation of taxa on the basis of correlation of different characters.

Prior to publication of the famous book '*Origin of Species.*' taxonomists believed in essentialism. It puts forward that diversity in nature is the poor expression of certain essential characters in species. According to them only individuals exist in nature. The other alternative was empirical approach which advocated that observations based on aggregate of characters, not essential ones, would lead to a natural system.

The Darwin's theory of evolutionary taxonomy is followed by most of the present day taxonomists. It explains that a natural classification is the manifestation of evolutionary relationship between different groups. Their fundamental similarities based on homologous structures demonstrate common ancestry, rather than on analogous structures which look similar superficially as a result of adaptation and convergent evolution. The idea of common descent for various animals provided a meaningful theoretical interpretation to taxonomic work. It clearly explains that evolution has created different species in nature and the task is to discover and arrange them in a natural and evolutionary sequence. This concept, however, did not affect the already established classification based on similarities or dissimilarities since the theory of common descent also resulted in the groupings of taxa on same lines. During the same period a search began for missing links and the reconstruction of hypothetical primitive ancestors. The phylogenetic tree for living organisms prepared by Haeckel (1866) was helpful in promoting such activity.

Darwin had realised the phenomenon of transmission of variations, leading to speciation, from parents to offsprings without proper explanation. The answer came through carefully controlled experiments, in cross breeding, by Mendel (1822-1884) who discovered the principles of heredity. These principles formed the basis for evolution and biological classification.

By the end of the nineteenth century, a large number of new species of major animal groups were already discovered. As a result, there arose a need to concentrate on cataloguing, describing and classifying the known taxa which was not a very interesting proposition.

Hitherto, taxonomists confined their studies on samples preserved in various repositories, and is popularly termed as Museum Taxonomy. In essence it was continuance of the 'Typological' concept although it was apparently not in vogue.

Most of the identification schemes were based on purely morphological characteristics ignoring intraspecific variations. Many species were either known by a single 'Type' or on meagre material. But increased collection activity resulted in large series of specimens of species from distant places within the distributional range revealed certain variations. This gave rise to the idea that species are composed of groups of populations distributed in space and time.

The term '*New Systematics*' was given by Huxley (1940) to express species as a group of interbreeding populations in nature which are reproductively isolated from other such populations. In the light of this, a species represents a biological unit of this universe. It may rightly be said that New Systematics is not a substitute for classical taxonomy, but only complementary to it. Being limited to study of populations, this concept has not contributed towards theories of classification but it did help in better understanding of the process and trends of evolutionary biology.

The population taxonomy may not be applicable to the groups that are not fully explored and are at alpha stage. There is an urgent need for such groups to

be explored in vast areas for procuring a large series of representative material. It would serve as a tool for arriving at various taxonomic conclusions. Although the species are recognised as biological interbreeding units in nature, it is not possible to verify this aspect through breeding experiments for all the known species. However, it can be deduced from a large number of individuals encountered in nature from distant areas at different intervals, of a certain species, that these are products of breeding process going on in the nature.

The current period marks the re-examination of whole theory of taxonomy by various authors and in certain cases revival of nominalistic approach to taxonomy through computers, etc. Besides this, introduction of biochemical and cytological studies are helpful in better understanding of certain phylogenetic problems in organisms.

Species and Related Categories

The microbiologists, geneticists and zoologists express different opinions about a species.

In terms of zoological taxonomy a species may be defined as consisting of interbreeding natural populations which may differ markedly among themselves, yet resemble each other more closely than the members of any other groups and which are reproductively isolated from such other groups. Although the idea of population gained momentum in recent years, it was recognised much earlier even in pre-Darwinian period.

As now understood, subspecies are geographical races separated due to certain geographical barriers. It is the only infraspecific category recognised by the 'International Code of Zoological Nomenclature'.

The individuals belonging to local or distant populations may differ morphologically to a varying degree with various intermediate forms. Linnaeus rarely used the term Variety rarely in the sense for not properly understood situations. Later on, some naturalists used this term for an assemblage of individual variants or races. In order to avoid confusion such infraspecific categories recorded prior to 1961, the benefit of doubt should be given to the author and an attempt should be made to confirm through available information whether it represents a geographical race. In that event it takes the name of the original author and the year in which it was first described. It is advisable to name such infraspecific categories in vernacular to avoid complications of nomenclature. The study of such categories is of great importance in better understanding of the dynamic nature of species, which is a biological entity in nature. Often lack of knowledge on this aspect has resulted in too many synonyms in certain species. Generally samples of distant populations apparently looking quite distinct, are connected by various intermediate forms in the nature. But if only two extremes are available, then these may be often mistaken for two distinct species. The intraspecific variations were studied in detail for certain species of Dermaptera by Srivastava (1979). The study reveals that lack of

appreciation of such variations may result in the recognition of various species that are based on individual variants only. Besides, Race and Cline and a few other neutral terms such as *Group* or *Complex* are applied informally to phenon or unit which are not properly understood. Certain taxonomists working on insects, birds and mammals, use the word geographical races as interchangeable for subspecies.

Zoological Code of Nomenclature

In order to standardise the names of various animal taxa, to be understood internationally, the British Association under the chairmanship of Strickland in 1842 came forward with a solution in this direction. As a result, the Strickland Code emerged. Besides, in 1877 the Dall Code was brought out followed by National Code by French and Germans in 1881 and 1894, respectively.

Subsequently, International meetings were organised to provide a set of rules to name the animals, commonly known as the International Code of Zoological Nomenclature. The Code was adopted at the Fifth International Congress of Zoology at Berlin, in 1901 and released only after the Sixth Congress held at Berne, in 1904. It was gradually modified during the Seventh and Eleventh Congresses after comprehensive discussions and re-editing of various articles and then was finally adopted at the Fifteenth Congress at London, in 1958 and released in 1961. Its revised edition was brought out in 1964 after the Sixteenth Congress held at Washington, in 1963. It consisted a Preamble, 86 Articles (Article 31 repealed in 1963), five Appendices, an official Glossary and a detailed Index, all in parallel English and French languages. Recently, a third edition of the Code has been published in 1985.

The Preamble of the Code (1961) reads as follows that explains its aims and objectives: *"The International Code of Zoological Nomenclature is the system of rules and recommendations authorised by the International Congress of Zoology. The object of the Code is to promote stability and universality in the scientific names of animals, and to ensure that each name is unique and distinct. All its provisions are subservient to these ends, and none restrict the freedom of taxonomic thought or action"*.

References

- De Candolle, Augustin, P. 1813. *Théorie élémentaire de la botanique*. Chez Deterville, Paris, France.
- Darwin, C. 1859. *On the origin of species by means of natural selection or the preservation of favoured races in the struggle for life*. John Murray, London, U. K.
- Haeckel, E. 1866. *Generelle Morphologie der Organismen*, II. Georg Reiner, Berlin, Germany.
- Huxley, J. S. (ed.). 1940. *The New Systematics*. Clarendon Press, Oxford, U. K.
- Mayr, E. 1966. The proper spelling of taxonomy. *Syst. Zool.*, 15: 88.
- Mayr, E. 1969. *Principles of Systematic Zoology*. McGraw Hill, Inc., U.S.A.
- Srivastava, G. K. 1979. Intraspecific diversity in Dermaptera. *Proc. Sym Zool. Surv. India*, 1: 53 - 70.

Promoting Taxonomy : Why and How ?

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The animal and plant life exists in every nook and corner of the earth, the only living planet, in myriads of 'forms', shapes and sizes. Though each species is unique and different from the other in its structure and ways of life, yet all are linked with one another, closely or remotely, be these animals or plants, in a 'web of life'. It is these inter-relationships of the organisms, be it the tiny, single-celled protozoans or the mighty, highly specialised and finest product of evolution the mammals, that are extremely precious and having made it possible for life to be sustained on earth and keep on evolving, slowly but surely into different species under the impact of environment and through the, now well-known and established, process of Natural Selection. The importance and relevance of taxonomy in studying and understanding biological diversity has already been stressed, adequately and convincingly (Jairajpuri, 1990).

The taxonomy provides us the correct identification, distribution, classification and inter-relationships of organisms enabling us to carry out further explorations systematically and helps us in organizing these items of information in such a manner that we can retrieve them quickly and correctly, as and when required. The importance of identification of species in environmental research and management as well as in biological programmes is unquestionable. Apart from this no work, worthwhile and reliable, can be carried out in the field of entomology, parasitology, nematology, plant pathology, fisheries, etc. or for that matter in any branch of medical, veterinary and agricultural sciences without the proper knowledge of taxonomy or the identification, classification and distribution of the species involved. Could anyone imagine treating an infection properly without identifying correctly the pathogen? Is it possible to control or eradicate vector-borne diseases or crop pests without their identification? The answer to all these is an emphatic "no" as one would be virtually groping in the dark without proper identity of the target organisms. Wrong identifications and diagnoses are likely to create more problems and confusions, some of which could be of a very serious nature leading to waste of time, efforts and money. This has happened so very often in the diagnosis and treatment of parasitic infections in man and livestock, in the control of mosquitoes and other species of vectors and also that of agricultural pests.

Now that we stand convinced with the arguments and justifications that have been given for encouraging taxonomic study and research, the most logical step would be to work out the ways and means (*Action Plan*) to accomplish the task in an organized and systematic manner. It is considered necessary to familiarise the students of biology right from their school days (matriculate level) with the basic knowledge of evolution and biological diversity, and fundamentals of identification and classification of animals. At 10 + 2 (senior secondary or intermediate) level this knowledge must be suitably widened to incorporate some more aspects, like ecology, ecosystem and environment. At the graduate level a full course on taxonomy be given and this should be at par with other courses like those on physiology, ecology, histology, etc. Practical training in identification of local fauna and flora will be highly useful. Excursions to Zoological gardens Sanctuaries, National parks and if possible to Biosphere Reserves also, would give the students further experience of and exposure to biological diversity and the concept of ecosystems.

At postgraduate or master's level a separate but optional advanced course on taxonomy, dealing with all relevant aspect in totality, should be introduced. This course will be meant only for those students who wish to take up the study of biological diversity and taxonomy for the purposes of research. Adequate knowledge of evolution and genetics as separate courses along with taxonomy may be given both at the graduate and post-graduate levels, as taxonomy can neither be clearly understood nor appreciated without a thorough background of these two aspects. The students should be fully exposed to modern techniques and methodology, often referred to as 'experimental taxonomy', so that they do not remain confined to the 'conventional' microscope like the 'classical' taxonomists. A good background of ecology would be an advantage in taxonomic studies particularly those pertaining to distribution, adaptations, etc. of animals and plants.

The composition of faculty of a biology/zoology/botany department of a university must be such as to include some specialists on taxonomy who should not only carry out research on biological diversity themselves but also encourage and guide students to take up taxonomy as a profession. But students would be attracted to this field of study only if it does not decrease but improve their chances of employment. Employability is an extremely important factor in promoting any subject or discipline and the same applies to taxonomy. The Government, therefore, must provide jobs exclusively in taxonomy so that the subject gets proper recognition and the vast biological diversity of the country gets due attention, both for the purposes of conservation and its utilisation for humanity in a sustainable manner without creating any environmental problems and ecological imbalances.

Organizations like the Zoological and the Botanical Surveys of India have a special responsibility in promoting taxonomic studies and that too of a very high

order so that same may serve as a model for the others. There should be very close interaction between the two Surveys which appears to be largely missing at present. This should involve some joint programme of work pertaining to ecosystem study, environmental impact assessment, studies on animal-plant interactions, etc. A close co-operation, collaboration and co-ordination must be established not only between the two Surveys, but also between similar institutes of the country like FRI, IARI, IVRI, CMFRI, NIO, etc., which carry out studies on biological diversity though on a limited basis and pertaining to their own area of activity. This calls for the establishment of a co-ordinating committee which should meet periodically to review and monitor the progress of work, to explore areas of collaboration and to avoid unnecessary duplication of research. The Ministry of Environment which administers the Zoological and the Botanical Surveys of India and also the Forest Research Institute of India must take a lead in forming such a committee. The earlier it is done, the better it will be for the growth of biological research in India.

The potential of universities in promoting research ought to be recognized as the bulk of scientists who man the various institutes and the ZSI, BSI, come mainly from the universities. There is a need to organize, on a annual basis, a symposium on taxonomy which would provide a proper forum for the exchange of ideas, for developing mutual collaboration in different fields, for focussing attention on those areas where expertise is not available in the country and for finding out the ways and means to develop such expertise. Some research institutes or universities, but more appropriately the Zoological and Botanical Surveys of India, may periodically offer general courses on taxonomy, methodology of collection and preservation of material for taxonomic study, specialized courses on Taxidermy or on particular animal groups (e.g., insects, helminths, snails, earthworms, snakes, etc.) in which scientists from all over India can participate. ZSI has already taken a lead in this direction and it is hoped that the trend shall not only continue but be strengthened and widened further. It is also suggested here that periodic in-service refresher courses should be organized by the two Surveys to which experienced taxonomists from all over India be invited, if need be, to deliver lectures. For promoting the cause of taxonomy further and also for creating interest in the fauna and flora of the country, it is suggested that the ZSI/BSI should jointly organize exhibitions on biological diversity in different parts of the country on suitable occasions. During the period of exhibition, films on animal and plant life can be shown and eminent scholars be invited to give talks on the fauna and flora of the country with emphasis on their utility for mankind. Such exhibitions are already being organized by these organizations but they are mostly limited to either New Delhi or Calcutta. The regional stations of the ZSI and similarly that of BSI must come forward and play a positive role in this matter.

In the end, it may be stressed once again that taxonomy is an important discipline of biology, perhaps much more relevant in the present context of

research on environment and biology than in the past. Its utility and importance will grow more and more with time and, therefore, it is necessary that serious efforts should be made to encourage teaching and research in taxonomy using both the conventional and modern methodology.

Reference

Jairajpuri, M. S. 1990. Taxonomy in environmental management and modern biology : an overview. *In : Taxonomy in Environment and Biology*. 1-14. Director, Zoological Survey of India, Calcutta.

Phylogenetics and Biogeography : A Synthetic Approach

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It is well known that plants and animals in a particular area do not occur as a chaotic mass of intergrading groups of individuals, but as numerous independent breeding units or population. These population are known as species, the demarcation of which on the basis of multiple characters is the task of a Taxonomist. Every species occupies certain area or space and breaking up of a species into daughter species is closely related to space it occupies. The origin and successive evolution of a group of species from the stem species in time and space establish some relationship which is known as phylogeny. It was realized long ago that spatial relationship of organisms can be used for determining 'Phylogenetic relationship' or phylogenetics (Hennig, 1966). The basic units of such phylogenetic system are certainly the species, specially the monophyletic groups which in turn, are, the real units of evolution. The dispersal and evolutionary change of species had taken place in time and space within hierarchical sequences - 'Nature's Hierarchy' (Brundin, 1966). The species, both extinct and extant, break down into genera, families, orders, etc., by the process of phylogenetic unfolding in time and space from a single ancestral species by cleavage, giving rise such Hierarchy's system. However, the geographical vicariance and the possibility of using it in phylogenetic systematics is not limited to relationships of lower taxa. There are relationships between distribution in space and systematic classification of higher taxa (Hennig, 1966).

On the other hand, biogeography seeks to establish the pattern of order - 'Nature's Hierarchy' apparently in chaos of diversity of life forms present on earth. As such, it concerns with evolutionary mechanism wherein both plants and animals originate, evolve and organise themselves in assemblage showing patterns of distribution and affinity. Further, it tries to find out why certain species are found in certain areas, but not in others and what is the place of origin, mode of dispersal, evolution, etc.

Since the evolutionary change of organisms has taken place over a long span of time and space, Nature's Hierarchical system cannot be reconstructed without knowing the historical past of organisms (fossil history) in the perspective of Palaeogeography and Palaeoclimatology. The spacial and temporal distribution of a species or a group of species is the subject matter of historical biogeography

based on which the present day biogeographical pattern of any region can be explained in a meaningful manner.

From the foregoing account, it is quite clear that phylogenetics and biogeography complement one another and their concomitant study is essential in reconstructing the 'Nature's Hierarchy'

The main purpose of the present article is not to deal with the traditional principles and processes of Phylogenetics and Biogeography in isolation, but to highlight the most modern synthetic approach of phylogenetics and Biogeography in constructing hypothesis regarding the centre of origin, dispersal, evolution, etc. of biota in the light of most modern concept developed by Hennig (1966) and Brundin (1966), and followed by others.

The foundation of synthetic approach has been initiated in the recent past by the proponents of phylogenetic systematics (e.g. Hennig, 1966; Brundin, 1966; Nelson, 1969; Cracraft, 1973) suggesting that the construction of phylogenetic relationships enables one to clarify the distributional patterns of primitive and derivative taxa in respect of the events of continental drift. Thus, one can arrive at a parsimonious hypothesis regarding the centre of origin, dispersal, evolution, etc. Moreover, it helps in reconstructing the faunal history in late Mesozoic and early Cenozoic era, when the continental drift is known to have occurred.

Reconstruction of Nature's Hierarchy

Principles and Methods : To understand and reconstruct 'Nature's Hierarchy', Brundin (1966) following Hennig (1966) had adopted to a three-step procedure comprising (i) a comparative study of the biological species and their properties, (ii) investigation of the relative age of homologous characters of species in transformation series in geographical areas, and (iii) the phylogenetic - biogeographical synthesis.

The last step being the subject matter of present discussion, includes establishment of strictly monophyly by exclusive use of joint possession of derivative extremes and search for sistergroup by additional use of the geographical distribution of the actual species. This is the reconstruction method proposed by Hennig (1966) followed by Brundin. The causal biogeography can be defined as the study of the history in time and space of strictly monophyletic groups. It is intimately connected with the reconstruction of the phylogenetic hierarchy, and searching for geographical replacement within properly reconstructed sistergroup system becomes the biogeographical main method. The sister-groups is referred to the species groups that arose from the stem species of a monophyletic group by one and the same splitting process.

The biogeographical method starts from the observation that sistergroups often differ in their geographical distribution and they generally replace each other in different geographical areas. In the same process, the sister groups of higher taxa is also determined. It is easy to determine that most distinct sister-

groups should be distributed in relatively widely separated continental masses as found in the Southern Hemisphere. This is one of the reasons for selecting circum-Antarctica midges by Brundin.

Brundin and Hennig's rule has considered parallelism between morphological and geographical progression. They have established their hypothesis on the belief that 'the speciation by cleavage of a stem-species is a product of time, progression in space and isolation of peripheral population' Hence, it is clearly understood that a careful establishment of strictly monophyly and sister-group relationship is essential requirement for realistic interpretation of a distribution pattern.

Once the phylogenetic sequence of any taxa is determined and if that is placed in the geographical perspective, then it is possible to construct a hypothesis regarding the centre of origin, dispersal and evolution of the group on a sound basis. For example, if it is shown by comparison that a species X is phylogenetically more closely related to species Y than to any other known species of the world, then the species X and Y are considered as sister-group, because they are daughter species in the recent fauna. Hence a dichotomy of a properly constructed phylogenetic diagram can be established. When such diagram is placed in the geographical perspective, the biogeographical pattern is best understood.

Sometimes and specially in young and advance groups rich in species very much identical to each other, there are species aggregates where the problem cannot be solved because of their adaptive characters. In such cases we have to be satisfied with establishment of strictly monophyletic status of actual group (Group B of fig. 3) while monophyly is defined as to have evolved from one stem ancestor.

For further clarity of the sythetic theory of phylogenetics and biogeography, if we examine the map of Australasia (Fig. 1) where each black dot mark represents the occurrence of an endemic species. The species are supposed to be members of a group, A+B+C+D+E, indicating strictly monophyletic. We can suppose further that the distribution picture is the result of step by step dispersal from southeastern Asia via Indonesia and New Guinea to Australia. Consequently, it is admitted that a phylogenetic diagram of the type shown in Fig. 2 would be in accordance with the supposed dispersal. In such a case, Australian group E is the most advanced (apomorphic), and recent group being located at the extreme periphery and a member of the youngest sister-group pair, D+E. The stem-species series a/b/c/d/e of fig. 2 indicate a sequence of decreasing age and increasing apomorphy (advanced) that corresponds with relative recency of common ancestry of the recent groups A-E. Although, it is a hypothetical explanation, it could be explained in the distribution pattern of the termite genus *Parrhinotermes*.

This is the synthetic approach as proposed by Brundin and explained thoroughly by his study on Circum-Antartica Midges (Diptera). Such study also

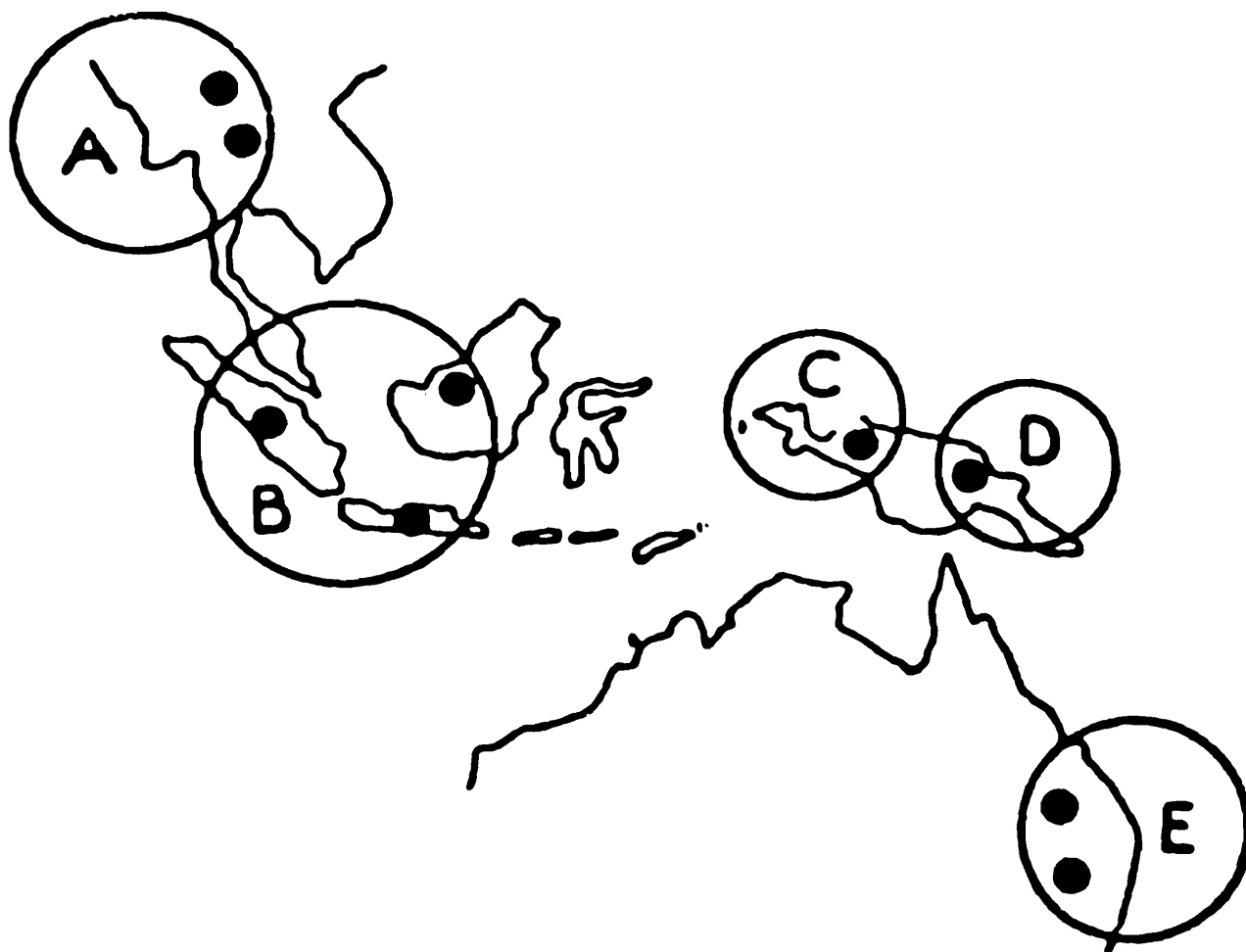


Fig. 1. Geographical distribution of the group A+B+C+D+E.

helps in the reconstruction of faunal history in predrift of continent in Mesozoic era. Very recently, Cracraft (1973) has rightly indicated that the historical biogeography includes the construction of hypothesis about the (i) phylogenetic relationship (ii) probable distribution of ancestral species, (iii) probable path of dispersal, and (iv) palaeogeography and palaeoclimatological factors influencing distribution pattern.

As such, it indicates that the palaeogeographic and palaeoclimatological events in the Mesozoic and early Cenozoic era had profound influence on the distribution and evolution of biota around the world.

Examples based on Insects

A. Diptera :

The historical biogeography concerns with evolutionary events during the whole geological time scale. The salient characters of the present day biogeography can be traced back from the past history of organisms. The process

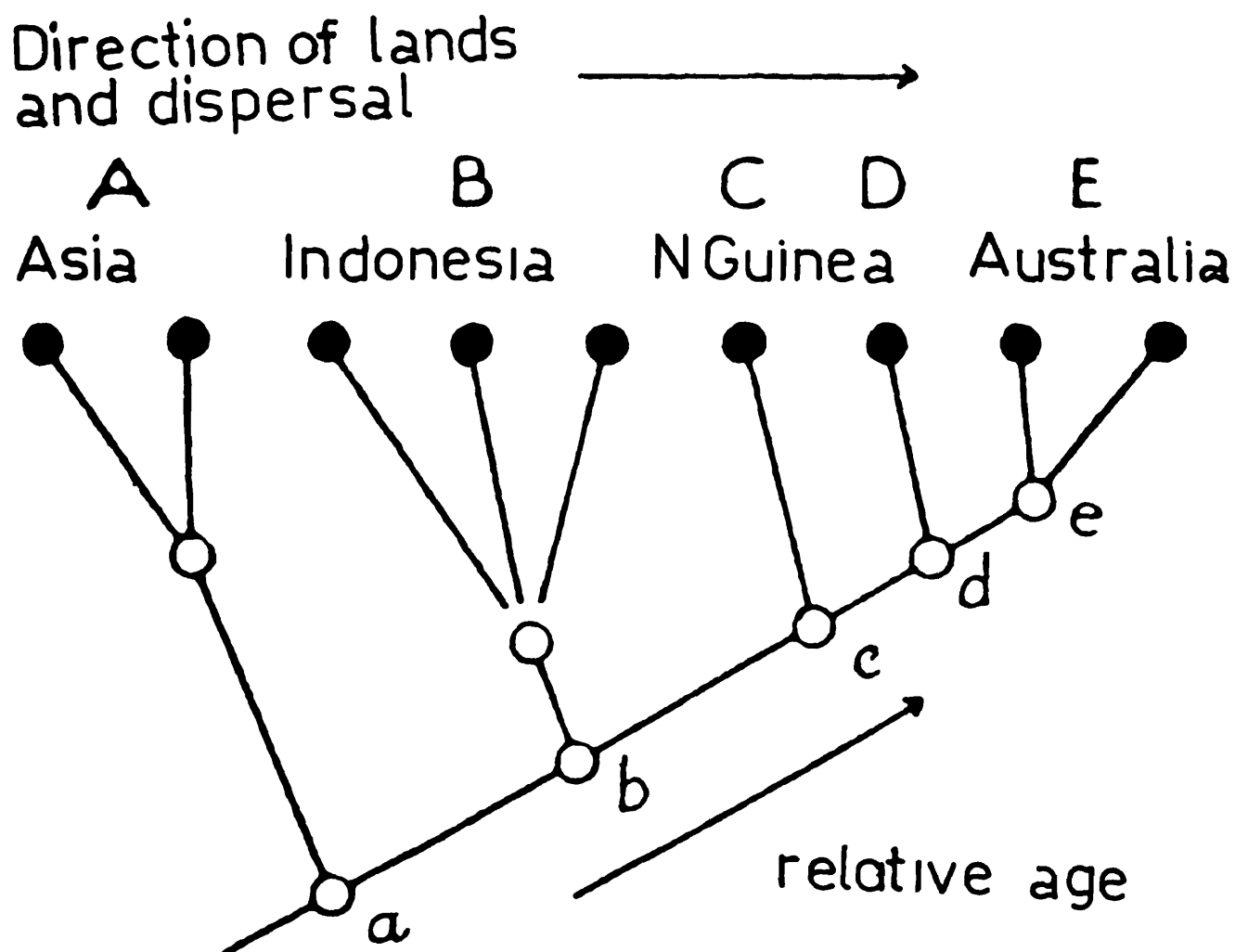


Fig. 2. Phylogenetic relationships of the groups A/B/C/D/E by supposed step-by-step dispersal of the group A+B+C+D+E from southeastern Asia via Indonesia and new Guinea to Australia.

of phylogenetic unfolding in time and space of a higher taxa from a single ancestral species into one or more daughter species is the main model of evolution. While gradually changing morphological characteristics are found in a member of related taxa, the phenomenon is called character progression or transformation series. Such character progression shows an order paralleling the orderly distribution of the same taxa. A good example is elaborated in Brundin's (1966) monograph on the taxonomy of chironomid midges and geography of the Southern Hemisphere. Brundin (1966) following Hennig (1966) proposed for the first time a synthetic approach to Phylogenetics and Biogeography to understand the origin, dispersal and evolution of Circum-Antarctic Chironomids (Chironomidae : Diptera) with reference to the events of the continental drift. These are small non-biting, primitive flies, the larvae of which occur in the cold mountain streams of the continents in the Southern Hemisphere with a few exception. The striking feature of their distribution is the great similarity of these midges in long separated continents isolated by vast stretches of ocean where many genera

are peculiar to the south in common and even species in common.

Brundin tried to explain such distribution pattern and adopted the synthetic approach as explained before. As such, he framed a phylogenetic sequence based on the analysis of plesiomorphic (primitive) and apomorphic (advanced) characters and searched for the sister-groups of the monophyletic taxa in different isolated continents. In other words, the framed phylogenetic trees based on both fossils and living taxa had been put on the geographical perspective to construct a persimonious hypothesis regarding the centre of origin, dispersal pathways and evolutionary trends of these primitive midges.

For further clarification, in the subfamily Podonominae, the *Boreochlus* group of Laurasia is the apomorphic sister-group of the *Archaeochlus* of southern Africa and both the groups belong to the African-Laurasian tribe Boreochlini which, in turn, belong to the sister-group of the tribe Podonomini (South America, New Zealand, Australia). The Neocomian genus of Lebanon is more apomorphic than the *Archaeochlus* group and more plesiomorphic than *Boreochlus* group. It has been indicated further that the Podonominae probably are the sister group of the Aphroteniinae (South Africa, southern South America, Australia-Tasmania) and that these subfamilies are probably the sistergroup of the world wide subfamily Tanypodinae. Reasonably, it can be proposed that chironomid evolution and dispersal had reached a fairly advanced stage well before the Jurassic - a time prior to the initiation of the continental drift. Evidently, it can be concluded that 'the disjunct distribution pattern of old chironomid groups with southern temperate origin, evolved in direct connection with successive fractioning by continental displacement of formerly continuous distribution areas. As such, the synthetic approach indirectly proves that the continental drift occurred after the Jurassic as indicated by the geological evidence.

The world distribution of two tribes Boreochlini and Podonomini of Podonominae is shown in Fig. 3 and 4. The Circum - Antarctic distribution and inferred dispersal in subfamilies Diamesae and Heptagyiidae are shown in Fig. 5. Likewise, the geographical distribution and phylogenetic relationships as shown by the southern hemisphere tribes of the subfamily Diamesinae are shown in Fig. 6.

Coming to a more specific example, in the tribe Podonomini, many genera are found in the southern temperate regions except one genus and one species in the north. This indicates that the centre of evolution of the tribe was in south. Not only the tribe is represented on three widely isolated land masses of South America, Australia and New Zealand, but also each has species of the same genera indicating very close phylogenetic line. Again this is in favour of permitting considerable movement of genetic material between these land masses (Brundin, 1966).

However, it is an interesting question to ask how these closely related species happen to occur on such widely disjunct land masses. The most satisfactory answer

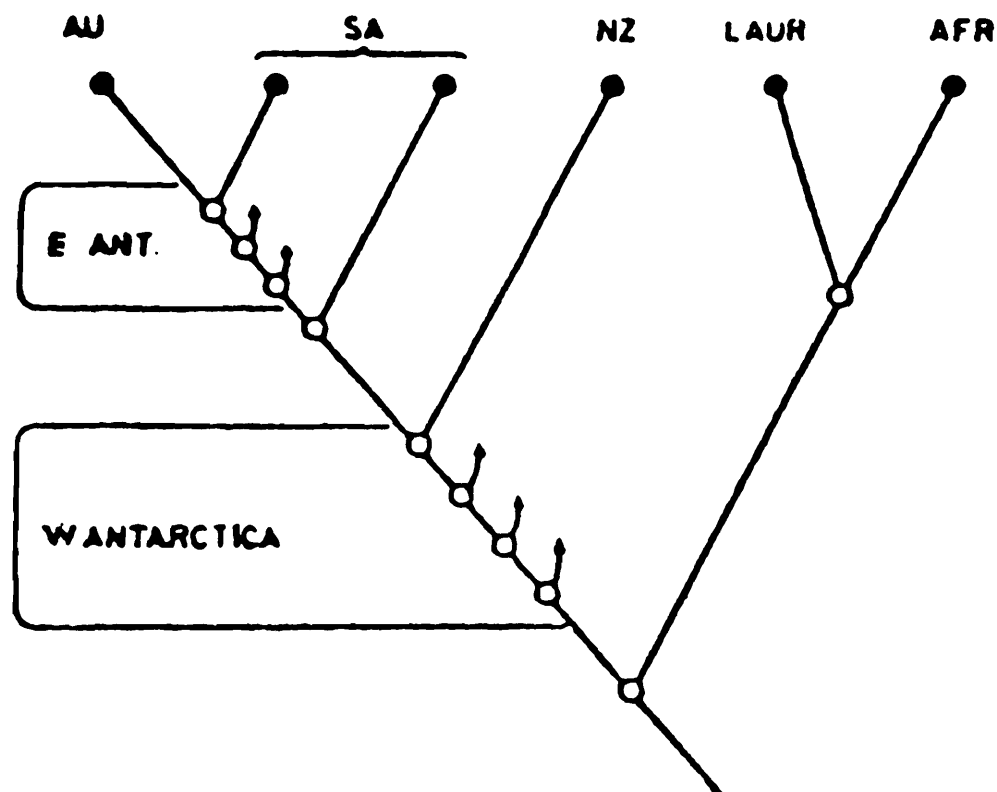


Fig. 3. The connection between phylogenetic relationship, relative age and geographical distribution in cold adapted chironomid groups of austral origin. Circles with attached arrows indicate the multiple occurrence of accordant transantarctic connections within monophyletic group. the different evolutionary and biogeographical role played by East and West Antarctica after the separation of South Africa from the other southern lands in the Upper Jurassic is also indicated. (From Brundin, 1970)

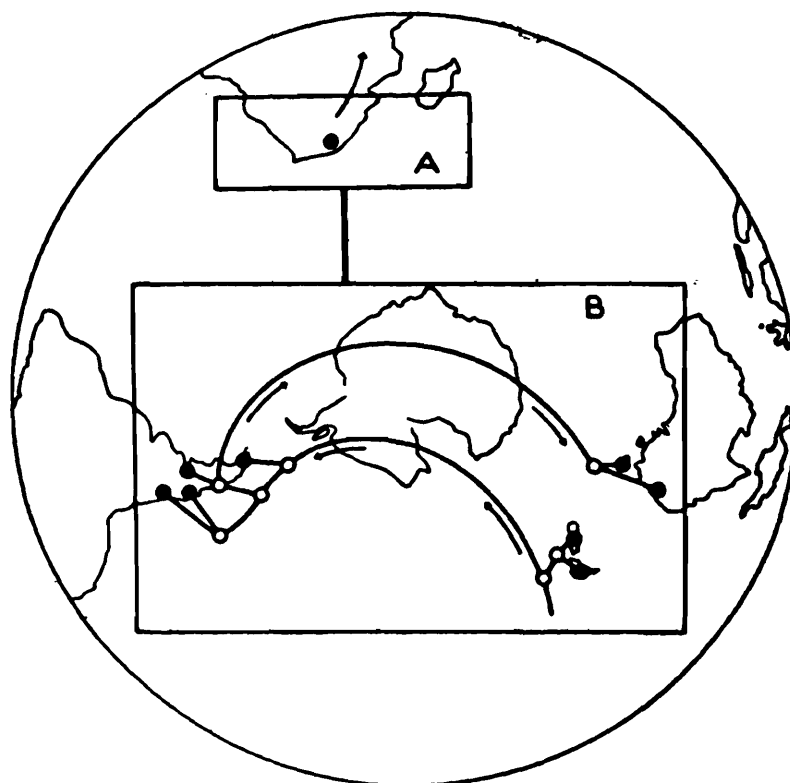


Fig. 4. Circum-Antarctic distribution and inferred transantarctic dispersal in the subfamily Podonominae (Diptera, Chironomidae). A : the tribe Boreochlini; B : the tribe Podonomini. The phylogenetic diagram (within the frame of 'B') refers to the situation in the genus Podonomus, where the species group of New Zealand is plesiomorphic and the species group of Australia is apomorphic in relation to the corresponding sister groups in South America.

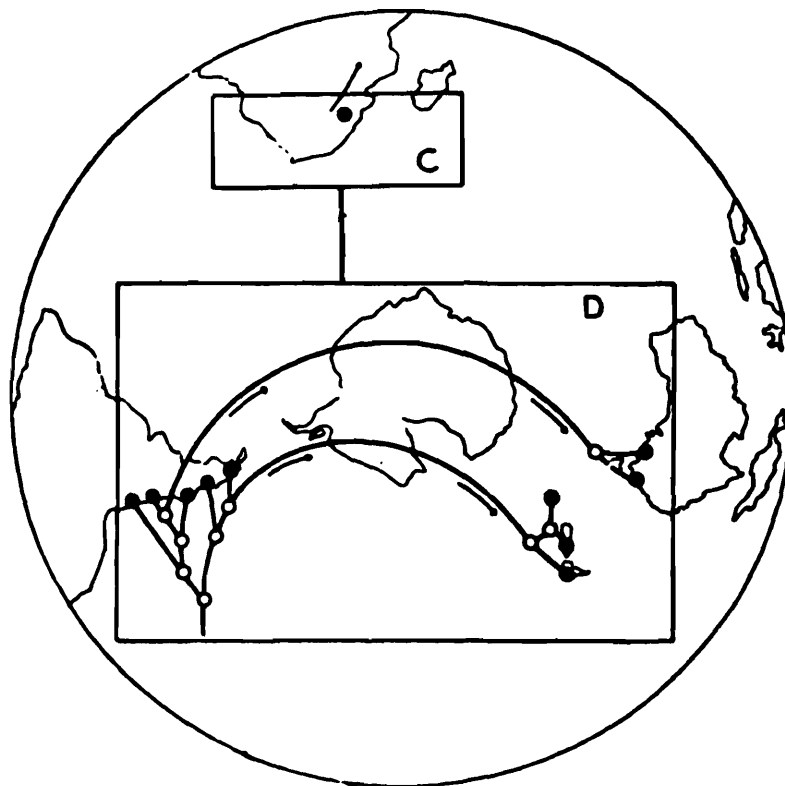


Fig. 5. Circum-Antarctic distribution and inferred transantarctic dispersal in the subfamily Diamesinae (Diptera, Chironomidae). C : the Diamesae; D : the Heptagyini, where the group of New Zealand (genus *Maoridiamesa*) and the group of Australia (the tonnoiri group of the genus *Paraherptagyia*) are body apomorphic in relation to the corresponding South American sister groups.

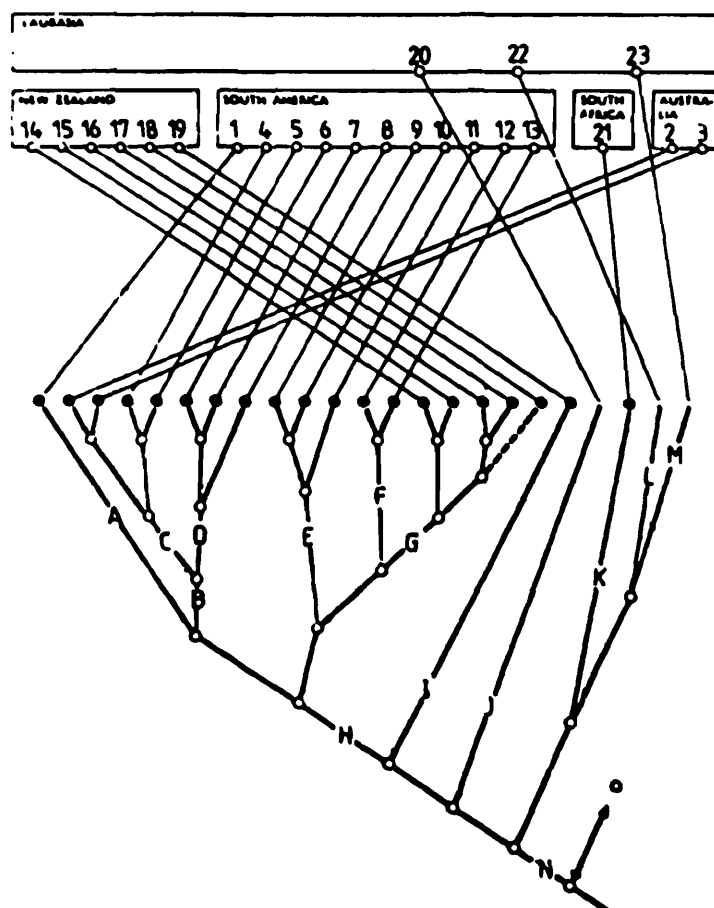


Fig. 6. Geographic distribution and phylogenetic relationships as shown by the southern hemisphere tribes of the subfamily Diamesinae (Chironomidae, Diptera). From Brundin 1966.

has emerged out of the phylogenetic and biogeographical analysis put forth by Brundin through his Chironomid study in the Circum-Antarctica land masses.

There are at least four possible ways in which closely related species occur in widely separated parts of the world.

1. The first possibility can be almost certainly rejected. Transportation of these insects through human agency can be ruled out partially due to the fact that there could have been many species present in North America and Eurasia. It would be very difficult to explain why none of the tribe Podonomini could reach South Africa.
2. The second possibility is more plausible, but still more unlikely. There was migration of population across the tropics from South America perhaps, over Bering land Bridge and into eastern Eurasia and down to Australia and New Zealand and the present distribution is a relict of the much more extensive distribution. The reason for rejecting this argument is that if such migration had occurred many more species would have remained in the northern temperate where suitable conditions for chironomids exist just as they do in the south.
3. The third possibility is that these small, highly mobile, flying insects drifted as aerial plankton from one continent to another on the prevailing westerly wind current in these temperate latitude. There is reason to argue against acceptance of this suggestion for chironomids studied by Brundin. We would expect South America and Africa to have more related species just as Australia and South America have congeneric species.
4. Fourth possibility is the most reasonable explanation for the chironomids. It is thought that the evolution of this subfamily occurred on a single land mass, which latter split up to produce the disjunct distribution as observed at present.

The result of study of Circum-Antarctic chironomid group cannot be explained without direct reference to the theory of continental drift. Brundin has estimated that the history of the chironomids goes back to at least Upper Jurassic, prior to the break up of the Gondwana land.

Continental drift : During the last decade the earth science has been undergoing a scientific revolution in the concept of global plate tectonics. To the biologist, one of the most important aspects of plate tectonics is our new understanding of continental drift.

As a result, the concept of permanence of oceans and continents is a dead issue and the fact of continental drift can no longer be rejected as unimportant issue while attempting to reconstruct faunal histories. The impressive changes in palaeogeography and palaeoclimatology took place in the late Mesozoic and early Cenozoic when many, if not most of the present vertebrate families were

originating and/or differentiating and these physical events have significant effects on the evolution of flora and fauna (Cracraft, 1973). Clearly plate tectonics has brought explanatory significance for the evolution of the biota of the world.

Now coming back to the chironomid midges which have originated in the middle Jurassic period (155 m.y.o.) when all the southern continents were in contact. It appears that first split in Gondwanaland occurred along what is now the Mid-Indian Ocean Ridge in the Permian about 280 million years ago. In the Triassic, the now Mid-Atlantic Ridge split North America from Europe and Africa, a process that completed in the Cretaceous, 135 m.y.o. when South America split from Africa. Sea floor spreading has separated these continents more and more and continued to do so at about 2cm/year.

Evidence suggests that Africa was widely separated from Gondwanaland before South America, Antarctica and Australia drifted far apart. This explains why South America and Australia have more closely related chironomids than does South Africa. This pattern is also observed in the insect taxa Ephemeroptera, Plecoptera, Curculionidae, Mycetophilidae, Formicidae and many others (Price, 1975). Likewise, in the light of the break up of Gondwanaland, that some primitive insects show affinities between India and Australia (e.g. ledriae, leaf hoppers) and, India and South America (e.g. termites). The distribution of more recently evolved taxa can be more easily explained by involving dispersal over land or sea, sometimes under the influence of wind and ocean currents. Therefore, the biogeographic patterns of these taxa differ in many features from the more positive groups.

B. Isoptera

It has been postulated that the families and genera of termites have differentiated in the Mesozoic and Tertiary and that the living termites were in existence and dispersed to the major tropical areas of the world by late Mesozoic time (Emerson, 1955). The termites, as we know today, their distribution, are solely confined to the Circum-tropics with a few genera extended to the warm temperate regions. However, the examples of disjunct distribution among termites are not uncommon. Such patterns can be easily explained in conceiving hypothesis pertaining to several land bridges around the world. There are only two genera, *Porotermes* and *Stolotermes* of the family Hodotermitidae which need to be discussed in the light of present synthetic approach to understand their geographical origin, dispersal and evolution.

It is presumed that the Hodotermitidae is in certain respect much more primitive than so called primitive Mastotermitidae. Hodotermitidae arose from some now extinct hypothetical Isoptera which gave rise to Mastotermitidae. It has been postulated that there is good correlation between the phylogeny and the geographical distribution of termites, providing further evidence in elucidating the time and place of origin of only these genera. *Porotermes* and

Stolotermes are found together in Tasmania, Australia and South Africa, one (*Porotermes*) in Chile and one (*Stolotermes*) in New Zealand. Emerson (1955) postulated that both these southern temperate genera were dispersed through Antarctica during the Triassic period when Gondwanaland was in existence. The genera are monophyletic and their sistergroups are present in the southern tips of the southern Continents once united as conceived today. The distribution pattern of these two primitive genera can be explained in the light of synthetic approach of phylogenetic-biogeographical study as discussed for chironomids.

From the clarification made above it is possible to determine the time and place of origin and dispersal patterns of many organisms through concomitant study of phylogeny and distribution pattern of primitive organisms. Such study also helps in construction of predrift condition of continental landmasses. The distribution of more recently evolved taxa can be explained in conceiving dispersal phenomena over seas or under the influence of wind and ocean currents as well as major land bridges. The biogeographical pattern of such taxa differs in many features from more primitive group.

Historical Biogeography of India

So far, it has been shown how the synthetic study of phylogenetics and biogeography helps in constructing the hypothesis about the centre of origin, dispersal and evolution of some primitive insects particularly in the widely separated continents in the southern hemisphere. Such study can also be applicable to the evolution of biota within the continents. Once the continents have drifted apart, the evolution of continental fauna becomes more or less independent and is the characteristic of that continent. The present day biogeographical patterns in the major continents is a vast subject, the discussion of which is beyond the scope of the present article.

Much of the biogeographical pattern of India as we know today seems to be highly tentative and less sound due to less exploration of vast magnitude of biota including their fossils. However, the most acceptable biogeographical pattern of present day biota of India is treated recently in an excellent book entitled "Ecology and Biogeography in India" edited by Mani (1974).

However, turning to the historical biogeography which happens to be the main essence of the article, is extremely fragmentary due to our poor knowledge of phylogeny and fossil history of the primitive organism once occurred in India. But without the historical background of the biota, it is impossible to explain the present day pattern. As such, it is an unifying concept as also mentioned by Mani (1974) that "the salient characters of the present day biogeography in India may be traced back to the pattern, which prevailed in the past and to the interaction of a complex set of factors, which operated on those patterns in the past, including the geomorphological changes in the region, prolonged differentiations, radiations and interchanges" However, it is now well known that the fauna and flora that differentiated in the Peninsula were indeed the

original elements of India. This complex arose from the ancient stock of Lemuria and the still older Gondwana floras and faunas. There are some evidence of fossils that has led to an idea that India was a part of old Gondwanaland. For example, Permian Southern flora was dominated by seedfern, *Glossopteris* which was distributed over South America, South and Central Africa, Australia, Antarctica and India - land mass is collectively known as Gondwanaland.

Mesozoic and Tertiary Palaeogeography and Palaeoclimatology of India

The relationships between the Indian and far Southern floras were apparently very close, indicating its association with Southern Continents from the late Carboniferous to the Eocene. Land-living reptiles are also found as fossils in the peninsular India. Palaeomagnetism seems to place India very far south of its present position. However, its Cenozoic fauna is known only after it became connected with Asia in the Middle Eocene and was invaded by the Asian tropical fauna.

It is well known that the palaeogeographic and palaeoclimatic events in the Mesozoic and Cenozoic of India as elsewhere, had profound influence on the present day faunal distribution and evolution. These events need to be considered while discussing the centre of origin and pathways of dispersal of any biota in India. Accordingly, these aspects have been briefly discussed here in the interest of the students of biogeography for utilization of data compiled from the literature.

Palaeogeography : The drift of India : The exact position of India within Gondwanaland is quite a debatable question. Some authors (Smith and Hallam, 1970) placed north western India close to or in contact with Africa, but they do not admit contact between eastern India and western Australia because it then probably would leave large gaps between Africa and India/Antarctica. Other workers (Ahmad, 1961 and others) disagree and place India and Australia in contact. Palaeomagnetic evidence according to Creer (1970) support a closer fit of India to Africa. On the other hand, it is proved that polar wander curves for Australia and India are quite similar from the Cambrian to the Cretaceous. This suggests that India and Australia formed a single landmass, but this does not necessarily imply that they were in direct contact.

On the other hand, there is no detailed geological evidence in support of contact of Africa and India in a predrift configuration. Although, there is marked similarities in some of the fossil fauna of India and Africa, which at least suggests a geographical closeness (Hallam, 1967). Likewise, there is poor geological evidence of contact between India and Antarctica, inspite of some matching sequences of Permo-Carboniferous rocks in both Antarctica and India. Although exact timing of drifting of India from Gondwanaland is not clear, it seems almost certain that the drift of India did not take place in the Jurassic as postulated by Dietz and Holden (1970). Various geological data, specially those from sea floor spreading suggest that drifting of India probably began in the

middle to late Cretaceous (Smith and Hallam 1970). They specially postulated that India separated from Antarctica/Australia by after Albian times (100 m.y. ago). It has been shown that by the late Cretaceous, about 75 m.y. ago, India was isolated and significant portion of the Indian Ocean were already formed. Further movement of India was initiated again about 36 m.y. ago

Palaeoclimatology of India : According to Smith and Hallam (1970) 'The Upper Cretaceous marine fauna of the coromondal coast of India shows strong similarities with those of Assam and South Africa, but is very different from that of the Narmada Valley which has close affinities with the faunas of Africa and Europe' These differences suggest that a land barrier extended from Africa and Madagascar to central peninsular India until at least the close of the Cretaceous.

India was either stationary or slowly drifting in equatorial latitudes during the major period of Cretaceous. The evidence is strong that most part of India had tropical - subtropical climate throughout the Tertiary. Cretaceous corals are known from the northwest part of the country (Gill, 1961). The flora consists of about 167 megafossil species and was 'entirely tropical, consisting of estuarine, fresh water, evergreen and deciduous types' (Lakhanpal, 1970). Other Eocene floras along with those from the Deccan Traps indicate that in the early Tertiary an equable warm and moist climate prevailed over the whole area under the influence of warm sea around.

There were some large Miocene floras, but Oligocene floras are rare which indicate prevailing tropical climate with the upliftment of the Himalaya in the Miocene and later in the late Pliocene-Pleistocene, climates were altered in some places. The area with uniform moist and warm desert between Africa and India became arid in course of time. The disappearance of the Tethys sea and the rise of the Himalaya has presided ultimately over the climatic condition of India. As such, climate became less uniform and lost much of its continentality.

Conclusion

It is needless to mention that the synthetic approach of Phylogenetics and Biogeography is most vital step to reconstruct 'Nature's Hierarchy System' and provide insight into the reconstruction of continents in Mesozoic and Cenozoic era. Historical biogeography has gained much scientific foundation than before. Unfortunately, such studies are still limited to some groups of animals. Constraints are manifold. The fossils are less explored and less known than needed for the purpose. Fossil history of large majority of animal groups is just like a torn piece of book wherein most of the chapters are missing. As such, available data create a lot of confusion in discussion making. Exploration of present day biota particularly in the major inaccessible areas of the world as well as in the remote islands is done with minimum satisfaction. As a whole, such investigations are laborious and time consuming causing hinderence of development of the subject. The purpose of inclusion of the events of palaeogeography and palaeoclima-

tology in India is to inspire the students of Biogeography working on Indian biota to be involved in the critical study of phylogenetic-biogeographical synthesis being comparatively young discipline of science of taxonomy.

References

- Ahmad, F. 1961. Palaeogeography of the Gondwana period in Gondwanaland, with special reference to India and Australia, and its bearing on the theory of continental drift. *Mem. geol. Surv. India*, 90: 1-142.
- Brundin, L. 1966. Transantarctic relationships and their significance as evidenced by Chironomid midges.- *K. Svenska. Vet. Akad. Handl.*, (4) 11 : 1-142.
- Brundin, L. 1970. Antarctic land faunas and their history. *Antarctic Ecology*, 4: 1-53.
- Brundin, L. 1972. Phylogenetics and biogeography. *Syst. Zool.*, 21: 69-79.
- Cracraft, 1973. Continental drift, paleoclimatology and the evolution and biogeography of birds. *J. Zool. Lond.*, 169: 455-543.
- Creer, K.M. 1970. A review of Palaeomagnetism. *Earth Sci. Rev.*, 6: 369-466.
- Dietz, R.S. & Holden, J.C. 1970. Reconstruction of Pangaea break up and dispersion of continents, Permian to present. *J. Geophys. Res.*, 75: 4939-4956.
- Emerson, A.E. 1955. Geographical origins and dispersions of termite genera. *Fieldiana Zool.*, 37: 465-521.
- Gill, E.D. 1961. The climates and Gondwanaland In : Kainozoic times. In *Descriptive Palaeoclimatology*, 332-353. (Ed.), A.E.M. Nairn, New York.
- Hallam, A. 1967. The bearing of certain Palaeozoogeographic data on continental drift. *Palaeogeography, Palaeodim., Palaeoecol.*, 3: 201-241.
- Hennig, W. 1966. *Phylogenetic Systematics*, Urbana, Univ. Illinois Press.
- Lakhanpal, R.N. 1970. Tertiary flora of India and their bearing on the historical geology of the region. *Taxon.*, 19: 675-694.
- Mani, M.S. (Ed.) 1974. *Ecology and Biogeography in India*, W. Junk, The Hague.
- Nelson, G.J. 1969. The problem of historical biogeography. *Syst. Zool.*, 18: 243-246.
- Price, P.W. 1975. *Insect Ecology*, John Willey and Sons, New York.
- Smith, A.G. & Hallam, A. 1970. The fit of the southern continents. *Nature, Lond.*, 225: 139-144.

SEM in Taxonomy

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The SEM provides three dimensional images of objects in its normal mode of operation as it records not the electrons passing through the specimen but the electron beam impinging on it. Therefore, the sample may be of varying thickness and size, only that it should fit in the instruments evacuated sample chamber. The secondary electrons do not have to be focussed but are simply collected. Moreover, because the envelope of the impinging beam resembles a sharp needle, the instrument achieves a great depth of field.

The SEM is capable of a range of magnifications that overlap the range of light microscope at lower end and the range of transmission electron microscope at the higher end. The SEM is useful over a magnification range from about 15 diameters to about 1,00,000 diameters. As the magnification increases the relative depth of field does not decrease but remains constant, and the increasing resolution of detail ends at a magnification of about 20,000 diameters.

It may seem surprising but there are a few organisms, mainly insects that can be observed while they are still alive. All stages in the life history of the beetle, *Tribolium* can hold enough water to survive the high vacuum of the specimen chamber for as long as an hour. Since the living specimens act as conductors under low current electron bombardment, they do not have to be coated with metal.

In contrast to conventional TEM, the SEM utility is in the area of information transfer from larger surfaces, which need not be flat or ultra thin. This paper attempts to describe some of the techniques of SEM that have utilized this information transfer capability in taxonomy.

SEM can be utilized for complimenting objective and analytical information since these techniques of imaging and observations record functional characters of the specimens under study. Thus SEM can be utilized to extend our vision as well as to accumulate analytical data. In addition to being an attractive method of information presentation by way of micrographs, such subjective contact with the specimens allows a more fundamental investigation of taxonomic details with respect to structure-function relationship. This technique of obtaining biological imaging information of the specimens is very useful in taxonomic identification.

The most striking attribute of the images presented by the SEM is ease of interpretation. An insect looks as an insect should. Hence we must trust our eyes when we see the insect as revealed by SEM. This is usually justified for a wide variety of objects when secondary electrons provide the signal. SEM is the best tool for taxonomic identification of the insect specimens with the aid of which additional information on the intraspecific variation can be obtained and species relationships in a particular group of insects can be best established.

Specimen Preparation

The requirements of specimen preparation for SEM are no less rigorous and demanding than those of TEM or any other form of microscopic investigation like microtomy, etc. The investigator using SEM will often find that most of the time is spent in specimen preparation as compared to time spent in actual viewing with the microscope. Specimen preparation begins with selection of good and clean specimens or appropriate tissue material and proceeds through necessary fixation, dehydration and conductivity considerations.

Selection of specimens : If a biological object contains information distributed on a surface than in contact with either air or a solution, the preparation for SEM is relatively simple and does not require dissection or sectioning techniques. Such surfaces, however, must be selected quite carefully with respect to fixation and dehydration in order to prevent the introduction of unsuspected artifacts. At time the type of information that is required will remain invariant under certain deformations, in particular certain topological properties of shape. For most purposes, however, the surface integrity must be maintained without distortion and the proper handling of these samples and specimens through proper fixation and step-wise dehydration as outlined below is very important. It is essential to make sure that the information displayed on the surface of the specimen must appear as if seen with the eye.

Fixation : For SEM examination, the specimens are generally fixed in formaldehyde-glutaraldehyde fixative of high osmolality. These methods are thoroughly discussed and certain specialized applications of fixation of biological specimens for SEM have been investigated.

Dehydration and Drying : The need in SEM preparation is to remove water completely usually through graded series of alcohols or acetone. Freeze-drying is probably the most often used technique to remove water from SEM preparations with a minimum of artifactual changes. Generally the specimen surface is least distorted following freeze-drying from a non-polar solvent, e. g., amyl acetate can be substituted for the tissue water. Several commercial freeze-drying units are available which could be used, and it takes a few hours only. A second method of removing the water from the specimen without damaging effects of surface tension is the critical point drying technique. In a two-phase system such as the liquid water in equilibrium with the specimen, there is a point in terms of the environmental temperature and pressure applied to these phases where the

liquid phase will become indistinguishable from the vapour or gas phase. At this point the liquid will be converted to the gas which can then be removed from the system without the surface tension effects associated with air-drying. The values of temperature and pressure, where this transition occurs, is called the "Critical Point"

Water is not used for the critical point process because of its extremely high pressure and temperature values, therefore, the water of the specimen is replaced, first by an intermediate liquid and then by the transitional liquid having the critical point within the range of design characteristics of a laboratory apparatus. Generally amyl acetate is used as the intermediate liquid and CO₂ as the transitional liquid and these operations are performed in commercial CPD apparatus which operate with CO₂. Drying in general distorts and obscures soft and wet specimens hence it is not used widely.

Coating : Improving conductivity of the specimens is essential for viewing in SEM. Since it is generally desirable to maintain the electrical potential of the specimen surface at ground level, the specimens for SEM are usually coated with a thin layer of conducting material by commercial vacuum evaporator prior to viewing in the instrument. Most frequently the conducting layer consists of a layer of carbon, which provides for a well covered surface, followed by an outer layer of heavy metal, usually gold or palladium, that has been evaporated on the sample in order to improve the secondary electron coefficient and to limit somewhat the interaction volume.

Viewing Techniques

SEM departs from the traditional spatial focussing method of image formation. Most images are formed by focussing radiation after it has left the specimen in such a way as to produce the necessary one-to-one correspondence between points on the specimen and points on the image. The SEM utilizes instead the image through a time sequence of points, a technique similar to that used in television imaging.

The SEM might be described as consisting of two systems. The probing system into which the specimen is placed and the display system which forms the visual image. The visual image can be photographed and the SEM micrographs form a record of the specimens.

SEM Applications in Taxonomy

In the recent years SEM has been widely used by taxonomists to clearly differentiate morphological characters in order to clarify the taxonomic position of species. For example members of the genera *Stethynium* and *Schizophragma* are egg parasites and hence are important biological control agents. However, the species of both genera are poorly known and have been misidentified. Recently these genera have been redescribed with the aid of SEM and mistakes corrected in the literature regarding the status and generic placement.

The tribal and subtribal structure of the braconid subfamily Opiinae is dismantled and several changes in the generic classification are made. *Thoracoplites* and *Aspiloden* are removed from the Opiinae. *Uteles* and *Pseudorhinoplu* are elevated to generic rank and *Bracanastrepha* is treated as a subgenus of *Uteles*. Wharton described relationships of species groups formerly included in the subtribe *Biosterina* and discussed its phylogeny with reference to detailed scanning of mouthparts.

We know a little about the developmental biology of ants, despite their ecological, sociobiological and economic importance. The general morphology of larvae of the genus *Solenopsis* was described but the number of larval instars were not determined for any species of *Solenopsis*. Tube coating SEM examination of live larvae of *Solenopsis* clarified the discrepancies and provided a means to identify the developmental stages of fire ant larvae. Tube coat allows fire ant larvae to survive longer exposures to the electron beam than silver paint. Various workers studied the significance of cuticular structures like mandibles, labellae, thoracic appendages, etc., as diagnostic characters in the taxonomy using SEM and then revealed distinct differences both between genera and between species.

Our studies on SEM with antennal appendages of castor moths *Parallalia* and *Achoea* revealed significant differences between the sexes. The difference between the sexes was observed more in the males than in females suggesting their role in chemoreception. Three morphological types of *sensilla trichodea* were identified from SEM. Fine structural details of various morphologically distinct sensillae could be studied with aid of SEM. A detailed ultrastructural study on characteristics of the Weevil, *Neochetena eichhorniae* belonging to Coleoptera, Curculionidae for the biological control of *Eichhornia crassipes* was elucidated in the authors lab. *Azolla* is small aquatic fern with immense agronomic importance in nitrogen fixation. Species identification is important for its economic use. The use of SEM in the taxonomical identification of *Azolla* species has been thoroughly reviewed recently. Phytocrystalline habit modifications have chemical and physical origins governed by the genetics of the biological system. Synthetic growth of Calcium Oxalate crystals provides a useful tool in determining the factors producing habit modifications like those found in plant crystals. SEM has also been applied in avian taxonomy. Several representative species of thrupids and fringillids suggest that the cardinal, *Cardinalis cardinalis* resembles the thrupids more than it resembles the other fringillids. All the Carduinae are quite alike, but they differ from the other fringillids. SEM can contribute towards the elucidation of functional, evolutionary and developmental aspects of feather micromorphology as well as taxonomic questions. Further developments in the field of electronics and computer sciences may surely alter the very character of SEM thereby providing conclusive evidence for definite taxonomical placement of biological specimens.

Preparation of Zoological Materials for SEM

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The Scanning Electron Microscope (SEM) was developed in 1960's thereby enabling scientists to view the surface structures of samples in three dimensions by scanning in its entirety, i.e., point to point and line by line with the help of a narrow beam of primary electrons under ultra vacuum. This has brought revolution in the field of metallurgy, electrical industry, ceramic and glass industry, mineralogy, micropalaeontology, as also in the chemical, biological and medical sciences. In biological sciences, the surface study of vital morphological ultrastructures and X-ray microanalysis of elements under high resolution and magnification has enabled the scientists to work out in depth the taxonomical complexities, evolution and diversity of living organisms.

Stewart and Boyde (1962) were first to observe the surface structure of teeth. This was followed by the study of hairs, bones, wood, and soft tissues. It is far easier to examine hard materials having dry surfaces than the soft tissues, because the former can directly be taken into SEM vacuum chamber after removing mucus and dust particles. Since water constitutes the major part of plant and animal cells it has to be removed carefully from the tissues without causing any distortions. It is therefore necessary that all efforts be made to preserve the three dimensional topography of the materials otherwise the diagnostic value of some structures or organisms will be lost. For this the biological material has to be totally dehydrated before observations can be made in high vacuum. Besides this, the density of most of the biological samples needs to be enhanced for making them electrically conductive under high vacuum electron probe of SEM.

Sample Preparation

So far no single satisfactory method has been developed for the preparation of biological specimens. During preparation of specimen care is to be taken to ensure that the samples are properly dehydrated, density is enhanced and the specimens are electrically conductive. Much has already been written on the various preparative techniques as applied to plants, animals, microbes, etc. and hence it is not considered necessary to describe all methods that have been used so far in SEM as details of these are available in standard books, journals or

periodicals. The following are some of the publications dealing with these techniques: Echlin (1968), Boyde and Barber (1969), Heywood (1969), Marszalek and Small (1969), Small and Marszalek (1969), Goldstein *et al.* (1981), etc.

The various methods can be classified as follows:

1. ***Non-treatment*** : Hard specimens which do not require any fixation and dehydration such as bones, teeth, hairs, nails, and hard-surfaced insects/acarines with cuticular layers, etc. A few organisms, mainly insects, may even be observed in live condition. These may directly be studied but after removing moisture, dust or mucus from their body surfaces.
2. ***Physical methods*** : The freeze-fixation method is generally used by cooling the moisture in the tissues. The techniques may further be subdivided as follows:
 - i) ***Freeze method*** : The tissues are rapidly frozen with the help of a cryo unit. In recent years, the Cryotechniques have widely been used as in this method artifacts can be avoided which are generally caused by chemical treatment, dehydration, etc. The specimen prepared as above may be studied directly under SEM in almost natural condition.
 - ii) ***Freeze dry method*** : The specimens are rapidly frozen and dried after freezing by sublimation in high vacuum. A number of commercial freeze drying units are available in the market. Unfortunately, the specimen surface may get cracked due to increase in the volume caused by the freezing of moisture in the tissues.
 - iii) ***Critical point drying method*** : The specimens are completely dehydrated with ethyl alcohol or amyl acetate and thereafter heated to a temperature up to 40°C in a chamber (bomb). The specimen is placed into mesh cage holder before taking it to the chamber. The chamber is flushed out with liquid CO₂ to replace amyl acetate. This method provides better results than freeze method which adds artifacts in the tissues due to crystallization of ice. However, sometimes the ethyl alcohol or acetate solidifies inside the cells in the critical point drying also. As a result the fat melts and the tissues become brittle. This technique was first used by Anderson (1951).
3. ***Fixation and dehydration method using chemicals*** : This method is to fix and dehydrate proteins (lipids) in cell by using chemicals and is generally used for specimens having soft tissues.

Two types of fixatives are used : (i) metallic fixative (O₅S₄, KMnO₄) based on oxidization reaction, and (ii) aldehyde fixative (formaldehyde and glutaraldehyde, etc.) based on reduction reaction. Glutaraldehyde is good for fixing the proteins but not for lipids. In case the tissue surface is adversely

affected after glutaraldehyde fixation, then the specimen should be fixed with osmium tetroxide solution which is good for fixing lipids and phospholipids.

There are three fixation methods: (i) single fixation by oxidization or reduction reaction, (ii) combined fixation by simultaneous oxidization and reduction, and (iii) double fixation by oxidization after reduction. In addition, a few more methods, like "perfusion method" (fixation by infecting fixative into living animal's blood vessels), are also used. The combined fixation and double fixation give good results for SEM work.

In fact, the techniques and timings vary from laboratory to laboratory depending upon the nature of tissues. It is generally believed that the *double fixation method* provides good results for animals. This method is described below :

1. The outer surface of the specimen should be made free of any extraneous and foreign materials (blood, mucus and dirt, etc.) in physiological saline.
2. Cut or trim the specimen, maximum to the size of stub, because large tissues are difficult to be fixed.
3. Place the specimen in 2.5% glutaraldehyde (pre-fixation) for about 24-48 hours depending upon the size and nature of tissues. Change the fixative twice during pre-fixation.
4. Wash the specimen with 0.1 M cacodylate or phosphate buffer (pH 7.2).
5. Transfer the specimen to 1% osmium tetroxide solution in phosphate buffer for two hours post-fixation. The specimen may be left for months at this stage.
6. Wash with 0.1 M cacodylate or phosphate buffer to remove the fixative sticking to the tissues.
7. Dehydrate in ascending order of acetone/alcohol (50, 70, 80, 90 and 100%) for 10-30 min. each.
8. Take the specimen into the atmosphere for drying or dry them rapidly in a stream of hot air (45°C). The dried specimen may be taken directly for observation under SEM.

OR

Change in iso-amyl acetate and absolute alcohol for 2-5 min. each in ratio of :

Absolute alcohol	Iso-amyl acetate
2	1
1	1
1	2

and finally in 100% iso-amyl acetate for 20 min. The specimens may be rolled on a filter paper so that excessive iso-amyl acetate may be removed. The specimen should then be transferred to mesh cage holder which may then be placed in the chamber for critical point drying (pressure should be zero before opening the chamber).

9. Once the amyl acetate is removed, the temperature is increased up to 40°C. During heating, CO₂ goes through critical point and forms gas without formation of a phase boundary. The pressure is released and CO₂ is allowed to escape and the specimens are ready for coating.
10. Stick the specimen on a stub with adhesive/conductive paint before taking for vacuum evaporation.
11. The specimens are taken for coating in vacuum evaporator. Surface coating is necessary to increase the conductivity of the specimens so that the charge-up and damage due to heat in SEM is prevented. The coating is in the form of evaporated carbon or heavy metals such as gold, gold palladium alloy, etc. Proper care should be taken to obtain uniform coating.
12. Specimens are ready for observation under SEM.

The entire process may be divided into the following steps :

- i) Fixation, ii) Washing, iii) Dehydration, iv) Critical point drying,
- v) Coating specimens with thin metal film, vi) Observations and photography.

The above steps may be accordingly modified to achieve best results depending upon the nature of the sample.

References

- Anderson, T. F. 1951. Techniques for the preservation of three-dimensional structure in preparing specimens for the electron microscope. *Trans. N. Y. Acad. Sci, Ser. 11* , 13:130.
- Boyde, A. & Barber, V. C. 1969. Freeze drying methods for the scanning electron microscopical study of the protozoan *Spirostomum ambiguum* and the statocyst of the cephalopod mollusc *Loligo vulgaris*. *J. Cel. Sci.* 4 : 223-239.
- Echlin, P. 1968. The use of the scanning reflection electron microscope in the study of plant and microbial material. *J. R. Microsc. Soc.* 88: 407-418.
- Goldstein, J. I., Dale, I., Patric, E., David, C., Charles, F. & Epicllif, S. 1981. *Scanning electron microscopy and X-ray microanalysis for biologist, material scientist and geologists*. Plenum Press, New York and London.
- Heywood, V. H. 1969. Scanning Electron microscopy in the study of plant materials. *Micron.* 1: 1-421.
- Marszalek, D. S. & Small, E. B. 1969. Preparation of soft biological materials for scanning electron microscopy. *Proceedings 2nd Annual Scanning Electron Microscopy Symposium*, 231-240.
- Small, E. B. & Marszalek, D. S. 1969. Scanning electron microscopy of fixed, frozen and dried protozoa. *Science*, 163, 1064-1065.
- Stewart, A. D. G. & Boyde, A. 1962. Ion etching of dental tissues in a scanning electron microscope. *Nature* 196: 81-82.

SEM in Nematode Taxonomy

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The structural peculiarities of nematodes make them excellent models for biological research and also provide opportunity for detailed studies on their morphology and anatomy. The relatively simple organisation and the transparency of the tissues are undoubtedly the characteristics that have made possible indepth studies on nematode structure with the light microscope. But their transparent bodies coupled with inherent limitations of light microscope (LM) optics has often been the cause of uncertainty in studying the fine structures. It is in elucidating these minute characteristics that the scanning electron microscope (SEM) has played an important role.

One of the first ultrastructural studies using the transmission electron microscope (TEM) on nematodes was carried out by Ferris and Siegel (1957) when the cyst wall structure of *Globodera rostochiensis* was studied. Scanning electron microscopy studies on nematodes began only after 1965 when these instruments became available commercially. Since then there has been a steady rise in the use of SEM for studying the morphology and taxonomy (Fig. 1). Now-a-days, most species descriptions and revisions are supplemented with SEM observations. However, the cost of the instrument and its restricted availability has been a major contributing factor for the almost complete absence of such studies from the developing countries.

Some of the features of the nematodes which are of interest in taxonomy and which have been well elucidated are the lips, labial plate, sensilla, amphids, lateral lines and other cuticular markings and ornamentations. Besides external characteristics, internal structures have been extracted and viewed with SEM. Thus, the stylets of some nematode groups have been studied and made use of as a character in distinguishing closely related species (Eisenback, 1982). Similarly, the spicules of many genera have been characterized (Rammah & Hirschmann, 1987). Not only the hard cuticularised parts but also individual cells such as the sperms can also be isolated and viewed with the SEM (Eisenback, 1985a). A short account of some of the studies which underline the role of the scanning electron microscope in nematode taxonomic research is presented.

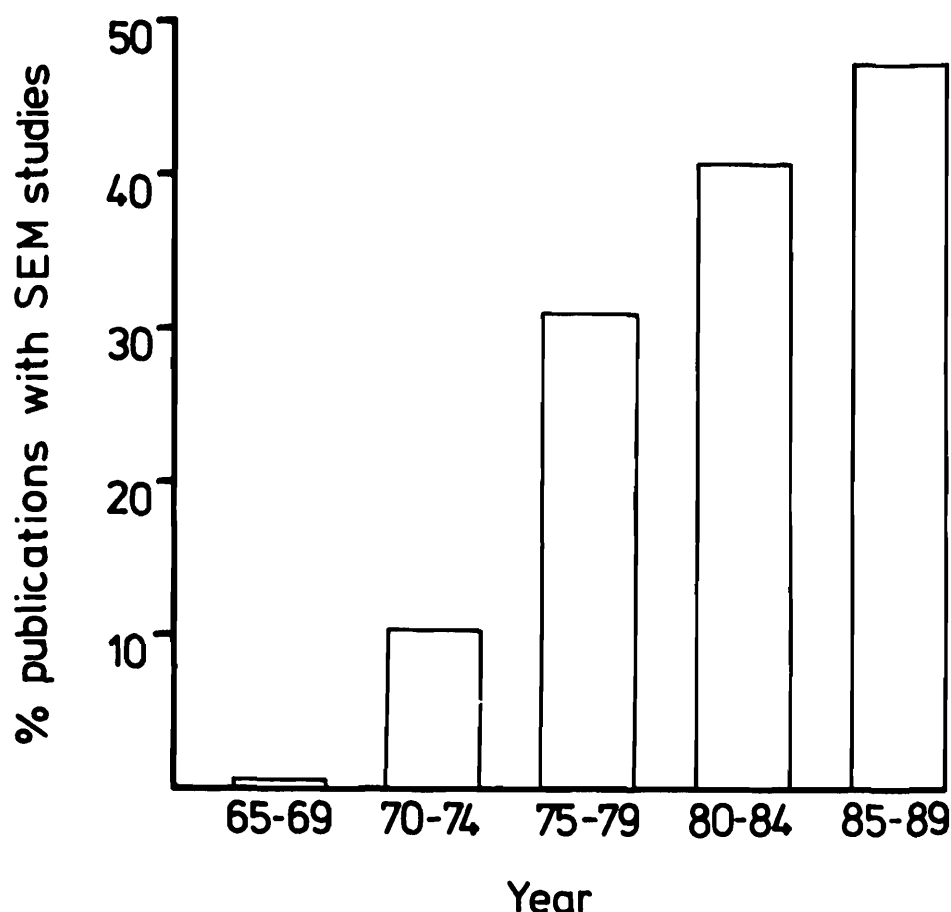


Fig. 1. Application of SEM in the study of nematode morphology and taxonomy.

External Features

Lip region : A host of structures on the lip region provide important and reliable features for the identification and differentiation between nematode groups/species (Fig. 2). In *Panagrolaimus* spp. the shape and separation of the lips have been used to distinguish four groups of species – i) with six discrete lips distinctly separated, ii) with six discrete lips but no separation, iii) with a duplex arrangement of the lips and iv) with amalgamated lips. This character has been used in preference to morphometric characters in the identification of at least one unknown species of *Panagrolaimus* (Bostrom, 1987). In Acrobelinae where elaborate morphological features are present on the lip area, SE micrographs have revealed complete details which may not be easily resolved with the light microscope (Sauer *et al.*, 1979; Sauer & Annells, 1984). A study of the cephalobid, *Cervidellus* spp., also revealed the complex nature of the labial and cephalic probable and it was suggested that taxonomic problems within Cephalobidae may not be resolved without SEM studies (Bostrom, 1985). Elaborate labial structures are also found in the rhabditid, *Diploscapter orientalis* (Fig. 2,H), and besides the labial hooks, which are modified dorsal and ventral lips, the laterals which project forward have a distinctly fimbriated margins (Tahseen & Ahmad, unpublished).

In members of the family Tylenchidae (Fig. 2A,C) SEM has played an important role in the elaboration and interpretation of face views. The shape of

the labial plate, the nature of the amphidial apertures and the labial sensilla have been found to be important characters on the basis of which seven groups have been proposed (Geraert & Raski, 1987). SEM of the lip region also provided reliable characteristics for the identification of species. This is particularly important in the case of *Meloidogyne* where the shape of the labial disc and lips and the expression of the labial sensilla are important features for species identification (Hirschmann, 1985; Eisenback, 1985). Similarly, lip structures are also important in the differentiation of *Heterodera* species. In Pratylenchidae, besides other characters, the variation in the degree of fusion of the median homologous lips is an important feature in generic diagnosis (Luc, 1987). The organisation of the labial disc and lip sectors as seen with SEM provide additional characters for the identification of genera of the families Belonolaimidae (Fortuner & Luc, 1987) and Hoplolaimidae (Fig. 2H,E) (Fortuner, 1987).

Loof (1985) basing his studies on SEM observations of the lip region (oral disc and amphidial apertures) of *Hemicycliophora* arranged the species into three groups. He also synonymized *Loofia* Siddiqi, and *Aulosphora* Siddiqi, with *Hemicycliophora* because the lip region type did not coincide with the generic differentiation and pointed out that there was no correlation between head structures and other characters like tail shape and lateral fields. The organization of the lip region and the expression and dispositioning of the labial sensilla may also be useful in generic/specific characterizations in dorylaims (Fig. 2F) and diplogaterids (Fig. 2D). Lip structure, however, may be variable and should be studied thoroughly before proposing their utility. Variations may occur within populations or even within species and this is particularly characteristic in *Atalodera lonicerae* juveniles (Othman *et. al.*, 1986).

Cuticular markings : The nematode body is generally striated transversely. These striations may be fine, moderate, coarse, or at times very deep and prominent known as annules. Fine striations may be so faint that they are not visible in the light microscope. Striations may be used to distinguish groups and genera and even characterise species. Transverse striations were thought to be smooth in members of Tylenchidae but Raski and Geraert (1984) showed that in *Miculenchus elegans* they have 4-5 bead-like swellings near the lateral lines and beyond that have forward and backward projections forming a zig-zag pattern. SEM of *Lelenchus leptosoma* revealed shallow but distinct striations on the body which had previously been described as smooth (Raski & Geraert, 1985). Species of *Malenchus* viz., *M. nanellus* and *M. parthenogeneticus* show longitudinal subdivisions of the striations into small ridges once again belying the smooth nature of the cuticle as seen in the light microscope (Geraert & Raski, 1986). Cuticular ornamentations found in many members of Criconematoidea have been revealed in good detail by SEM and may be used as an important taxonomic character. Thus, *Criconemella avicenniae* has rows of knobs on the annules (Nicholas & Stewart, 1984) while *Ogma saqi* annules have scales provided with spines (Raski & Valenzuela-A, 1987). Jairajpuri and Southey's (1984) study on

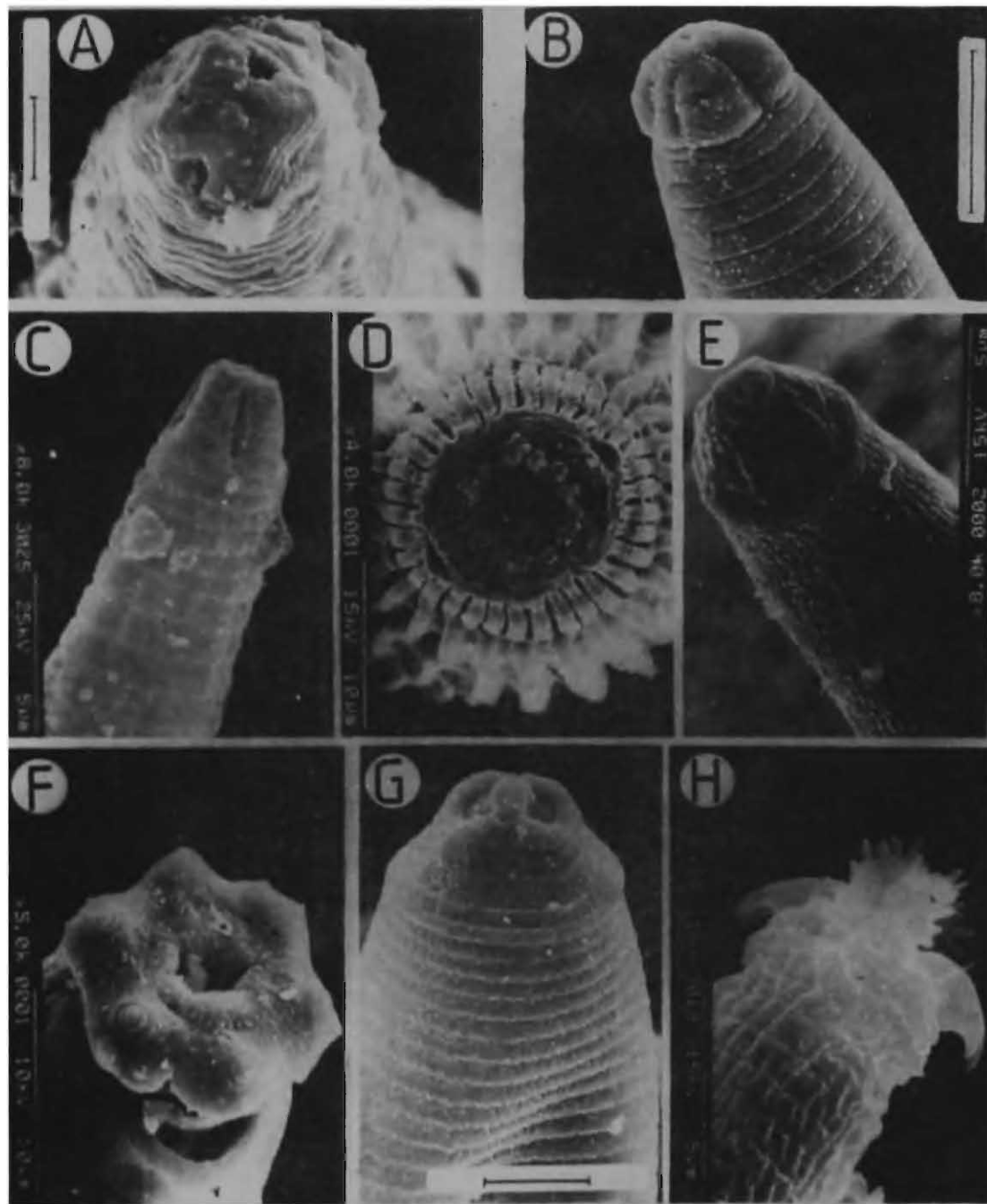


Fig. 2. SEM of lip region : A Face view of *Filenchus* sp.; B Anterior end of *Hoplolaimus* sp.; C - Anterior end of *Filenchus* sp.; D Face view of *Mononchoides* sp.; E Anterior end of *Helicotylenchus* sp.; F *Aporcelaimus* sp.; G -*Hemicycliophora* sp.; H *Diploscapter orientalis*.

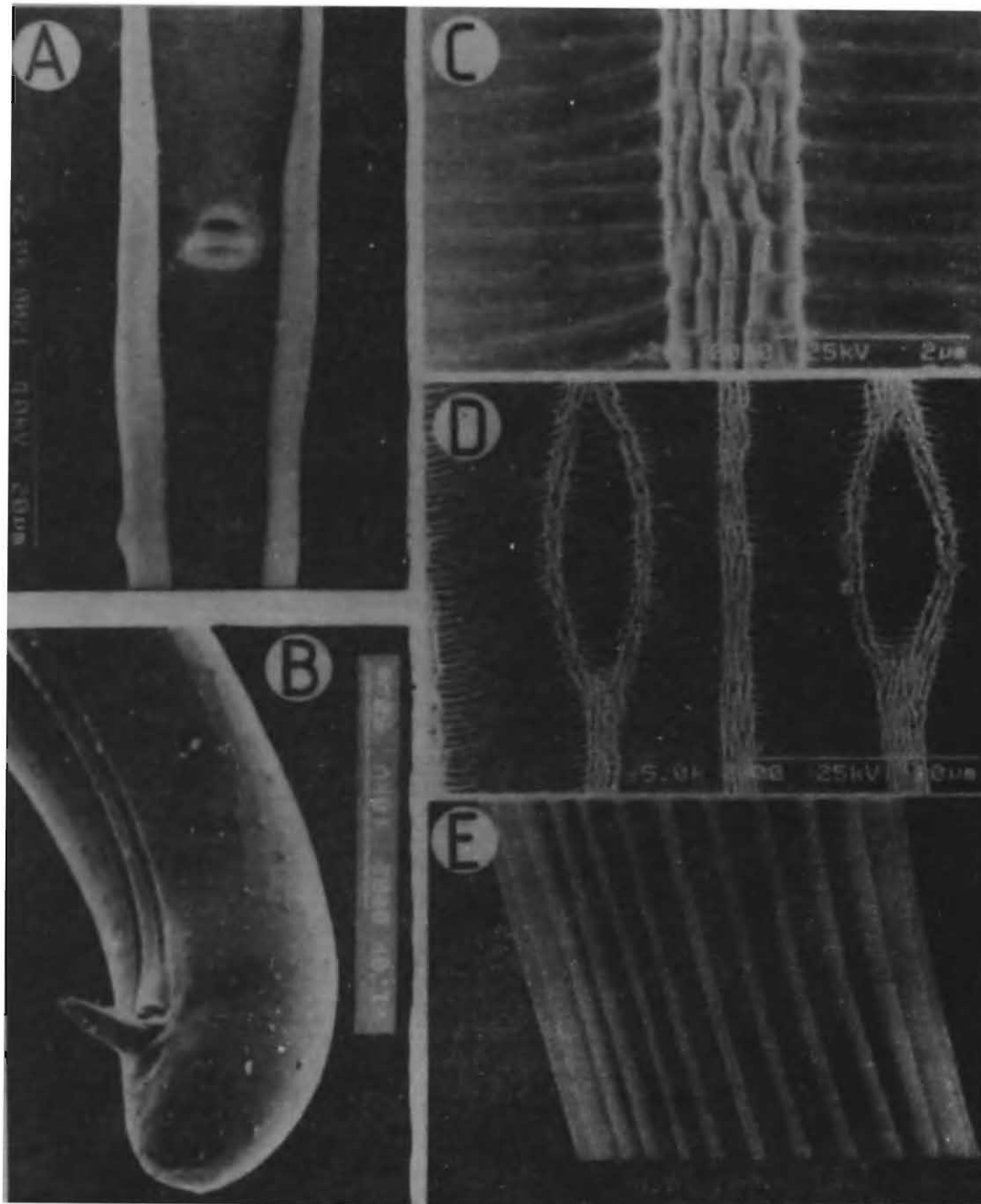


Fig. 3. SEM of various body regions : A- Caudal region of *Nagelus* sp.; B- Caudal region of *Dorylaimus stagnalis*; C- Longitudinal ridges of *Dorylaimus stagnalis*; D- Longitudinal ridges showing loops in *Dorylaimus stagnalis*; E- Longitudinal ridges of *Mononchoides fortidens*.

Nothocriconema shepherdae showed that the extra-cuticular layer found in many criconematids, is not a part of the body and hence should not be given much taxonomic value.

The lateral lines are generally an important character and may be used in the diagnoses of genera in the superfamily Tylenchoidea. The finer details of these lines sometimes provide characters for species differentiation. The genus *Malenchus* was long characterised as having two lines in the lateral fields until SEM revealed their extremely variable nature. Species of the genus have now been found to have four lines (*M. parthenogeneticus*), six lines (*M. williamsi*) or even twelve or more lines (*M. macrodorus*) (Geraert & Raski, 1986). A similar conclusion was drawn when the genus *Filenchus* was studied (Raski & Geraert, 1986). Besides the lateral lines, other longitudinal markings may also be present on the nematode body. In the tylenchid, *Coslenchus costatus*, they may be simple longitudinal ridges dividing the body cuticle into small blocks (Geraert & Raski, 1988). However, in the dorylaim, *Dorylaimus stagnalis*, the longitudinal ridges are complex structures appearing like a broad band in SEM views (Fig. 3,C). Each ridge (band) is composed of several smaller cuticular folds (Shafqat *et al.*, 1990 in press). As the ridges show bifurcation and also form loops (Fig. 3D), Shafqat *et al.* (in press) suggested that caution be exercised when it is used as a quantitative character. In the diplogasterid, *Mononchoides fortidens*, each ridge is a larger cuticular fold distinctly transversely striated (Fig. 3E) and running the entire body length (Ahmad, unpublished).

Cyst markings : Vulval cone structures of cyst nematodes provide important characters for species identification. SEM studies on features such as the preanal ridges, perineal ridges and the radial ridges, which are not readily discernable in the light microscope, have been used readily to distinguish closely related species. These characteristics suggested that the closely related species *Heterodera glycines*, *H. lespedezae*, *H. schachtii* and *H. trifolii* could be easily distinguished. In addition, the five races of *H. glycines* could also be separated utilising the aforementioned features. In a study on *H. trifolii*, Hirschmann & Triantaphyllou (1979) observed that although six populations of this species could be distinguished using morphometric data, SEM revealed additional structural differences in the vulval area. On this basis, they (l.c.) suggested that these populations may represent different subspecies.

Other features : A comparison of *Radopholus similis* and *R. citrophilus* with the scanning electron microscope showed that besides differences in the lip and vulval area, the cloacal spicular orifice of *R. citrophilus* had 3-7 genital papillae which were either absent in *R. similis* or if present were much smaller and fewer in number (Huettel & Yaegashi, 1988). Cloacal and caudal regions of males may provide additional characters in species identification (Fig. 3 A,B). Similarly, egg shell markings (Fig. 4 A) may also be important.

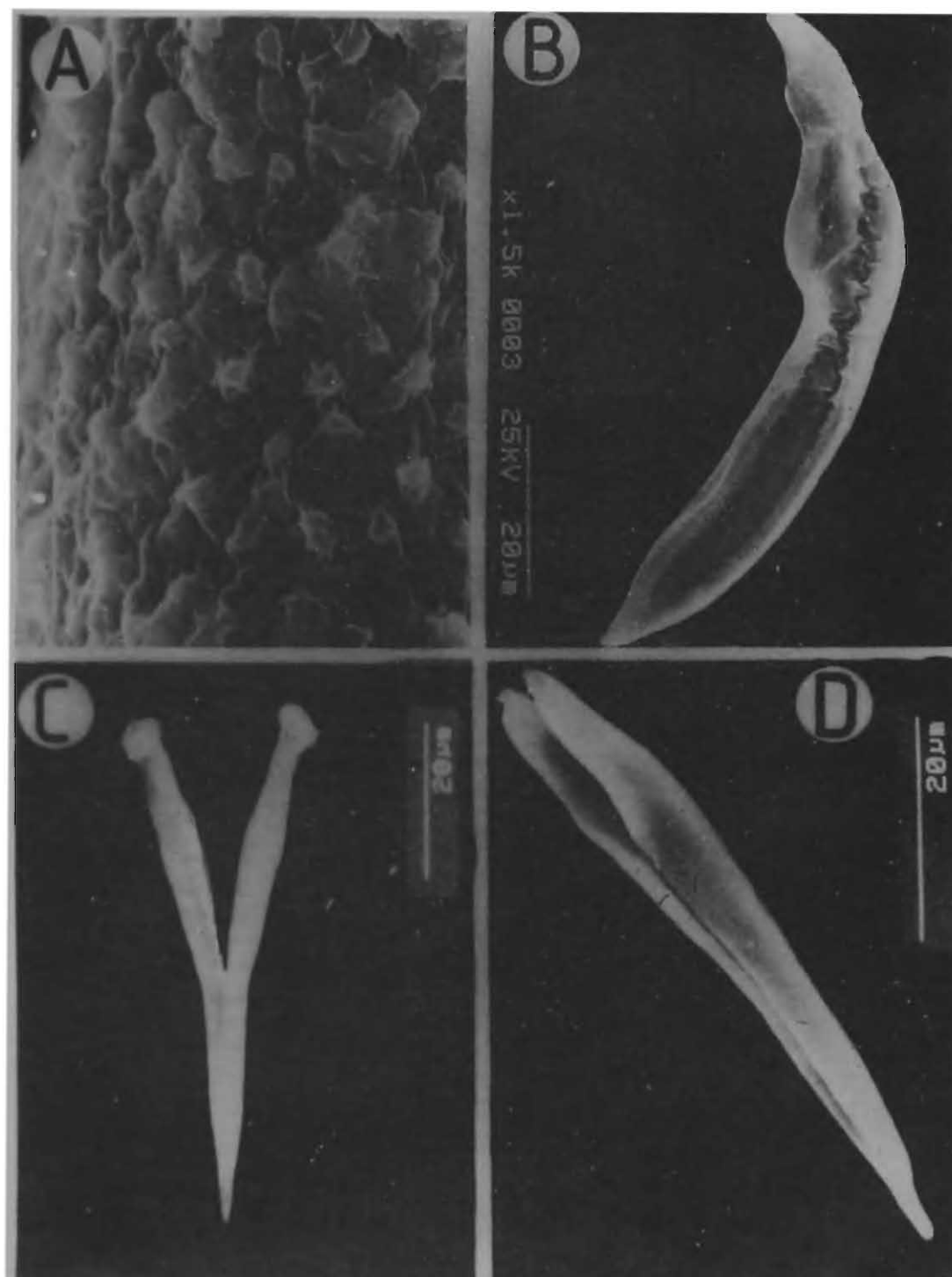


Fig. 4. A - Egg shell surface of a cephalobid nematode; B - Spicule of *Dorylaimus stagnalis*; C Spicule of *Mesorhabditis* sp.; D - Gubernaculum of *Mesorhabditis* sp.

Internal Parts

In recent years, techniques to study the internal structure by SEM have been developed. This is generally limited to the hard cuticularized parts in the nematode body such as the stylet and spicules. Stylet morphology, i.e., shape of conus, shaft and the knobs, is more pronounced in SEM observations and has been used as a character in the differentiation of species of *Meloidogyne* (Eisenback et al., 1981 : Jepson, 1983). Thus, when spear profiles of the four most common species of *Meloidogyne* are compared, the stylet of *M. hapla* appears delicate with set off knobs; *M. arenaria* is very broad with robust knobs; *M. incognita* is distinctly curved at the conus and *M. javanica* stylet is only very slightly curved (Eisenback et al., 1981). SEM study of isolated spicules has revealed that they are morphologically identical exhibiting a mirrorimage relationship (Rammah & Hirschmann, 1987). This is in contradiction to some earlier studies where spicules are said to be unequal in some tylenchid species when studied *in situ* (Hogger & Bird, 1974). In addition, it was observed that the dorylaimoid spicule differed from the others in that it was less sclerotized and lacked a cytoplasmic core opening found in others (Fig. 4 B, C). Individual and isolated sperms have been observed with SEM but studies are few (Eisenback, 1985b). More detailed and comparative studies may provide additional characters for species characterization.

Conclusion

As long as morphology plays an important role in nematode taxonomy, the utility and importance of the scanning electron microscope will be felt. The high resolving power and easy-to-interpret three dimensional images are features not obtainable with the light microscope. Many morphological structures observed with SEM have subsequently been seen with the light microscope and are, thus, of practical value in species identification (Rammah & Hirschmann, 1987). In addition, LM images of whole mounts may lack clarity and contrast because of interference of surrounding tissues. Despite these facts, the light microscope is not dispensable as far as the study of internal organisation and morphometrics is concerned, or even when depicting structural relationships in camera lucida drawings. The electron microscope, nevertheless, will continue to play a significant role in nematode taxonomy.

References

- Bostrom, S. 1985. Descriptions of *Cervidellus serratus* (Thorne, 1925) Thorne, 1937 from Sweden and *C. neftasiensis* n. sp. from Tunisia, with a note on some recently proposed genera (Nematoda : Cephalobidae). *Nematologica*, 31: 365-374.
- Bostrom, S. 1988. Description and morphological variability of three populations of *Panagrolaimus* Fuchs, 1930 (Nematoda : Panagrolaimidae). *Nematologica*, 34: 144-155.
- Eisenback, J.D. 1982. Morphological comparison of head shape and stylet morphology of second stage juveniles of *Meloidogyne* species. *J. Nematol.*, 14 : 339-343.

- Eisenback, J.D. 1985a. Diagnostic characters useful in the identification of the four most common species of root-knot nematodes (*Meloidogyne* spp.). In : *An Advanced Treatise on Meloidogyne*, Vol. I, 95-112 (Eds.) J.N. Sasser & C.C. Carter. Published by the Deptt. of Plant Pathology & Genetics and U.S. Agency for International Development, Raleigh.
- Eisenback, J.D. 1985b. Techniques for preparing nematodes for scanning electron microscopy. In : *An Advanced Treatise on Meloidogyne* Vol.II. 79-105 (Eds.) K.R. Barker, C.C. Carter & J.N. Sasser. Deptt. of Plant Pathology & Genetics and U.S. Agency for International Development, Raleigh.
- Eisenback, J.D., Hirschmann, H., Sasser, J.N. & Triantaphyllou, A.C. 1981. *A guide to the four most common species of root-knot nematodes (Meloidogyne spp.) with a pictorial key*. Deptt. of Plant Pathology & Genetics and U.S. Agency for International Development, Raleigh.
- Ferris, V.R. & Siegel, B.M. 1957. Electron microscopy of golden nematode cyst wall. *Nematologica*, 2: 16-18.
- Fortuner, R. 1987. A reappraisal of Tylenchina (Nemata). 8. The family Hoplolaimidae Filipjev, 1934. *Revue Nematol.*, 10: 219-232.
- Fortuner, R. & Luc, M. 1987. A reappraisal of Tylenchina (Nemata). 6. The family Belonolaimidae Whitehead, 1960 *Revue Nematol.*, 10: 183-202.
- Geraert, E. & Raski, D.J. 1986. Unusual *Malenchus* species (Nematoda : Tylenchidae). *Nematologica*, 32: 27-55.
- Geraert, E. & Raski, D.J. 1987. A reappraisal of Tylenchina (Nemata). 3. The family Tylenchidae Orley, 1880. *Revue Nematol.*, 10: 143-161.
- Geraert, E. & Raski, D.J. 1988. Study of some *Aglenchus* and *Coslenchus* species (Nemata : Tylenchidae). *Nematologica*, 34: 6-46.
- Hirschmann, H. 1985. The genus *Meloidogyne* and morphological characters differentiating its species. In : *An Advanced Treatise on Meloidogyne*, Vol. I. 79-93 (Eds.) J.N. Sasser & C.C. Carter. Deptt. of Plant Pathology & Genetics and U.S. Agency for International Development, Raleigh.
- Hirschmann, H. & Triantaphyllou, A.C. 1979. Morphological comparison of members of the *Heterodera trifolii* species complex. *Nematologica*, 25: 458-481.
- Hogger, C. & Bird, G.W. 1974. Secondary male sex characteristics of *Hoplolaimus galeatus*. *J. Nematol.* 6: 12-16.
- Huettel, R.N. & Yaegashi, T. 1988. Morphological differences between *Radopholus citrophilus* and *R. similis*. *J. Nematol.*, 20: 150-157.
- Jairajpuri, M.S. & Southey, J.F. 1984. *Nothocriconema shepherdae* n. sp. (Nematoda : Criconematidae) with observations on extra-cuticular layer formation. *Revue Nematol.*, 7: 73-79.
- Jepson, S.B. 1983. Identification of *Meloidogyne* : a general assessment and a comparison of male morphology using light microscopy with a key to 24 species. *Revue Nematol.*, 6: 291-309.
- Loof, P.A.A. 1985. Scanning electron microscope studies on the genus *Hemicycliophora* de Man, 1921 *sensu lato* (Nematoda : Criconematidae). *Revue Nematol.*, 8: 113-123.
- Luc, M. 1987. A reappraisal of Tylenchina (Nemata). 7. The Family Pratylenchidae Thorne, 1945. *Revue Nematol.*, 10: 203-218.
- Nicholas, W.L. & Stewart, A. 1984. *Criconemella avicenniae* n. sp. (Nematoda : Criconematidae) and *Enchodelus coomansi* n. sp. (Nematoda : Nordiidae) associated with the roots of the mangrove *Avicennia marina* (Forsk.) Vierh. *Nematologica*, 30: 429-436.
- Othman, A.A., Baldwin, J.G. & Bell, A.H. 1986. Comparative morphology of *Atalodera* spp. and *Thecavermiculatus* spp. (Heteroderidae) with scanning electron microscopy. *J. Nematol.*, 18: 275-287.
- Rammah, A. & Hirschmann, H. 1987. Morphological comparison and taxonomic utility of copulatory structures of selected nematode species. *J. Nematol.*, 19: 314-323.

- Raski, D.J. & Geraert, E. 1984. A new species of *Miculenchus* Andrassy, 1959 and further notes on *M. salvus* (Nematoda : Tylenchidae). *Nematologica*, 30: 419-428.
- Raski, D.J. & Geraert, E. 1985. New species of *Lelenchus* Andrassy, 1954 and *Ecphyadophora* de Man, 1921 (Nematoda : Tylenchidae) from southern Chile. *Nematologica*, 31: 244-265.
- Raski, D.J. & Geraert, E. 1986. Review of the genus *Filenchus* Andrassy, 1954 and description of six new species (Nematoda : Tylenchidae). *Nematologica*, 32: 265-311.
- Raski, D.J. & Valenzuela-A, A. 1987. Descriptions of four new species of Criconematidae, male of *Ogma terrestris* (Tylenchida : Criconematoidea) and *Tylaphelenchus yamani* n. sp. (Aphelenchina : Aphelenchoididae). *Nematologica*, 33: 149-166.
- Sauer, M.R. & Annells, C.M. 1984. Lip region structure in Acrobelinae (Nematoda : Cephalobidae). *Nematologica*, 30: 140-150.
- Sauer, M.R., Champman, R.N. & Brezeski, M.W. 1979. External morphology of some Acrobelinae. *Nematologica*, 25: 482-486.
- Shafqat, Samina, Ahmad, I., Ahmad, W. & Bilgrami, A.L. 1990. A scanning electron microscopic study on *Dorylaimus stagnalis* (Dujardin, 1845). *Revue Nematol.*, 13 (in press).

SEM in Cladoceran Taxonomy

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In taxonomic study of freshwater Cladocera, morphological characters in most instances have provided the body of descriptive material used in classification. Surprisingly, scanning electron microscopy (SEM) has hitherto been utilized only in a few instances in the examination of diagnostic characters of freshwater Cladocera (Domont, 1981; Frey, 1982; Venkataraman and Krishnaswamy 1984; 1989; Kokkin and Williams, 1987) despite its extensive application to study other aspects of cladoceran biology (Guldner, 1969; Schultz and Kennedy, 1976; Dumont and Van de Velde, 1976; Schultz, 1977; Crittenden, 1981; Zahid, 1981). Hitherto, no comparative study has been made to utilize the micrographs for identification and preparation of a key for the species. The present study deals with the scanning electron microscopic observations made on the morphology of 20 freshwater Cladocera from tropical India and their application on taxonomy.

The taxonomic character of *Pseudosida bidentata* Herrick is a spine-like projection on the distal margin of the postabdomen which is lacking in *P. szalay* Daday. The SEM Plate I (1) provides this diagnostic morphological character not available with the light microscope.

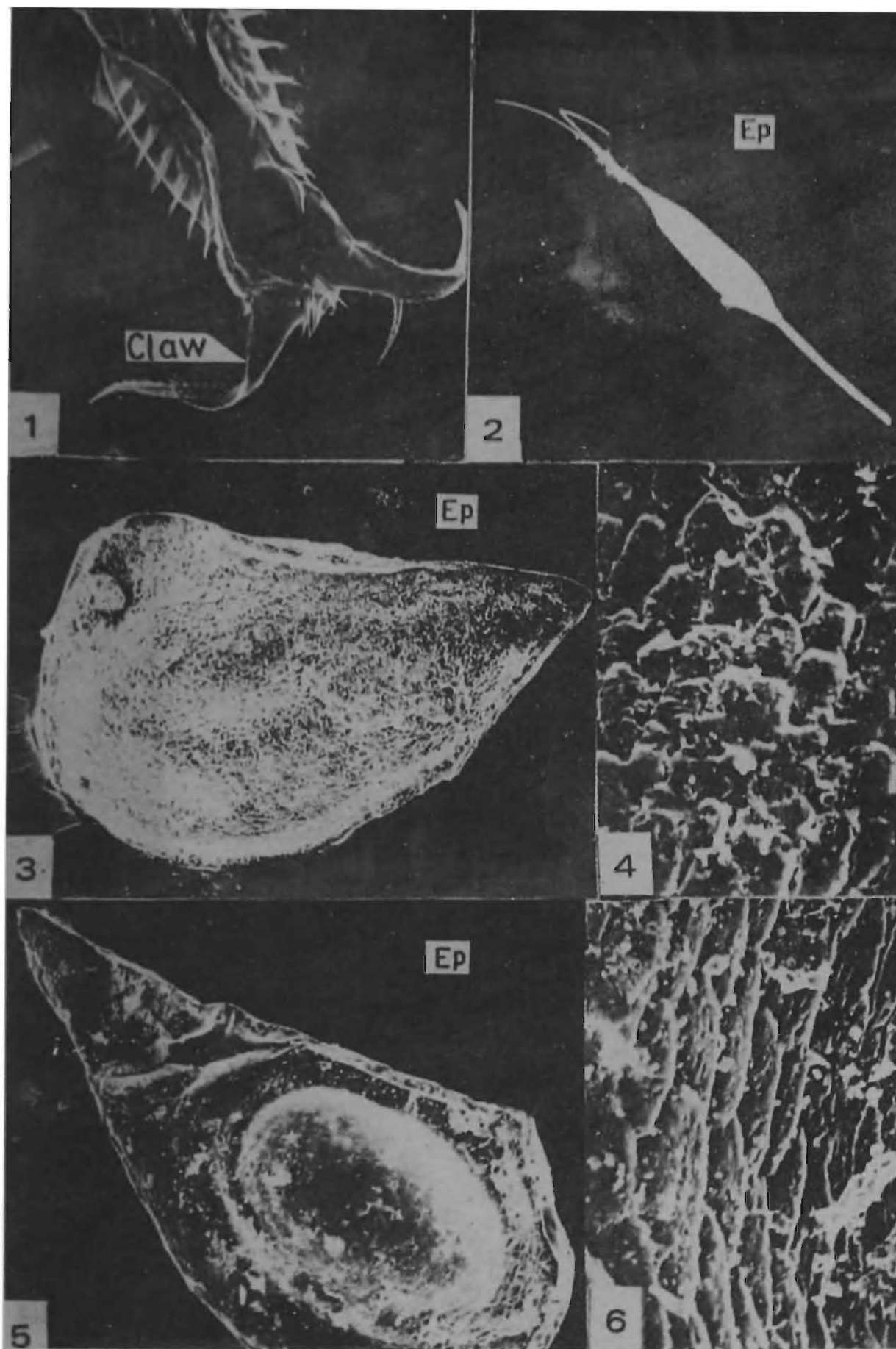
SEM Plate I (2 – 6) show the morphology of sexual eggs of *Daphnia projecta* Hebert, *Simocephalus vetulus elizabethae* (King) and *S. acutirostratus* Sars. Under high magnification (Plate I, 4 and 6), the sexual eggs of *S. vetulus elizabethae* and *S. acutirostratus* show distinct variation in their external ornamentation. However, these eggs under light microscope appeared the same except for their size.

SEM Plate II (7 and 8) show the morphology of *Ceriodaphnia cornuta* Sars. The honey-comb like appearance of the surface of *C. cornuta* is a very important morphological character to identify this species. SEM Plate II (9) shows the hexagonal markings on the surface of sexual egg of *Moina micrura* Kurz which differentiates this species from *M. weismanni* Ishikawa in which it consists of raised knobs. Likewise, the number of hooks on the tip of male antennule is one of the diagnostic features to differentiate *M. micrura* from *M. weismanni*, with 3 and 4 hooks, respectively. SEM Plate II (10) shows the presence of 4 well developed hooks on the antennule of *M. weismanni*. SEM Plate II (11 and 12)

show the postabdomen and the pectens on the claw of *Ilyocryptus spinifer* Herrick. The number and arrangement of lateral denticles are clearly seen in the micrograph. SEM Plate III (13 and 14) show the morphology of a chydorid cladoceran *Dedaya macrops* (Daday). The ornamentation on the surface of the shell of this species is unique and the SEM picture provides a clear morphology which is not visible with the light microscope. Likewise, the pitted appearance in the shell of *Chydorus parvus* Daday and fine granular structure of the shell of *Ch. ventricosus* Daday and its postabdomen are clearly seen in the Plate III (15 - 18). The presence of posteroventral corner spine is a characteristic feature of some species of chydorid cladocerans. This important diagnostic feature can be seen in the species *Ch. barroisi* Richard (Plate IV, 19 - 20) in which it is not terminal while it is terminal in *Dunhevedia crassa* King (Plate IV, 21 - 22). The surface of the shell of *Pseudochydorus globosus* (Baird) has hexagonal markings which is clear in Plate IV (24). SEM Plate V (25 - 29) shows the characteristic features of *Alona monacantha tridentata* (Stinglin). The presence of three connected head pores is one of the characteristic features of this species and forms an important taxonomic tool to classify whether it belongs to the subfamily Chydorinae with main pores plus two small pores or to the subfamily Aloninae with three main pores as seen in *A. monacantha tridentata*. SEM Plate V (30 and 31) shows the shell morphology of *A. davidi* Richard and its postabdomen. The lateral groups of denticles and the claw pectens are clearly seen in the SEM picture (Plate V, 31). *Grabtolebris testudinaria* (Fisher) is one of the rare littoral chydorid Cladocera present in the tropical marshes with characteristic ornamentation like a brick wall. The presence of three posteroventral corner spines of the species is clearly shown in Plate VI (34). SEM Plate VI (36 and 37) also shows the ornamentation on the head shield and head pore respectively. *Leydigia ciliata* Gauthier is a littoral chydorid cladoceran of the reddish-brown turbid ponds in southern Tamil Nadu. SEM Plate VII (38 - 43) shows the morphology of its shell, postabdomen, pectens on the claw, shell surface of the male, male postabdomen with vas deferens and the ornamentation on the sexual egg. The presence of pectens on the claw is a diagnostic feature which differentiates this species from the closely related *L. acanthocerocoides* (Fisher) with no pectens on the claw (Smirnov, 1971). *Biapertura karua* (King) a common chydorid cladoceran in the marshes of tropical region, has three spines on the posteroventral corner (Plate VIII, 44 - 46) which clearly differentiate this species from *B. verrucosa* (Sars) occurring in the same habitat. *Euryalona orientalis* (Daday) found throughout the tropical region has a situation in the ventral margin and the ornamentation on the surface of its shell is an important character to differentiate this species from others. The size and number of pectens on the claw of this species as exhibited by the micrographs are also unique (Plate VIII, 47 - 49).

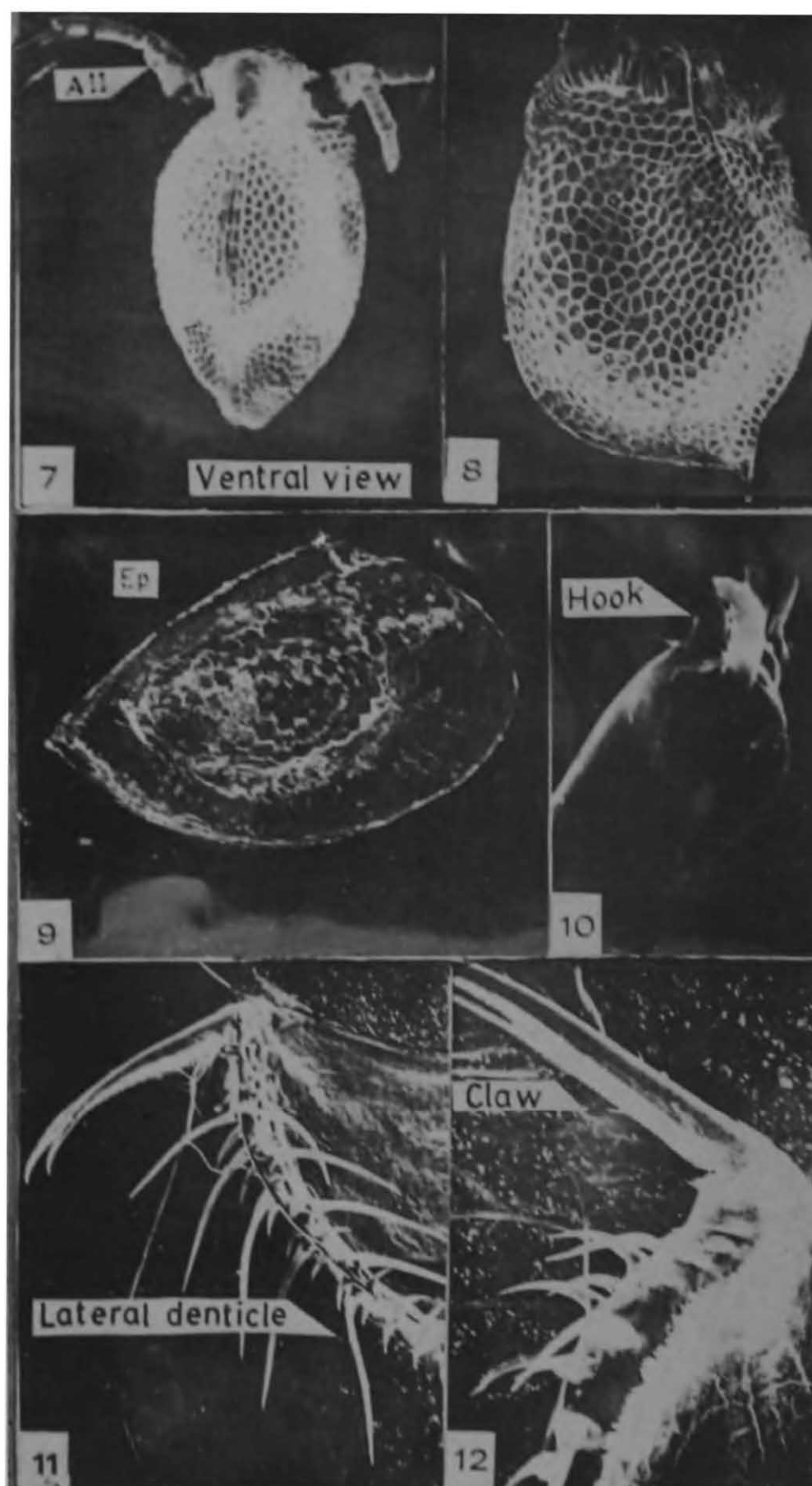
Conclusion

The distinguishing features of the species of Cladocera are external markings on the carapace, presence of spine on the posteroventral corner of the shell, the

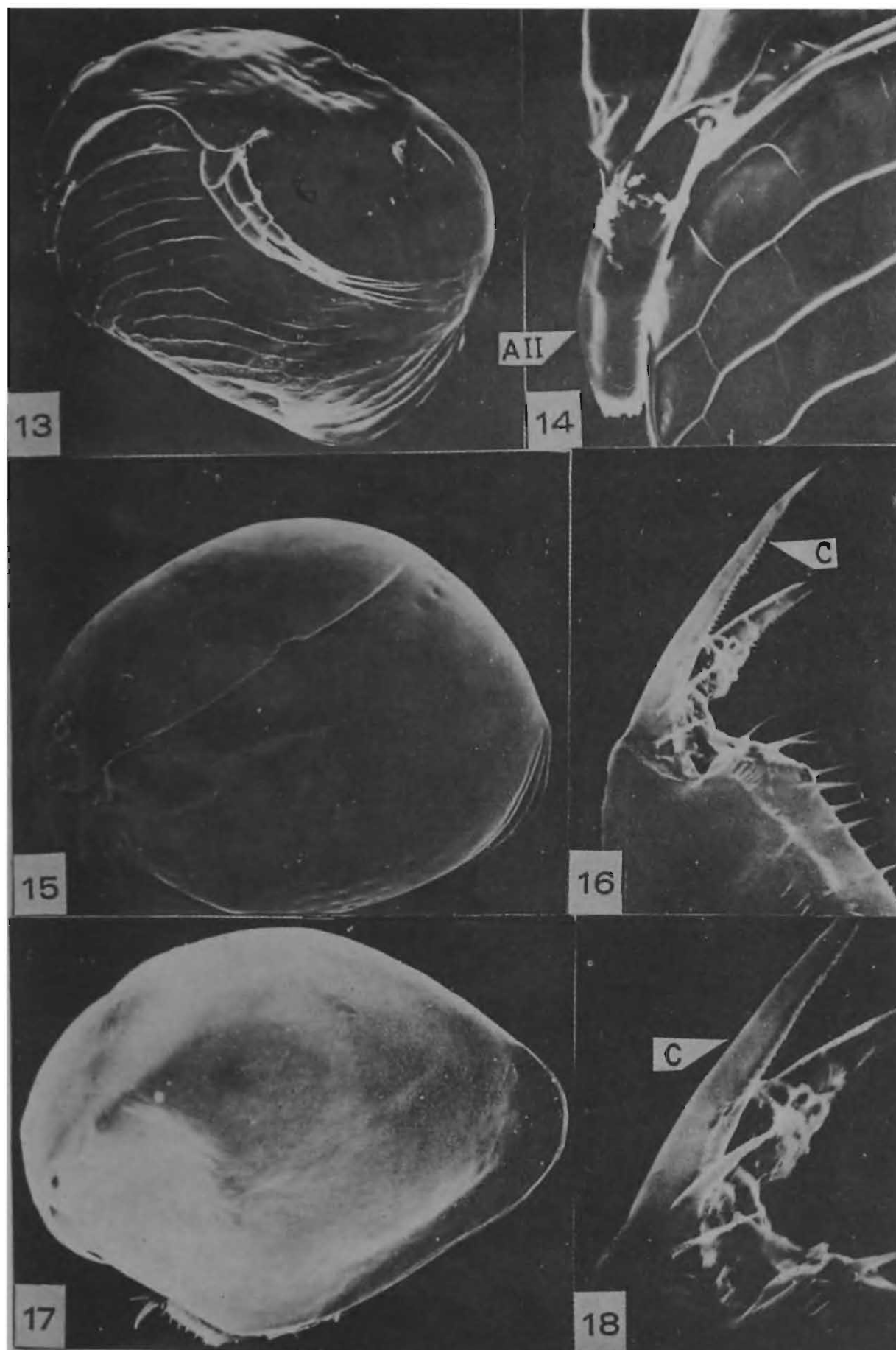


Ep — ephippia; A II — antennule; C — claw; Pvc — posteroventral corner; Pa — postabdomen; Hs — head shield; Hp — head pore; Vs — vasdeference.

Plates I Scanning electron micrographs of species of Cladocera, 1. *Pseudosida bidentata* : female postabdomen (750 X); 2. *Daphnia projecta* : ephippia (90 X); 3. *Simocephalus vetulus elizabethae* : ephippia (225 X); 4. Ephippia : surface (1500 X); 5. *Simocephalus acutirostratus* : ephippia (165 X); 6. Ephippia : surface (1500 X).



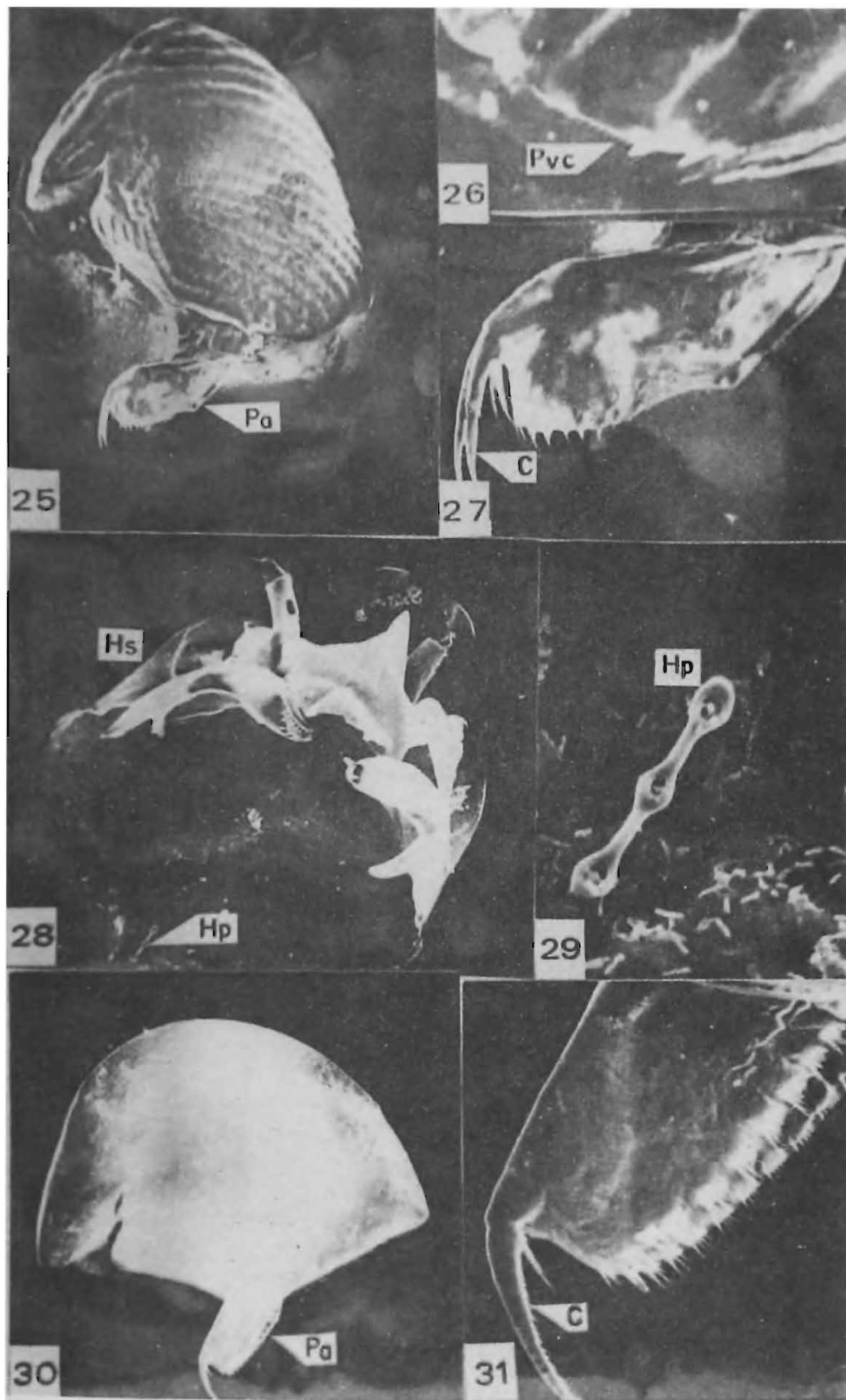
Plates II Scanning electron micrographs of species of Cladocera, 7. *Ceriodaphnia cornuta* : female ventral view (300 X); 8. Lateral view (420 X); 9. *Moina micrura* : ephippia (420 X); 10. *Moina weismanni* : male antennule (3000 X); 11. *Ilyocryptus spinifer* : female postabdomen (750 X); 12. Postabdomen enlarged (1500 X).



Plates III Scanning electron micrographs of species of Cladocera, 13. *Dadaya macrops* : female lateral view (540 X); 14. antennule (2000 X); 15. *Chydorus parvus* : female lateral view (600 X); 16. *Chydorus ventricosus* : female lateral view (600 X); 16. *Chydorus ventricosus* : female postabdomen (1500 X); 17. lateral view (300 X); 18. Claw (2000 X).

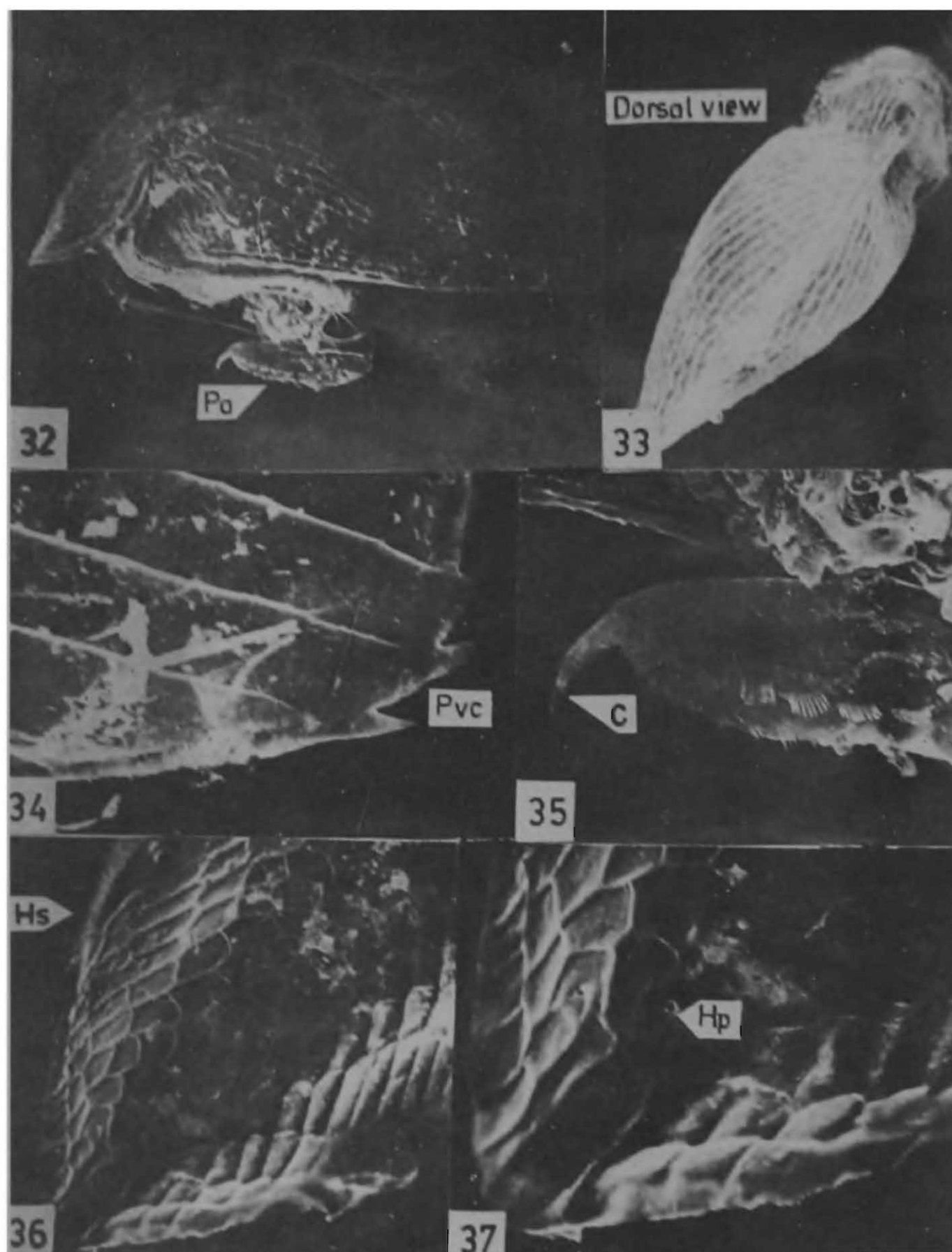


Plates IV Scanning electron micrographs of species of Cladocera, 19. *Chydorus barroisi* : female lateral view (750 X); 20. Posteroventral corner (3000 X); 21. *Duhevedia crassa* : female lateral view (300 X); 22. Posteroventral corner (900 X); 23. *Pseudochydorus globosus* : female ventral view (300 X); 24. Lateral surface (1500 X).

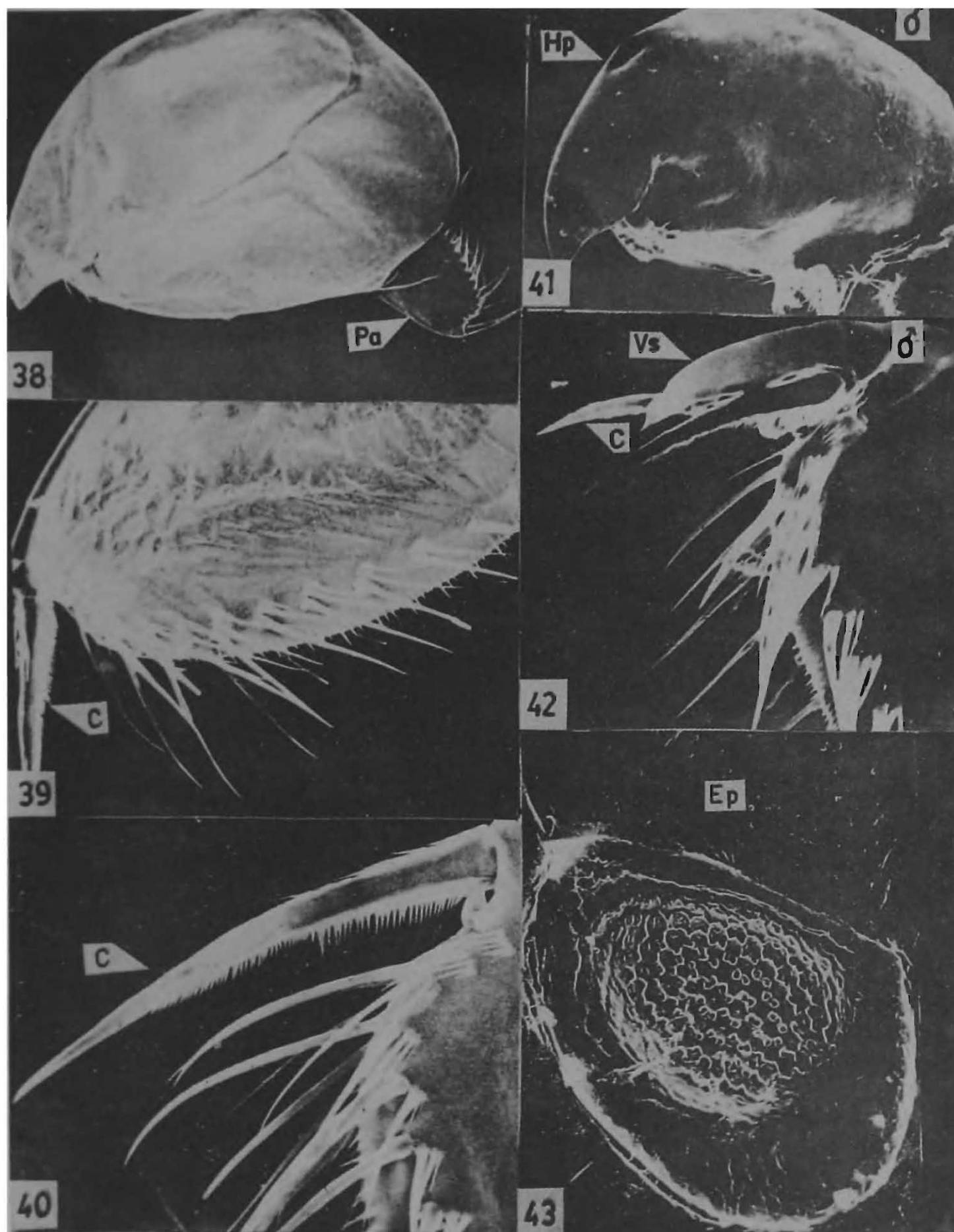


Plates V

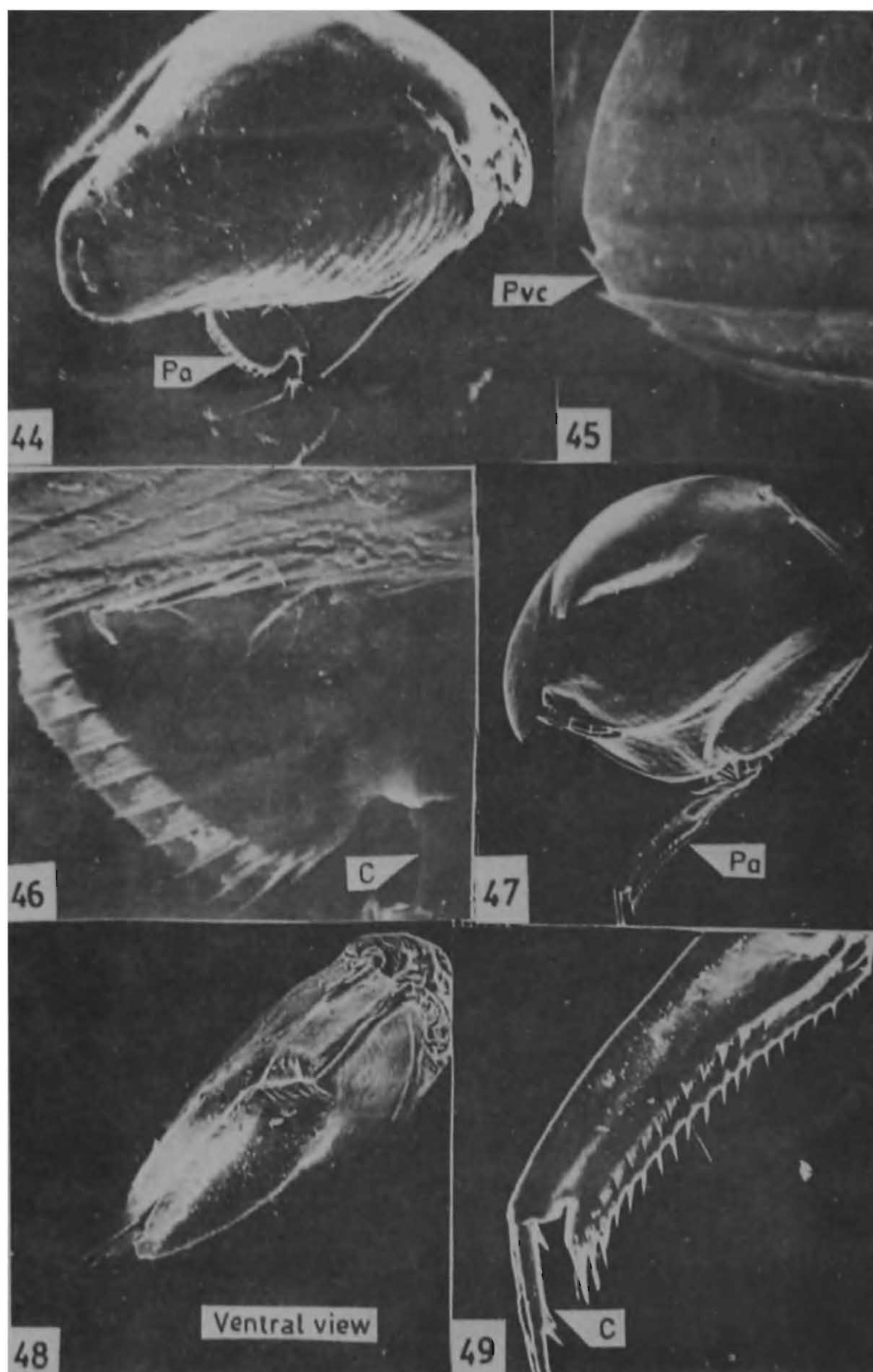
Scanning electron micrographs of species of Cladocera, 25. *Alona monacantha tridentata* : female lateral view (450 X); 26. Posteroventral corner spines (1250 X); 27. Postabdomen (1250 X); 28. Head shield (750 X); 29. Head pore (4500 X); 30. *Alona davidi* : female lateral view (3000 X); 31. Postabdomen (900 X).



Plates VI Scanning electron micrographs of species of Cladocera, 32. *Grabtoleberis testudinaria* : female lateral view (300 X); 33. Female dorsal view (400 X); 34. Posteroventral corner spines (3000 X); 35. Postabdomen (1250 X); 36. head shield (1000 X); 37. Head pore (1500 X).



Plates VII Scanning electron micrographs of species of Cladocera, 38. *Leydigia ciliata* : female lateral view (200 X); 39. Female postabdomen (750 X); 40. Female claw (1250 X); 41. Male lateral view (250 X); 42. Male postabdomen (1250 X); 43. Ephippia (400 X).



Plates VIII Scanning electron micrographs of species of Cladocera, 43. *Biapertura karua*: female lateral view (400 X); 45. Posteroventral corner (2000 X); 46. Postabdomen (2000 X); 47. *Euryalona orientalis* : female lateral view (200 X); 48. Ventral view (200 X); 49. Postabdomen (750 X).

number and arrangement of spines on the postabdomen, number of pores on the head shield, ornamentation in the ephippial eggs, etc. It is apparent from the present studies that the application of scanning electron microscopy to systematic studies of the freshwater Cladocera can provide a valuable tool to the investigator, particularly if micrographs of diagnostic features could be gathered into a reference atlas. While morphological characters should not be relied upon to the exclusion of other methods used in systematics (particularly in a group noted for ecomorphic variation), the SEM thus provides diagnostic advantages not available with the light microscope.

References

- Crittenden, R. N. 1981. Morphological characteristics and dimensions of the filter structures from three species of *Daphnia*, Cladocera. *Crustaceana*, 41(3) : 233 - 248.
- Dumont, H. J. 1981. Cladocera and free living Copepods from the Founta Djalon and adjacent mountain areas in West Africa, *Hydrobiol.*, 85: 97 - 116.
- Dumont, H. J. & Van de Velde, I. 1976. Some types of head-pores in the Cladocera as seen by Scanning electron microscopy and their possible functions. *Biol. Jb. Dodonaea*, 44: 135 - 142.
- Frey, D. G. 1982. The reticulated species of *Chydorus* (Cladocera, Chydoridae) two new species with suggestions of convergence. *Hydrobiol.*, 93: 255-279.
- Guldner, F. H. 1969. Electronmikroskopische Untersuchungen an Intestinaltrakt von *Daphnia pulex*. *Diss. der Med. Fak. der F.U. Berlin*.
- Kokkin, M. J. & Williams, W. D. 1987 Is ephippial morphology a useful taxonomic descriptor in the Cladocera ? An examination based on a study of *Daphniopsis* (Daphnidae) from Australian Salt Lakes, *Hydrobiol.*, 145: 67 - 73.
- Schultz, T. W. 1977. Fine structure of the ephippium of *Daphnia pulex* (Crustacea : Cladocera), *Trans. Am. Microsc. Soc.*, 96: 313 - 321.
- Schultz, T. W. & Kennedy, J. R. 1976. The fine structure of the digestive system of *Daphnia pulex*, *Tissue and Cell*, 8: 475 - 490.
- Smirnov, N. N. 1971. *The world Chydorid fauna* (In Russian). USSR Acad. Sci. Zool. Institute. Nova Ser. No 101, Leningrad.
- Venkataram, K. & Krishnaswamy, S. 1984. On the occurrence of *Leydigia ciliata* Gauthier, 1939 (Cladocera, Chydoridae) from Madurai, South India. *Current Sci.*, 53: 1097 - 1098
- Venkataraman, K. & Krishnaswamy, S. 1989. Application of Scanning electron microscopy in the taxonomy of Cladocera. *J. Bombay Nat. Hist. Soc.*, 86(2)
- Zahid, Z. R. 1981. A preliminary study on the structure and ultrastructure of the compound eye of *Simocephalus vetulus* Schodler (Cladocera). *Crustacea*, 40(2) : 127 - 131.

Cytotaxonomy of Animals

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Basing on morphological characters morphotaxonomists endeavour a system of classification of living organisms that reflects the natural relationships. However, the concept of the 'biological species' and that the speciation process is a gradual one due to isolating genetic mechanisms was advocated by Fisher (1930) and advanced by Mayr (1963, 1978). Students of speciation mostly not being geneticists seem not aware of it. Taxonomists primarily depend on morphological characteristics but information from other disciplines like cytology, genetics, ecology, embryology, etc., are incorporated. Thus the morphotaxonomy or alphataxonomy gave way to the modern or neo-taxonomy christened as omega-taxonomy, which incorporates informations from cytotaxonomy which pertains to cytogenetical informations specially the karyomorphological ones, numerical taxonomy based on maximum number of characters, ethotaxonomy relating to the animal behaviour, biochemical taxonomy based on biochemical parameters like DNA estimation, molecular hybridization, eco-taxonomy relating to various ecological parameters and so on. Many examples might be cited when a good species not being discernible by apparent morphological characters, could be established from findings of other disciplines. Among various supporting disciplines, cytotaxonomy is specially important and fundamental because species are an object of reality of some particular genetic continuity and the chromosomes are blue prints of ancestry, relationships, present and future trends of the species concerned.

That cytology is a very important helpful tool in taxonomy is undeniable (Manna 1969) and the number of taxonomically described species crossed the million mark but we have the chromosome data hardly of 10,000 (1.0%) species, and that too very unevenly investigated because of so many limiting factors like availability and suitability of materials, interest, techniques, etc.

The advancement of cytotaxonomy rests much on the innovations of finer new techniques. Near about the beginning of the 20th century the study of chromosomes from testes cells of invertebrates and vertebrate species by microtome sectioning was the common practice because of the readily available dividing cells all the time. The technique was improved by introducing smear

and squash methods. Earlier data were not always dependable specially of difficult materials though testes are still being used deploying improved techniques because of their importance in detecting heterozygosity, cause of sterility, sex chromosomes, meiotic behaviour of chromosomes, etc., as ovary is not suitable. In the mid-20th century innovation of the colchicine-hypotonic pretreatment for handling somatic chromosomes had a very startling impact in the study of karyosystematics specially of vertebrates. For somatic chromosomes *in vivo* bone marrow cells and *in vitro* short term culture of peripheral blood, leucocyte, fibroblast and various embryonic tissues handled by colchicine - sodium citrate-acetic acid-air dry/flame dry-Giemsa staining technique provided extremely clear structure. Further innovations of banding techniques around 1970 for C-(constitutive heterochromatin) banding, G-(Giemsa) banding, F-(fluorescence) banding, E-(enzymatic) banding, etc., and NOR (nucleolus organizing region) technique opened avenues of deeper critical comparison of intra- and inter-specific karyotypes for the karyosystematic evaluation.

Hybridization is a very important means in experimental taxonomy. The somatic cell hybridization of different species by the help of some fusogens like biological Sondai or New Castle viruses and chemical - polyethelene glycol provides a distinct advantage in finding out chromosomal homology. Even non-related species like man and mice show some common chromosomes. *In situ* DNA hybridization can also be applied. Interspecific hybridization has been a practice in experimental taxonomy before cellular and molecular hybridization. It provides access to compare the chromosomes of two species for their compatibility in the hybrid which is rare in nature but in captivity can be effected when mate of own species is not provided, kept in crowded condition, etc. Interspecific hybrids are on record in Lepidoptera, mosquitoes, *Sciara*, *Drosophila*, fish, amphibia, birds, mammals (horse and ass), etc. Species hybrids often result in sterility, the cytological basis of which was enumerated by White (1973) as due to (i) gametogenesis is arrested before the onset of meiosis, (ii) synapsis complete but stickiness and incomplete spindle impair anaphase separation, (iii) both synapsis and spindle mechanism are abnormal, (iv) synapsis absent but spindle is normal, (v) no synapsis and abnormal spindle while hybrids showing (vi) complete synapsis and abnormal spindle and anaphase separation and (vii) incomplete synapsis but normal meiotic division are somewhat fertile ones. Meiosis in species hybrids in heteropteran pentatomids and bedbugs, grasshoppers, gryllids, silk worm and other lepidopterans, amphibian *Titurus*, various species of *Drosophila*, etc has been reviewed by White (1973). While a good number of them are recorded in fishes (Denton 1973), very few have been cytologically investigated (Ojima, 1985) and it is utterly important for Indian major carps for cytotaxonomical paradox (Manna, 1984,1989).

In cytotaxonomy the main avenues of approach are structure including banding, size and behaviour of somatic and germinal chromosomes, analysis of polytene and lampbrush chromosomes in special cases when present,

m-chromosome generally in Heteroptera, macro-(M) and micro-(m) chromosomes of which the latter in vertebrates, aberrant meiosis in some groups as scale insects, fungus gnats (Sciaridae), Gall midges (Cecidomidae), Biting and Sucking lice, etc. An attempt has been made in the following to present as practicable very briefly the cytogenetical informations in different groups of non-chordates and chordates.

Non-Chordates (Invertebrates)

Protozoa : Very limited study of chromosome number in different species has been made. It is mostly done in some species of parasitic protozoans. Some interesting cytological observations recorded are the claim of telocentric chromosomes in hypermastigote flagellate, *Holomastigotoides*, endopolyploid nuclei as macronuclei of ciliates and the so-called primary nuclei of some Radiolaria and polytene structure of chromosome of macronuclei of some ciliates. The macronuclei, generally originate from diploid micronucleus, divide amitotically, vary in number, structure and chemical constitution are characteristic of Ciliophora. In lower ciliates a peculiar cycle of nucleolar activity known as karyological relics is found in different but not closely related families. In higher ciliates macronuclei are large, highly polyploid and vary in size and shape. The macro-chromosome of *Stylonichis* and *Nyctotherus* undergoes a typical transversely banded structure somewhat like Diptera. In *Nyctotherus* the chromosomes join end-to-end to form a single giant polytene element with two ends free while in *S. mytilus* some 250 polytene chromosomes join in 1 or 2 chains and *S. muscorum* show 50 to 60 free polytene chromosomes. The degree of polyploidy is determined by DNA value.

Mesozoa : They are supposed to be the connecting link between Protozoa and Metazoa and are claimed to have $2n$ number in 3 species ranging between 6 and 100 in old literature (Makino, 1956). They require confirmation.

Porifera : The chromosome number of 7 species under 5 genera ranges from 8 to 32 (Makino, 1956) might indicate polyploid origin. Cytotaxonomical evaluation is unwarranted for meagre data.

Coelenterata : Some 27 species under 17 genera of 3 families show the $2n$ range between 12 and 32 chromosomes of which 12 seem the modal number (Makino, 1956). Bisexuality is common though hermaphroditism also occurs. Apomictic thelytoky (diploid parthenogenesis) might occur but no chromosome study has been made.

Platyhelminthes : These triploblastic acoelomate invertebrates are commonly hermaphrodite and bisexuality is exception. In about 100 species of Turbellaria $2n$ numbers range between 4 and 40 (Makino, 1956). $2n=4$ in species of 11 genera, viz. *Castrella*, *Dalyellia*, *Parvovortex*, *Amphibollela*, *Krumbachia*, *Phaenocera*, *Prorhynchella*, *Rhychomesostoma*, *Solenopharynx*, *Acrohynchus*, and *Gyratrix* ; $2n=6$ in species of 7 genera, viz. *Macrostomum*, *Provortex*,

Gastrada, *Mesostoma*, *Trignostomum*, *Typhloplana*, and *Microkalyptorhynchus* ; $2n = 8$ in species of 5 genera, viz. *Paravertex*, *Byrsophlebs*, *Mesostoma*, *Opistosoma* and *Planaria* while species of some other genera are also mostly with low $2n$ numbers ranging upto 24 or more. According to the histogram prepared by White (1973) of 51 hermaphrodite Rhabdocoela, species number ranges from 2 to 20 with a very high peak at 2. Freshwater planarians are all hermaphrodite but self-fertilization is prevented. Thelytoky besides pseudogamy is unknown in triclads but not in Rhabdocoela. Unlike Turbellaria, polyploidy seems absent in hermaphrodite Cestoda and Digenetic Trematoda. In some 49 digenetic trematodes the n numbers range from 6 to 14 with a peak at 11 observed in 23 species, and in 15 species of cestodes between 5 and 8 with a peak at 5. The cyclical parthenogenesis is claimed in *Fasciola*. The sex chromosome is not clearly demonstrated.

Nemathelminthes : More than 200 species show 5 of *Echinorhyncus* $2n=8$ and 2 of *Gigantorhyncus* $2n=6$ under Acanthocephala, and about 200 species of Nematoda belonging to different groups from the very early time show $2n$ range between 2 (incidentally lowest among all diploid animals and 48 (Makino, 1956; Triantaphyllou, 1983). Most groups have low diploid numbers and bisexuality is the rule. In Ascaridae several species of *Ascaris* show $2n$ range from 2 (*A. megalocephala univalens*) to 48 in germinal cells but they fragment to form high number in somatic cells as exception to Muller's telomere hypothesis of chromosome structure. The chromosomes are polycentric in germinal cell. Several species of *Heterakis* under Heterakidae show $2n=9$, XO:XX, in *Rhabdis* under Rhabdiasidae $2n=11$ and 13 with XO:XX, in *Strongylus* under Strongylidae $2n=11$, XO:XX while 1 or 2 species in different genera under families Trinellidae ($2n=8$), Acuariidae ($2n=11$) Ancyracanthidae ($2n=11$), Chromadoridae ($2N=14$), Cruzeidae ($2N=12$), Curullanidae ($2N=12$), Filariidae ($2n=12,16$) and so on. A variety of sex chromosome mechanisms has been claimed in nematodan species as XO, $X_{1-2}0$, $X_{1-5}0$, XY, NeoXY, $X_{1-8}Y$, even ZW which facilitated possibly due to dissociation of polycentric/holocentric chromosome. Several root-knot nematodes reproduce by apomictic thelytoky with polyploidy. Several bisexual species of *Heterodera* and *Meloidogyne* ($n=9$) show some apomictic biotypes with $4n, 5n, 6n$ constitution. In *Rhabditis* a number of forms are thelytokous hermaphrodites which reproduce by pseudogamy. A free living nematode, *Dibloscapter coronata* has $2n=2$ chromosome like the species of *Ascaris* (Triantaphyllou, 1983).

Annelida : Over 100 species under different classes show $2n$ numbers range between 6 and 100 (Makino, 1956). In Archiannelida 2 species of *Dinophilus* have $2n=20$ while 1 species each of 2 other genera have $2n=4$ and 8. In Chaetopoda, 17 species of 2 genera under Polychaeta $2n$ ranges from 4 to 30 but lower in most cases while about 75 species of 17 genera under Oligochaeta $2n$ ranges from 16 to 100 (in *Tubifex*) but most of them show $2n=20$ and 64. In Hirudinina, 13 species under 9 genera $2n$ ranges between 16 and 40 of which 16 is modal number in 5 genera. In Echiurida, *Thalassema mellita* show $2n=12$ and 24 while *Urechis caupo* has $2n=36$. In Sipunculida, all the 3 species of *Phascolosoma* and *Sipunculus* show

$2n=20$ chromosomes. Leeches and earthworms are hermaphrodite though a number of species reproduce parthenogenetically with abnormal or suppressed spermatogenesis. Lumbricidae and Enchytraeidae are mostly parthenogenetic but at least 8 out of 42 species are sexually reproducing in the former and 27 out of 74 species of the latter are polyploids (Christensen, 1961). In true earthworms 4 genetic systems are found as (a) diploid sexual species, (b) polyploid sexual species, (c) automictic polyploids and (d) apomictic polyploids. *Dendrobaena rubinda* including forms 'typica', 'tenuis', 'subrubicunda', 'norvegicus' and 'constricta' is complex superspecies with $2n=34$, $4n$, $6n$, $sub8n$ and $3n$ while *D. octaedra* is apomictic thelytokous having $6n=108$, aneuploids (112-117, 124, 99) in different geographical regions studied by Omedeo (see White, 1973). The discovery of cytobiotypes in earthworms is an example of the importance of cytotaxonomical investigations.

Trochelminthes (Rotifera) : Only 5 species of *Asplanchna* and *Hydatina* show n number ranging from 5 to 26. Thelytoky seems only the method of reproduction, some with cyclical parthenogenesis, males are unknown but unfertilized larva might develop into male. The cytological data are very poor and neglected.

Bryozoa (2 species with $n=6-11$), *Kamptozoa* (2 species of *Pedicellina* $2n=22$) and *Phoronida* (2 species of *Phoronis* $2n=6, 12$) as aberrant groups are cytologically very poorly investigated (Makino, 1956).

Mollusca : They are well known for fossil records. Basing on the cytological data of Butot of living forms, White (1973) prepared a histogram of haploid numbers of some 430 species between 5 and 36 under Euthyneura, Streptoneura, Bivalvia, Amphineura and Cephalopoda. The haploid number in about 320 species of Euthyneura ranges from 5 to 34 with a very high peak at 18 and second lower peak at 29, in 102 streptoneuran species from 6 to 36 but also a peak at 18, in 6 species of Bivalvia the range is 12 to 16 with a very small peak at 12 while 1 species each of Amphineura and Cephalopoda show 9 and 6 respectively (Butot, 1967). A variety of reproductive mechanisms exist in Mollusca. Opisthobranchs and pulmonates are largely hermaphrodites which possibly led to evolutionary polyploidy. Somewhat degenerate spermatogenesis occurs in many prosobranchs giving rise to 'apyrene' (lacking nucleus) and 'oligopyrene' (contains a few chromosomes) sperms. Males with XO and XY are claimed in some prosobranchs and pulmonates. Thelytoky is seen in American ($2n=12$), British isles ($4n$) and Indian freshwater snails of which Indian *Melanoides* are apomictic with diploid ($2n=32$) and a pentaploid/hexaploid (90-91) races and other congeneric species are $4n$ forms. The small size of chromosome prevents detailed analysis. Parthenogenesis seems absent in Pulmonata.

Echinodermata : They are bisexual but some are hermaphrodites. The cytological studies are very limited (Makino, 1956). 5 species of *Asterias* and 1 of *Cribrella* under Asteroidea show diploid range of 18 and 36 chromosomes. One species each shows diploid number of 8 in *Antedon* of Crinoidea, 28-36 in

Stichopus under Holothuroidea and $n=18$ in *Opihocoma* under Ophiuroidea. 22 species under 9 genera of Echinoidea show the diploid range of 18 to 52 while congeneric species of *Arbacia*, *Echinus*, and *Hipponoe* and intraspecific variations are recorded in *E. esculentus*, *E. miliaris*, *Toxopneustes variegatus*, etc. Male heterogamety with XO and XY are claimed while hermaphrodites are lost.

Arthropoda : It is largest phylum among invertebrates and cytological studies are most exhaustive specially in insects. Among 5 living classes as Crustacea, Insecta, Arachnida, Myriapoda and Onychophora data are maximum and of varied type.

Crustacea : Among different groups, 38 species of Decapoda show characteristically very high diploid numbers ranging from 82 to $376 \pm$ with no peak. Males are heterogametic with XO, XY, $X_1 X_2 O$ and $X_{1-8} O$. In Euphyllopoda, among 6 species, *Artemia salina* are cytologically very intrigue because chromosomally polymorphic, having 12, 84, 168, thelytoky like plants but taxonomists put them as different species. Female heterogamety with ZW is claimed rarely. The asexual biotypes coexist and form large dense population, known as agamic complex together with biotypes of 2n sexual one, 2n and 4n thelytokous strains form superspecies. Occurrence of DNA bodies due to gene amplification is another peculiarity of the brine shrimp. Under Cladocera about a dozen of species show low 2n numbers of 8 to 30 and the cyclical parthenogenesis is recorded before 20th century, though the cytogenetic mechanism remains unresolved. In *Daphnia* thelytokous reproduction continues but in unfavourable condition males are produced though sex chromosome not identified. No bivalent formation is seen. Under Ostracoda species of *Cyprinotus*, *Cypris*, *Platycypris*, *Heterocypris*, *Cyclocypris*, etc., show 2n range from 12 to 24, chromosomes are small, males are heterogametic with XO, neo-XY, and multiple series of X_{2-30} , $2X_6Y$, XY_{3-6} and so on. The X's form pseudobivalent with the Y when present. Apomictic thelytoky occurs in *Heterocypris* and some other genera. Under Copepoda nearly 50 species in 18 genera show the diploid range from 6 to 34 of which several species of *Diaptomus* show $2n=8-34$, *Cyclops* $2n=6-24$, etc., while some other genera show very little variation (Makino, 1956). The terminal heterochromatic segment of DNA origin due to gene amplification is seen in 5th or 6th cleavage of *Cyclops*. Female heterogamety for ZO and ZW occurs in a number of species but chiasma is absent. Under Cirripedia 3 species of 3 genera show $2n=26$ and 32. They are mostly hermaphrodite showing no sex chromosome difference. Under order Isopoda over 40 species in 18 genera show the diploid range from 26 to 32, chromosomal polymorphism in a marine species, supernumerary, small males of *Ione* ectoparasite to female like *Bonellia*, being hermaphrodite sex chromosome is seen in few as female heterogamety of ZW, ZW_1W_2 , polyploid parthenogenesis in *Trichoniscus* ($2n=16$) with geographical biotypes 'elizabethae', 'coelebs' in different parts in Europe, etc., are the cytological highlights. Under Amphipoda about 2 dozens of species under a dozen of genera show 2n range from 26 to 104 though 2n around 52-54 more common

which are also found in several species of *Gammarus*, XY:XX sex mechanism and some species show supernumerary chromosome as in *Gammarus* and *Marinogammarus*.

Arachnida : They comprise spiders, scorpions, ticks, mites, king crab, etc. Spiders are cytologically studied quite extensively. Araneida : Over 300 species of spiders including later addition mostly by Indian workers to 240 reviewed by White (1973). $2n$ range from 8 to 96 of which about 80% species show a continuous range from 20 to 34 chromosomes with a peak at 30 and a lower one at 26, heterogametic males are overwhelmingly X_1X_2O , about 10% XO, very few are $X_1X_2X_3O$ while the Y is characteristically absent. Thelytoky is unknown.

Scorpionidae : About a dozen species of scorpions show wide $2n$ range of 6 to 120 with low to moderate numbers in Buthidae while Vejovidae has highest one. Translocation heterozygotes specially in Brazilian scorpions, *Tityus* and *Isomerus*, no chiasma during spermatogenesis, controversial claim of holocentric chromosome, interspecific variation of $2n$ numbers of 6,10,17,19 in different populations are of good cytological interest. Thelytoky is deemed to be present. The scorpion-spider, *Thelyphorus* has $2n=25$, XO while 2 species of Pseudoscorpionida have $n=41, 34$ with X_1X_2O males.

Acarina : Over a dozen of species of ticks and mites show $2n$ range from 4 to 26. Some cytological features are haplodiploidy in several families, 13 species of Tetranychidae show male haploidy while males are diploid and heterogametic in Gamasidae, RNA mass eliminated at anaphase of both meiotic division of *Pediculopsis*, spermatogenesis achiasmatic, disputable claim of holocentric chromosomes, sex chromosomes mostly not demonstrable but an XO is claimed, several thelytokous forms in mites which are automictic while tick, *Haemaphys* reproduces parthenogenetically with occasional functionless males.

Other Orders : Phalangida (Opilionida) - Over a dozen of species under a dozen of genera show $2n=16$ to 32 with congeneric species and genera differ narrowly in $2n$ numbers while the king-crab, *Tachypleus* under Xiphosura has $2n=26$, and *Porocephalus* females show $2n=10$ under Linguatulida.

Myriapoda : Under sub-class Progoneata, 2 species under 2 genera of Diplopoda (millipedes) show $2n=16$ and 25 in males with XO in *Pachyiulus* while nearly 2 dozens of species under 8 genera of Chilopoda (centipedes) under Opisthogoneata show $2n$ range between 14 and 63 with congeneric and intergeneric variations, male heterogamety with XO, post reductional XY in Scutigerae, 4X5Y in 1 species of *Otocryptops* (Cryptopidae) while some species of *Thereuopoda* claimed to have both holocentric and localized centromere in metaphase.

Onychophora : The aberrant interlinking arthropod of Neotropical region, among several sub-genera and species only *Peripatus* sp. $2n=28$ in both sexes is reported, while another aberrant species of *Macrobiotus* under Tardigrada ("Bear-animalcule") shows $2n=10$ chromosomes in female; no sex chromosome is seen.

Insecta : The cytological data are too vast to review within limited space.

Apterygota : *Thysanura* (Silver fish) - Two species of *Lepisma* are reported with $2n=34$, X_1X_2O in male and another species with $n=29$, XO . *Collembola* (Spring Tail) - They show low $2n$ of 6 and 8, presence of polytene chromosomes in salivary gland in Neanuridae like Diptera in limited species so far studied.

Pterygota : Some orders have been very extensively studied for cytotaxonomy, etc.

Orthoptera : Under suborder Caelifera few hundred species belonging to different superfamilies are cytologically known (White, 1973) which show karyotypic conservatism for diploid number and sex chromosome mechanism. Under family Eumastacidae, $2n=21$, XO male is most common while highly polymorphic Morabine show from 17 deviation to 13 to 21 and XO , XY and X_1X_2Y . Deviation XO to XY or to X_1X_2Y in 3 other subfamilies while $2n=21$ in 9 subfamilies. Proscopiidae show $2n=19$ XO male. The $2n=23$, XO male characteristically seen in Trigonopterygidae, Pneumoridae, Xyrontidae, Charilaidae, Ommexechidae, Lentulidae, Pauliniidae and Acrididae while $2n=19$, XO males in Pamphagidae and Pyrgomorphidae. Deviations of the diploid number and the sex chromosome could be accounted by fusion and fission for autosomal number, X-autosome translocation for sex chromosome change from XO . Species belonging to Tetrigidae and Tridactylidae show $2n=13$, XO male with not a single deviation. The long-horned grasshoppers, Tettigoniodea show $2n$ range from 20 to 35 with the haploid mode of 16. The parthenogenetic *Sago sago* has $4n=68$. Males are XO , rarely neo XY and X_1X_2Y . Chromosomal polymorphism in *Jamaicana* and thelytoky in *Sago* and *Poecilimon* are recorded. Phasmidae - in about 2 dozens of stick and leaf insects male diploid numbers range from 21 to 63 with XO , rarely neo- XY in *Podacanthus*. Congeneric species differ in number due to facultative parthenogenesis in some cases. Mantidae - Out of nearly 100 species, 57 with XO males show the diploid range from 15 to 39 chromosomes while about 40 species with X_1X_2Y show $2n = 23-31$ with a mode at 27 chromosomes, are grouped as Monosomata and Trisomata respectively and the latter originated by mutual translocation. The chromosomal polymorphisms, synaptonemal complex in spite of achiasmatic spermatogenesis rarely thelytoky are some special features in mantid cytology. Blattidae - cockroaches show the diploid range from 23 to 33 with $XO:XX$ sex mechanism and translocation heterozygotes in some populations of *Periplaneta* are reported. Grylloidea - The cytological data of about 100 species of crickets and 3 species of mole crickets reviewed by Manna (1981) show that in Gryllidae the $2n$ range from 11 to 29 with XO male, the same in Gryllinae with the peak at 21 and Nemobiinae with the peak at 17. In Trigonidiidae $2n$ range from 11 to 19 with peak at 15. Sex chromosome polymorphisms of XO and XY with $2n=18$ autosomes is seen in Occhanthidae. *Scychellsia* sp. ($16X_1X_2Y$ male) under Phalangisidea, *Euscyrtus* sp. ($16X_1X_2Y$) and *Eneoptera* sp. ($8X_1X_2Y$) show unique 'determinate disjunction' lying independently at metaphase I. Chromosomal polymorphisms,

supernumerary chromosome and thelytoky are known in Gryllidae while several congeneric species of *Gryllotalpa* show very marked chromosomal polymorphisms in world population with number ranging 15-25 and XO, XY males. Two species of Grylloblatidae show $2n=30$, XY male.

Dermaptera : Earwigs show $2n$ range from 10 to 40 with a peak at 24 in XY males of 16 species, $2n=7, 21, 25$ and 37 with a peak at 25 in 9 species with X_1X_2Y and 1 species with $2n=38X_1X_2X_3Y$. Chromosomes are holocentric and sex chromosomal races exist in *Forficula*. **Isoptera** : Three species of termites show $2n=52$ but no sex chromosome identifiable. **Plecoptera** : Few species of stonefly show narrow diploid range from 10 to 26. Males of *Perla* and *Perlodes* show XO, XY, X_1X_2O and $X_1X_2X_3Y$ which form accessory plates towards a pole while XY form pseudobivalent at metaphase I. **Embioptera** : One thelytokous species of *Haploembia* shows bisexual form with $2n=19$, XO:XX in Japan and $2n=22$, $3n=33$, in African races. **Psocoptera** : One species of *Cerastipsocus* shows $2n=17$ XO. Six species of Biting Lice (*Anoplura*) and 2 species of Sucking Lice (*Mallophaga*) $2n$ varies from 7 to 24 with 12 possibly as mode show holocentric chromosomes, aberrant male meiosis, unique and bizzare chromosome cycle, etc., indicating close similarities of 2 orders. **Thysanoptera** : Thrips, female of *Heliothrips* has $2n=32(?)$. It seems haplodiploidy is common while few show thelytoky. **Odonata** : Dragonflies possibly have holocentric chromosome. Nearly 250 species show the haploid range from 3 to 15 with peak at 13 in Anisoptera and 6 to 15 with peak at 13 in sub-order Zygoptera and $n=14$ in one species of Anisozygoptera, mostly with XO, rarely with neo-XY male and thelytoky not reported. The meiotic behaviour recalls similarity to exopterygotes.

Homoptera : Over 900 species show diversified cytological characteristics among 3 major divisions : (1) Colenorrhyncha known from one species from Australia is reported to have $2n=22/23$ chromosomes in males. (2) Sternorrhyncha comprises (i) Coccina, (ii) Aphidina, (iii) Psyllina and (iv) Aleurodina show very diverse cytogenetic systems. (i) Coccidae - In scale insects the chromosome numbers vary widely between 2 and 28, parthenogenesis is very common and the pattern are termed as lecanoid, diaspidid and comstockilla system which correspond to taxonomic groupings. They show aberrant meiotic behaviour and the chromosome cycles are somewhat like Biting and Sucking Lice reviewed by White (1973). (ii) Aphidae - The chromosome number of about 400 species of Aphids is listed by Manna (1980) to which at least 50 species could be added out of some 4000 species taxonomically described. The $2n$ numbers range from 4 to 24 and up with a mode probably at 12. The sex chromosome in male is overwhelmingly XO, few are X_1X_2O , $X_1X_2X_3O$, rarely $X_{1-4}O$ but no Y. Male meiosis modified, chromosomes are holocentric, variation in chromosome numbers found within and between species, thelytoky is main mode of reproduction and cyclical parthenogenesis occurs as well. (iii) Psyllidae - Seven species show $2n=25XO$ with haplodiploidy, males are haploid. (iv) Aleurodidae - only 2 species of white flies cytologically known which show closeness to Auchenorrhyncha. (3) Auchenorrhyncha - About 400 species belonging to 17 families, $2n$ range in

males from 7 to 35 holocentric chromosomes with a peak at 21, XO:XX more common, stereotype meiotic behaviour, parthenogenesis not reported, neoXY in *Parabolocratus* is seen among good number of species studied by us (Manna, 1969).

Heteroptera : The cytotaxonomy of them has been reviewed from time to time (Manna, 1951,1958,1962,1983a; Ueshima, 1979). About 1240 species cytologically known under 46 families/ $2n$ number range from 4 to 80 with a peak at 14. Basing on the $2n$ numbers, size, m chromosome, differential behaviour, number and meiotic metaphase arrangement and pre - and post - reduction of sex chromosome, etc. cytotaxonomical evaluation in the generic and supergeneric levels had been made. Sex chromosomes in males are XO, X_{1-40} , XY, X_nY , X_nY_n , etc., reviewed by Manna(1982) and characterize some group. Supernumerary chromosome, chromosome polymorphisms are known but parthenogenesis is unknown. The claim of holocentric chromosome is refuted (Manna, 1985). Pentatomidae, Lygaeidae, Coreidae, Miridae and Cimicidae have been very extensively studied.

Neuroptera : Some 60 odd species under 10 families show $2n$ range from 24 to 26 in 2 species of Raphidiidae, 20 and 22 in Sialidae and Ascalaphidae, 10 and 16 in several species of *Chrysopa* under Hemerobiidae, 14 in *Hemorobius* under Hemerobiidae, 18 in Mantispidae, 14 to 26 in Myrmeleonidae, 8 and 18 in Coniopterigidae and 14 in Osmylidae and Sisyridae. Males are XY and characteristically the X and Y do not pair but oppositely polarized at metaphase I.

Mecoptera : Few species of Scorpion flies show $2n=43$ and 45, males are XO, meiosis is achiasmate in *Panorpa* with archaic 'Panorpoid Complex' and achiasmate in others. A case of neoXY reported, unlikely by X-autosome exchange.

Trichoptera : Over 2 dozens of species under 9 families show haploid range of 6 to 30 with an exception of 50 in *Agryonetes*. Like closely related Lepidoptera RNA lump lags in spindle equator, endopolyploidy in spinning glad, achiasmatic meiosis, females are ZO and ZW, thelytoky is seen in some region.

Lepidoptera : Some 700 species of moths and butterflies in spite of cytologically not ideal show haploid numbers from 7 to ca.220 but a very marked mode at 29-31 and a lower one at 23-24. Some taxonomical evaluation is possible in the generic and supergeneric level, chromosomal polymorphisms in some 15 species, supernumerary in some, interspecific and intergeneric hybrids specially in sphingid moths, F1 chromosomal correlation with parental species, potency of sex determining genes variable in different geographical races in gypsy moth, tychoparthenogenesis, complete thelytoky with $2n$, $4n$ races holocentric chromosomes, etc., are cytological specialities.

Coleoptera : Among 2,20,000 taxonomic species of beetles meagrely 1200 odd species belonging to different taxa show the type no. 20 ($18+Xyp$) between a $2n$ range of 8 to 89 (Makino, 1956; Smith, 1960; Smith and Virkki, 1978;

Virkki, 1983). Among 3 suborders, Archostomata represented cytologically by *Micromalthus debilis* in aberrant Micromalthidae show haplo-diploidy male with 10 and female with 20, paedogenetic reproduction, viviparous type produces only females while oviparous ones give male offspring. In Adephaga $2n$ ranges from 10 to 38 of which $2n=18+X_{yp}$ forms modal number. The largest suborder Polyphaga comprises 112 families, one-third of which cytologically show wide diversities in diploid numbers, sex chromosome mechanism, parthenogenesis, etc., in the generic and supergeneric level though the modal number is $2n=18+X_{yp}$. Very noteworthy works on chromosomal polymorphism among others are of *Chilocorus* (Smith, 1966) and *Pissodes* (Manna and Smith, 1969; Virkki, 1983). The sex chromosome mechanisms show great variety, XO in 16 out of 43 families while in others with the Y, form X_{1-12} and Y_{1-6} in a variety of combination. The size of the Y in relation to the X form XY (almost equal), XY_r , X_y , XY_p , etc., 6 types shown by Smith. X_{yp} is absent in Adephaga. Parthenogenesis is recorded in various families like Ptinidae, Chrysomellidae, Ciidae, Curculionidae, etc., which are mostly thelytokous types with different degrees of ploidy and form some races. Prereduction is the rule but post reduction of XY is seen in *Hyperaspis* while a number of variations in sex chromosome behaviour are recorded.

Hymenoptera : Some 64 species belonging to 11 families unevenly studied show mostly haplodiploidy, few diploid and parthenogenetic species. The haploid numbers in male ranges 16 in Apidae, 10, 11 and 30 in Braconidae, 8 in Chalcidae, etc. The chromosome number in saw flies ranges $n=6$ to 21, ants 4, 26-27, etc. Males show various modified spermatogenesis with no bivalent formation. Synapsis and chiasma are somewhat regular in diploid males of *Habrobracon*. Both automictic and apomictic thelytoky in sawfly, parasitic wasp, etc., possibly originated from haplodiploidy. The cyclical parthenogenesis is seen in gall-wasp. The sex chromosome is not distinguishable.

Diptera : In this, *Drosophila* so to say is the grammar of cytogenetics of Eukaryotes. Anyhow about 550 species of Diptera show the diploid range from 4 to 20 chromosomes with peaks at 6 and 8 mainly due to several families of Nematocera, and a high peak at 12 due to various acalypterate and calypterate families including Drosophilidae. The cytosystematics of Drosophilidae has very critically been evaluated for the presence of salivary gland chromosomes (Patterson and Stone, 1952). The haploid number ranges from 3 to 6 in *Drosophila*, has been accounted mainly due to fusion, fission, pericentric inversion translocation, etc. (Stone, 1962). The same mechanisms are also applicable to other groups. The cyto-systematics of higher Diptera carried out by Boyes and others show almost all species of Sarcophagidae and a good number of Muscidae possess 6 pairs of chromosomes. However, a very complicated aberrant genetic system is met with in Sciaridae (Fungus gnats), Cecidomyiidae (gall midges) and Orthocladiinae of Chironomidae listed and reviewed by White (1973). Interspecific hybridization, genetic balance of sex determination, etc., have been worked out in *Drosophila*. Though male heterogamety is common with XO:XX and XY:XX sex determination but neoXY, X_1X_2Y or $X Y_1Y_2$ are recorded. In Crane

fly (Tipulidae) XY do not pair but segregate to opposite pole regularly. Thelytoky has been recorded in some species of Psychodidae, Simuliidae, Chironomidae, Lonchoptridae, Chamaemyidae, Drosophilidae and Agromyzidae.

Aphaniptera : Very limited number of species of fleas show male heterogamety, and *Leptopsylla musculi* show $2n=22$ XY, *Ctenocephalus canis*, $14XY(?)$, *Xenoxphyllus* $20X_1X_2Y$, etc., elimination rfr^{RNA}, supernumerary element, chromosomal polymorphisms for the presence of heteromorphic bivalents, etc., are known.

Chordates

Lower Chordates : In Urochorda about 2.5% species cytologically investigated show $2n$ number 24 in *Distaplia* and 18 in *Clavelina* under Clavelinidae, 20 and 40 in *Aplidium* and 18, and 24 in *Sydnium* of Polyclinidae; 8,33 in *Trididemum*, 30 in *Didemnon* and *Diplosoa* under Didemnidae of the suborder Aplousobranchiata; 12,18,28 in *Ciona* of Cionidae, 16,18 in *Ascidiella* and *Ascida* and 16 in *Phallusia* of Ascidiidae and 12 in *Corella* under suborder Phebobranchiata, 16,32 in *Styela*, 32 in *Bortryllus* and *Botrylloides*, 4 in *Dendrodoa* under Styelidae of suborder Stolidobranchiata, and among pelagic tunicates 8 in *Pirosoma*, 8,12 in *Cyclosalpa* of Pyrosomida, 8,10,12,24,26 in *Salpa* and 24 in *Thalia* of Salpida, 22 in *Doliolum* of Doliolida and 6,7,16 in *Oikopleura*, 8 in *Fritillaria* of Copelta, cytotaxonomically reviewed by Colombero(1973). The sex chromosome is not identified. Polyploidy and parthenogenesis played good role. Morphology of mitotic and meiotic and embryonic chromosomes serves as very valuable parameters in taxonomical evaluation advocated by Colombero (1973).

In Cephalochordata the diploid number in 3 species of *Branchiostoma* shows 44 in *lancelatus*, 32 in *belcheri* and 38 in *florida*, all acrocentric with XY:XX sex chromosome mechanism. The DNA value is low like Ascidia.

Higher Chordates : *Cyclostomata* - The cytotaxonomy of cyclostomes has been critically presented by Potter and Robinson (1973). The $2n$ numbers are 164 in *Ichthyomyzon*, 168 in *Petromyzon*, 94,96 in *Entosphenus*, 164 in *Okkelbergia*, 60 to 194 in *Lampetra*, and 76 in *Mordacia* among lampreys (Petromyzontiformes), and 50,52(?) in *Myxine* and 46 and 48 in *Eptatretus* among hagfish (Mixiniiformes), showing different species of different genera differ in numbers, chromosomes are generally acrocentrics, the two groups differ in modal number, DNA value is higher than lower chordates and some species show a giant centriole.

Pisces : Though the study of fish chromosomes started before the beginning of 20th century, a great stride has been made with introduction of various methods of handling somatic chromosomes around 1960 and onwards (Denton, 1973). Fish cytogenetics and cytotaxonomy have been reviewed by different workers in recent

years (Denton, 1973; Chiarelli and Capanna, 1973; Kirpichnikov, 1981; Ojima, 1985; Manna, 1983b; 1984, 1989). According to the latest review (Manna 1989), out of 20,000 taxonomic species, chromosomes of about 1700 species belonging to some 774 genera under 193 families, 37 orders of 2 superclasses, Chondrichthes and Osteichthyes are unevenly known. Among the extensively studied families, species ranging from 30 to 300 belonged to Characidae, Cyprinidae, Cyprinodontidae, Goodeidae, Poeciliidae, Chanidae, Centrarchidae, Cichilidae, Gobiidae, Laberidae, Pomacentridae, Salmonidae and Ictaluridae, all belonged to Teleostei. The $2n$ number ranges between 16 and ca.218 with modal number of 48 chromosomes of mixed morphology and not only of telocentrics claimed by others. Nearly 125 species under 48 families of Teleostei show male heterogamety for XO, XY and X1X2Y and female heterogamety for ZO, ZW and ZW1W2. Polyploidy is not too uncommon while thelytoky is found in freshwater poeciliid. Interspecific hybridizations are known but the cytological studies in F1 rare which would settle taxonomic status of Indian major carps while melanotic tumour occurs in species hybrids of *Xiphophorus*. Chromosomal polymorphisms occur in some species.

Amphibia : Among some 2500 taxonomic species, cytotaxonomy has been done in a few species (Makino, 1956; Morescalchi, 1973 1979; Manna, 1983b). In 13 species of Apoda (Gymnophiona) listed (Manna 1983b) the diploid numbers are 24 in 2 species each of *Ichthyophis* and 26 in *Uraeotyphlus* of Ichthyophidae; 1 species each with 24 in *Caecilia*, *Gymnophis* and *Siphonops*, 26 in *Dermophis Grandisoria* and *Cymnophis*, 30 in *Gegenophis*, and 38 in *Geotrypetes* under Caeciliidae and 1 species each with 20 in *Chthonerpeton* and 28 in *Typhlonectes* under Typhlonectidae. In several species of Urodella (Caudata) the $2n$ numbers are 40 to 62 with 56 as mode in 13 species of *Hynobius* and 56 in *Pachypalaminus* sp of Hynobidae; 62 and 64 in 2 species of *Cryptobranchus* of Cryptobranchidae; 28 in 8 species of *Ambystoma* of Ambystomatidae; 28(26 for loss 1 m-pair) in good many species under 20 genera in Plethronontidae; 28 in 3 species of *Amphiuma* of Amphiumidae, 24 in 2 species of *Salamandra* (Salamandrinae), 2 of *Tylotriton*, 2 of *Pleurodeles*, 1 of *Salamandrina*, 6 of *Triturus*, 3 of *Euproctus*, 1 each of *Cynops* and *Neurergus* while 22 in 1 species each of *Notophtalmus* and *Taricha* (Pleurodelinae) of Salamandridae; 38 in 1 species each of *Proteus* (blind) and *Necturus* of Proteidae; 42 and 46 chromosomes in *Siren intermedia* of Sirenidae. Anura (Salientia). A very large number of species in different families show diploid numbers as 44(42) in *Ascaphus* and 34 in *Leiopelma* of Ascaphidae; 36,38 in *Alytes*, 24 in *Bombina* and 28 in *Discoglossus* of Discoglossidae; 22,30 in *Pipa*, 24 in *Hymenochirus* and 36 in *Xenopus* of Pipidae, 22 in *Rhinophrynus* of Rhinophrynidae; 26 in *Leptobrachium* and *Megophrys* (Megophryinae), *Pelobates* and *Scaphiopus* (Pelobatinae) and 24 in *Oelodytes* (Pelodytinae) of Pelobatidae; 24 in *Oelodytes* (Pelodytinae) of Pelobatidae; 24 in 7 species of Mybatrachinae, 24 in Helcophryninae; 26,104(8n), 22,44(4n) in 22 species of Ceratophryninae, 26(mode) and 22 (mode) from 18-36, 44(4n) in 54 species of Leptodactylinae and 26 in Elosiinae under Laptodactylidae; 20 in *Dendrobates*

and 24 in *Prostherapis* of Dendrobatidae; 24, 26, 30 in 36 species of *Hyla*, 20 and 24 in other genera of Hylidae; 22 in 44 species of *Bufo* and 4 of others under Bufonidae; 22 to 28 in 12 species of Microhylidae; 24, 26(mode) in 25 species of *Rana* and 2 of others while 14 in *Arthroleptis* under Ranidae; and 24,26 (mode) in 10 species under Rhacophoridae. Morescalchi made a very elaborate cytotaxonomical evaluation basing on number, morphology, size (M and m), banding (see Manna, 1983b)etc. ZW female and XY male heterogamety are found but multiple one not reported. Experimental hybridization and lampbrush chromosome analysis are of some special features in amphibian cytology.

Reptilia : In about 6000 taxonomic species, cytotaxonomical evaluations have been made in few species (Matthey, 1949; Makino, 1956; Gorman, 1973; Rao and Ghosh, 1983). Basing of temporal structure of skull reptiles are put under superorders - Anapsida, Diapsida and Synapsida (extinct). Anapsida - In only living Order Chelonia the diploid numbers recorded are 52 in 3 species of Chelydridae; 56 in 6 of Kinosternidae; 54 in *Platysternon* of Platysternidae; 50(mode) and 52 in 15 species of Emydidae; 52 in *Gopherus* of Testudinidae; 58 in *Caretta* and 56 in *Chelonia* of Cheloniidae; 66 (mode), 64,52 in *Trionyx* and 1 of *Lissemys* of Trionychidae; 28 (mode), 26 and 34 in 7 species of Pelomedusidae and 58 in *Batrachemys* and 68 *Platemys* of Chelidae indicating 2n range from 26 to 68 with a mode at 52 chromosomes in *Chelonia* (Gorman, 1973). Diapsida - Among two living orders, Rhynchocephalia, the sole endemic Australian tuatara, *Sphenodon punctatus* has 2n=36 including 4 pairs m-like with no indication of sex chromosomes, and Squamata comprising very large number of species. Basing on karyotypes earlier Matthey put Lacertalia as (a) 'Complexe Gekonoide', showing no sharp distinction of M and m, (b) 'Complexe Iguanoide' with sharp distinction between M and m and (c) 'Complexe Scincolacertoide' Under Squamata the 2n numbers range from 32 to 63 with a clear mode at 38 in 25 species under 3 subfamilies of Gekkonidae, 38 in *Delma fraseri* in Pygopodidae, 42 in *Xantusia* of Xantusiidae; 27 to 36 in 11 alpha *Anolis* species, 28 to 40 in 7 beta *Anolis*, 30,36 in 3 anoline genera, 22 to 46 in more than 40 species of sceloporine and 26 to 40 with peak at 60 in 19 species of miscellaneous genera under Iguanidae; 34 to 54 in 14 species of Agamidae; 20 to 36 in 25 species of Chamaelcontidae; 24 to 32 in 23 species of Scincidae, 36 in *Gerrhosaurus* of Gerrhosauridae; 38 in 32 species of Lacertidae; 46 in 2 species of Microteiid; 34 to 56 in 17 species of Macroteiid besides 3n in 8 species under Teiidae; 30 and 48 in 10 species of Anguidae; 22 in *Anniela pulchra* of annicellidae; 38 in *Heloderma* of Helodermatidae; 40 in 5 species of *Varanus* under Varanidae; 26 to 50 with mode at 36 chromosomes in 19 species of Amphisbaenidae indicating the chromosome data of about 300 species of squama 2n range from 20 to 56, detailed karyomorphology shows taxonomical correlation, male heterogamety in 3 families, and that of female in one family, 3n parthenogenetic forms and M and m chromosomes are important in phylogenetic consideration. Order *Ophidia* : Over 100 species under 6 families show 2n range from 24 to 50 chromosomes but 70% possess 36 of which 16M+20m is found in large number of species in Boidae

and Viperidae. Several female heterogamety for ZW and some ZW1W2 discovered by Dr Lalji Singh from India (Rao & Ghosh, 1983). Order *Crocodylia* : All the 21 taxonomic species show cytologically $2n$ range from 30-40 with a mode at 32 chromosomes. All the species possess uniformly 18 m chromosomes while M chromosome numbers vary.

Aves : Out of about 8600 taxonomic species, not even 200 species are cytologically known (Makino, 1956; Ray-Chaudhuri, 1973; Kaul and Ansari, 1983) though some Indian workers in recent years extended the data. The diploid number are relatively high among other groups of vertebrates which range from 50 to 96+ but with a clear mode from 78 to 84 chromosomes. The presence of 6 to 8 pairs of M and more variable number of microchromosomes (m), female heterogamety for ZW is common, ZO is very rare and male heterogamety or multiple sex chromosomes not reported, the banding of chromosomes is applied now. The variable number, size and behaviour of the m-chromosomes put serious limitation in karyosystematics unlike reptiles. Moreover, limited number of species karyotyped in very high number of higher taxa prevents at present similar type of fruitful karyotaxonomic application like amphibia and reptiles.

Mammalia : Among about 4500 taxonomic species some 2,600 species are cytologically known, a large number of which are due to the innovations of colchicine - hypotonic - Giemsa technique supplemented with banding techniques mentioned before. The cytotaxonomy of mammals (Makino, 1956; Manna, 1969; Matthey, 1973; Hsu and Benirschke, 1967 to-date) shows it is limited because of number and restricted distribution. Out of 3 extant monotremes, $2n=63$, XY:XX in *Echidna* and $2n=53$, $XY_1Y_2:XX$ in *Platypus* recall reptilian affinity. In marsupials out of 230 living species the diploid numbers of about 100 species (Sharman, 1973) range from 10 to 24 with one species of $2n=32$, and the highest mode at 14 and a second at 22 chromosomes. Males are XY with few rare cases of X_1X_2Y and XY_1Y_2 . *Eutheria* : Out of some 2500 species, the diploid numbers range from 6 to 82 with frequency peaks highest at 38, and 2 lower ones at 42 and 48 in different taxonomic groupings. Intra-specific chromosomal variations are reported in many species, as rats, mice, man, etc., both for autosomes and sex chromosomes. Male heterogamety is the rule, most prevalent XY, some X_1X_2Y , XY_1Y_2 (Indian Muntjac), XO, etc., and the mechanism of evolution and variation of sex chromosomes had been discussed (White, 1973; Vorontsov, 1973). Matthey advocated fusion-fission mechanism play the vital role according to his 'Nombre Fundamental' hypothesis but all other structural rearrangement play none the less role. Some more extensively studied eutherian families are Phyllostomatidae and Vespertilionidae of Chiroptera, Bovidae of Artiodactyla, Cercopithecidae of Primates, Sciuridae, Cricetidae and Muridae of Rodentia.

Conclusion

The author wants to be excused for not being able to cite large number of

pertinent references and squeezing vast data due firstly to reason of space, and secondly it is a Herculean task, if not impossible to review cytotaxonomical data from protozoan to man and so on. It is ventured to expose the magnitude and as 'Jack of all trades, master of none' Anyhow more informations and references can be had from some reviews consulted and cited here. After all taxonomy would be more meaningful for environmental management when pertinent biological informations from different disciplines are incorporated.

The cytogenetic adaptations to environment are well documented in *Drosophila*, other insects, vertebrates and cytogenetical races, sibling species, etc., are known. The mechanism of chromosomal evolution is partly different in animals with localized chromosomes and holocentric chromosomes so far as the structural changes are concerned while it is not with parthenogenesis and polyploidy. Polyploidy is rare in animals than plants because of the bisexuality but it played important role in many cases. There is no fundamental difference in cytotaxonomical changes between invertebrates and vertebrates and the basic principles are the same but environments make the difference.

References

- Butot, L.J.M. 1967. Phylogenetic position of Heterurethra (Gastropoda : Euthyneura) in the light of cytotaxonomy. *Genen en Phaenen*, 11: 53-55.
- Chiarelli, A.B. & Capanna, E. 1973. Checklist of fish chromosomes. Editors review. In : *Cytotaxonomy and vertebrate evolution*. 205-232, Academic Press, London, New York.
- Christensen, B. 1961. Studies on cytotaxonomy and reproduction in the Enchytracidae, with notes on parthenogenesis and Polyploidy in animal kingdom. *Hereditas*, 47: 387-450.
- Colombera, D. 1973. The chromosomes of lower chordates. In : *Cytotaxonomy and vertebrate evolution*. 167-177. (Eds.) A.B. Chiarelli and E. Capanna Academic Press, London, New York.
- Denton, T.E. 1973. *Fish chromosome methodology*. Charles C. Thomas Publ., Springfield, Illinois.
- Fisher, R.A. 1930. *The genetical theory of natural selection*. Clarendon Press, Oxford.
- Gorman, G.C. 1973. The chromosomes of Reptilia, a cytotaxonomic interpretation. In : *Cytotaxonomy and vertebrate evolution*. 349-424. (Eds.) A.B. Chiarelli & E. Capanna. Academic Press, London, New York.
- Hsu, T.C. & Benirschke, K. 1967 & updated volumes. *An atlas of mammalian chromosomes*. Springer-Verlag Berlin, Heidelberg, New York.
- Kaul, Dipika & Ansari, H.A. 1983. Researches in avian cytogenetics. In : *Genetical research in India*. 286-306. XV Int. Genet. Cong. New Delhi, ICAR publication, New Delhi.
- Kirpichnikov, V.S. 1981. *Genetic bases of fish selection*. Springer-Verlag Berlin, Heidelberg, New York.
- Makino, S. 1956. *A review of the chromosome numbers in animals*. Ilokuryukan, Tokyo.
- Manna, G.K. 1951. A study of chromosomes during meiosis in forty-three species of Heteroptera. *Proc.zool.Soc.Bengal*, 4 : 1-116.
- Manna, G.K. 1958. Cytology and interrelationships between various groups of Heteroptera. *Proc. Xth Int. Congr. Genet.*, Canada (1956), 2: 919-934.
- Manna, G.K. 1962. A further evaluation of the cytology and interrelationships between various groups of Heteroptera. *Nucleus*, 5 : 7-28.

- Manna, G.K. 1969. Some aspects of chromosome cytology. Presidential Address. Sec. Zoology, *Proc. 56th Ind. Sci. Cong.* Bombay, Pt. 2 : 185-214.
- Manna, G.K. 1980. A check-list of chromosome numbers in aphids with comments. In : *The Aphids*. 160-193. (Ed.) B.K.Behura, Utkal Univ., Bhubaneswar.
- Manna, G.K. 1981. Chromosome dynamics in Grylloidea. *Nucleus*, 22: 163-174.
- Manna, G.K. 1982. Evolution of sex chromosome number and behaviour in Heteroptera. *J. Adv. Zool.*, 3 : 20-23.
- Manna, G.K. 1983a. Chromosomes in evolution in Heteroptera. In : *Chromosomes in evolution in eukaryotes*. 192-225. (Eds.) A.K.Sharma and A. Sharma. CRC Press, Boca Raton, Florida.
- Manna, G.K. 1983b. Cytogenetic studies on fishes and amphibia. In : *Genetical research in India*, 244-273. Proc. XVth Int. Genet. Cong., ICAR Publ. New Delhi.
- Manna, G.K. 1984. The progress in fish cytogenetics. *Nucleus*, 27: 203-231.
- Manna, G.K. 1985. Centromeric enigma in Heteroptera. In : *Recent advances in Zoology*, 77-88. (Eds.) C.B.L.Srivastava and S.C.Goel, Rastogi Publ., Allahabad.
- Manna, G.K. 1989. Fish cytogenetics related to taxonomy, evolution and aquatic genotoxicity. In : *Fish genetics in India*. 21-46 (Eds.) P. Das and A.G. Jhingran. To-day and To-morrow publ., New Delhi.
- Manna, G.K. & Smith, G.C. 1959. Chromosomal polymorphism and interrelationships among bark weevils of the genus *Pissodes* Germar. *Nucleus*, 2: 179-208.
- Matthey, R. 1949. *Les Chromosomes des Vertebres*. Rouge, Lausanne.
- Matthey, R. 1983. The chromosome formulae of eutherian mammals. In : *Cytotaxonomy and vertebrate evolution*. 531-616. (Eds.) A.B.Chiarelli and E. Capanna. Academic Press, London, New York.
- Mayr, E. 1963. *Animal species and evolution*. Belknap press, Harvard.
- Mayr, E. 1978. Modes of animal speciation. *Systematic Zoology*, 27: 478-482.
- Morescalchi, A. 1973. *Amphibia*. In : *Cytotaxonomy and vertebrate evolution*, 233-348. (Eds.) A.B. Chiarelli and E. Capanna. Academic Press, London, New York.
- Morescalchi, A. 1975. Chromosome evolution in caudate amphibia. *Evol. Biol.*, 8 : 338-387.
- Morescalchi, A. 1979. New developments in vertebrate cytotaxonomy. I. Cytotaxonomy of the amphibians. *Genetica*, 50: 179-193.
- Ojima, Y. 1985. Chromosome data retrieval system. Kansui Gakuin Univ., Japan.
- Patterson, J.T. & Stone, W.S. 1952. *Evolution in the genus Drosophila*. Macmillan, New York.
- Potter, I. C. & Robinson, E.S. 1973. The chromosomes of the cyclostomes. In : *Cytotaxonomy and vertebrate evolution*. 179-208. (Eds.) A.B.Chiarelli and E. Capanna. Academic Press. London, New York.
- Rao, S.R.V. & Ghosh, S.N. 1983. Chromosome of Indian reptiles. In : *Genetical research in India*. 274-285. Proc. XVth Int. Genet. Cong., ICAR Pub. New Delhi.
- Ray-chowdhury, Ratna 1973. Cytotaxonomy and chromosome evolution in birds. In : *Cytotaxonomy and vertebrate evolution*. 423-483. (Eds.) A.B. Chiarelli and E. Capanna. Academic Press, London, New York.
- Sharman, G.B. 1973. The chromosomes of non-eutherian mammals. In : *Cytotaxonomy and vertebrate evolution*. 485-530. (Eds.) A.B. Chiarelli and E. Capanna. Academic Press, London, New York.
- Smith, S.G. 1960. Chromosome numbers of Coleoptera. II. *Canad. J. Genet. Cytol.*, 2 : 66-88.
- Smith, S.G. 1966. Natural hybridization in the Coccinellid genus *Chilocorus*. *Chromosoma*, 18 : 380-406.
- Smith, S.G. & Virkki, N. (1978). *Animal cytogenetics : Coleoptera*. (Ed.) B.John. Borntraeger, Berlin.
- Stone, W.S. 1962. The dominance of natural selection and the reality of super-species (species groups) in the evolution of *Drosophila*. *Cold Spring Harbor Symp. Quant. Biol.*, 20: 256-269.

- Triantaphyllou, A.C. 1983. Chromosomes in evolution of nematodes. *In : Chromosomes in evolution of eukaryotic groups.* 77-101. (Eds.) A.K.Sharma and A. Sharma. CRC Press, Boca Raton, Florida.
- Ueshima, N. 1979. Hemiptera and Heteroptera. *In : Animal Cytogenetics.* Vol.3, Insecta 6. (Ed.) B. John, Gebruder Borntraeger, Berlin.
- Virkki, N. 1983. Chromosomes in evolution in Heteroptera, *In : Chromosomes in evolution of eukaryotic groups.* 41-76. (Eds.) A.K. Sharma and A. Sharma CRC Press, Boca Raton, Florida.
- Vorontsov, N.N. 1973. The evolution of sex chromosomes. *In : Cytotaxonomy and vertebrate evolution.* 619-657. (Eds.) A.B. Chiarelli and E. Capanna. Academic Press, London, New York.
- White, M.J.D. 1973. *Animal cytology and evolution.* 3rd Edition, University Press, Cambridge.

Malaria Control : Cytotaxonomy in the Management of Vector Populations in India

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Taxonomy plays an important role in all basic and applied biological sciences. The classical taxonomy deals with morphological characters of organisms and the identification goes up to species level. Among Diptera in many genera within a species (in the classical taxonomic sense) populations do not interbreed, suggesting the existence of biological species. This phenomenon is commonly encountered in the Genus *Anopheles* and has been studied rather extensively in a few taxa which are vectors of malaria. These populations which are morphologically alike but reproductively isolated are known as sibling species. Sibling species are, therefore, by definition morphologically indistinguishable, and if there are morphological differences, these are only minor and only statistically significant. However, sibling species can be distinguished on biological criteria, such as larval habitats, feeding and other behavioural traits; genetic crossing experiments; differences in the banding pattern in polytene chromosomes, structural variations in mitotic and meiotic chromosomes and also electrophoretic variations in enzyme systems. There are other methods of distinguishing sibling species viz., variation heterochromation in mitotic and meiotic chromosomes visualized by various banding techniques, cuticular hydrocarbon profiles, RNA and DNA probes etc. But these methods can be developed once the sibling species have been identified, application of these methods in detecting the species complexes is rather difficult. Thus, studies on species complexes have become prerogative of geneticists, cytologists and biochemists.

Sibling species are, therefore, reproductively isolated evolutionary units with distinct gene pools hence biological characteristics which determine their potential in the transmission of disease. A detailed knowledge of the biology of sympatric or allopatric sibling species is essential in understanding the transmission dynamics of malaria and to use this information in organising malaria control operations on a more scientific basis at reduced operational cost. There are about 14 *Anopheles* taxa so far identified as species complexes, and are important vectors of malaria in different parts of the world.

The two most extensively studied species complexes within the genus *Anopheles* are *A. maculipennis* in Europe and *A. gambiae* in Africa. In the *A. maculipennis* complex, seven sibling species were identified from the differences in the morphological patterns on their eggs. Four of the sibling species were found to be malaria vectors with varying levels of efficiency, while the other three were nonvectors (Bruce-Chwatt and Zueleta, 1980). Hybrid sterility observed in crosses between populations led to the recognition of sibling species in *A. gambiae* (White, 1974). Six species have now been identified in this complex. *A. gambiae* (species A), *A. arabiensis* (species B), *A. quadriannulatus* (species C), *A. bwambae* (species D), *A. melas* and *A. merus*. They differ in their breeding and resting habitats, and in their vectorial capacities - the zoophilic *A. quadriannulatus* is not considered to be a malaria vector (White, 1974).

The Anopheles fauna of India : There are about 54 *Anopheles* species in India. In any given habitat about 15-20 species may be encountered, some species are more abundant than others and there is a great seasonal variation in their abundance. About 9 anophelines are implicated in the transmission of malaria in India. These are *Anopheles culicifacies*, *A. stephensi*, *A. minimus*, *A. fluviatilis*, *A. sundaicus*, *A. balabacensis* (= *dirus*), *A. annularis*, *A. philippinensis* (= *nivipes*), and *A. jeporiensis*. Recently *A. subpictus* was also incriminated in Pondicherry (Panicker *et al.*, 1981) and Baster, M. P. (Kulkarni, 1983).

Sibling species complexes : In India among the vector species *A. culicifacies* (Green and Miles, 1980, Subbarao *et al.*, 1983 and 1988a) and *A. subpictus* (Suguna, 1982) have been identified as species complexes and work is in progress in regard to *A. fluviatilis* and *A. annularis*. *A. minimus* has been identified as a complex of three species (Sucharit *et al.*, 1988) and *A. dirus* a complex of 4 species (Wibow *et al.*, 1984 and Baimai *et al.*, 1988) in Thailand. Indian populations of *A. dirus* and *A. minimus* have not been examined so far. In *Anopheles stephensi* 2 varieties viz. type form and *mysorensis* were reported. This classification was based on the number of ridges on the eggs (Sweet and Rao, 1937 and Rao *et al.*, 1938). Recent survey have indicated another variant, intermediate form (Subbarao *et al.*, 1987a). All three forms were found in semi urban areas while only *intermediate* and *mysorensis* were found in rural areas. Crosses between rural and urban populations revealed no post copulatory barriers and cytological examination of these population revealed no precopulatory isolating mechanism. Thus, there is no evidence for considering these populations to be biological species, and the three egg ridge number variants are referred to as ecological variants.

Work on the *A. culicifacies* complex has progressed quite rapidly and has enhanced our knowledge both on basic and applied aspects. The taxon comprises of 4 sibling species designated as A, B, C and D (Subbarao *et al.*, 1988a). This identification is based on fixed paracentric inversions of polytene chromosomes. Structural variations in Y-chromosomes at metaphase stages have also been observed but species A and C cannot be differentiated and species D karyotype is

not known (Vasanthan *et al.*, 1982, 1983). Cuticular hydrocarbon profiles have also been used to identify with about 78% accuracy (Milligan *et al.*, 1986). Species specific inversion genotypes have been used to study the distribution and the composition of the sibling species in the country. Results so far have shown that sibling species B is found almost throughout the country wherever *A. culicifacies* is encountered and the distribution of other species varies from one region to another (Subbarao *et al.*, 1988a). Species A is found from north to south with high proportions in north which gradually decline towards south. Sibling species C is found from west to east and species D is found west and in central India in some pockets. In central India all four species are sympatric. The distribution of sibling species known to date is given in fig. 1. Further studies are in progress.

Studies on the responses of sibling species to commonly used insecticides in public health has shown that species A is more susceptible to DDT than B (Subbarao *et al.*, 1988b). In areas where A and B are sympatric spraying of DDT would, therefore, selectively eliminate species A leaving species B to multiply. Vector incrimination studies have shown that species B has almost negligible role in the malaria transmission (Subbarao *et al.*, 1988c). Therefore, although there may be high densities of *A. culicifacies* after DDT spraying due to resistance in species B, there would be epidemiological impact on the transmission as a result of reduction in vector populations i.e., species A. Such a phenomenon has been reported by the NMEP but for the first time it was conclusively demonstrated by field studies in Ghaziabad (Subbarao *et al.*, 1988b Sharma 1986). Response of sibling species A and B to dieldrin (used in the bio-assay tests to monitor susceptibility levels to BHC) was about equal. Based on these studies it was possible to recommend the continuation of DDT spraying even though there was resistance to DDT in *A. culicifacies sensu lato* in the areas where species A and B are sympatric. In case of change from DDT is required, use of BHC is discouraged and malathion is recommended as both A and B are fully susceptible. Further, in areas where malathion is being sprayed it was observed that species A develops resistance after 7-8 years of spraying and at a much slower rate than in species B (Raghavendra, unpublished). In areas where species B and C are sympatric, malathion spraying for longer periods is not recommended as species C develops resistance much faster than species B (Raghavendra, unpublished) and in case of change over the use of malathion instead of DDT was advisable. Results revealed that species C is a vector but not as efficient as A and species D is equally efficient as A (Subbarao *et al.*, unpublished). Malaria transmission is there almost throughout India where *A. culicifacies* is found as two or more sibling species are present everywhere except in northeastern parts where species B alone was found (Subbarao *et al.*, 1988a and b). However, the intensity of transmission varies depending on the predominance of the sibling species. Long term ecological studies revealed that species A prefers dry climate and species B builds up during the rainy season and increases in postmonsoon months (Subbarao *et al.* 1987b). Since populations of

species B build up during the rainy season and species A are encountered almost throughout the year, the transmission of malaria in north India is regulated by climatological factors.

Application in malaria control : Based on several years of basic and applied research on *A. culicifacies* the following information relevant to the management of vector populations have emerged which has been transferred to the National Malaria Eradication Programme.

1. Under DDT spray, species A remains susceptible for a longer period whereas species B develops resistance much earlier. Further, in areas where DDT was replaced by HCH and is being sprayed for the past several years susceptibility in species A is much higher than in species B i.e., reversal to DDT susceptibility. Hence, DDT sprayed in areas showing DDT and HGC resistance would bring about epidemiological impact of spraying. It would, therefore, be advisable to monitor resistance status in sibling species and not in *A. culicifacies s.l.*
2. Sibling species A and B develop resistance to HCH at the same rate. Spray of HCH should therefore be discouraged. If resistance to DDT develops, the preferred insecticide should be malathion or any other replacement insecticide.
3. Species A remains susceptible to malathion even after about a decade of constant spraying of malathion. Species D behaves like species A. It would, therefore, be advisable to control epidemics and malaria outbreaks with malathion and revert back to DDT. Alternatively the most rational approach would be control malaria during epidemics with malathion and apply bioenvironmental methods during the inter epidemic periods. This would result in great savings to the programme.
4. In areas with species B and C, species C which is the vector species develops resistance to DDT, HCH and malathion faster than species B. Resistance to malathion had developed at a very fast rate in Gujarat and Maharashtra. In such areas it would be advisable to apply DDT and use any other insecticide like fenitrothion or a synthetic pyrethroid to suppress transmission and intensify bioenvironmental methods particularly during inter epidemic or low transmission periods.
5. In many areas *A. fluviatilis* plays a major role in the transmission along with *A. culicifacies*. *A. fluviatilis* is fully susceptible to DDT and other insecticides and therefore DDT should be used.

It may be noted that the above observations do not apply to any such areas where the sibling species complex has not been studied or other vectors are transmitting malaria.

Based on the above research experience spraying strategy as given in Table 1 may be adopted to control malaria on scientific lines.

6. Malariogenic stratification of areas based on the distribution of sibling species: in areas where B is present malaria control could be managed by chemotherapy alone; in areas with low transmission potential due to low proportion of species A, bioenvironmental methods could be used and in areas with high proportion of species A, integrated vector control methods would be applied most suitably.
7. Studies on sibling species have helped to understand the transmission dynamics of malaria in different malaria endemic areas of the country.
8. Ecological information relating to in larval breeding habitats and chemical composition of water etc., are being generated to study reasons for the natural distribution of various sibling species in certain parts of the country. This information may be useful in developing innovative control strategies.

References

- Baimai, V., Poopittayasataporn, A. & Kuchalo, U. 1988. Cytological differences and chromosomal rearrangements in four members of the *Anopheles dirus* complex (Diptera : Culicidae). *Genome* 30 : 372-374.
- Bruce-Chwatt, L. J. & Julian de Zueleta, 1980. *The rise and fall of malaria in Europe*. Oxford University Press, London.
- Green, C. A. & Miles, J. J. 1980. Chromosomal evidence for sibling species of the malaria vector *Anopheles culicifacies* Giles. *J. Trop. Med. Hyg.*, 83: 75-78.
- Kulkarni, S. M., 1983. Detection of sporozoites in *Anopheles subpictus* in Bastar district, Madhya Pradesh. *Indian J. Malariol.*, 20: 159-160.
- Milligan, P. J. M., Phillips, A., Molyneux, D. H., Subbarao Sarala K. & White, G. B. 1986. Differentiation of *Anopheles culicifacies* Giles (Diptera : Culicidae) sibling species by analysis of cuticular components. *Bull. Ent. Res.*, 76: 529-537.
- Panicker, K. N., Geeta Bai, M., Bheema Rao, U. S., Viswarm, K. & Suryanarayanamurthy, K. 1981. *Anopheles subpictus* : vector of malaria in coastal villages of southeast India. *Current Sci.*, 50 : 694-695.
- Rao, B. A., Sweet, W. C. & Subbarao, A. M. 1938. Ova measurements of *A stephensi* type and *A. stephensi* var. *mysorensis*. *J. Malaria Inst. of India*, 11: 261-266.
- Sharma, V. P. 1986. Impact of DDT and HCH spraying on malaria transmission in villages with DDT and HCH resistant *Anopheles culicifacies*. *Indian J. Malariol.*, 23 : 27-38.
- Subbarao, Sarala K., Vasanth, K., Adak, T. & Sharma, V. P. 1983. *Anopheles culicifacies* complex. Evidence for a new sibling species, species C. *Ann. Entomol. Soc. Amer.*, 76: 985-988.
- Subbarao, Sarala K., Vasanth, K., Adak, T., Sharma, V. P. & Curtis, C. F. 1987a. Egg-float ridge number in *Anopheles stephensi* : Ecological variation and genetic analysis. *Med. and Vet. Entomol.*, 1 (3) : 265-271.
- Subbarao, Sarala K., Vasanth, K., Adak, T. & Sharma, V. P. 1987b. Seasonal prevalence of sibling species A and B of the taxon *Anopheles culicifacies* in villages around Delhi. *Indian J. Malariol.*, 24(1) : 9-16.
- Subbarao, Sarala K., Vasanth, K. & Sharma, V. P. 1988a. Cytotaxonomy of malaria vectors in India. In : *Biosystematics of Haematophagous Insects*. 25-37. (Ed.) M. W. W. Service. Oxford University Press.

- Subbarao, Sarala K., K. Vasantha and V. P. Sharma, 1988b. Response of *Anopheles culicifacies* sibling species A and B to DDT and HCH in India : implications in malaria control. *Med. and Vet. Entomol.*, 2(3) : 219-223.
- Subbarao, Sarala K., Adak, T., Vasantha, K., Joshi, H., Raghavendra, K., Cochrane, A. H., Nussenzweig, R. S. & Sharma, V. P. 1988c. Susceptibility of *Anopheles culicifacies* species A and B to *P. vivax* and *P. falciparum* as determined by immunoradiometric assay. *Trans. Roy. Soc. Trop. Med. and Hyg.*, 82 : 394-397.
- Subbarao, Sarala K., Vasantha, K., Raghavendra, K., Sharma, V. P. & Sharma, G. K. 1988d. *Anopheles culicifacies* : sibling species composition and its relationship to malaria incidence. *J. Amer. Mosq. Contr. Assoc.*, 4(1) : 29-33.
- Sucharit S., Komalamisra, N., Leemingsawat, S., Apiwathnasorn, C. & Thongungkiat, S. 1988. Population genetic studies on the *Anopheles minimus* complex in Thailand. *Southeast Asian J. Trop. Med. Pub. Hlth.*, 19(4) : 717-723.
- Suguna, S. G., 1982. Cytological and morphological evidence for sibling species in *Anopheles subpictus* Grassi. *J. Commun. Dis.*, 14 : 1-8.
- Sweet, W. C. & Rao, B. A. 1937. Races of *A. stephensi* Liston, 1901. *Indian Medical Gazette* 72: 665-674.
- Vasantha, K., Subbarao, Sarala K., Adak, T. & Sharma, V. P. 1982. Karyotypic variations in *Anopheles culicifacies* complex. *Ind. J. Malariol.*, 19(1) : 27-32.
- Vasantha, K., Subbarao, Sarala K., Adak, T. & Sharma, V. P. 1983. *Anopheles culicifacies* : Mitotic karyotype of species C. *Indian J. Malariol.*, 20(2) : 161-162.
- White, G. B., 1974. *Anopheles gambiae* complex and disease transmission in Africa. *Trans. Roy. Soc. Trop. Med. Hyg.*, 68: 278-301.
- Wibowo, S., Baimai, V. & Andre, R. G. 1984. Differentiation of four taxa of the *Anopheles balabacensis* complex using H-banding patterns in the sex-chromosomes. *Can. J. Genet. Cytol.*, 26: 425-429.

Chemotaxonomy : A Viewpoint

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In general, taxonomic studies have been mostly confined to identification and labelling of the specimens *i.e.* alpha level taxonomy. The taxonomist finds it difficult to extend his domain beyond this level due to limitations imposed by what are now regarded as classical parameters such as morphological characters and which constitute the very base of such studies. Restrictions such as these could lead to erroneous assumptions regarding taxonomic placements. Therefore, a modern taxonomist must aim at encompassing any branch of study which enables him to reach his goal. The current trend in taxonomy, therefore, is to employ as many supportive parameters as possible which could aid taxonomist in the placement of taxa in their appropriate categories and ultimately in tracing their phylogenetic relationships.

Mayr (1978) has cited a number of taxonomic characters in the book, "Principles of Systematic Zoology" Space limitations, however, prevent a discussion on the significance of the use of such parameters in taxonomic studies. Suffice it to note that biochemical characters in taxonomic studies have been made use of since last 40-50 years and, hence could be considered as one of the comparatively recent taxonomic parameters. There is an enormous specificity of macromolecules at every taxonomic level and this information is being extensively exploited by the workers. In this presentation, therefore, an attempt has been made to focus attention on the importance of some of the biochemical characteristics from the viewpoint of chemotaxonomy.

Species, Genome, Gene and DNA

In taxonomy a species is generally considered as a base taxonomic unit. A species is an interbreeding population of the same kind and having similar characters. The knowledge of genetics is expanding at such a tremendous rate that even in the classical population genetics a species is referred to as an agreement of individuals with a common gene pool (genome). The theory of speciation suggests that mutations randomly occur in populations and natural selection subsequently operates in the expression of such mutations. Divergence is thus created through a different selection process which on isolation leads to a new "species" or a taxon. Thus, in systematics it is necessary to compare the gene

pools or genomes so as to determine the closeness (identity) or remoteness (diversity) of the populations.

Theoretically it would be ideal to have information on the entire genome through an analysis of DNA employing either the finger printing or sequencing techniques. However, to analyse a sizable natural populations for comparison of their DNA would not only be expensive in terms of resources but also time consuming. Therefore, it is pertinent to select the next available alternative, namely the characteristics of proteins, so as to understand the expression of genes.

Proteins and Their Use in Taxonomy

Unstable and Stable Proteins :

Due to the large number of genes in a single individual, the number of proteins synthesised is also equally large. Some of these proteins, like intermediates, are "short-lived" and are metabolised rapidly. Others like certain enzymes are inductive i.e. they are synthesised only in the presence of specific environmental inducers. Both these groups of proteins are unstable and, therefore, are of little significance in taxonomy. However, another group of proteins such as constituent enzymes, haemoglobins, eye lens proteins, cytochrome-C etc., are highly stable i.e., they are relatively uninfluenced by the environment. Such stable proteins can be looked upon as useful parameters which aid in understanding genomic diversity and, therefore, can be considered as significant in taxonomic research. In the field of chemotaxonomy the stable proteins which are commonly analysed are haemoglobins, serum proteins like transferrins and haptoglobins, eye lens proteins, keratins and a host of enzymes (Table 1).

Table 1. Table showing commonly used Proteins in Taxonomy

Sl. No.	Names of proteins	Tissues	Taxonomic Levels
1.	Plasma proteins	Blood & Haemolymph	<i>Annelida to Mammalia</i>
2.	Haemoglobins	R. B. C.s in Blood	Vertebrates
3.	Crystalines	Eye Lens	Vertebrates
4.	Keratins	Hairs	<i>Mammalia</i>
5.	Muscle proteins	Muscles	<i>Annelida to Mammalia</i>
6.	Enzymes	Blood, Plasma, haemolymph & other tissues.	<i>Annelida to Mammalia</i>

Separation of Proteins :

Proteins are ideally studied by employing techniques such as crystallography, peptide finger printing or amino acid sequencing. However, all these techniques

are time consuming and need expert labour and extensive resources. In addition, the level of resolution achieved by these methods may not be of use or of interest to a taxonomist. Comparatively electrophoretic separation of proteins not only gives a high resolution but the technique is much faster and extremely cost effective.

Electrophoreses : Types and Use :

Essentially electrophoretic separation of proteins is based on the ionising property of a protein molecule which is differentially charged in a buffered medium. As a result, when such charged molecules are subjected to an electric field they migrate according to the charges on their surface. Electrophoretic separation is further dependant on the supporting media or in which molecular separations are carried out. The choice of the technique is governed by the degree of resolution to be achieved, quantities of material available and storage properties. All the techniques have been adequately described in standard text books (Wright, 1974 and Whitaker, 1967). Some of the useful electrophoretic methods which are being used in taxonomic studies are briefly discussed below :

Paper electrophoresis (Horizontal and vertical) :

The traditional method of paper electrophoresis was widely used in the earlier days of experimental taxonomy. However, it is seldom employed now because of the incomplete resolution of fractions, greater running time, relatively large quantities of sample requirement and storage problems. In spite of its shortcomings, the technique of paper electrophoresis is often adequate for certain proteins such as haemoglobins at low resolution of simpler band patterns.

Cellulose Acetate electrophoresis :

This is an excellent supporting medium similar in many ways to paper in its handling and storage characteristics. It gives a better resolution in lesser time and requires smaller quantities of sample than the paper electrophoresis. This method is useful for resolution of faster moving molecules like haemoglobins, plasma proteins and some of the enzymes.

The above techniques help in the preliminary scanning of a large sample size for the detection of protein variants.

Starch gel electrophoresis :

The medium was commonly used in the detection of enzyme variants in populations. Its advantages are that it gives a better resolution and handling and staining techniques are easier. In addition, the gels can be sliced horizontally. The sliced gels from a single experiment can be used for multiple detections.

Polyacrylamide gel electrophoresis (PAGE) :

Today, acrylamide gel is perhaps the best medium for obtaining a very high degree of resolution even with the smallest quantity of sample. Further, PAGE

can be adopted for the detection of variants of all proteins, including enzymes. The gels can be easily handled, stained and preserved for a longer time. In addition, the time required for the run is significantly less. PAGE can be coupled with SDS (Sodium Dodocyl Sulphate) to estimate the molecular weights of specific protein to obtain better understanding of the degree of variation.

The selection of specific material and methodology depend on the extent of enquiry and the level of resolution required to answer the questions raised.

Analysis of Band Patterns in Population

Each band resolved on the gel apparently represents one protein and, therefore, expression of at least one allele. Thus, a single band pattern suggests a homozygous condition for that gene controlling the synthesis of the protein in question. On the other hand more than one band suggests the involvement of greater number of gene loci and thereby illustrates polymorphism.

Dobzhansky (1970), while supporting polymorphism at the gene loci, has discussed the opposing view held by geneticists in classical theory and the balanced theory. The classical theory maintains that polymorphism or heterozygosity at any given locus is rare, as such genetic variability might lead to unbearable genetic loads. On the contrary the balanced theory postulates that as a rule most of the gene loci are polymorphic and complete monomorphism of homozygosity is an exception. Works of Lawontin (1974) and Ingale (1986) support the balanced theory.

Comparison between populations

Analysis of proteins not only brings out polymorphism within a population but also a comparison of isolated populations for the expression of specific gene loci (Fig. 1 & 2). For this purpose the pattern of protein bands obtained for a population can be translated into the gene/allele frequencies by a simple gene counting method (Ferguson, 1980). This method assumes that a protein (band) with similar mobility is controlled by an identical allele even in different populations and the variations observed within the populations are controlled by two or more codominant alleles (Nozawa *et al.*, 1982). Further, from the gene frequency data, genetic identities or distance with standard errors can be calculated for every group of populations compared. The data thus obtained can be used for the analysis by the method of Nei (1972 & 1975) to estimate genetic identities (I) and differences (D) and the phylogenetic divergence time. These estimated values can be used to draw dendograms by the un-weighted pair group method (UPGMA) (Sneath and Sokal, 1973) for evaluating the relationship amongst the concerned populations (Fig. 3). By interpreting the dendograms a taxonomist can judge the necessity for inclusion or separation of the taxon under study so as to give a justifiable status. However, Cain (1968), Sarich (1977) and Mayr (1978) have suggested that caution should be exercised while using the data on genetic distances, identities etc., for assessing the taxonomic levels at

Abbreviations used in the figures

Sm : *Suncus murinus*; Fc : *Felis chaus* ; Pp : *Panthera pardus*; Pl : *Pantera leo*; Mm : *Muntiacus muntjak*; Aa : *Axis axis*; Rrr : *Rattus rattus rufescens*; Rn : *Rattus norvegicus*; Bb : *Bandicota bengalensis*; Bi : *Bandicota indica*; Bg : *Bandicota gigantea*; Lt : *Loris tardigradus*; Hs : *Homo sapiens*.

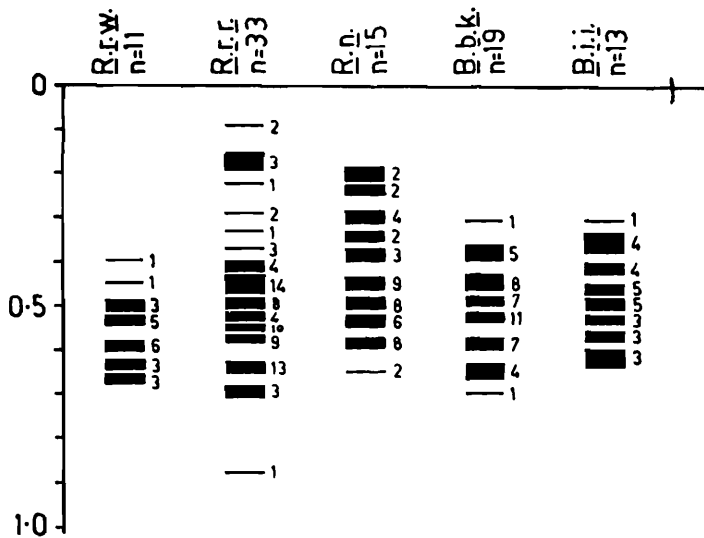


Fig. 1. Diagrammatic representation of the Electrophoretic Patterns of the Hemoglobins in the Five Commensal Rodent Species

1 *R.r.w.*–*Rattus rattus wroughtoni* (Hinton); 2 *R.r.r.*–*Rattus rattus rufescens* (Gray); 3 *R.n.*–*Rattus norvegicus* (Berkenhout); 4 *B.b.k.*–*Bandicota bengalensis kok (lordi)* (Gray); 5 *B.i.i.*–*Bandicota indica indica (malabarica)* (Bech); 6 n.–No. of specimens; 7 Nos. near the bands–No of occurrence of each band in the population

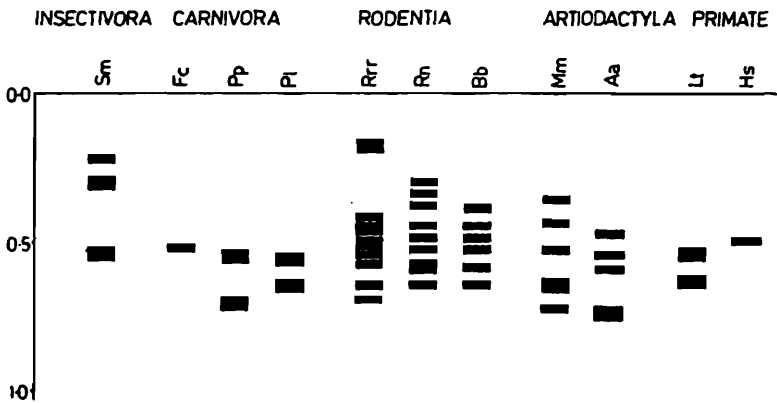


Fig. 2. Diagrammatic representation of the Electrophoretic Patterns of the Haemoglobins in the Selected Species belonging to the five Mammalian Orders

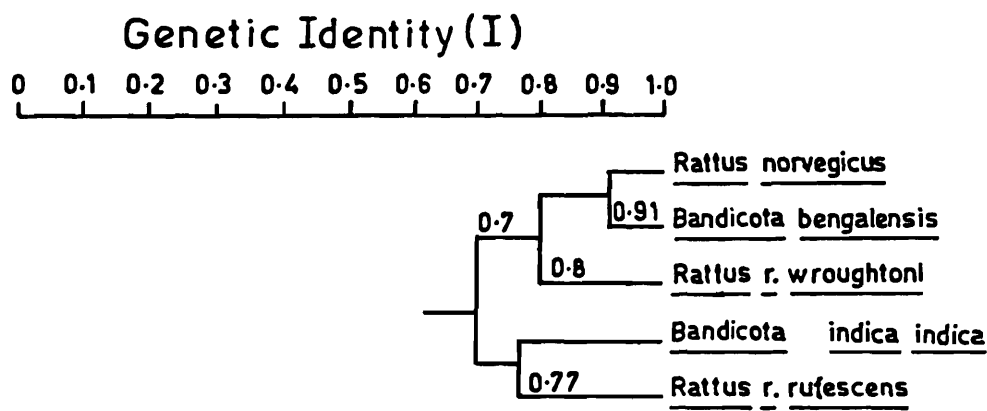
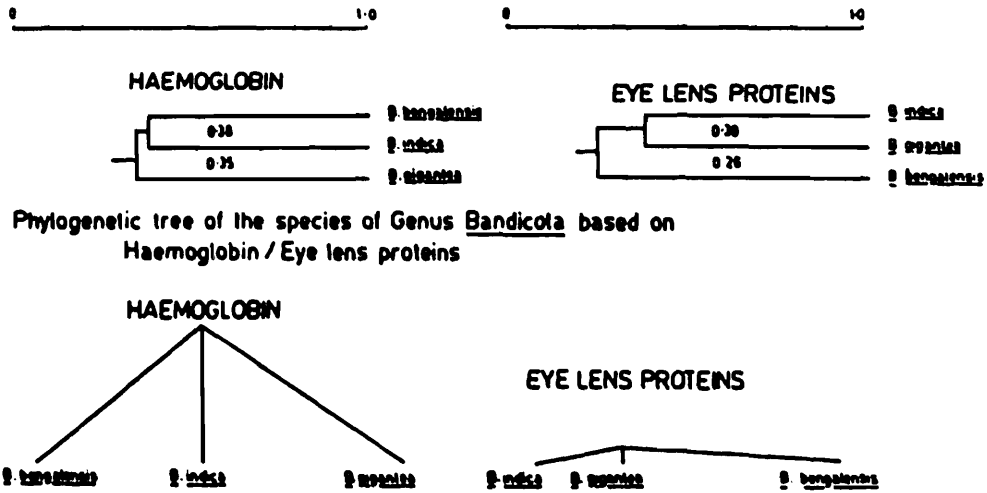


Fig. 3. Dendrogram showing relationships of five commensal rodent species generated according to UPGMA method of cluster analysis (Sneath and Sokal, 1973)

HAEMOGLOBINS				EYE LENS PROTEINS			
	B. bengalensis	B. indica	B. gigantea		B. bengalensis	B. indica	B. gigantea
B. bengalensis	—	0.38	0.28		—	0.06	0.12
B. indica	0.98	—	0.35		2.12	—	0.39
B. gigantea	1.27	1.05	—		2.814	0.95	—

Fig. 4. Estimates of genetic-identity (above diagonal) and genetic distance (below diagonal) among the species of the Genus *Bandicota*



Dendrograms showing the relationship of the species of the Genus *Bandicota* based on the UPGMA method of cluster analysis and also based on the data in the table

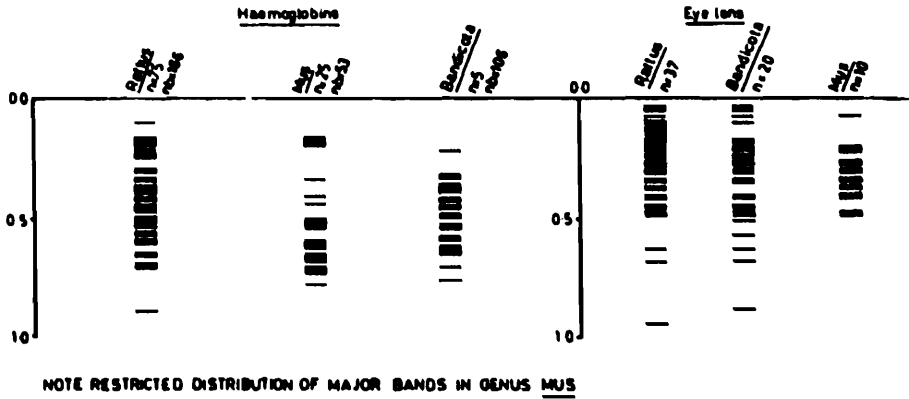


Fig. 5. Diagrammatic representation of the Electrophoretic Patterns of the Species specific proteins in the Rodent Genera

which the populations ought to be separated. Thus, a judgement of a taxonomist regarding taxonomic placement of a population should be based on phenotypic expression with a better understanding on genomic differentiation, rather than on laying stress on phenotypic expressions alone.

Selected Cases

A survey of literature brings out several examples where the analysis of protein has been successfully used to resolve taxonomic controversies. A brief mention of some of these cases would be within the scope of discussion in the present paper.

Fishes : Genus : Coregonus (Ferguson, 1980) :

Coregonine fishes (*C. pollan*, *C. lavaretus* and *C. albula*) found in the lakes of Britain and Ireland were divided into three species by the earlier biologists. Later, the Irish species, *C. pollan*, was considered conspecific with one of the two British species (*C. lavaretus* or *C. albula*). This was due to intermediate morphology of Irish fish when compared with the British ones. Electrophoretic studies carried out by Ferguson (1974) and Ferguson *et al.* (1978) showed that *C. pollan* was distinctly conspecific with the Alaskan - Siberian species (*C. autumnalis*) rather than with any of the British species.

Birds : Species : Psittacula intermedia (Sane *et al.*, 1986) :

Three Indian parakeets (*P. krameri*, *P. cyanocephala* and *P. himalayana*) were suspected to be the parent forms of a hybrid, *P. intermedia* (Hussain, 1959). On the other hand, other authors notably Biswas (1959) and Walters (1985) suggested that the available evidence, though inconclusive, pointed to it being a discrete taxon. Sane *et al.* (1986) conclusively supported the opinion of Biswas (1959) on the basis of biochemical differences.

Rodents : Genus : Peromyscus (Avisé *et al.*, 1974) :

Avisé *et al.* (1974) pointed out that two subspecies of *Peromyscus boylii* from Mexico and South-Western United States share common alleles virtually at all loci and, thus, should be treated as the same population. On the other hand, *P. (boylii) attwateri* differs from *P. boylii* in allelic composition at several loci and also in morphological and chromosomal characters. Hence, *P. (b.) attwateri* should be treated as a separate species.

Rodents : Genus : Bandicota (Pradhan *et al.*, 1989) :

Pradhan *et al.* (1989) have proposed an additional species in the Genus *Bandicota* on the basis of morphological, osteological and biochemical studies. The dendrogram drawn on the basis of UPGMA analysis of the gene frequency data on haemoglobins and eye lens protein showed distinct differences between the *Bandicota* populations (Fig. 4).

Thus, it can be seen from the above examples that while constructing a phylogeny a taxonomist should attempt to study genomic differentiation and isolation in closely related populations.

Protein Band Patterns as Key Character

On the basis of protein analysis the chemical characteristics of a population can be considered as a key character in taxonomic evaluation if the pattern of expression as resolved by electrophoretic separations for a population can be established for a taxonomic category (Fig. 5). No doubt, such compilation will be an onerous task. However, considering the science of chemotaxonomy being just a few decades old, one may visualise a time when characteristic profiles for species specific proteins will be available for most of the taxa. The situation is parallel for the utilization of chromosomal characteristics in taxonomy. Marshall (1972) has used chromosome number and morphology as one of the characters in differentiating species of *Mus*

Conclusion

The job of the present taxonomist involves identification and labelling of a specimen on the basis of well established keys. A problem arises when a phenotypic variant is brought in for identification. The immediate response of a taxonomist is usually to split off and create a new taxon. Many a times a phenotypic variation develops through an environmental interaction rather than an alteration in the genome (ecotypes in plant species and thermal variants in *Daphnia* spp.). Even sexual diamorphism can occasionally misled a taxonomist. Thus, a study of additional parameters such as chemical, chromosomal etc., are of immense value to a taxonomist in arriving at a justifiable conclusion.

Studies in chemical taxonomy increase the resolving power for the differences at the genomic levels of populations. This information can be effectively used to raise the level of understanding of the dynamics of the evolutionary process whereby the diversities of the past and future can be located. The taxonomist of tomorrow may gain an insight from such diversities to fill up the lacunae which is not possible today.

Finally to conclude in the words of A. J. Cain (1968), "All that the really competent taxonomist needs is to know everything about his subject and about the group he works on. Since this is hardly possible he must go to others for help. The new taxonomy is peculiarly a field in which team work is necessary" Hence, an interaction of the taxonomists with biochemists, geneticists and any one else with a special knowledge will be most rewarding.

References

- Avise, J. C.; Smith, M. H. & Selander, R. K. 1974. Biochemical polymorphism and systematics in the genus *Peromyscus* VI. The *Boylei* species group. *J. Mammal.*, 55(4) : 751-763.

- Biswas, B. 1959. On the Parakeet *Psittacula intermedia* (Rothschild) (Aves : Psittacidae). *J. Bombay nat. Hist. Soc.*, 56: 558-562.
- Cain, A. J. 1968. The assessment of New types of Character in Taxonomy. In : *Chemotaxonomy and Serotaxonomy*. 229-234. (Ed.) J. G. Hawkes, (Academic Press), London
- Dobzhansky, Th. 1970. *Genetics of Evolutionary Process*. Columbia Univ. Press.
- Ferguson, A. 1974. The genetic Relationships of the Coregonid Fishes of Britain and Ireland indicated by Electrophoretic Analysis of Tissue Proteins. *J. Fish. Biol.*, 6: 311-315.
- Ferguson, A. 1980. *Biochemical systematics and evolution*. : Blackie, London
- Ferguson, A; Himberg, K. J. M. & Svardson, G. 1978. Systematics of the Irish Pollan (*Coregonus pollan* Thompson) : An Electrophoretic comparison with other Holarctic Coregoninae. *J. Fish Biol.*, 12: 221-233.
- Husain, K. Z. 1959. Is *Psittacula intermedia* (Rothschild) a valid species? *Bull. Br. Orn. Club*, 79: 89-92.
- Ingale, S. T. 1986. Biochemical Taxonomy of Vertebrate : Contribution to the taxonomy of the commensal rodent : Genus *Bandicota*., Ph.D. Thesis accepted by Bombay University.
- Lawontin, R. C. 1974. *The Genetic Basis of Evolutionary Change*. Columbia Press, New York
- Marshall, J. T. Jr. 1977a. A synopsis of Asian species of *Mus* (Rodentia, Muridae). *Bull. Amer. Mus. Nat. Hist.*, 158: 173-220.
- Mayr, E. 1978. *Principles of Systematic Zoology*, (Ed.) TMH, New Delhi.
- Nei, M. 1972. Genetic distance between populations. *Amer. Nat.*, 106: 283-291.
- Nei, M. 1975. *Molecular Population Genetics and Evolution*. Amsterdam.
- Pradhan, M. S., Mondal A & Agarwal, V. C. 1989. Proposal of an additional species in the Genus *Bandicota* Gray (Order : Rodentia; Family : Muridae) from India. *Mammalia*, 53(3) : 369-376.
- Sane, S. R., Kannan, P., Rajendran, C. G., Ingale, S. T. & Bhagwat, A. M. 1986. On the taxonomic status of *Psittacula intermedia* (Rothschild). *J. Bombay nat. Hist. Soc.*, 83(Suppl.) : 127-134.
- Sarich, V. M. 1977. Rates, sample sizes and the neutrality hypothesis or electrophoresis in evolutionary studies, *Nature*, 265: 24-28.
- Sneath, P. H. A. & Sokal, R. P. 1973. *Numerical Taxonomy*. W. H. Freeman & Co., San Francisco.
- Walters, M. 1985. On the status of *Psittacula intermedia* (Rothschild). *J. Bombay nat. Hist. Soc.*, 82(1) : 197-199.
- Whitaker, J. R. 1967. *Paper Chromatography and Electrophoresis*, Vol. 1 : *Electrophoresis in stabilizing media*. Academic Press, London.
- Wright, C. A. 1974. *Biochemical and Immunological Taxonomy of Animals* (1st Ed.) : Academic Press, London.

Strategies for Faunistic Explorations

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Parker and Haswell in 1898 in the preface of their famous text-book wrote, *There can be little doubt that the study of Zoology is most profitably as well as most pleasantly begun in the field and by the sea-shore, in the Zoological Garden and the Aquarium.* This has stood the test of time. Some practical aspects of zoological field work are given in this article. Suitable modifications can be made according to the area/animal group/circumstances.

Taxonomic studies need two pre-requisites : specimens and the literature on the subject. For the first, while unidentified examples are collected from the field, identified collections are available in the musea and repositories. Faunistic explorations are made for observations as well as collecting of specimens. A lot is learned by observing populations in the field. There are two kinds of surveys : general faunistic surveys, dealing with as many groups of animals as possible; and specific surveys on one or two selected group(s).

The actual period of faunistic survey may be either a day, a week or a month or more, but multifarious kind of preparations are to be made before the survey, and a lot of sorting, labelling, analysis and documentation are to be done after the survey. Thus, each field survey has three phases associated with it.

Pre-Survey Preparations

During this period one has to finalize a number of items, viz.:

1. The area to be surveyed (collect maps, local information and select halting places, called 'camps').
2. Itinerary (date-wise, place-wise and according to the object of survey).
3. Booking of journeys and camp sites (make rail/air bookings in advance for all journeys; write to and book Dak Bungalow/Rest House/Hotel, etc., for the proposed period of halt). Carry the reservation papers/permits in original.
4. Instruments and field collection kit : One shall not assume that this or that item will be available and purchased in the field. Carry all essential items in the ready-to-use state) (Annexure I). One must also learn how to handle

a particular instrument before proceeding on the survey trip. Carry enough refills/spares of consumable and fragile articles.

5. Decide modes of journey during the survey. Experience will show that it is useful to have a vehicle at your disposal. However, when going with a vehicle, keep enough supply of fuel and spares and be ready for unexpected exigencies, particularly in remote areas.
6. Find out the best habitat of concerned animal group(s). Locate these in the map, if possible. Note water-bodies, forests, crops in the area and their season, climate during the survey period, etc. (Annexure II).
7. Make efforts to get some contact persons in the concerned area (naturalists, teachers of zoology, nature clubs, etc.). Note their full addresses and telephone nos. Valuable informations on populations and habitats in the area can be had from such contacts.
8. Personal belongings : Always carry an Identity-Card. Carry suitable garments and bedding (according to season), rain coat, mosquito net, torch and batteries, locks, field shoes (gumboots in rainy reason), water bottle and a small tiffin box. Towels, candles, cotton, dettol, band-aid, carbolic soap, sewing needle with thread, personal medicines, etc. must also be carried. This list can be improved upon according to need.
9. Funding : Make adequate provision of money for the survey work. Keep extra amount for unforeseen expenditure. Carry part of the funds in Traveller's Cheques, if possible.

Survey Work

Before conducting survey and collecting work, it is in the fitness of things to inform the local police station about the party's object. This must be done if fire-arms are being carried by the party. Permit for collecting reptiles, birds and mammals, must be obtained beforehand from the Chief Wildlife Warden of the concerned State.

Timing of the Field Work : The survey should be undertaken in the season when the populations of the desired animal groups are expected to be maximum. After reaching the halting place or 'camp', select out suitable localities (called 'stations'). Then select the appropriate hours of work. These may vary from group to group. Generally early morning (dawn) to late morning, and from late afternoon to evening (dusk) hours are better. But obviously the nocturnal animals like moths, owls, carnivores, etc. have to be explored at night. Various habitats of terrestrial animals (mainly invertebrates) such as : under stones, under bark of trees, decaying logs, scar on stems, leaf axils, flowers, etc. in the wild and cultivated vegetation may be explored (Annexure II). With experience, it would become very easy to locate the site of occurrence of a particular group of animals.

Rivers and canals are to be surveyed on banks, in shallow and deep waters and on the bed (e.g. by dredging). Large aquatic animals like crocodiles, dolphins, etc., should be observed from country/mechanised boats. Tide tables to be consulted and low-tide timings to be noted in marine areas. Movement inside the forest has to be made cautiously, making least possible noise. It has to be done in a planned way, equipped with map and compass. It would be better if more than one person explore the forest together. One should preferably engage a local guide conversant with the people/language, during the survey work especially in unknown areas.

Sample Size : Sampling is important for the groups to be collected. Sample size and randomization should be determined as per standard methods. However, a few precautions are necessary. Some animals have become rare and are threatened with extinction. Any such animal should be collected only when it is absolutely necessary to do so. A few hundred species of mammals, birds, reptiles, amphibians, fishes and insects have been included under different 'Schedules' of the Wild Life (Protection) Act, 1972. Animals of Schedule I are not to be captured (it is illegal to keep even dead animal or any part of it). Animals of Schedule II are also restricted, but their capture may be permitted for scientific purpose by authorized forest officials. Hence, it would be wise to see a current list of the Schedules. While collecting one shall control certain instincts, for example: (i) habit of yelling "kill it, kill it" on the very sight of a snake, without bothering to see whether it is poisonous or not and if there is any cause for alarm; and (ii) capturing larger butterflies, which are common and taxonomically less interesting than the smaller and minute ones. Eggs/egg cases or breeding individuals should not be collected or disturbed.

In case of common and abundant species, one should try to collect a representative series, having both sexes, immature stages and various castes (in social insects) or winged forms (e.g. aphids) wherever applicable. In certain groups, where the taxonomy is based on a particular sex or caste, special attempt should be made to collect that. It is desirable that one should collect a reasonably good series of specimens for investigations on population dynamics, polymorphism and evolutionary trends; but never collect more number of specimens just for the sake of higher number.

Field Data and Collection : Specimens of animals collected in the field should be provided with a field label immediately. If a proper label is not possible, then give a brief label or code number. However, it should be done quickly, for one may forget from where and in what circumstances that specimen (or its lot) was taken. For birds and mammals, the field (original) label is very valuable. It is written in the field by collector. A subsequent (final) label is added in these cases after the identification and registration of specimen. In all cases, the related data should be noted in a field note-book, against the corresponding serial (code) number.

Animals are to be observed carefully and extensively in the field. The collector should ensure that there is no 'disturbance to habitat', *i.e.* if any object or structure is removed from its place, try to put it back. For biological and behavioural data, notes should be written in the field note-book. When in hurry, these may be made in a fast hand and in telegraphic language. If the sounds are to be recorded, carry a tape-recorder. Photography is an important part of faunistic explorations. Take photographs of the area, habitat, animal colonies and habits. A few days stay at a camp will reveal the best time for photography.

Notes shall be made of all related aspects, *viz.*, pug marks, nidification, trails, burrows, mounds, galls, prey-predator relationship, etc. For example, in the case of homopteran sucking insects, moving lines of ants on bushes/trees are a sure sign of the former's presence, because the ants move over these insects for gathering 'honeydew'

Fixing and Preservation : Detailed methodology have been worked out for narcotising, fixing and/or preservation of various animal groups. Some publications issued by the Zoological Survey of India on the details of collection, preservation methods and expertise available in different groups, have been indicated in the end of this article (1968-1990).

Preservation of collected material is imperative for many groups of animals. For example, after collecting a live fish or earth worm, it is to be narcotised in water with gradual addition of formaline, and also preserved in 10% solution of it (add common salt in formaline solution to neutralize the acidic effect). Another example may be given for insects and microarthropods. After sweeping in the grass with an insect net, pull all contents including debris in the insect killing bottle. A little later, pour out these on a white paper or rexine sheet and then carefully pick up insects and other microarthropods with a fine brush. These shall be sorted grossly, and then stored in paper envelopes or tubes containing 70% rectified spirit (ethyl alcohol).

As far as possible, specimens are not to be touched with hands. If inevitable, then gloves should be used. Otherwise handling is to be done with forceps or hair brush of suitable size, according to the animal concerned.

Field Notes : In the field one may come across various types of vegetation, soil and other environmental conditions. It will be useful to make note of them, particularly if there is any relationship or effect of these on the animal communities under observation. Various meteorological parameters, such as maximum-minimum temperature, relative humidity, light conditions, etc., and physiographic factors, such as altitude, etc. shall be noted. A data-sheet (questionnaire) should be prepared for observations, based on the pattern after Misra (1968). Depending upon the availability of material and informations, one can assess whether it will be worthwhile to visit the same locality again.

Station Book : Back in the field camp every day, one has to put entry in the 'Station Book' Write down details pertaining to all scientific matters. A Station Book is a good source, in future, for finding out various particulars. Note topography, distances, general condition of fauna (flying, sedentary, breeding) and about those animals which were not collected but observed. Also complete the labels of every packet/vial/example showing the exact place and date of collecting. A preliminary sorting of the material brought that day and the proper preservation and packing are to be made. Birds and mammals are to be skinned. Before that measurements are to be taken, *e.g.*, in case of small mammals note the length of head and body, tail, hind foot and ear. Note sex of the specimen. In case of birds, besides noting sex also note colour of iris and soft parts, and the condition of the gonad. Fishes, snakes, etc. to be individually wrapped in cotton. Invertebrates have to be properly narcotized and fixed. One shall not leave any thing pending for the next day. From the field laboratory periodical letters may be sent to concerned authorities informing the progress of work. Thus, every minute of the survey period should be utilized in the field.

Post-Survey Operations

Final Sorting and Labelling : It will be misleading to think that with the return from the survey trip, the faunistic exploration work has been completed. Rather a lot more is yet to be attended after the actual survey. The first job is the final sorting (Class, Order, Family-wise) of collections. Their listing and tabulation of other data are to be made. Final label is to be given to each vial, paper envelope, rolled skin or jar. All labels should be small. If possible get it printed in minute type-face and fill up the particulars of locality, date and host in water-proof ink. Numbering of any sort be avoided, since one may not find out in future what 'No.17' or 'sl. no.114' stands for. Write full names, not abbreviations, since 'A.P.' may mean Andhra Pradesh as well as Arunachal Pradesh, and 'st' may mean station or stone.

After the developing and printing of photographs, the legend on their back be written as early as possible, otherwise one may forget. However, the photographs to be included in a manuscript should preferably be 'black & white' Make enlarged prints, of good contrast, on glossy paper for this purpose.

Tour Report : A 'Tour Report' is prepared showing the Object, Station- and Camp-wise data of survey, break-up of materials brought and the salient field notes. Give brief particulars of party, itinerary with distances, latitude & longitude of stations, and meteorological readings. Add some relevant photographs with legend, and one or two maps of the area surveyed. If it is possible, one shall attempt to provide a tentatively identified list of animals encountered during the survey. Two or more copies of Tour Report be prepared, as per the need.

Identification of Collections : One may study and identify material if he has the expertise and also the relevant literature. Comparisons are to be made with

authentically identified specimens. Otherwise the specimens may be sent to experts. For sending specimens to the experts or to departments like Z.S.I., one shall be aware of some facts and shall take a number of precautions in the despatch of materials. These have been explained in Annexure III.

Documentation : As soon as the survey work is completed, preparation of a list of species known from the area of study, or an 'Inventory' is to be prepared. ('State of Art Report' published by Z.S.I. may be seen).

Analysis of data on various ecological parameters and their influence on the distribution of various species is worth noting. With these analyses of observations and/or completing the faunal list of the area, one may come across one or many findings which are worth-publishing. Manuscript of a short note or a detailed paper may be prepared for the purpose, in the format and according to the 'Instructions to the contributors' of the chosen journal. It will, however, be better if the manuscript is first shown to one or two established workers in the subject and improved in the light of their suggestions, before communicating it to the journal.

Annexure I

A Tentative List of Collecting Equipments and other Articles required for Faunistic Explorations

General

1. Kit bag - shoulder bag made of water-proof thick cloth, with as many pockets as possible (one for each party-member).
2. Boxes made of light material like hard cardboard, plastic or fibre glass, of assorted sizes.
3. Leak proof jars (or Kilner jars).
4. Glass/plastic tubes (Preferably glass tubes with plastic corks) of different sizes.
5. Headlight or electric torch with batteries.
6. Labels/cut label papers.
7. Camera with films.
8. Enamel trays.
9. Polythene bags, assorted sizes.
10. Rubber bands, White twine and Jute thread.
11. Sieve trays, Berlese funnel, etc.
12. Herbarium press (in case of plant animals related)
13. Absorbent cotton rolls.
14. Axe, shovel, knife, etc..

15. Malmal (muslin) cloth, a few metres, and Rexine or rubberised white cloth, 2 mts.
16. Rectified spirit (some litres), and other requisite chemicals.
17. Field Note-books and pens/pencils.
18. Portable hygrometer, max.-min. thermometer, altimeter and compass.
19. 'Petromax' with extra mantles.
20. Heating arrangements.

Besides the above, some other articles required for certain vertebrate and invertebrate groups are as follows:

Mammals & Birds : Fire-arms with ammunition; traps; field binocular; mist nets; measuring tape; syringe with hypodermic needles; chloroform; formaline; pointed dividers; scale; taxidermy articles (scalpel, scissors, knives, forceps, bone cutter, absorbent cotton, arsenical soap, rectified spirit, magnesium carbonate/oxide, salt, brushes, sewing needles, thread, etc.).

Reptiles : Nets; fire-arms with ammunition; syringe with hypodermic needles; scalpel; formaline; rubber gloves; etc.

Fishes : Cast net and other types of nets suitable to the area; formaline; syringe with hypodermic needles; cotton; containers; etc.

Insects : Insect net with handle; water net with a long handle; paper envelopes (translucent or opaque strong paper); hand or pocket lens; fine forceps; brushes; scissors; twig cutter; aspirator; Insect killing bottle (either cyanide or benzene soaked cotton); naphthalene; wax for sealing tubes; etc.

Annexure II.

Ecosm and Niches : Some Places to Explore

Marine : Shores: rocky, sandy or muddy. High tide (littoral), sublittoral and Archibenthic zones. Also Mangroves; Estuaries; Islands; etc.

Freshwater : Lotic system (running waters) - banks, floating and river bed fauna. Lentic system (stagnant waters) - lakes, ponds, wells, etc.

Terrestrial : Forests : Tropical evergreens; moist; littoral and swamps; dry deciduous; thorn; broad leaved; pines; etc.

In Mountains : moist temperate; subalpine and alpine (snow) zones.

Soils : Coarse, fine, loam, clay. Above or under soil; tunnels; subterranean vertical zones.

Desert : Semi-arid, arid or sand dunes.

Grasslands; Orchards; Crop fields; Gardens; Caves; etc.

Plants : On roots, stem, leaves (axil, midrib or margin), flowers and fruits (on or inside).

Algae; fungi; lichens; galls; under bark; on rotten wood, etc.

Host : Animal or plant host. Its organ or tissue. Ecto- or endoparasite.

Miscellaneous : Under stone; litter; on light; flesh; dung; drainage; graneries; in and around houses; etc.

Annexure III.

Guidelines for Sending Specimens for Identification

Zoological Survey of India gets a large number of lots of zoological specimens for identification. These are attended to as a public service to the Universities, Research Institutions, Govt. departments, Societies as well as to individuals, without taking any fee. As insects form 3/4th of animal kingdom and as many agricultural and medical personnel deal with the insects, these notes are made keeping insect lots in mind, but with suitable modifications these shall apply to other groups of animals as well. Following guidelines are for the senders, to facilitate identification and better service.

1. Address : Material should be sent either through a messenger or by the Registered post. Address all packages and letters to:

The Director , Zoological Survey of India,

Prani Vigyan Bhawan, M Block , New Alipore, Calcutta 700 053.

2. ZSI Lot No. : On receipt of the material, an acknowledgement receipt is issued by the Identification & Advisory Division, assigning a 'ZSI Lot No.' to all consignments received for identification. The sender shall quote this ZSI Lot No. in subsequent correspondence.

3. Sorting : It will be helpful if the sender himself sorts out his material - Insects at least upto Orders, other arthropods and vertebrates upto Classes, and invertebrates upto Phyla. If the sorting is to be done in Z.S.I., it would obviously take more time in identification.

4. Preservation : For correct identification, specimens must be properly preserved, since identification of badly preserved specimens is difficult, at times, even impossible. Thus, insects belonging to Coleoptera, Lepidoptera, Hymenoptera, Diptera, Odonata and Heteroptera adults should be sent 'dry', i.e. after killing put them in paper packets or preferably pin on entomological pins. A properly pinned and set specimen can be taken up for identification straightaway. Insects like the termites, aphids, coccids, lice, apterygotes, etc. and the immature stages of generally all insects, should be sent 'wet', i.e. in 90% ethyl alcohol or any other recommended preservative, in glass tubes with air-tight stoppers. One tube should contain only one kind of material.

5. Labelling : Please supply the following data on labels - (i) name of State, district and place; (ii) date of collection; and (iii) name of collector. In case of parasites, mention the host and its infested tissue. For phytophagous insects, mention the name of plant.

6. Identification of an insect requires specialization. Therefore, it is suggested that a series of specimens, containing both sexes, may be sent. At present it is not possible to identify the taxa from immature specimens (larva, pupa, nymph), unless they are accompanied by adults. Specimens mutilated during the course of anatomical, cytological studies, etc., are difficult to attend to.

7. Packing : When insects are just sent within an envelope or wrapped in a thin layer of cotton, without more padding all around, the specimens break invariably. Sometimes tubes of wet collections are sent without adequate padding and packing of the tube, the result frequently is breaking of or opening of the tube and drying of the specimens. Therefore, send all specimens with proper padding in a sturdy packet. Pinned insect specimens be supported by cross pins and kept in a hard box with bottom lining of cork sheet.

The boxes thus made ready or the wrapped tubes should again be put in a bigger carton, with sufficient packing materials all around, so that the parcel can withstand rough handling during the transit.

While we take reasonable care of the specimens, Z.S.I. is not responsible for any damage or loss of the material during transit etc. The senders are advised to keep duplicate specimens, if available.

8. Mention clearly if the sender desires to get back his/her specimens after the identification. Sometimes Z.S.I. would like to retain some specimens for the 'National Zoological Collections of India'; when it is found unrepresented in the collections.

9. Authorship of new species : The specimens sent by a sender may sometimes turn out to be a new species, not known to science. But this is possible to find out only by an expert, after a thorough study. If a scientist finds out after his study that the specimens represent a new taxon, then he is in his right to describe, name and publish it as the sole author. It is according to the international practice. Mere collecting of specimen(s) will not automatically entitle the sender to become the sole author or joint author of a research paper dealing with that lot of specimen(s). However, where a sender has done preliminary identification himself or herself and he or she desires only a confirmation from the expert scientist, or in cases where a sender helps the Z.S.I. scientist with additional data needed for the proper description of the species, he or she will be one of the authors of the paper. The collector's name is duly acknowledged in all taxonomic papers.

10. **Expertise** : Genera and species of insects are so innumerable, that no single organization can identify each and every specimen. This is due to various limitations, *e.g.* lack of either relevant taxonomic literature, or comparable authentically identified specimens, or expertise. Sometimes efforts are made to consult outside experts on that group, who in turn take their own time. Such situations often lead to the false impression that the department unnecessarily is delaying in identification, which is not true.

Selected Z.S.I. Publications on the Subject

1968. A Handbook for Zoological Collectors : 152 pp. (out of print).

1980. State of Art Report : Zoology : 302 pp.

1980. Proceedings of the Workshop on Techniques in Parasitology : 148 pp.

1982. Handbook of Insect Collection, Preservation and Study : 65 pp.

1986. Manual : Collection, Preservation and Identification of Insects and Mites of Economic Importance : 307 pp.

1988. Management of Mammal Collection in Tropical Environment : 654 pp.

1989. Beginners' Guide - Field Ornithology : 94 pp.

1990. Handbook of Collection and Preservation of Animals : 255 pp.

Reference

Misra, R., 1968. *Ecology Work Book*. Oxford & IBH Publ. Co., New Delhi.

Museum Collections

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There are museums in India, like the National Museum of Natural History, New Delhi and the Madras Government Museum, Madras, which emphasise on the display of zoological specimens. But they do not maintain a reserve collection for research. Others, like the Bombay Natural History Society, Bombay and the Zoological Survey of India, Calcutta, not only possess a large zoological collection for research but also take care of the zoological galleries of the Prince of Wales Museum, Bombay and the Indian Museum, Calcutta, respectively. However, the Bombay Natural History Society is mainly concerned with the study of natural history, and has only a limited number of technical staff for the maintenance of collection. The Zoological Survey of India is devoted to the exploration of faunal resources of the country, maintenance of a large zoological collection right from Protozoa to Mammalia, conducting taxonomic and allied researches and also maintenance of its display galleries at the regional offices, depicting the regional fauna. The department is manned by a number of scientific officers and supporting scientific and technical staff to look after the collection and research.

There are some other research institutes in India which maintain collections for research but belong to only one or more groups of fauna. The important ones are the Indian Agricultural Research Institute, New Delhi, and the Forest Research Institute, Dehra Dun, which mainly maintain entomological collections, and the Central Marine Fisheries Research Institute, Cochin, and the National Institute of Oceanography, Goa, which maintain collections of marine animals specially of invertebrates and fish. IARI has recently, started the maintenance of nematode collections too. In addition, the Zoology departments in many universities maintain museums but those are solely for academic purpose. Taxonomists attached to universities also maintain good collections including the type specimens of the group on which they work.

History of the Collections of the Zoological Survey of India

The first systematic and scientific collecting of zoological specimens, in India, for faunistic and taxonomic studies began in the 19th century under the auspices of the Royal Asiatic Society of Bengal. In the early days, under the Asiatic

Society, attention was paid to the collecting of vertebrates, particularly birds and mammals. Further, the collections of the Society were enriched by such valuable specimens as were obtained by the first (1868) and second (1875) expeditions to Yunnan, the Persian Boundary Commission (1870-72), the second Yarkand Mission (1873-74), the Dafla Expedition (1874-75), etc. From the year 1875, all these specimens became part and parcel of the newly established Indian Museum. The zoological collections of the Indian Museum were augmented by actual collecting in the field by members of the staff, by accepting donations of the specimens from individuals and institutions as also through exchange with other museums, such as the Berlin Museum, Batavian Museum, Karachi Museum, British Museum of Natural History, etc. However, under the natural history section of the Indian Museum, an increasing degree of attention was given to the collecting of invertebrate group of animals. As a result of this, quite a substantial collection of both vertebrates and invertebrates had accumulated.

The establishment of the Zoological Survey of India on 1st July, 1916 was the outcome of a century of research in systematic zoology and basically the official recognition of the practical value of pure zoology.

The Zoological Survey of India inherited the zoological collections of the Indian Museum which also included the entire animal collection of the Asiatic Society. One of the several important functions assigned to the Survey was to act as the guardian of the 'Standard Zoological Collections of India' which is now known as the National Zoological Collections of India. The collections were termed as standard because they consisted of specimens identified by recognised specialists in various groups of animals, including the type specimens. These collections are, therefore, used as standards for comparison.

The Zoological Survey of India commenced its work with a staff of 4 scientific officers under Dr. T. N. Annandale as its Director. The work of the Survey in the early years was primarily exploratory. To ascertain the general characters of fauna, field work was considered to be one of the most important duties of the Department. The first organised survey undertaken by the newly established Department was to study the Indian freshwater molluscs with a view to investigating the possibility of their acting as vectors of human schistosomiasis. The period between 1931 and 1946 was a critical phase in the history of the Zoological Survey of India, firstly due to overall financial depression in the country and secondly due to exigencies of the Second World War. As a result, the work was mainly confined to the proper maintenance of the very rich material present in the Survey. However, with the advent of the country's Five Year Development Plans, the scientific activities of the department were enhanced by leaps and bounds. Since then the Survey is gradually expanding the horizon of its activities. It has now developed into a major national institution, with 16 Regional and Field Stations.

Extensive and intensive field explorations are undertaken by the Survey in different parts of the Indian Union for the studies of faunistics, systematic

zoology, animal ecology, wildlife, zoogeography, animal behaviour, animal population and marine biology. Recent efforts have been made towards an integrated approach to zoological investigations, so as to have more purpose oriented research comprising biological, bioethological, cytotaxonomic and ecological aspects. Despite the inclusion of other areas of research in ZSI's programme, taxonomy continues to play the pivotal role. It is one of the greatest repositories of the type specimens in South Asia.

The present holdings of the Zoological Survey of India are about 1 million zoological specimens belonging to 70,000 species, including a large number of type specimens. The major part of the collection is from the Indian region, but a good number of representative samples are also available from other countries. The department is manned with about 170 scientific officers and 350 scientific and technical staff who are engaged in the maintenance of the collection, and research.

Importance of Museum Collections

Museum collections are maintained for achieving three general objectives : education, display and research. However, one of the main, but often unrealised, reasons that the collections are made and maintained to preserve a record of the animal resources of the country. There are many species which in the course of time have, in all probability, become extinct from India, such as Pink-headed Duck, Lesser One-horned Rhinoceros, Hunting Leopard, etc., but can only be seen in the collections of the musea. In addition, these collections serve as base-line data for documenting the past distribution of animals. These collections should thus be viewed as precious records of our national natural heritage.

The value of collections in an institution like the Zoological Survey of India is both intrinsic and extrinsic (Schlitter, 1988). The intrinsic value is measured in monetary terms. It derives its worth from the essential nature of the specimens. For example, collections may contain tanned fur of fur-bearing animals (cats, sheep, jackals, squirrels, beavers, etc.), ivory in the form of teeth or tusks (elephant, waterhog, wild pig, walrus, narwhale, etc.), selected parts of specimens usable in medicinal (rhino-horn, musk, etc.), religious (bones, claws, hooves, hair, etc.), and decorative (mounted trophies, butterflies) purposes, skins of various species of mammals and reptiles (zebra, elephants, deer, cats, snakes, crocodiles, monitor lizards, etc.), and feathers of some species of birds (peacock, jungle fowl, etc.), which are all potential sources for commercial exploitation. Hence, museum collections that include such specimens have increased intrinsic value. Although the value of our national zoological collections should not be judged in terms of money but, if evaluated, it is worth millions of rupees.

Yet it is in the extrinsic value of the collections wherein there is highest justification for maintaining a large zoological collection. The extrinsic value of the collection, as mentioned earlier, is mainly of three-fold nature. It is in the area of systematic research or what is commonly known as the 'Museum

Taxonomy', that these collections have the greatest value. Specimens are essential to carry out collection-oriented research. These form the basis to the studies on taxonomy, distribution, and zoogeography of a particular group of fauna directly, and to applied studies with goals directed towards solving a specific problem indirectly.

One of the fundamental principles of all scientific studies is that the results of studies can be verified and repeated (Yates, 1985) which is only possible if we save and maintain the specimens on which the research is based. Specimens collected as part of any ongoing studies, not only serve as vouchers but also as raw material for further study by others. By utilizing new techniques like karyology, serology, electrophoresis, scanning electron microscopy, etc., many of the widely distributed species have been splitted into several species. For example, till recently, the Brown Spiny Mouse which is found throughout India, was regarded as one species *Mus platythrix*. Based on the study of chromosomes and ectoparasites, this species was splitted into two separate species, namely, *Mus platythrix* and *Mus saxicola*. Subsequently, certain morphological characters were actually found out that distinguish these two species. One point kept in mind is that a specimen is never used up. It can provide raw material for countless studies (Genoways, 1988).

Consequent to numerous environmental changes such as deforestation for modified land use, reclamation of wetlands, increasing arid conditions, etc., the geographical ranges of many species are changing rapidly. However, without the base-line data, these changes can neither be documented nor their meaning interpreted. These zoological collections and their data may be utilised in studies on ecology, life history, faunal changes, biogeography, medical entomology, parasitology, etc.

A question most commonly asked is, why do we need more than one specimen of any one kind, specially that of common species? This is pertinent because it would certainly reduce the number of animals to be removed from natural populations and, in turn, would reduce the space and funds necessary to maintain large collections.

An understanding of the extent of variation in a population is necessary for any study involving identification which may be due to age, sex, season and geographical area, as also can be of individual nature. To be able to assess we need large series of specimens of both sexes, from all seasons and age groups from a relatively restricted area. Such series of individuals are needed for thorough understanding of geographical variations. Since, it is not possible to collect enough specimens of rare or secretive species in nature, hence, samples of common species are generally collected and maintained in large numbers for detailed study of variations.

Another arises what constitutes a reasonable sample size ? This has no precise answer as it all depends on how many variables are to be studied. Generally for

statistical analysis of any character 10 is the minimum sample-size and 20 the ideal one. However, 50-75 specimens are required where individual, age and sexual variations are to be assessed. The sample may even be larger where geographical variations are to be studied in a widely distributed species.

Maintenance of Museum Collections

The collections are generally maintained either wet or dry. The invertebrates, protochordates, fishes, amphibians, most of the reptiles and smaller mammals are preserved wet either in 70% ethyl alcohol or 4% formaldehyde solution. Some of the invertebrates like sponges, insects, shells of molluscs, echinoderms except holothurians and turtles, crocodiles, birds, mammals and skeletons are preserved dry. Microscopic forms, however, are mounted on glass slides and stored in slide cabinets.

The smaller wet-preserved specimens like insects are stored in glass tubes of suitable sizes which, in their turn, are kept in large jars for additional protection. These tubes and outer jars are both filled with preservative and suitably labelled. The larger specimens are stored in glass jars and filled with preservative. These jars containing the specimens are arranged on the shelves of steel racks in the sequence of zoological classification.

The dry specimens like the sponges are stored in glass jars. Insects are set on pins and stored in insect-boxes or insect cabinets. Mollusc shells and echinoderms are stored in card board boxes of suitable sizes, with enough cotton-padding to prevent damage. These, in turn, are arranged on steel almirahs. Rolled skins of birds and mammals are kept species-wise in card-board boxes, which are finally kept in the drawers of wooden cabinets. Flat skins of large mammals are kept in folded condition in card board boxes/ drawers of wooden cabinets, depending on their size. Skulls are either tied with the respective skins after putting the same in skull-bags or are kept separately in glass vials and placed in the same container. Skeletal material is stored in card board boxes, steel trunks, on shelves of steel racks or hung on the wall. Naphthalene balls/powder or paradichlorobenzene are used as insect repellent for dry specimens.

Standards for Collection

Because the specimens and its associated labels are ultimate source of information for future studies, it is the duty of the staff of the institution to pay maximum attention to the care of the specimens. The American Society of Mammalogists recognising the need for quality care of collections, established a set of minimum standards for collection maintenance (Anderson and Choate, 1974; Choate, 1978). Though these standards were primarily suggested for the maintenance of mammal collection but these, with suitable modifications, hold good for other collections as well.

These standards are, therefore, mentioned below :-

1. Collections should be administered by non-profit public or private institutions.
2. A collection must have at least one professional curator for each major group of fauna, who is directly responsible for its maintenance.
3. Collections should be housed in buildings that provide adequate protection from fire, moisture, dust, excessive heat or light, and other physical hazards.
4. Specimens should be stored in insect-, dust- and light-proof containers.
5. Collections must be periodically inspected and fumigated.
6. Specimens should be preserved and prepared in a manner that insures their utility and durability.
7. Specimens should be arranged according to a specific plan that is recorded.
8. Field notes and ancillary data should also be preserved as a part of the permanent record for each specimen.
9. Data on specimen labels, in field notes, in the permanent catalogues, and wherever else recorded in the collection must be accurate.
10. A permanent catalogue/register of all specimens in the collection be maintained.
11. Collections should be accessible to all qualified users.
12. Loans with other institutions should be handled in a professional manner.
13. Type specimens should be stored in cases marked accordingly, and made accessible to only qualified scientists.
14. The institution must intend to continue support of the collection at least at a level necessary to maintain these standards. Should institutional priorities be changed at some future time specially in universities, the institution should express a willingness to transfer the collection to another public institution which will insure its perpetual maintenance.
15. Acquisition and possession of specimens of all groups of animals must accord with international and local regulations pertaining there to.

Type Material

The most important possession of a museum collection is its type specimens. Hence, special attention must be given on their safety, care and maintenance.

Different categories of types have been suggested in literature, but only the primary types (Holotype, Paratype, Syntype, Allotype, Lectotype and Neotype)

are really important. Of the primary types, the most important ones are the holotype and paratype. Holotype may be defined as 'the single specimen designated as the type by the original author of the species from the material he has described his new species at the time of its publication' (Mayr, 1969). Paratype is a specimen(s) other than the holotype which was before the author from the type locality at the time of preparation of the original description and was designated so by the original author.

The Zoological Survey of India has about 15000 primary types in its collection right from Protozoa up to Mammalia. The data on these types have recently been computerized.

For a number of obvious reasons, type specimens are not taken care of in many of the institutions in India. Many of the non-taxonomists even may not be knowing what the types are? As a result many of the valuable type specimens are either lost or seriously damaged beyond repair. Therefore, some important points about the care, safety and preservation of the types are mentioned here.

1. Holotype should be deposited in appropriate national institutions like the Zoological Survey of India offering long term protection, and which make them available to bonafide specialists, for study.
2. When a large number of paratypes are available, some of these may be shared with other appropriate institutions in the country and outside.
3. Type specimens must be suitably preserved, periodically checked and looked after.
4. Type specimens should be properly labelled in as much detail as possible, with the words Holotype, Paratype, Allotype, etc., written on it prominently.
5. Each type specimen should have a registration number, and the details of the specimens noted in a separate register for type specimens only against its corresponding number (Das, 1988). Need not to mention that separate registers should be maintained for different major groups of fauna. If funds permit, data of these type specimens be printed.
6. Type specimens must be kept separate from the general collection, in the direct custody of the curator/Officer-in-Charge, and should be labelled/marked in red, so that in case of emergency they can be easily located and protected first.

Loss of Type Specimens from India

It is highly regrettable that a steady loss of type specimens by way of export to foreign institutions, still continues from some of our institutions. According to Roonwal (1963), this loss is mainly due to the ignorance of some of our zoologists regarding i) the value of the loss, ii) the existence of large and important type

repositories in our country like the Zoological Survey of India, as also iii) the bias towards foreign museums.

It is an appeal to all fellow scientists (taxonomists) to ensure that under no circumstances are the type specimens, particularly the primary types, be deposited in foreign institutions. In a large country like ours which has rich and diverse fauna and adequate facilities for the deposition and care of types, there is no justification whatsoever of depositing types elsewhere. Scientists of other countries who describe species from material collected in India, are also requested to see that part of the type series is deposited in an Indian repository.

References

- Anderson, S. & Choate, J. R. 1974. Report and recommendations: Advisory Committee for Systematic resources in mammalogy, *Am. Soc. Mammal.* : 30
- Das, P. K. 1988. Accessioning and registration. *Proc. Wkshp Mgmt Mammal Colln Tropical Environ., Calcutta* (1984), : 225-238.
- Choate, J. R. 1978. Revised mammal standards, and the systematic collections that meet them. *J. Mammal.*, 59: 911-914.
- Genoways, H. H. 1988. Philosophy and ethics of museum collection management. *Proc. Wkshp Mgmt Mammal Colln Tropical Environ., Calcutta* (1984), : 5-26.
- Mayr, E. 1969. *Principles of Systematic Zoology*. Tata McGraw - Hill Publishing Co. Ltd., New Delhi.
- Roonwal, M. L. 1963. The deposit, care, preservation and scientific importance of type specimens and other zoological collections in India. *Recent Adv. Zool. in India* (Proc. 1st Summer School Zool., Simla, 1961), 111-121. Delhi Manager of Publs. Govt. of India.
- Schlitter, D. D. 1988. The value of recent mammal collections. *Proc. Wkshp Mgmt Mammal Colln Tropical Environ., Calcutta* (1984), : 637-646.
- Yates, T. L. 1985. The role of voucher specimens in mammal collections : characterization and finding responsibilities. *Acta zool. fenn.*, 170: 81-82.

Terrestrial Invertebrate Fauna of Antarctica

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The exploration of Antarctic fauna started with the exploitation of seals in the southern ocean. After the publication of Captain James Cook's book entitled 'Circumnavigation' in 1777, sealers from the USA and Britain came down like flies and quickly reduced fur seals nearly to extinction.

The first whaling station in the Antarctica was established at south Georgia during 1904. It was founded by the Argentina. From this small beginning the extension of whaling station to the South Orkney Islands and South Shetland Islands grew within a short period. The whaling activities stimulated the British Government to establish and define the 'Dependencies of the Falkland Islands' by proclamation in 1908; of course this definition also contained a territorial claim to the Antarctic Peninsula. The scientific investigation on Antarctic whale fauna started with a note of a Norwegian, J. A. Mørch, which he wrote to the British Museum (Natural History) in London in July, 1910. He suggested that every whale catcher should record a logbook of every whale killed, with details of place, species, sex, if pregnant, occurrence of plankton in water and weather data. On the basis of this information, the chart of whale distribution and frequency with time could be prepared. This is in short how the faunal exploration in Antarctica started. The Antarctic fauna so far explored can broadly be divided into invertebrate fauna and vertebrate fauna. Among invertebrates the land invertebrate fauna will be dealt in the present paper.

Soils

The soil is very scarce in the Antarctica. Icefree areas occupy only 2% of the Antarctic Continent and occur mainly in the Peninsula, along the Trans-Antarctic mountains, and in other scattered coastal areas. Most soils are formed on glacial moraines. These moraines are formed largely from comminuted sand stone and larger fragments of harder and more resistant dolerites, consequently the proportion of fine particle size material, largely quartz sand, can be relatively high in the soil parent material. The climate of Antarctica is for the most part cold and arid. In so far as soil formation is concerned, the most important feature is the temperature resulting in a very slow rate of chemical process, a very low level of biological activity and more importantly a very low level of moisture.

availability. The weathering rates are extremely slow in Antarctica; the time scale available for soil formation is very long. It has been shown that some surfaces exposed by glacial retreat have been exposed to weathering processes as much as 2-4 million years (Armstrong 1978). In other places it can be shown by extrapolation that the solid may be very much older than this, having formed on surfaces that have been exposed to weathering for periods longer than 4 million years under the climatic conditions very similar to those of the present day (Cambell and Claridge, 1975).

Invertebrate Fauna

No true terrestrial vertebrate animals are present in Antarctica. The abundant macroscopic land fauna is composed of invertebrates particularly the arthropods - insects (mainly springtail or Collembola) and arachnids (mostly mites or Acarina). Bigger invertebrates, *viz.*, annelids (earthworms and enchytraeids), land molluscs, the higher insect Orders (Diptera, Hymenoptera and Coleoptera) and spiders (Araneida), are confined to climately less severe areas, *eg.*, parts of maritime Antractic and Sub-Antarctic Islands. In these areas microscopic invertebrates, *eg.*, protozoans, rotifers, tardigrades and nematodes are numerous in soil and peat, which become free of ice in the austral summer. The arthropods living in the land of Antarctic areas comprise five groups of Acari, namely mesostigmata, prostigmata, astigmata, cryptostigmata and metastigmata; as well as collembola, biting or feather lice on birds, sucking lice on seals, bird fleas and two species of chironomid midges. The land fauna in the Antarctic Continent is very small in comparison to warmer parts of the earth, and is incompletely known. The Antarctic regions are clearly divided into three ecological zones : Sub-Antarctic zone, Maritime Antarctic zone and Continental Antarctic zone. From Table - 1 it is clear that Sub-Antarctic and Maritime Antarctic zones have more number of invertebrate fauna in comparison to Continental or Greater Antarctic zone. The entomological investigations in Antarctica parallel the general exploration of the continent, but the study of nonarthropod invertebrates were much behind arthropod work. Majority of the terrestrial arthropods were discovered by the early expeditions at the turn of the twentieth century. The first arthropod collections were made by the members of the Belgian Antarctic Expedition during 1897-1899. The collections were made from the Antarctic Peninsula. There after, for nearly 50 years there was no report of arthropod collection. The rest of the arthropod fauna has become known during the last 20-25 years. The notable contributions made in this respect were of Gressitt (1970) of the Bishop Museum in Hawaii, and the members of the British Antarctic Survey (Holdgate, 1970). Literature reveals that during sixties, substantial surveys were made to know the distribution and basic ecology of soil arthropods in Maritime zone (Strong, 1969). Due to the wide dispersion and geographical isolation of many of the Sub-Antarctic Islands the research on terrestrial invertebrates in this zone developed less rapidly than other Antarctic Zones. In the next decade the discovery of many new taxa and extension of the known distribution of many invertebrate groups is expected.



Fig. 1. Antarctic soil. An ice free area at Schirmacher Oasis, back ground showing Indian "Maitri" Station.

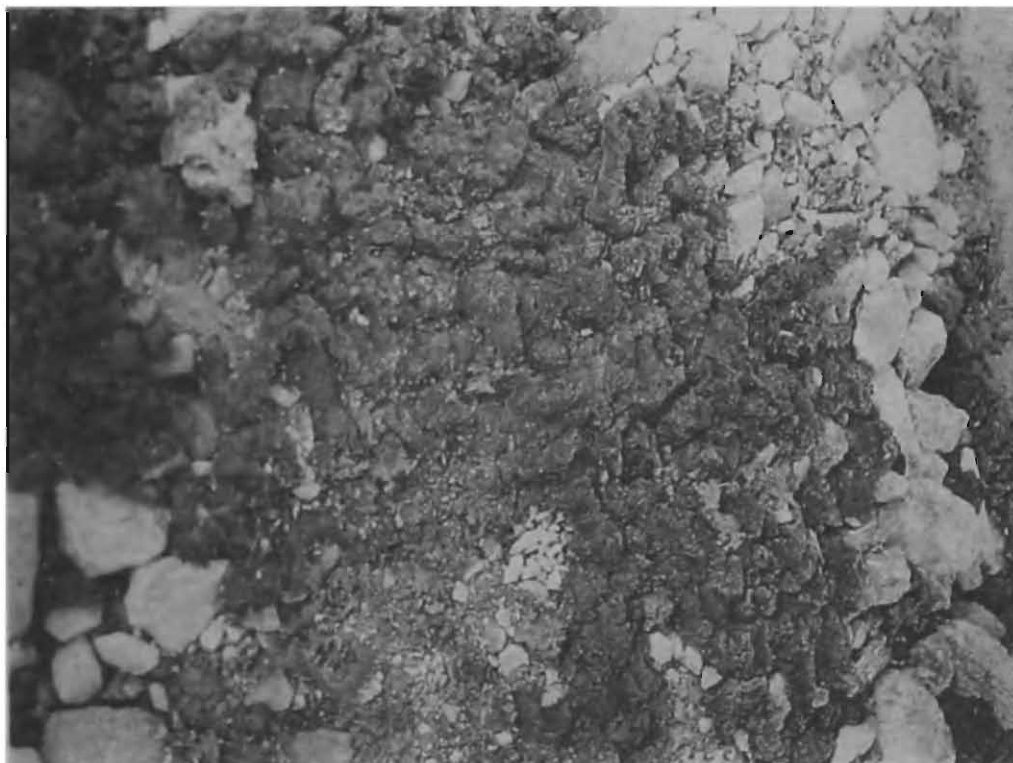


Fig. 2. Close-up view of moss-soil area in the Continental Antarctica.



Fig. 3. A view of sub-antarctic Island (The Prince Edward Island).



Fig. 4. Marion Island. A Sub-antarctic Island.

Table 1. Occurrence of Number of Species of different Groups of Invertebrate Fauna, in Three Distinct Zones of Antarctica.

Group	Sub-Antarctic	Maritime Antarctic	Continental Antarctic
	Zone	Zone	Zone
1	2	3	4
Protozoa	*124+83b		*68,33
Rotifera	?	?	13
Nematoda	22	40	10
Annelida	4	(2)	0
Mollusca	3	0	0
Tardigrada	?	17	6
Arthropoda	358	*68,5 ^a	*78,3 ^a
<i>Crustacea</i>	1	(1)	0
Copepoda	?	(1)	0
Isopoda	1	0	0
<i>Insecta</i>	210	35,2 ^a	49,1 ^a
Collembola	37	8	10
Psocoptera	3	0	0
Mallophaga	61	25	34
Anoplura	6	?	4
Hemiptera	4	0	0
Thysanoptera	2	0	0
Lepidoptera	3	0	0
Diptera	44	2	0
Chironomidae	9	2	0
Other Dipteran families	35	0	0
Siphonoptera	6	?	1
Hymenoptera	4	0	0
Coleoptera	40	2a	1a
Arachnida	144	*32,3a	*2a
Araneida	14	0	2a
Phalangida	1	0	0
Pseudoscorpionida	1	0	0
Acarina	128	*32,3a	29*
Mesostigmata	46	*4	4
Metastigmata	3	*3	0
Prostigmata	20	10	0
Cryptostigmata	32	14	18
Astigmata	27	1,3a	*4,3
<i>Myriapoda</i>	3	0	?
Pauropoda	2	0	0
Symphyla	1	0	0
Total (excluding Protozoa)	387	*127,5a	*107,3a

?: Number unknown, *: number uncertain, a : introduced species,
b : occur in both the Sub-Antarctic and Maritime zones (Table Source : Block, 1984).

According to Brundin (1970) the dispersal of insects and other arthropods by wind currents in the Antarctic has been of considerable interest, primarily to determine their Zoogeographical relationships and the probable rates of present day immigration as an indication of past colonization patterns and processes. The lack of good fossil record (six species only) makes a consideration of the origin of the Antarctic terrestrial fauna difficult. Aptery and flightlessness in the insects are common. Endemism occurs in certain groups, possibly resulting from the local evolution.

It is seen from Table - 1 that the major groups occurring are the arthropoda and the microarthropods (Collembola and Acarina) in particular. This is because they are numerically dominant groups of invertebrates in Antarctic land fauna, as a result, maximum number of informations are available on them. Informations on higher insect groups are not clear due to nonavailability of complete data.

Explored Invertebrates (Groupwise)

1. **Protozoa** : The terrestrial Protozoa was recorded for the first time from this continent by Richters (1907). These were testae amoebae collected by the German and Swedish Expedition (1901-1903) members, from the different localities of the Sub-Antarctic Zone. A consolidated review of literature was published by Smith (1987). It reveals that a good amount of work has been done since 1960. From greater Antarctic zone Sudzuki (1964) reported 26 testae and five naked amoebae, 23 ciliates and 9 flagellates in moss grown water. Heal *et al.* (1967) found 18 testae species in grassy soil of Signy Island. Thereafter others have recorded 53 testae species from Marion Island and 24 ciliates from Antarctic Peninsula. Though, at present the records of terrestrial Protozoa are not at all complete, Smith (1978) showed 124 species from Sub-Antarctic and Maritime Antarctic island areas. Altogether there were 35 testae and 10 naked amoebae, 31 flagellates and 48 ciliates.

Ecology : Interesting observations have been made by Smith (1978) on Protozoa living in Chintrap Penguin guano that when Penguin left the rookery and pH was lowered, aggregation of more acid tolerant Protozoa were not present during next 15 months.

2. **Rotifera** : Murray (1910) recorded the first Antarctic rotifers. Sudzuki (1964) recorded 13 species of rotifers from water associated with moss on land.

Ecology : Jennings (1976) observed at Signy Island the number of rotifer fauna ranged from 28 to 931 and found that there was no marked seasonal changes in their population density.

3. **Tardigrada** : The first record of Tardigrada was by Murray (1906) from South Orkney Island in Sub-Antarctic Zone, and identified five species. From Antarctic Peninsula 11 species have been reported. So far 28 species of

tardigrade under seven genera have been recorded from this continent. This represents about 6% of the species and 35% of the world genera in terrestrial habitats (Sudzuki, 1979).

Ecology : Jennings (1979) has made a study of the population dynamics of the tardigrades in two moss sites at Signy Island and found maximum population in wet moss carpet (713) and minimum in dry moss carpet (309).

4. **Nematoda :** The first account of terrestrial nematode from this Continent was made by De Man (1904). Spaul (1972) discovered a new genus and species, *Antarctenchus hooperi* ; tylenchid nematode from Maritime zone. Spaul (1973) recorded 30 species under 19 genera from Signy Island. Loof (1975) described some Dorylaimoidea from Maritime zone. Maslen (1979) described three new species from each of the genera *Aphelenchoides* and *Teratocephalus*, from the collections made in Maritime zone. Maslen (1980) provided up to date record of nematodes of Antarctica, distributed in three zones. According to him 40 species have been recorded from the Maritime zone, of which 34 were endemic; 10 species were recorded from the Continental zone, of which 7 were endemic; and 22 species of which 12 were endemic were recorded from Sub-Antarctic Zone. According to Block (1984) the reasons of the high endemism of the Maritime and Continental nematode fauna are not known. Recently specimens of nematodes have been collected from the Schimarchar oasis, in the Continental zone by the present author.

Ecology : Very little ecological work has been done on the Antarctic nematodes. Tilbrook (1973) studied and compared the population densities, which were $1.2 \times 106m^{-2}$ and $5.1 \times 106m^{-2}$ respectively at Signy Island and South Sandwich Island. It was also observed by the present author that over 60% of nematode fauna occurred in the upper 0-3 cm layer of moss soil at Schimarchar Oasis area.during summer.

5. **Oligochaeta :** Benham (1922) and Pickford (1932) observed earthworms in many Sub-Antarctic Island, but not a single earthworm till date has been recorded from the Continental zone of Antarctica. Four species of Oligochaeta occur on Macquarie Island, three of them being enchytraeids.

Ecology : The earthworm *Microscolex kerguelarum* is the most dominant species at Marion Island. Burger (1978) estimated about 1354 worms in m^2 ; he also found that during winter the worms formed an important food of two bird species, namely the Seathbills and the Kelpgulls, particularly in Marion Island.

6. **Mollusca :** Till date there is no record of occurrence of Mollusca in the Maritime and Continental Antarctic zones. Only three species of gastropod land snails have been recorded from some of the Sub-Antarctic Island. *Notodiscus hookeri heardensis* was first described by Dell (1964) from a Sub-Antarctic Island. Subsequently he reported a snail (*Phrixagnathus*

hamitoni) and a European slug (*Agriolimax reticulatus*), which is an introduced one.

Ecology : No good ecological data are available.

Arthropoda :

7. *Crustacea* : There is no authentic record of terrestrial copepods in the Antarctic region. Only one species of isopoda, namely *Antarctoniscus jeanneli*, has been recorded from this Continent.

8. *Insecta* :

a) *Collembola* : The credit for the first discovery of insects from the Antarctica should be given to Willem (1901). He described three species of springtails; these were collected in Antarctic Peninsula during 1898 by the Belgian Antarctic Expedition, were *Friesea grisea*, *Cryptopygus antarcticus* and *Parisotoma octooculata*. Carpenter (1902) described the species *Isotoma kioostadi* which was collected from Victoria Land by the British Antarctic Expedition, in 1899. The Antarctic collembola have been reviewed in detail by Wise (1971). The Sub-Antarctic zone bounds rich Collembola fauna with 37 species, followed by Continental and Maritime Antarctic zones with 17 species. Block (1984) pointed out that Collembola together with the Acari have penetrated to terrestrial habitats further south than any other arthropods. Two collembolan species, namely *Biscoia subpolaris* and *Anurophorus subpolaris*, together with three species of Acari, were found at 83°50'S. Rapoport (1971) has reported the higher degree of pigmentation in Antarctic Collembola.

Ecology : The study of collembolan ecology was attempted in the Continental zone by Janetschek (1967) at Victoria Land. He studied the environmental effects on the distribution patterns of Collembola. The population density reduced with increasing latitude and altitude; he also pointed out that the favourable conditions for breeding were limited to the short summer period. It was observed that the species *Cryptopygus antarcticus* was the dominant arthropod in the Antarctic region. According to Wallwork (1973), out of the total Antarctic collembolan fauna encountered 70% are endemic. All notable ecological works on Collembola in Antarctica were carried out in the Sub-Antarctic Islands or in Maritime zone.

b) *Psocoptera* : Gressitt (1970) reported three species of psocids. All of them are confined to the Sub-Antarctic Zone.

c) *Mallophaga* : The occurrence of biting lice was maximum in the Sub-Antarctic zone. Gressitt (1970) listed 37 species of lice from South Georgia and 34 species from Macquarie Island. He listed 61 species from Sub-Antarctic Islands, 25 species from Maritime zone and 34 species from

Continental zone. Clay and Moreby (1970) compiled and prepared a list of Mallophaga collected from 58 species of birds in the Sub-Antarctic Islands.

Ecology : Rate of infestation of South Polar Skua (*Catharacta maccormicki*) was very high; about 14-25 lice per host.

- d) *Anoplura* : According to Block (1984), there are likely to be as many species of sucking lice as there are seal species in the Antarctica. The sucking lice is restricted to Pinnipedia (seals), with no record from furseals (Otariids). Scientists have reported that Antarctic fur seal is devoid of any kind of ectoparasites. Clay and Moreby (1970) recorded five species of *Anoplura* from Antarctica.

Ecology : Some ecological and physiological observations have been made on the louse (*Lepidophthirus macrorhini*) collected from the Elephant seal, by Murray (1958).

- e) *Hemiptera* : Eastop (1970) recorded two species of aphids, namely *Jacksonia papillata* and *Rhopalosiphum padi*, from Sub-Antarctic Islands. One coreid bug (*Phthiocolis antarcticus*) has also been recorded from Sub-Antarctic Islands.
- f) *Thysanoptera* : Stannard (1962) reported two species of family Thripidae in the Sub-Antarctic zone, namely *Physemothrips chrysodermus* and *Anaphothrips secticornis*.
- g) *Lepidoptera* : Altogether three species have been recorded; all from the Sub-Antarctic Islands. Enderlein (1905) recorded *Pringleophaga kerguelensis* of family Tineidae, another worker described *Embryonopsis halicella* of family Yponomeutidae, and Common (1970) described *Eudoria mawsoni* of Family Pyralidae, the last from Heard Island.
- h) *Diptera* : Gressitt (1962) listed 15 species from Macquarie Island, a Sub-Antarctic Island, representing 10 families. Wallwork (1969) reported that the true flies do not penerate Antarctica, except two species of Chironomidae i.e. midges, namely *Belgica antarctica* which is wingless and *Parochlus steinenii* winged. Gressitt (1970a) listed 13 species from South Georgia.

Ecology : Very little ecological informations are available. Peckham (1971) studied *Belgica antarctica* at Anvers Island and correlated larvae abundance with the soil chemical substrate.

- i) *Siphonoptera* : Only one species of fleas is reported from the Antarctic continent, by Smit and Dunnet (1962), namely *Glaciopsyllus antarcticus*. At first it was collected from a chick of the Silver-grey petrel and later on collected from the nest of the Snow petrel. Besides, there are six species of fleas known from the seabirds in the Sub-Antarctic Islands.

Ecology : Dunnet (1964) has discussed the host relations of fleas in the Antarctic region.

- j) *Hymenoptera* : Only four species of Hymenoptera are reported so far from the Sub-Antarctic Islands.. Yoshimoto (1962) recorded two species of families Scelionidae and Diapriidae.
- k) *Coleoptera* : Gressitt (1970) recorded eight species of Coleoptera from South Georgia Island; one species of family Carabidae, one species of Dytiscidae, two species of Lathridiidae, two species of Staphylinidae and two species of Perimylopidae. It is note worthy that all the beetles are considered to be introduced species in Antarctic region (Wallwork, 1969). Coope (1963) recorded single water beetle *Lancetes claussi* and two species of Perimylopidae beetles namely *Perimylops antarcticus* and *Hydromedion sparsutum*.

Ecology : Smith (1977) recorded maximum Perimylopidae densities upto 220 per sq. meter.

9. *Arachnida* :

- a) *Araneida* : Gressitt (1970) listed 14 spider species from Sub-Antarctic Islands.
- b) *Pseudoscorpionida* : Only one species, namely *Austrochthonius insularis*, has been found in the Sub-Antarctic Islands, by Gressitt (1970).
- c) *Acarina* : The first mite species discovered from the Antarctic region was a Cryptostigmatid, *Oribata antarctica*, collected in the 'Belgica' Expedition of 1897-1899. Till date over 150 species of Acari have been listed from the Antarctic and Sub-Antarctic regions. Wallwork (1969) has listed the Acarina as follows :
 - i) *Mesostigmata* : The majority being found in the Maritime and Sub-Antarctic Zones; so far 50 species have been recorded. The species *Gamasellus racovitzai* is probably the widely distributed species in the lesser Antarctica.
 - ii) *Metastigmata* : Willson (1970) recorded three species of ticks from the seabirds in the Antarctic region, of which *Ixodes uriae* has been recorded from 45 host species.
 - iii) *Prostigmata* : According to Wallwork (1973) considerable taxonomic and distributional information exists for this group and 41 species are found in the Antarctic region. *Nanorchestes antarcticus* has been described from the extreme southernmost limit (85°32' S; 153°W).
 - iv) *Cryptostigmata* : Wallwork (1973) listed 41 species of oribatid mites from all the three Antarctic Zones. The cryptostigmatid mites of the Sub-

Antarctic and Continental zones are distinctly different, but the Maritime zone is transitional, being derived from Sub-Antarctic zone (Wallwork, 1969).

v) *Astigmata* : Tilbrook (1973) and Goddard (1977), have given considerable taxonomic and morphological informations for 18 species. Griffiths (1977) has erected a new family for *Glycacarus combinatus*, collected from the nest of White Chinned Petrel in Sub-Antarctic Island.

Ecology : Gressitt (1965) have done some ecological work mainly with two Prostigmata : *Stereotydeus mollis* and *Nanorchestes antarcticus*, at McMurdo sound area. They found the densities were in the range of 20-2000 specimens per square meter. Temperature tolerances have been reported in Antarctic mites by several scientists like Fitzsimons (1971) and Young (1979).

10. *Myriapoda* :

- a) *Pauropoda* : Scheller (1974) has observed two specimens in a Sub-Antarctic Island.
- b) *Symphyla* : Scheller (1974) described a single new species *Symphylella subantarcticus* from a collection of 27 specimens.

Zoo geography

It is known from the continental drift theories that about 65 million years ago the Antarctic Continent was attached with South America and Australia. During this time the Continent had a rich flora and fauna, due to prevalence of favourable climatic conditions. This attachment between the terrestrial masses could be explained by the biogeography of the circumantarctic flora and fauna. Brundin (1967) observed that within insects close relationships are found between species from different Continents, viz., the chironomid midges from South America, Australia and New Zealand. Due to the climatic changes that took place, the original fauna of Antarctica hardly exists today.

As stated earlier the South polar region has been divided into three zones on the basis of climate and vegetations. The fauna of different zones includes high proportion of endemism. The Sub-Antarctic zone has much richer fauna, eg. according to Trave (1981) about 70 species of Collembola have been recorded. Somme (1985) has nicely illustrated the great variations in faunal composition of mites when different areas are compared. Marion, Crozet, Kerguelen and Heard Islands are considered as one area, Macquarie Island as another area, while South Georgia and the Maritime zones are treated together as the third area. He found that ten species of Cryptostigmatic mites are endemic to South Georgia and the Maritime Zone. This fauna is also influenced by its close proximity to South America, having nine species in common with that Continent. In that way, some from Macquarie Island also occur in New Zealand. The fauna of Marion Island

has nine species in common with Macquarie, but are very different from South Georgia and the Maritime Zone. Twentyfour out of 37 from this eastern group of Islands are common, which may be considered a separate, biogeographical province (Trave, 1981). Wallwork (1973) observed that the Collembola of the Sub-Antarctic Zone comprises a western group, an eastern group and a circum-Antarctic group. He showed that in the west seven species are endemic to South Georgia and the Maritime Zone, and so far 36 out of 55 species have only been recorded from Marion, Crozet, Kerguelen and Heard Islands. The western and eastern fauna of Collembola are quite different. Some of the Sub-Antarctic Collembola also occur in south America and New Zealand, and a few have an even wider distribution.

Conclusion

Somme (1985) has rightly pointed out that our knowledge of Antarctic terrestrial invertebrates is still fragmentary, and more works on their taxonomy, zoogeography, population and physiology are needed. Very little work has been conducted on these aspects in the accessible areas. Physiological data have mainly been obtained from summer season and laboratory animals. Therefore, there is immense scope for studying the invertebrate animals directly in their overwintering habitats in remote nunataks and islands in the Antarctica. The choice of habitats in the Antarctic is greatly restricted by the availability of moisture. The occurrence of mites and Collembola on nunataks and coastal land areas of the Continent are mainly confined to the sparse vegetation of moss and lichens, where very little moisture is retained. The survival under the harsh conditions of the South polar region is imaginable. The organisms must tolerate both extreme low winter temperature as well as short, cold summer, and their adaptations must involve several kinds of ecological and physiological mechanisms.

References

- Armstrong, R.L. 1978. Late Cenozoic McMurdo volcanic group and dry valley glacial history, Victoria land, Antarctica. *N. Z. J. Geol. Geophys.*, 21: 685-98.
- Benham, W.B. 1922. Oligochaeta of Macquarie Island. *Australasian Antarctic Expedition 1911-1914. Scientific Report*, 6: 1-38.
- Block, W. 1984. Terrestrial habitats *In : Antarctic Ecology*, Vol. I. 163-236. (Ed.) R.M. Laws.
- Brundin, L. 1967. Insects and the problem of austral disjunctive distribution. *Ann. Rev. Entomol.* 12: 149-168.
- Brundin, L. 1970. Antarctic land faunas and their history. *In : Antarctic Ecology*, 1: 41-53. (Ed.) M.W. Holdgate, Academic Press, New York and London.
- Burger, A.E. 1978. Terrestrial Invertebrates : a food resource for birds at Marion Island. *South African J. of Antarctic Res.*, 8: 87-99.
- Campbell, I.B. & Claridge, G.G. 1975. Morphology and age relationship of Antarctic Soils. *Bull. R. Soc. N.Z.*, 13: 83-8.
- Carpenter, G.H. 1902. Insecta. Aptera, Collembola. *In : Report on the collections of Natural History made in the Antarctic Regions during the voyage of the 'Southern cross.'* 1-344. British Museum (Natural History), London.

- Clay, T. & Moreby, C. 1970. Mallophaga and Anoplura of subantarctic islands. *Pacific Insects Monograph*, 23: 216-220.
- Common, I.F.B. 1970. Lepidoptera : Yponomeutidae of Heard Island. *Pacific Insects Monograph*, 23: 229-233.
- Coope, G.R. 1963. The occurrence of the beetle *Hydromedion sparsutum* (Mull) in a peat profile from Jasor Island, South Georgia : *British Antarctic Survey Bulletin*, 1: 25-26.
- Dell, R.K. 1964. Land snails from sub-Antarctic islands. *Trans. Royal soc. New Zealand, (Zoology)*, 4 : 167-173.
- De Man, J.G. 1904. Nematodes libres. In "Resultats du voyage due S.Y. 'Belgica en 1897-1898 sous le commandement de A. de Gerlache de Gomery, etc." *Zoologie*.
- Dunnet, G.M. 1964. Distribution and host relationship of fleas in the Antarctic and subantarctic. In : *Biologie Antarctique*, 223-239. (Ed.) R. Carrick, M.W. Holdgate and J. Prevost, Hermann, Paris.
- Eastop, V.F. 1970. Hemiptera : Homoptera : Aphididae of south Georgia. *Pacific Insects*, 23: 227.
- Enderlein, G. 1905. Pringleophaga, cine neue Schmetter Ungsgattung aus dem antarktischen Gebiet. *Zool. Anz.*, 29: 11-125.
- Fitzsimons, J.M. 1971. Temperature and three species of antarctic arthropods. *Pacific Insects Monograph*, 25: 127-135.
- Goddard, D.G. 1977. "Ecological studies on the terrestrial Acari of Signy Island, south Orkney Island, in the maritime Antarctic" Ph.D. thesis, University of Leicester.
- Gressitt, J.L. 1962. Insects of Macquarie Island. Introduction. *Pacific Insects*, 4: 905-915.
- Gressitt, J.L. 1965. Terrestrial animal. In : *Antarctica*, 351-371. (Ed.) T. Hatherton, Methuen, London.
- Gressitt, J.L. (Ed.) 1970. Subantarctic entomology, particularly of south Georgia and Heard Island. *Pacific Insects*, 23: 1-374.
- Gressitt, J.L. 1970a. Subantarctic entomology and biogeography. *Pacific Insects*, 23: 295-374.
- Gressitt, J.L. (Ed.) 1976. Entomology of Antarctica. *Antarctica Research Series* 10: 1-395.
- Gressitt, J.L. & Shoup, J. 1967. Ecological notes on free living mites In North Victoria land. In : *Entomology of Antarctica*, 10: 307-320. (Ed.) J.L. Gressitt. *Antarctic Research Series*.
- Griffiths, D.A. 1977. A new family of astigmatid mites from the Iles Crozet, sub-Antarctica : Introducing a new concept relating to ontogenic development of idiosomal setae. *J. Zool. (Lond.)*, 182: 291-308.
- Heal, O.W., Bailey, A.D. & Latter, P.M. 1967. Bacteria, fungi and protozoa in Signy Island soils compared with those from a temperate moorland. *Phil. Trans. of the Royal Society, B* 252: 191-197.
- Holdgate, M. W. (Ed.) 1970. *Antarctic Ecology* Vols 1 and 2 Academic Press, New York and London.
- Janetschek, H. 1967. Arthropod ecology of south victoria land. *Antarctic Research Series* 10 : 205-293.
- Jennings, P. G. 1976. The Tardigrada of Signly Island, South Orkney Islands, with a note on the Rotifera. *British Antarctic Survey Bulletin*, 44 : 1-25.
- Jennings, P. G. 1979. The signy Island terrestrial reference sites : V. Population dynamics of Tardigrada and Rotifera. *British Antarctic Survey Bulletin*, 47 : 89-100.
- Loof, P. A. 1975. Dorylaimoidea from some sub-Antarctic island. *Nematologica*, 21: 219-255.
- Maslen, N. R. 1979. Six new nematode species from the maritime Antarctic. *Nematologica*, 25: 288-308.
- Maslen, N. R. 1980. Addition to the nematodes fauna of the Antarctic region with keys to taxa. *British Antarctic Survey Bulletin* No. 49: 207-229.
- Murray, J. 1906. Scottish national Antarctic Expedition : Tardigrada of the South Orkneys. *Trans. Royal Soc. Edinburgh*, 45: 323-334.
- Murray, J. (Ed.) 1910. Antarctic Rotifera. In : *British Antarctic Expedition. 1907-1909. Reports on the Scientific Investigations. Biology*, 41-65. Heinemann. London.

- Murray, M. D. 1958. Ecology of the louse *Lepidophthirus macrorhini* Enderlein 1904 on the elephant seal *Mirounga leonina* (L.) *Nature* (Lond.), 182 : 404-405.
- Peckham, V. 1971. Notes on the chironomid midge *Belgica antarctica* Jacobs at Anvers Island in the maritime Antarctic. *Pacific Insects*, 25: 145-166.
- Pickford, G. E. 1932. Oligochaeta 2. Earthworms. *Discovery Reports* (Cam.) 4.
- Rapoport, E. H. 1971. The geographical distribution of Meotropical and Antarctic Collembola, *Pacific Insects*, 25: 99-118.
- Richters, F. 1907. Die Fauna der moosrasen der Gausskengs and einiger Sudlicher Inseln. *Deutsches Sudpolar Expedition*, 9: 259-302.
- Scheller, V. 1974. Two pauropodidae species (Myriapoda, pauropoda) from the subantarctic crozet island. *Entomologica Scandinavica*, 5: 59-65.
- Smit, F. G. A. M. & Dunnet, G. M. 1962. A new genus and species of flea from Antarctica (Siphonaptera : Ceratophyllidae). *Pacific Insects*, 4: 895-903.
- Smith, H. G. 1978. The distribution and ecology of terrestrial protozoa of sub Antarctic and maritime Antarctic islands. *British Antarctic Survey Scientific Reports*, 95: 1-104.
- Smith, V. R. 1977. Notes on the feeding of *Ectemnorhinus similis* waterhouse (Curculionidae) adults on Marion Island. *Oecologia* (Berlin), 29: 269-263.
- Somme, L. 1985. Terrestrial habitats invertebrates. In : *Key environment Antarctica*, 106-117. (Eds.) W. N. Bonner and D. W. H. Walton, Pergamon Press.
- Spaull, V. W. 1972. *Antarctenehus hooperi* n.g., n.sp. (Nematoda : Dolichodoridae) from signy Island, South Orkney Island, with the erection of a new sub-family. *Nematologica*, 18: 353-359.
- Spaull, V. W. 1973. Seasonal variation in numbers of soil nematodes at Singy Island, South Orkney Island. *British Antarctic Survey Bulletin*, 33 and 34: 47-56.
- Stannard, L. J. 1962. Insects of Macquarie Island. Thysanoptera : Thripidae. *Pacific Insects*, 4: 933-936.
- Strandtmann, R. W. 1970. Acarina; eupodiform prostigmata of south Georgia. *Pacific Insects*, 23: 89-106.
- Strong, H. 1967. Ecology of terrestrial arthropods at palmer station Antarctic Peninsula. *Antarctic Research Series*, 10: 357-371.
- Sudzuki, M. 1964. On the micro fauna of the Antarctic region. I. Moss water community at langhovde. *Biological results of the Japanese Antarctic Research Expedition*, Series E. 19: 1-41.
- Sudzuki, M. 1979. On the micro fauna of the Antarctic region. III. Micro-biota of the terrestrial interstices. *Memoirs of the National Institute of Polar Research Tokyo, Special issue* 11 : 104-126.
- Tilbrook, P. J. 1973. The signy Island terrestrial reference sites : I. An introduction. *British Antarctic Survey Bulletin*, 33 and 34, 65-76.
- Tilbrook, P. J. 1973a. "Terrestrial arthropod ecology at Signy Island, south Orkney Islands" Ph.D. Thesis, University of London.
- Trave, J. 1981. Biogeographic des oribates (Acariens) subantarctique. *C.N.F.R.A.* 48 : 149-158.
- Wallwork, J. A. 1969. The zoogeography of Antarctic cryptostigmata. In : *Proceedings of 2nd International Congress of Acarology*, 17-20. (Ed.) G.O. Evans, Hungarian Academy of Sciences, Budapest.
- Wallwork, J. A. 1973. Zoogeography of some terrestrial micro-Arthropoda in Antarctica. *Biological Reviews*, 48: 233-259.
- Willem, V. 1901. Les Collembolles recueillis Par l'Expedition Antarctique Belge. *Annals of the society for Entomology of Belgium*, 45: 260-262.
- Wilson, N. 1970. Metastigmata : Ixodidae of South Georgia, Heard and Kerguelin. *Pacific Insects*, 23: 78-88.
- Wise, K. A. J. 1971. The collembola of Antarctica. *Pacific Insects*, 25: 57-74.
- Yoshimoto, C. M. 1962. Insects of Macquarie Island. Hymenoptera : Diapriidae. *Pacific Insects*, 4 : 973-974.
- Young, S. R. 1979. Effect of temperature changes on the metabolic rate of an Antarctic mite. *Journal of comparative physiology*, 131: 341-346.

Species Diversity and Management in Wetland Ecosystems

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The Indian peninsula with a total area of 329 million hectares is very rich in biological diversity, and it is estimated that about 45,000 species of plants occur in the country; the vascular plants themselves comprising about 15,000 species, of which more than 60 percent are endemic (Khushoo, 1986). The country is equally rich in its fauna. It is estimated that of the 80,000 species of animals described so far, from India, 67,000 are insects, 4000 molluscs, 6,500 other invertebrates, 1700 fishes, 140 amphibians, 420 reptiles, 1200 birds and 340 mammals (Art Report, Zoological Survey of India, 1980). It is quite likely that the number of species described so far will increase to about 1,50,000 when our faunal resources are analysed. As the magnitude of biological diversity is enormous, it is impossible to take up the conservation of the entire genome present in the biosphere. Thus, according to Gadgil (1987), the priorities on the nature of conservation to be taken up must be on a sound rationale of economic, scientific, aesthetic and cultural basis. Otherwise, the impact of man is so great in recent years, that the chain of events is likely to affect the diversity of species. Wetlands which are known for their diversity and abundance of genetic resource should get priority in conservation.

Wetlands

Wetlands comprises a unique habitat exhibiting many features of the aquatic and terrestrial ecosystems. The wetland is also identified as an ecosystem wherein the biotic community undergoes changes with time, from aquatic to marshy to mesophytic types, and provides suitable niches for fishes, residential and migratory birds, good resource for food, fodder and other important biological products. Wetland communities are highly dynamic as they are located at the interface of terrestrial and aquatic ecosystem. The species richness in such an area is quite high, as it offers a specialised habitat for many macrophytes, invertebrates and vertebrates. The richness is mainly attributed to the "Spatial heterogeneity", that is, the greater the number of niches, the greater is the opportunity for successful invasion by a species (Jacobs, 1975).

The basic components of a wetland ecosystem are: 1) the water regime, where the physical and chemical characteristic of water determine the nature of the wetland. The hydrological characters, such as flow rate, flood frequency and water quality control the composition of the wetland communities; 2) sediment and substrate which influence the ability of the vegetation to establish in such areas, and serve to maintain a steady flow of nutrients and energy thorough the system; 3) decomposers which release the nutrients required from the organic matter; and finally, 4) vegetation which support the major biota *viz.* wildlife.

Definition

According to the Ramsar convention - 1971, wetlands are defined as "Areas of marshes, fens, peatlands of water, whether natural or artificial, permanent or temporary with water, that is static or flowing, fresh, brackish or salt including the areas of marine water, the depth of which at low tide does not exceed six meter" According to Cowardin *et. al.* (1979), wetlands has been defined as "land where the water table is at or above the land surface for long enough each year to promote the formation of hydric soils and support the growth of hydrophytes as long as other environmental conditions are favourable" However, the U S Department of Interior, Fish and Wildlife Authority adopted a modified definition of Cowardin *et. al.* (1979) as "The wetlands are lands of transition between terrestrial and aquatic systems wherein the water table is usually at or near the surface or the land is covered by shallow water"

Classification of Wetlands

Factors such as source of water, velocity, flow rate and frequency of inundation have a major bearing on the physical and chemical properties of wetland substrate. This in turn influences the character and health of the ecosystem, as reflected by the species composition, nutrient cycling, etc. Thus, hydrology controls the process of sedimentation, aeration, biological transformation and soil adsorption. These factors form the basis for the classification of wetlands.

National Policy

Wetland convention 1971 is unique among the International conventions because it is concerned with the conservation of an ecosystem as a whole. The convention was launched in view of the fundamental ecological functions of wetlands particularly as areas of flood control, recharging of aquifers, regulating water quality, reducing sediment load and areas of aquaculture, apart from being waterfowl habitat and rich resource of genetic diversity.

Realising the importance of wetlands, conservation of wetland ecosystem has been taken up in the seventh five year plan and a national committee has been constituted by the Government of India, under the Ministry of Environment and Forests. In a meeting held on 2nd April 1987, the expert committee recognised ten wetlands as areas of conservation for preparation of management action plan.

Subsequently, on 8th December 1988, six more wetlands were added to the list making a total of sixteen (Table - 1).

Table 1. Selected Wetlands in India for Conservation and Management by the Ministry of Environment and Forests, Government of India

Sl.No.	Wetland	State	Area in Ha	Ecological Status
1.	Kolleru	Andhra pradesh	90,000	Freshwater
2.	Wular	Jammu & Kashmir	18,900	Freshwater
3.	Chilka	Orissa	1,14,000	Brackish
4.	Loktak	Manipur	26,600	Freshwater
5.	Bhoj	Madhya pradesh	1,000	Freshwater
6.	Sambhar	Rajasthan	7,200	Saline
7.	Pichola	Rajasthan	1,480	Freshwater
8.	Ashtamudi	Kerala	4,335	Brackish
9.	Harike	Punjab	4,100	Freshwater
10.	Ujni	Maharashtra	35,700	Freshwater
11.	Sukna	Chandigarh	228.6	Freshwater
12.	Sasthamkotta	Kerala	375	Freshwater
13.	Renuka	Himachal pradesh	670	Freshwater
14.	Kabar	Bihar	6,737	Freshwater
15.	Nalsarovar	Gujarat	18,400	Brackish
16.	Kanjili	Punjab	14	Freshwater

Source : Ministry of Environment and Forests, New Delhi.

Wetlands in India

Wetlands are either natural or manmade and are distributed in different geographical regions of the country (Map 1). Origin of wetlands is diverse. Kashmir has a wide range of natural lakes at altitude varying from 1585 to 1600 m above sea level. These lakes occur mainly in the flood plain of river Jhelum, and are derived either from enlarged ox-bows or abundant flood channels (Dattera and Patterson, 1939). The lake includes Dal, Anchal, Mansbal and Wular. Many high altitude wetlands are formed by the glacial action, such as Kumaon lakes in Uttar Pradesh (Vijayan, 1986). small lakes in limestone tracts of Khasi and Jaintia hills of Assam are believed to have been formed by

dissolution of underlying rock (Jhingran, 1982). Pichola - Fatesagar Complex of Rajasthan are formed as a result of movement of fine loose clay and sand particles by wind. Similarly, salt lakes of Sambhar (Rajasthan) are depressions created by the shifting dunes, forming swamps. Most of the wetlands in Bihar are of ox-bow type (eg., Kabar), formed as a result of shifting of river courses in the geologic past.

The Gangetic plains extending over 1200 km from east to west and about 400 km from north to south are constituted of alluvial deposits laid down by Ganga and its tributaries. These rivers keep on changing their course, and thus creating/ extending flood plains and ox-bows, and constitute the largest wetland in the country. Similarly, many south Indian rivers such as Cauvery, Godavari and Krishna form several wetlands in different areas. The most important one is Kolleru in Andhra Pradesh, covering 900 sq.km of shallow freshwater. This is, perhaps, the largest freshwater wetland in Peninsular India.

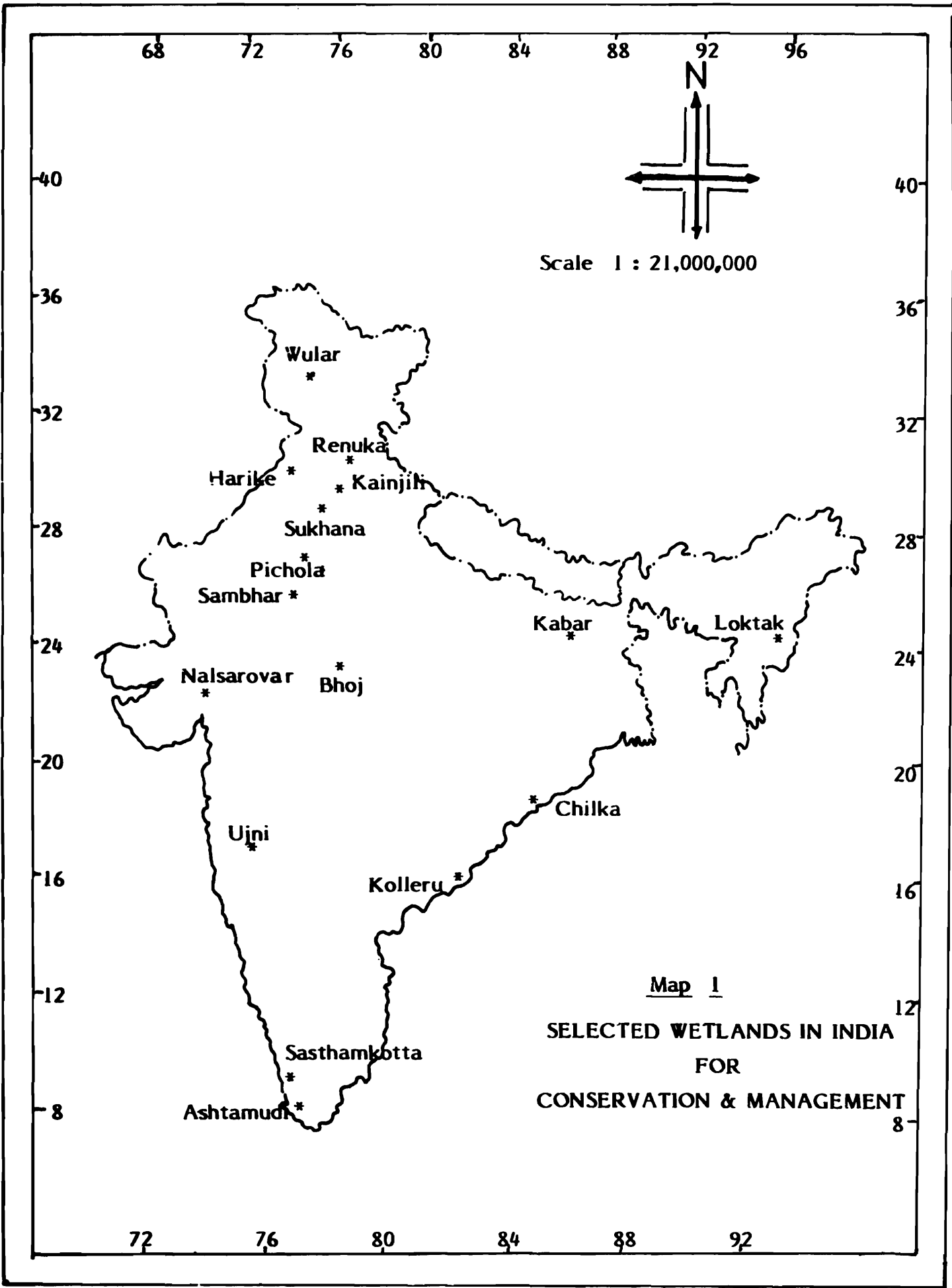
India has a vast coast line stretching over 3,600 km, with sandy shores, mangroves, backwaters, lagoons, mudflats and estuaries adjoining the coast (Hussain, 1988). The major coastal wetlands of the country are Chilka (Orissa), which, with an area of 1040 sq. km., is the largest brackish water lake. Pulicat, located in Tamil Nadu and Andhra Pradesh is the second brackish water lake, with a total water spread area of 77,000 hectares. Similarly, Ashtamudi (Kerala) with an area of 4,335 hectares, is a brackish water located in the region of Arabian Sea in the West. These coastal wetlands are dependent on flooding by sea water on one side, and river water on the other, forming a high productive estuarine ecosystem.

The best manmade wetland in the country is Keoladeo National Park of Bharatpur (Rajasthan) created about 250 years ago, by the then rulers of the state. It is a classic example of man's ingenuity to convert a natural rainfed depression into a permanent waterfowl reserve by containing and regulating water column by means of various dykes, canals and sluice gates (Vijayan, 1986). The construction of several multipurpose projects in the states of Punjab, Haryana, Uttar Pradesh, Himachal Pradesh, Madhya Pradesh and others has resulted in the formation of large reservoirs, creating manmade wetlands in the country.

Species Diversity in Wetland Ecosystem

Macrophytic Vegetation

Wetlands are often subjected to expansion and contraction in area with changes in the water level due to the fluctuations in receiving water and rainfall. The species richness in vegetation varies, depending on the period of flooding. Areas flooded for long periods have lower species diversity than less frequently flooded areas. In presence of high concentration of salts and sulphides in salt marsh water such as Pulicat lake, the species diversity is low, but a definite zonation and distribution of vegetation is noticed. In contrast, flowing water can



be assumed to act as a stimulus to diversity, probably due to its ability to renew minerals and reduce anaerobic conditions. Hydrology also stimulates the diversity when the action of water and transported sediments create "Spatial heterogeneity" opening up new ecological niches, as can be seen in Kabar and Kolleru wetland. However, flowing water also creates a very uniform surface that might cause monospecific strands of *Typha* and *Phragmites* species to dominate.

Peat bogs occur in many wetlands of the country. Peat formation is noticed in high altitude ranges (2,000 m and above) of Northeastern Himalayas and Nilgiris. Peat is characterised by grasses, sedges and mosses. Besides these, *Carex rubigens*, *Cyanotis villosa*, *Cyperus* sp., *Eriocolon* sp., *Juncus* sp., *Linderina* sp., *Isachnae kunthkiana*, and *Utricularia* sp. are also found in association with peat vegetation. Acid swamps with dominant vegetation of *Sphagnum*, most characteristic of temperate climate is absent. *Myristica* swamps are found in southern most parts of Kerala, the floor of such swamps being traversed by looped knee roots of *Myristica* species. Species commonly encountered are *M.malbarica*, *M.dactyloides*, *M.magnifica*, *Kneema attenuata*, *Hydnocarpus alpine* and *Lophopetalum toxicaria*.

Apart from richness and diversity of flora, the presence of large number of 'Wild' relatives of cultivated plants that would enable the breeder to augment the reservoirs of gene pools for desirable characters, make the wetland unique. "Wild" species that are found in the country are *Oryza*, *Elettaria*, *Panicum*, *Saccharum*, *Zinziber*, *Cannavalia*, *Curcuma*, *Coffea*, *Cinnamomeum*, *Dioscoria* etc. (Nair and Daniel, 1986). A survey conducted by Regional Aurvedic Centre, Vijayawada during April 1987 has revealed the presence of thirty medicinal plants in Kolleru region.

A wetland is characterised by extensive growth of macrophytic vegetation, mainly emergent, submerged and floating plants. As a result, the dissolved oxygen is abundant during day time due to photosynthesis. Such an area which is well aerated and nutrient rich is of great economic importance as it supports a large invertebrate fauna, forms a feeding ground for fishes and protects them from predators among submerged vegetation. Such wetland vegetation harbours several air breathing snails such as *Pila virens*, *Lymnaea* sp., *Indoplanorbis* sp., *Bellamya* sp., and on sandy channels *Lamellidens marginalis* (For eg. Kabar wetland in Bihar) forms an excellent source of food for several migratory and resident birds visiting the area. These gastropods, which are abundant in macrophytic vegetation, have feeding habits similar to that of the earthworms leaving large quantities of mud as 'cast' on the surface. This undoubtedly plays an important role in the breakdown and decomposition of plant material, thus enriching the soil fertility.

Ichthyofauna

Though the fishery resources of the country are vast and varied, the fish

production is about 3.5 million tonnes per year. Inland fisheries extend over 3 million hectares of reservoirs, 1.5 million hectares of tanks, 1.5 million hectares of estuaries and backwaters, besides 140,013 km of rivers, tributaries and channels. India's riverine fishery comprises five major systems, the Ganga, the Brahmaputra and the Indus system in the north, and the peninsular east and west coast river systems in the south.

The diversity of ichthyofauna is in turn related to the great variety of habitat available in the continent *viz.* flood plains, swamps, coastal lakes, freshwater lakes and reservoirs. Many flood plains and coastal zones are important breeding and nursery areas, where as many lakes and rivers provide locally and nationally important fish yields. About twothirds of the fish and shell fish species that are harvested commercially are associated with wetlands. Thus, one of the major values of wetland is high fish production in most of the sites.

Day (1889) listed 1418 species of freshwater and marine fishes under 78 families and 342 genera from the faunal limits of India. However, the number of species has risen to 1700, under 600 genera distributed among 200 families. Of these, 233 genera with 742 species falling under 64 families and 16 orders are known to be freshwater and brackish water species (Jayaram, 1982). The region is also noted for its rich and diverse cyprinoid and siluroid fishes and for the conspicuous absence of Ganoids, Dipnoi and Cyslostomes.

Inland fishes are into three groups according to their ability to tolerate salt water during the distributional movements *viz.* peripheral, secondary and primary. Peripheral fish live in both fresh and sea water (gobids and clupeids), secondary fishes live in freshwater but are sufficiently euryhaline to disperse along the main coast (*Tilapia* - an exotic fish recently introduced in India) and primary freshwater fishes are tolerant of freshwater which, therefore, presents a formidable barrier to their distribution (Cyprinids).

Ichthyofauna in the wetland ecosystem in India is abundant and varied. The great diversity of fishes is found among the dense vegetation and offshore habitats, eg. a total of 172 species of fishes have been recorded from Hooghly - Matla estuary, of which 73 occupy freshwater zone and 99 higher salinity ranges (Hora and Mukerjee, 1953). 185 species of fishes are recorded (excluding clupeoids) from Godavari estuary, of which, 72.8 percent are euryhaline, 12.2 percent are almost marine and 15 percent are freshwater forms (Jhingran and Gopalakrishna, 1974). The coastal lakes of Pulicat and Chilka exhibits 65 and 152 species of fishes respectively (Chacko *et. al.*, 1953; Jhingran, 1983). Kabar wetland, exhibits 48 species as recorded in our recent surveys. 62 species are recorded at Kolleru wetland (Baburao, personal communication). 36 species of fishes are recorded from rivers and lakes of Kashmir belonging to four orders, five families and 18 genera indicating the richness of the fauna even in the temperate climate of the country (Das, 1962).

The species composition of the wetland is threatened by overexploitation during the lean season leading to the depletion of the gene pool, as all types of trapping methods are employed. Apart from this, efforts to exploit the flood plains and coastal zones for agriculture, aquaculture and housing (Salt lake area, Calcutta) has led to the catastrophic impact on the fish population in many areas. Furthermore, letting out of the water into the nearby streams, release of industrial, agricultural and domestic wastes into the water and removal of macrophytes are also additional factors for the dwindling population.

Avifauna

Wetlands occupy an estimated six percent of the world's land surface, and India has an area of about 25,89,266 hectares located in different geographic regions of the country. The importance of such a fragile ecosystem is already understood as areas of high genetic diversity with rich faunal and floral components. Wetlands are particularly important as breeding and / or feeding grounds for many residential and migratory birds. As already mentioned, 16 wetlands are recognised in the country for conservation, as these attract large number of residential and migratory birds viz. Keoladeo National Park, Bharatpur (Rajasthan), Chilka (Orissa), Pulicat (Andhra Pradesh & Tamil Nadu), Nalsarovar (Gujarat), Kabar (Bihar), Kolleru (Andhra Pradesh), and Harike (Punjab). The Indian bird fauna contains numerous species which have their distribution centred on wetlands and hill tracts. Species diversity is generally less in grassland, as these areas are mainly anthropogenic centres. Ripley (1982) recorded 2094 forms of birds belonging to 1200 species and 400 genera in the Indian subcontinent (including Srilanka, Bangladesh, Pakistan and Bhutan), of this 417 forms (19.9 percent) belonging to 318 species (26.5 percent) and 146 genera (36.5 percent) are found in wetlands of India. Among wetland birds Charadriidae, has the largest representation followed by Anatidae and Ardeidae (Vijayan, 1986).

Species diversity of avifauna in several wetlands has been worked out by various workers using banding data. The Chilka lake hosts over 150 species in peak winter migratory season, of these, 32 percent are aquatic, 22 percent are waders and 46 percent are terrestrial birds. A major concentration in terms of species abundance are dabbling ducks (*Ana penelope*, *A. sstrypera*, *A. clypeata*, *A. querquedula*), diving ducks (*Aythya nyroca*, *A. ferina*, *A. fuligula*), etc., which spread throughout the lake (Hussain, 1988). Kabar, a freshwater wetland in Bihar includes 109 species of residential and 59 species of migratory birds. The lake Pulicat harbours over 150 species of birds, of which flamingoes and pelicans are most important. Kolleru, the largest freshwater wetland in the country, has over 136 species of birds (Nagulu, personal communication). The Point Calimere (a brackish water wetland, not included in the present list of wetlands of India) hosts over 230 species of birds, of which 14 percent are permanent residents, 32 percent are local migrants, 33 percent are long distant migrants and rest are

stragglers. Although the wetlands in Kashmir valley resemble those of temperate condition, they provide a broad spectrum of dispersal ground for many aquatic birds. Based on Shanon - Weiner Index, the species diversity of wetland birds is found to be highest in Bharatpur followed by Karera, Harike and Chilka (Vijayan, 1986).

Information on the population of wetland birds is fragmentary except for the work of Vijayan (1986). According to him, 264 forms (63 percent) are common, while 81 forms (19 percent) are uncommon and 72 (17 percent) are rare. And, of the 417 species recorded so far, 115 species (28 percent) are resident, 81 (19 percent) local migrants, 156 (37 percent) migrant and rest are resident migrants, breeding migrants, stragglers, etc. Apart from these population dynamics, information on the food and feeding habits of the wetland birds is very fragmentary. Hence, as a part of conservation of this diverse group, studies on population dynamics, species diversity, geographical distribution, nesting, food and feeding habits of the bird fauna are of prime importance. These will enable us to understand the role of wetlands and their management as a waterfowl habitat.

Role of Wetland Invertebrates

In common with other invertebrates, the diverse avifauna of the Indian sub-continent has strong tropical affinity. Most of the species inhabit densely wooded areas, but a large number are also associated with coastal water (Pulicat, Chilka, Nalsarovar). These coastal brackish marshes support a diverse and abundant population of birds. The reason for species diversity can be attributed to the structural diversity of the vegetation as in Kabar wetland or abundant invertebrates. For eg. 33 species of polychaeta, 58 species of copepoda, 54 species of decapoda, 34 species of gastropoda, 45 species of lamellibranchiata, 15 species of isopoda, etc. in the lake Chilka have been reported, that can sustain the requirements of breeding population. The importance of invertebrates can be well understood in wetlands by studies of Krapu and Swanson (1975), and Sudgen (1973), as invertebrates accounted for 97 - 99 percent of food consumed by male and female Northern Shoveller (*Anas clypeata*) during the breeding season. According to Swanson (1988), the invertebrate constitute the major food source, the principal food being Cladocera (28 percent), Anostraca (9 percent), Copepoda (9 percent), Gastropoda (32 - 36 percent) and Insecta (9 percent). Similarly, *Anas strepera* live on a diet dominated by plants during most part of the nonbreeding season and on invertebrates (45 - 62 percent) during the breeding season. Invertebrates dominated the diet of juvenile Mallards and immature Blue-winged Teals. Studies conducted on the food habits of dabbling ducks (Anatini) demonstrated high consumption of adult Diptera, while they are emerging from water surface. High consumption of invertebrates during the breeding season has been interpreted as a response to a physiological demand for protein during egg production and period of rapid growth.

Management and Environmental Priorities of Wetland

Management

Article 3 - 1 of the Ramsar convention states that "not only the contracting parties formulate and implement their planning so as to promote the conservation of wetlands included in the list "but also shall promote, as far as possible, the wise use of wetlands in their territory" The convention gives no precise guidelines in the management of the wetland; however, it is generally accepted that the aim of the management should be to prevent the change of the ecological character in the wetland, especially the natural ones.

Sterns (1978) lists several specific management goals such as to (1) maintain water quality, (2) reduce erosion, (3) protect from floods, (4) provide a natural system to process air borne pollutants, (5) provide a buffer between urban residential and industrial segments to ameliorate climate and physical impact such as noise, (6) maintain a gene pool of marsh plants and provide examples of complete natural communities, (7) produce wildlife, (8) control insect population (9) provide habitat for fish spawning and other food organisms, (10) produce food, fodder, fibre, etc., (11) provide aesthetic and psychological support and (12) expedite scientific inquiry.

In order to achieve a desired goal for the conservation of any ecosystem, an intensive management inventory is essential, which provides specific information on the problems based on the resource survey taken up by the specialists. Such inventory is lacking in our country. The following informations are essential for the better management of the wetland ecosystem *viz.* (1) data collection in relation to physical, chemical and biological characters of the wetland, (2) identification of specific problems such as resource survey, socio-economic dependency, identification of specific group that needs attention in relation to its use and preservation, (3) conservation measures needed for preserving biological diversity, (4) protective and restorative measures to retain the normal condition, and (5) scientific inquiry which will aid in research, education and aesthetic values of the system.

Environmental Priorities

Wetlands exhibit several features of a fragile ecosystem as they comprise unique habitats of aquatic and terrestrial ecosystems. As already mentioned, the richness and diversity of the species are due to the "spatial heterogeneity" which is mainly controlled by physical and chemical characters of the water, sediment, substrate, nature of the consumer and decomposer on the primary producer. One of the priority item for the management of the wetland is, therefore, to understand the long term and short term fluctuation in the system.

Wetlands are vulnerable to man's activities especially in the form of pollution leading to changes in the structure and relationships of several groups of organisms. Environmental change often affects the diversity of the fauna and

flora. A study on the physical and chemical characters of the water regime in wetland is essential to understand the environmental problem.

The coastal wetlands depend much on the dynamics of freshwater from the river and salt water from the sea. Influence of salt and freshwater makes the system more complex, productive and biologically diverse. An understanding of the proper functioning of the wetland is essential for their management and conservation.

Coastal brackishwater, especially Chilka and Pulicat and freshwater like Harike, Kabar, and Bharatpur attract large number of birds for roosting and breeding. Attention to study the population dynamics of avifauna in India have been meagre. Hence, there is necessity of status survey of the wetland birds for the effective management of wetlands.

Wetlands are rich in plant and animal species (genetic diversity). Several catchment areas adjoining wetlands are also equally rich in wildlife, especially birds. Nutrient and energy are constantly moving in such an ecosystem (Likens and Borman, 1974). It is necessary to protect these areas because of the dynamic interaction between fresh and salt water or land and freshwater.

The senescence of vegetation is important in the formation of litter. This, in turn, forms the food for several detritivorous animals. An understanding of litter is a key element in the productivity of the wetland. This eventually determines the value of the site for animal life.

Several wetlands are exploited as areas of commercial fisheries and innumerable fishermen are dependent on these (Kabar, Pulicat, Chilka, Kolleru). Similarly, in several brackishwater lakes, bivalves and gastropod molluscs are commercially exploited for calcium, and water is used for salt extraction. An understanding on the distribution of the fauna and its abundance, in relation to various environmental parameters are essential, in addition to the socio-economic survey of the area.

Macrophytes and macroinvertebrates form the chief food for several fishes and birds. Therefore, an understanding of the invertebrate ecology and macrophytic distribution is essential in order to understand the food web complex of wetlands.

Wetland Values

Wetlands are known for their genetic diversity and a rich resource of flora and fauna. All these constitute an important gene pool for potential exploitation and management. In an ecological sense wetland 'Value' is mainly related to primary production in providing food energy that drives the ecosystem (Mitsch and Gosselink, 1986). The importance of wetland is due to the following characters :

1. In many temperate countries several fur bearing mammals such as Beaver,

Mink, Muskrat, Otter, etc. are abundant in swamps and coastal marshes apart from crocodiles and alligators.

2. Wetlands are the best known areas for the abundance of water fowl than any other ecosystem.
3. About twothirds of fish and shell fish species harvested commercially are associated with wetlands.
4. Wetlands are known to produce herbaceous trees, shrubs and herbs used as fire wood, timber, fish traps, synthetic fibres, dye for cloth, several tannins, medicinal plants, wild varieties of several commercially exploited food grains, paper products, etc.
5. Wetlands are highly dynamic areas having many endangered and threatened species which need immediate conservation measures for protecting them.

Apart from these, wetlands are known to have several ecosystem values such as :

1. Flood mitigation
2. Storm abatement, as many coastal wetlands acts as "storm buffers"
3. Aquifier recharge, i.e., ground water recharge
4. Wetlands are known to control the flow and regulation of organic and inorganic nutrients and toxic material from water that flows into them.
5. Areas of aesthetic, cultural and educational value.

References

- Anonymous 1980. *State of Art Report*, (Ed.) Director, Zoological Survey India.
- Anonymous, 1989. *Conservation of Wetland Ecosystem*. Ministry of Environment and Forests, New Delhi.
- Chacko, P.I., Abraham, J.G. & Andal, R. 1953. Report on the survey of flora, fauna and fishes of Pulicat lake, Madras state, India. *Contr. Freshwater Fish. Biol. Stn.*, 8: 1 - 20.
- Cowardin, L.M., Carter, V., Golet, F.C. & La Roc, E.T. 1979. Classification of wetlands and deepwater habitats of United States. *U.S. Fish. Wildlife Service Publ. FWS/OBS - 79/31*, Washington D.C.
- Day, Francis, 1889. *The Fauna Brit. India, including Ceylon and Burma : fishes*.
- Das, S.M. 1964. The Ichthyofauna of Kashmir, Part-I. The speciation of Kashmir fishes with two new records. *Ichthyologica, Vol. III* (1-2) : 57-62.
- Daterra, H. & Paterson, T.T. 1939. *Studies on the ice age in India and associated human culture*. Carnegie Institute, Washington.
- Gadgil, M. 1987. Lecture notes and abstracts of first Asian School on Conservation Biology. *Technical Report No. 50*. I.I.S., Bangalore.

- Hora, S.L. 1923. Fauna of Chilka lake, Fish- part- IV. *Memoir Indian Mus.*, 5(11) : 737 -769.
- Hora, S.L. & Mukerji, D.D. 1953. Table for the identification of freshwater fishes with description of certain families. FAO Fish Tech.paper.
- Hussain, S.A. 1988. Coastal wetlands. Major ecological entities for wading and shore birds. In : *The Ecology and Management of Wetlands*, Vol. 1. 203-212. (Ed.) D.D. Hook *et. al.*, Timber Press, Portland.
- Jacobs, J. 1975. Diversity, stability and maturity in ecosystems influenced by human activities. In : *"Unifying Concepts in Ecology"*, 187-207 (Eds.) W.H.Dobbeq and R.H.Lowe-Mc Connel. Dr. W.J.B.V. Publ., The Hague.
- Jayaram, K.C. 1982. *Hand Book of Freshwater Fishes*. (Ed.) Director, Zoological Survey of India, Calcutta.
- Jhingran, V.G. 1983. *Fish and Fisheries of India*. Hindustan Publ. Corpn. (India), New Delhi.
- Jhingran, V.G. & Gopalakrishna, V. 1974. *A Catalogue of Cultivated aquatic organisms*. FAO Fish Tech. Paper (Bo).
- Khushoo, T.N. 1986. *Environmental priorities in India and Sustainable Development*. Presidential Address, Indian Science Congress, New Delhi.
- Krapu, G. L. & Swanson, G. A. 1979. Some nutritional aspects of reproduction in Prairie nesting Pintails. *J. Wildlife Mgmt.*, 39: 156 - 162.
- Likens, G.F. & Bormann, F. H. 1974. Linkages between terrestrial and aquatic ecosystems. *Bioscience*, 24: 447 -456.
- Mitsch, W.J. & Gosselink, J. G. (Ed.) 1986. *Wetlands*. Van Nostrand Reinhold Co., New York.
- Nair, N.C. & Daniel, P. 1986. The floristic diversity of the Western Ghats and its conservation - A Review. *Proc. Indian Acad. Sci. (suppl)*, 91-110.
- Ripley, S.D. 1982. *A Synopsis of Birds of India and Pakistan*. Bombay Natural History Society, Bombay.
- Spagnesi, M. (Ed.) 1982. *Proceedings of conference of wetlands of International importance especially as a waterfowl Habitat*. Volume VIII.
- Stearns, F. 1978. Management potential, summary and recommendations. In : *Freshwater Wetlands : Ecological process and Management potential*, 359-369 (Eds.) R.E.Good, D.E.Whigham, R.L.Simpson. Academic Press, New York.
- Sudgen, L.G. 1937. Feeding ecology of Pintails, Gadwals, American Widgeon and lesser scaup duckling. *Canadian Wildlife Service, Report Series 24*.
- Swanson, G.A. 1988. Aquatic habitats of breeding waterfowl. In : *Ecology and Management of Wetlands*, vol. 1, 203-212 (Eds.) D.D. Hook *et. al.*, Timber Press, Portland.
- Vijayan, V.S. 1986. On conserving the bird fauna of Indian wetlands. *Proc. Indian Acad. Sci (suppl.)*, : 91 - 101.

Taxonomy of Freshwater Insects

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The role of taxonomy in understanding and utilizing biotic component of various ecosystems around us had been immense. It is undoubtedly true that contribution of taxonomy to applied sciences, related to human welfare, have been both direct and indirect, being fundamental to all research. Insect communities constitute the most varied and important invertebrate biotic component of our freshwater resources. These are integral part of the food-chain of their respective ecosystem. Insects, thus, play a very significant and pivotal role in aquatic realm. Utmost need of perfect acquaintance with wide ranging insects brings into the picture, much desired and deserving role of insect taxonomists. It's due significance is crystal clear since various 'interest groups', both lay and professionals, have been continuously suffering owing to our incomplete knowledge of aquatic insects, particularly of their immature forms. Adequate understanding of insects also paves way for various aspects of human welfare, water management and utilization. This paper devotes itself to i) insects and aquatic ecosystems, ii) role of insect taxonomy and wide ranging aquatic insects, iii) aquatic adaptations and role of insect taxo-ecologists and iv) insect taxonomy and applied entomology (as fish food, predator, fish bait, medical & veterinary significance, bio-indicator of pollution, etc.).

Insects vis-a-vis Aquatic Ecosystems

Aquatic realm comprises three fourth of our globe which is the only inhabitable abode for subsistence and survival of human beings. Life originated in water, which is also essential for its survival. Fresh water ecosystem supports wide ranging biotic components. This ecosystem is of two types : Lotic (= Running water bodies) and Lentic (=placid water bodies). Adequate understanding of this ecosystem is essential for its optimum and judicious utilization. Insects constitute integral part of this ecosystem, where they are found in abundance, both qualitatively and quantitatively. They are significant in the 'foodweb' of their respective ecosystem. These are consumers of different levels (phytophagous, carnivorous) and even degraders (detritivorous) of foodweb of their environment.

Role of Taxonomy and Aquatic Insects

Freshwater insect community presents a most varied and wide ranging spectrum. This necessitates the front line role of insect taxonomists. Merritt and Cummins (1984) have very rightly focused this aspect, "Identification is the first step towards a basic understanding of biology and ecology of aquatic insects; this will eventually allow for the development of proper management strategies".

Insects, though constitute one of the major components of the airbreathing terrestrial arthropods but have also colonized aquatic realm as an offshoot of evolution at several levels and occasions. This faction, though, represents only a small proportion, in the ratio of about 1 : 13, it nevertheless presents the most amazing variety. Enormosity of these are further enhanced due to the number of insect orders and different stages of their life cycle involved, and multitude of adaptations for acquiring food, breathing, mating, ovipositing, etc.

Wide Ranging Aquatic Insects

There are all together 13 insect orders, which are aquatic. Out of these 8 are truly aquatic and 5 have fringe aquatic representation (Usinger 1965; Merritt and Cummins, 1984; Srivastava 1986).

Truly aquatic insect orders are further divisible into two categories : i) strictly aquatic, in which the whole order is aquatic and ii) partly aquatic, where only a part of the order is aquatic.

Strictly Aquatic Insect Orders : This group encompasses such insect orders where all members have to undergo aquatic phase in their life cycle from oviposition to ultimate stage larvae. However, their adults are terrestrial, airbreathing and winged forms. This category includes 4 orders Viz., *Ephemeroptera*, *Odonata*, *Plecoptera* and *Trichoptera*, which are briefly discussed, hereunder, with special reference to the Indian forms.

***Ephemeroptera* (Mayfly)** : These are integral part of lotic and lentic freshwater ecosystems. These are mostly primary consumers in food-web and constitute bulk of the fishfood. Aquatic phase occupies bulk of life-span and comprises of oviposition, egg and larval stage. In lentic ecosystem these inhabit 3 eco-niches, namely i) Rooted vegetation in littoral zone and are known as climbers e.g. Baetidae genera *Ameletus*, *Baetis*, *Cloeon*, *Proclaeon* and Heptageniidae genus *Ororotisia*; ii) Silt at the substratum and are called sprawlers e.g. Caenidae genus *Caenis*, *Ephemerellidae* genus *Ephemerella*. Former of these possess stiff legs and 'Opercular cover' over gills and in latter thinly fringed tail, and iii) *Benthic substratum*, where they dig and live inside burrows. These possess narrow head, mandibular tusk and digging front legs e.g. *Ephemerella* (Ephemeridae).

Among lotic freshwater ecosystem there are also 3 eco-niche groups, namely, (i) Free ranging forms, which have slender streamlined bodies e.g. Baetidae

genera *Ameletus*, *Baetis*, (ii) Close clinging forms, which remain attached to rocks and pebbles and have broad flatbody, depressed femora and sprawling tails e.g. *Caenidae* (*Clypeocaenis*), *Heptageniidae* *Heptagenia*, *Iron*, *Ironopsis*, *Rhithrogena*, *Leptophlebiidae* (*Notophlebia*), and (iii) Trash silt moss forms which dwell on or among these and have stiff legs, with spines, e.g., genera *Ephemerella*, *Indialis*, *Petersula*, *Potamanthus* and *Prosopistoma*.

Ephemeropterans are represented in India by 95 species, 36 genera, 12 families (Srivastava 1983, Hubbard and Peters 1978). Larvae of 18 Indian species are only known (Srivastava, 1986). (Table 1)

Odonata (Dragon and Damselfly) : This is a common order associated with freshwater ecosystem of both lotic and lentic nature. These are carnivorous, voracious predators and act as secondary or tertiary consumers in food-chain. Odonates are of much significance and of mixed interest, as these are the bulk consumers of noxious and disease causing mosquito vector and also serve as fishfood, besides predating young stages of fish. These are also known to consume ephemeropterans. Aquatic phase of life cycle comprises of eggs, prolarval and larval stages, and 70-95% of whole lifespan is passed in water. Oviposition is both endophytic (e.g. Zygopterans, Petalurid and Aeshnid Anisopterans); and exophytic (e.g. Anisopteran families Gomphidae, Cordulidae and Libellulidae).

Odonates occupy both rooted zone of aquatic vegetation, specially in lentic ecosystem and on substratum as benthic forms. Former is mostly represented by zygopterans and latter by anisopterans. Zygopteran larvae are long and slender, with variously shaped caudal gills, while the larvae of anisopterans are relatively tough, broadbodied, devoid of caudal gills and respire through gaseous exchange in their cloacal chamber.

Odonates are represented in India by 490 species, 134 genera, 19 families and 3 suborders. (Fraser, 1933, 34,36 and 57, Srivastava & Sinha, in press) (Table 1). Immature larvae of Indian Odonates are known only by a small proportion 103 : 409 i.e. 1 : 4.5.

Plecoptera (Stonefly) : These are known to inhabit non polluted, cool running water or rocky edges of cool lakes, with gravely or stoney substratum. In relatively warmer habitats, a few of these colonize running water in cool shade of dense forests. Aquatic phase of stone fly is comprised of eggs and larvae. The aquatic phase of these insects occupy three-fourth of the whole life span. Larvae are either primary consumers (e.g. members of the suborder Filippalia), or secondary consumers (e.g. members of the suborder Setipalia). Larvae of larger Perlid stoneflies are used as bait for angling, including their imitations. Presence of large stonefly creeper in a river is a mixed blessing, for its value as troutfood and bait. However, it is counter balanced by its noxious habit of preying mayfly larvae.

This order is relatively small; a little over 100 species under 7 families, and 2 suborders viz., Filippalia and Setipalia are represented in India. In the former,

both larvae and adults are phytophagous and in the latter larvae are carnivorous and adults are nonfeeding. Latter feature is shared with adults (subimago and imago) of mayflies.

Trichoptera (Caddisfly) : The aquatic phase of its life cycle comprises of eggs, larvae and pupae. Almost fourth-fifths of the lifespan is aquatic; maximum duration is of pupae. Oviposition is in or near water; some of the species deposit their egg masses above water on various objects e.g. limnephilids. On the other hand majority enter the water to attach their eggs with submerged objects. Larvae inhabit both lakes and streams, with definite preference for colder and unpolluted water. Some, however, live exclusively in swiftly flowing water e.g. Rhyacophilidae, Sericostomatidae, Odonotaceridae. Standing water body is inhabited by Phrygeneidae, while Molannidae, Limnephilidae and Leptoceridae inhabit both lotic and lentic water bodies. Larvae feed both on plant and animal matter chiefly insect larvae, crustacea, etc.). Caddis flies (larvae, pupae & adult) are significant as fishfood and some larvae are used as corebait.

Caddisfly larvae are known for building cases, which are their portable "houses". These cases are of different shapes, size and material. A few important ones are : (i) simple tubes burried in and at the bottom, and cemented (e.g. Phychomyiid, notably of genus *Phylocentropus*) (ii) Saddle cases of stones, with saddle stone strap (e.g. Rhyacophilids), (iii) Purseshaped case (e.g. Hydroptilids), etc. Some larvae are free living as in genus *Rhyacophila*; and some of these free-living forms weaves a fixednet and shelter. These may be 'fingernet' (e.g. Philopotamidae), 'Trumpet net' (e.g. Phychomyiidae) or specific 'Hydropsychidnet' (e.g. Hydropsychiidae).

Pupation is a must for caddisfly. This they do either by constructing a cocoon of silk on the side of stone, or else, as with the casebearing species, they seal up the ends of their cases with a mesh of web. Pupae are inactive and do not eat.

Order is represented in India by about 350 species under 12 families (Table 1).

Partly Aquatic Insect Orders : This group of aquatic insects includes those orders which are only in part aquatic i.e. all their species are not water dependent. Further these insects may pass whole or part of their life in water, utilizing either dissolved oxygen or surface air.

This eco-group is further divisible into to categories viz. quite fair aquatic insect orders and fringe semi-aquatic insect orders.

Quite Fair Aquatic Insect Orders : 4 insect orders constitute this eco-group, which are *Diptera*, *Hemiptera*, *Coleoptera* and *Neuroptera*. These are briefly discussed here.

Diptera (Flies, Gnats, Midges) : Dipterans constitute a very significant aquatic order as being vector of certain human diseases like Malaria, Filariasis, Dengue, Yellowfever and even malaria of veterinary importance. Certain

Table - 1 : STRICTLY AQUATIC INSECT ORDERS (WHOLE ORDER AQUATIC)

Sl. No.	ORDER (Common name) Total: Species/ Families	SPECIES INDIA : WORLD	TXONOMIC CATEGORY		AQUATIC PHASE					BIOLOGICAL CONTROL	FOOD		
			SUBORDER + No. of Family	FAMILY	OMPOSITION EXO/ENDO.	EGG	PROLARVA	LARVA	PUPA		HERBIVORES	CARNIVORES	DETRITIVORES
1	EPHEMEROPTERA (Mayfly) Species : 95 Suborder : - Families : 12	85 : 2150	- 12	BAETIDAE CAENIDAE EPHEMERELLIDAE EPHEMERIDAE EUTHYPLOCIDAE HEPTAGENIDAE LEPTOPHLBIIDAE PALINGENIIDAE POLYMITARCYIDAE POTAMANTHIDAE PROSOPISTOMATIDAE SIPHONURIDAE	+ Exo.	+	-	+	-	+	+	-	+
2	ODONATA (Damselfly & Dragonfly) Species : 490 Suborder : 3 Families : 17	490 : 7000	ZYGOPTERA 10	COENAGRIDAE PLATYSTICTIDAE PROTONURIDAE PLATYCNEMIDAE CHLOROLESTIDAE AMPHIPTERYGIDAE CHLOROCYPHIDAE EUPHAEIDAE CALOPTERYGIDAE AGRIIDAE	+ Endo.	+	+	+	-	+	-	-	+
			ANISOZYOPTERA	EPIOPHLEBIIDAE	+	+	+	+	-	+	-	-	+
			ANISOPTERA 6	CORDULEGASTERIDAE GOMPHIDAE AESHNIDAE CORDULIDAE LIBELLULIDAE MICRODIPLACTIDAE	+ Endo. + Exo.	+	+	+	-	+	-	-	+
3	PLECOPTERA (Stonefly) Species : 100 Suborder : 2 Families : 7	100 : 1200	FILIPALPIA 5	NAMOURIDAE CAPNIIDAE LEUCTRIDAE PELTOPTERYGIDAE TAENIOPTERYGIDAE	+	+	-	+	-	+	+	-	-
			SETIPALPIA	PERLIDAE PERLODIDAE	+	+	-	+	-	+	+	-	-
4	TRICHOPTERA (Caddisfly) Species : 350 Suborder : - Families : 19	350 : 4000	- 19	RHYACOPHILIDAE PHILOPOTAMIDAE LIMNephilidae LEPTOCERIDAE MOLANNIDAE STENOPYCHIDAE PHRYGENIIDAE BERAEIDAE ODONOTOCERIDAE SERICOSTOMATIDAE HYDROPTILIDAE POLYCENTROPIDAE PSYCHOMYIIDAE HYDROPSYCHIDAE CALMACOCERITIDAE PHILANSIDAE ADICOPHIDAE PLECTROPTARSIDAE PHILORHEITHRIDAE	+	+	-	+	+	+	+	-	-

Table - 2: PARTLY AQUATIC INSECT ORDERS (FAIR - 4 AND FRINGE* — 5 ORDERS)

Sl. No. + Total	ORDER (Common name) TOTAL: Species/ Families	SPECIES	TXONOMIC CATEGORY		AQUATIC PHASE				FOOD			APPLIED ASPECTS					
		INDIA : WORLD	SUBORDER + No. of Family	FAMILY	OVIPOSITION	EGG	LARVA	PUPA	ADULT	HERBIVORES	CARNIVORES	DETRITIVORES	FISH-FOOD	BAIT	BIOINDICATOR POLLUTION	BIOLOGICAL CONTROL	MEDICAL VET. IMP.
1.	DIPTERA Species : 2319 Suborder : 3 Families : 17	2319 : 10,000	NEMATOCERA 13	CULICIDAE CHIRONOMIDAE CENTROPOGONIDAE SIMULIDAE BLEPHAROCERIDAE DEUTEROPHLEBIDAE TIPULIDAE TRICHO CERIDAE PTYCHOCERIDAE NYMPHOMYIIDAE DYXIDAE CHAOBORIDAE THAUMALEIDAE	+	+	+	+	-								+
				BRACHYCERA 2	TABANIDAE STRATIOMYIIDAE	+	+	+		+	-	-	+	+	+	-	+
				CYCLORRHAPHA 2	SYRPHIDAE EPHYDRIDAE	+	+	+		+	+	-	+	+	+	-	+
2.	HEMIPTERA (Homoptera : Bugs) Species : 2619 Suborder : 1 Group : 2 Families : 11	300 : 3200	CRYPTOCERATA 3	CORIXIDAE NOTONECTIDAE BELOSTOMATIDAE	+	+	+	-	+	-	-	+	+		+	-	-
			GEMNICERATA 8	NEPIDAE GERRIDAE VELIIDAE HYDROMETRIDAE MESOVELLIDAE SALDIDAE NAUCORIDAE GELASTOCORIDAE	+	+	+	-	+	-	+	-	-	-	-	+	-
3.	COLEOPTERA (Beetles) Species : 500 Suborder : - Families : 15	500 : 5000	- 15	DYSTICIDAE HYDROPHILIDAE GYRINIDAE HALIPLIDAE HELODIDAE HETRO CERIDAE GEORYSSIDAE PSEPHENIDAE AMPHIZOIDAE DRYOPIDAE HYDRAENIDAE HYDROSCAPHIDAE ELMIDAE LIMNICHIDAE PSEPHENIDAE	+	+	+	-	+	+	-	+	-	-	-	-	-
4.	NEUROPTERA (Spongilla Flies)	3 : 30	-	SISYRIDAE	-	-	+	-	-	-	+	-	-	-	-	-	-
5.	MEGALOPTERA (Alder, Dobsonfly)	30 : 300	-	SIALIDAE CORDALIDAE	-	-	+	-	-	-	+	+	+	+	-	-	-
6.	HYMENOPTERA (Wasps)	-	APOCRITA SECTION : PARASITICA	ICHNEUMONIDAE CHALCIDIDAE DIAPRIIDAE SCELIONIDAE AGRIOTYPIDAE POMPIDAE	+	+	-	-	+	-	-	-	-	-	-	-	-
7.	COLLEMBOLA (Spring Tail)		ARTHROPLEONA SYMPHYPLEONA	ONYCHIURIDAE PODURIDAE HYPOGASTRURIDAE ISOTOMIDAE ENTOMOBRYIDAE SMYNTHURIDAE	-	-	+	-	+	-	-	-	-	-	-	-	-
8.	ORTHOPTERA (Crickets)	- -	- -	TRIDACTYLIDAE	-	-	-	+	+	-	-	-	-	-	-	-	-
9.	LEPIDOPTERA (Moth)	-	-	PYRALIDAE NOCTUIDAE	+	+	+	-	+	-	-	-	-	-	-	-	-

dipterans like midges, crane fly, brine fly etc., constitute important fish food and food of aquatic game birds. Aquatic dipterans inhabit both lotic and lentic freshwater ecosystems. These may be found suspended, free swimming, attached to or free moving among aquatic vegetation, or buried in mud, sand, gravel or under stones. These may be primary (being herbivorous), secondary or tertiary consumers (being predators or scavengers). Swiftly flowing water bodies harbour Blephariceridae, Deuterophlebiidae, Nyphomyiidae, Thaumaleidae, Simuliidae, Psychodidae (only genus *Maruina*), and standing water bodies harbour Chaoboridae, Culicidae, Dixidae, Chironomidae, Ceratopogonidae. Burrowers live in the bottom or margin of water bodies (e.g. rest of Chironomidae, and Ceratopogonidae, besides Tipulidae, Tabanidae, Stratiomyidae, Syrphidae, Doliochopodidae). In India, aquatic dipterans are represented by 2319 species, 260 genera 17 families 3 suborders. (Table-II).

Hemiptera (Homoptera Bug) : Aquatic hemipterans occupy a wide variety of lotic and lentic ecosystems. These may be aquatic or semiaquatic. Most of these are predators and constitute intermediate stages of the food chain as secondary or tertiary consumers.

Pond dwellers comprise of notonectids (back swimmers) and belostomatids (giant water bug). The former of these are predators of all invertebrates and large fish fry, and the latter feed on insects, snails, small fish and small frogs. Gerrids (water striders, pond scatters) occupy still part of the running water, Velids (small waterstrider, riffle bugs) inhabit more protected and secluded zone, and marsh traders (Hydrometrids) dwell in protection against plants, emergent grass, duckweed, etc. All these feed on small invertebrates. Marsh traders are of special significance being predator of anopheline larvae. Surface and shore of lakes and streams are inhabited by mesovellids (water trader), salicids (shorebug) and gelastocorids (toadbug), and all these feed on a variety of insects and snails. Corixids (water boatman) are truly aquatic both in their larval and adult stages of life cycle. These are most numerous of all aquatic hemipterans, both in number of species and individuals.

Hemiptera is a big order of insects, with about 4500 species represented in India. Only a part of the order is aquatic. This aquatic component is further divided on eco-habitat basis into "truly aquatic" living beneath water (e.g., members of Cryptocerata) and "semiaquatic" living on surface of water bodies (e.g. members of Gemnicerata) (Table 2).

Coleoptera (Beetles) : Coleopterans constitute one of the biggest insect orders, though aquatic representation is relatively not so large. Aquatic coleopterans, nevertheless, constitute a prominent component of both lotic and lentic water bodies. These are the source of food for fish e.g. dysticids, haliplids, etc., while gyrrinids consume even small fish, besides bloodworm and odonate larva. Among lentic fresh water bodies like ponds, lakes, etc., highest representation is found in shallow and small water bodies, with abundant plant growth. Here all families of aquatic beetles are found except amphizoids, ptilodactylids,

dryopids and elmids. Rocky shore line of such water bodies also harbour dytiscids, psephenids, elmids, chrysomelids, curculionids and hydrophilids. They are found on the margin of shallow weedy zone, protected from wave action. Lotic system harbours beetles, specially under stones, in the faster water even far away from the shore e.g. dryopids, elmids, psephenids, ptilodactylids, etc. Waterlogged wood and accumulation of leaves harbour amphizoids, hydraenids, hydrophilids, helodid, dryopid and elmids. Coleopterans are represented by 8 families, with true aquatic larvae and semiaquatic adults. There are 6 other families which have fringe aquatic representation. Dysticids and gyrids are quite common aquatic Coleopterans (Table 2).

Neuroptera (Spongilla Flies) : This order is holometabolous; only larvae are aquatic, rest terrestrial. Larvae are inhabitant of both lentic and lotic water bodies of tropical and temperate climate. These are intermediate in foodweb, being predacious. Sisyrid larvae are usually found associated with freshwater sponges, where they suck the fluid either remaining on its surface or in cavities. This order is much smaller and is represented world over by little more than 300 species under single family Sisyridae. (Table 2).

Fringe Semiaquatic Insects : Megaloptera, Hymenoptera, Collembola, Orthoptera and Lepidoptera are, though quite big insect orders but are mainly terrestrial. A very small proportion of these orders have aquatic representation. This 'eco-group' is termed fringe semiaquatic insects, because of only marginal aquatic representation.

Megaloptera (Alderfly, Dobsonfly, Fishfly) : These are one of the most primitive winged insects, close to Neuroptera, Mecoptera and Hymenoptera. Aquatic representation is only by two families, namely Sialidae (Alderflies) and Corydalidae (Dobsonflies). Larvae of these insects are aquatic and breathe by means of long, slender, tapering, lateral processes or tuft of filaments at the base of these processes. Sialid larvae are abundant in streams, rivers and even lakes, where substrate is soft and detritus abundant. Cordyalids (=Hellegrammites) inhabit springs, seeps, rivers, lakes, ponds and swamps. These feed on a wide variety of small aquatic invertebrates. On the other hand these also serve as food for fish, while larvae of larger species are significant being highly prized fishbait.

Hymenoptera (Wasps) : This order has only a few fringe aquatic representation. Although world over the order is represented by about 1,20,000 species, the Indian representation is by Symphyta (350 spp.) and Apocrita (7000 spp.). Aquatic hymenopterans were considered by Hagen (1965) as those species which are known or suspected to either live in or crawl under the surface of water to parasitize their host. However, Burgeles (1959) definition is considered more apt- "all species parasitizing aquatic state of insects" in its broader sense. Superfamilies Ichneumonoidae, Chalcidoidea, Proctotrupoidea and the family Pompilidae include species in which adults have adapted to penetrate water surface, utilizing air entrapped in their dense pubescence.

***Collembola* (Springtail)** : Majority of the members of this order are terrestrial and are not considered 'aquatic' in the true sense. They may feed and live primarily on water but they do not lay their eggs in water. A very small number of 'specialized aquatic species' form part of freshwater "Neuston", and feed primarily on diatoms, unicellular algae and plankton, trapped in the surface film. Rapport and Sanchez (1963) recognized only two types of 'neustonic-conditions' among *Collembola*. Transitory, formed by temporary rain pool, and permanent, formed by typical lake, lagoon or ponds.

Indian component of the order is comprised of about 200 species 15 genera and 5 families. Of these, only 24 species under 15 genera and 6 families are definitely known to have freshwater inhabitation (fish ponds, rain pool, lake margins, etc.). The names of the families are Onychiuridae, Poduridae, Hypogastruridae, Isotomidae, Entomobryidae and Sminthuridae.

***Orthoptera* (Grasshopper, Cricket)** : This order is at most a extreme case of semiaquatic representation and only a few records are available of their association with aquatic ecosystem. Only two species of Tridactylidae (*G. apicalis* Say and *G. minutus* Scudder) have been recorded under this category by Usinger (1956). Merritt and Cummins (1984) have recorded 4 families (namely Tridactylidae, Gryllotalpidae, Terigidae, Acrididae) comprising of 19 species, 7 genera in lotic and lentic habitats. These may even be associated with vascular hydrophytes in emergent zone or margins, among these Gryllotalpids are collectors or predators (engulfers) and other are generally shredders, herbivores or even predators of their ecosystems.

***Lepidoptera* (Moth)** : This order is also catagorised as semiaquatic fringe order, like the previous one. Only a few records of their aquatic association exist. Adaptations to aquatic association is best exemplified by the family Pyrilidae. In this family, the immature stages (egg, larvae, pupae) undergo their entire development in water. Larvae of the tribe Argyractini feed on algae and diatoms found on the surface of rocks, submerged in fast flowing streams, springs or even lakes. Pyralid subfamily Schoenobiinae (*Accentropus niveus* Oliver) is also known to have true aquatic existence. There are 8 other families which contain only a few species capable of aquatic or semiaquatic existence either in their immature or adult stages. Families concerned are : Cossidae, Arctidae, Phalaenidae, Tortricidae, Yponomatidae, Tineidae, Nepticulidae and Sphingidae. However, Pennak (1953) had placed all aquatic forms under *Elophila* and *Nymphula*. Larvae of 3 species of genus *Bellura* (Nocturidae) are also known to be aquatic.

Important Aquatic Adaptations of Insects

Insects have undergone a number of aquatic adaptations. Insect taxonomists have to confront with multitude of forms so evolved. Certain important adaptations are briefly indicated, hereunder.

Respiration : Aquatic insects have the following adaptations for their respiration. The cuticular respiration is very common in the immature stages of most aquatic insects. Bloodgills with haemoglobin has been utilized by chironomid larvae, also commonly known as 'blood worm'. Tracheal gills have been developed in many insect larvae e.g. mayfly, damselfly, stonefly, etc. Rectal gills are utilized in larvae of dragonfly, both in Anisoptera and Anisozygoptera. Atmospheric oxygen is also variously utilized. Air bubbles are entrapped and periodically replenished, e.g. in adult bugs and beetles. Direct contact with the atmosphere is established by breaking surface water with the help of hydrofuge hairs, tubes or surfaces e.g. adult beetles, bugs and rat tail larvae of Syrphids. Oxygen is also obtained by inserting tubes in roots and stems of aquatic plants e.g. in larvae of beetle *Donacia* and larvae of mosquito *Mansonia*.

Morphological Adaptations to Lotic Ecosystem

Aquatic insects have certain morphological adaptations to suit their environment. Body has become dorsoventrally flattened, broad, with smooth streamlined dorsum to counter current and water pressure e.g. in Heptagenid mayfly and perlid stonefly. Definite localized or portable shelter has been constructed in larvae of caddisfly. Friction pad by enlarged gills providing firm anchor with stones and pebbles has developed in mayfly larvae *Epeorus*, *Rhithrogena*. 'Falsesuckers' and 'pushing prolegs' have been developed in certain chironomid and deuteroephlebrids. Flattened wedged shaped head and fuscorial tibiae have been developed for burrowing into substratum e.g. many Gomphid dragonfly larvae. Sprawlers on sandy surface have developed, broad, flat body and long legs e.g. larvae of many Macromid, and Libellulid dragonflies. To counter swift current, hooks and silk attachments have been developed in Simuliid larvae; while only silk attachment are present in certain caddisflies e.g. hydropychids, philopotamids, polychomids, etc.

Morphological Adaptations to Lentic Ecosystem

The unique properties of water's surface tension constitute the environment of Neuston community e.g. water striders (Gerridae), whirling beetles (Gyrinidae), mosquito larvae (Culicidae), springtails (Collembola). Surface movement by preapical claws and non wettable velvety hydrofuge hair pile are utilized in water striders and bugs of related family of Veliidae.

Adaptations for Obtaining Food

Direct current carrying microorganisms are trapped with the help of silk nets e.g. caddisflies, chironomids, etc. Sucking movement by comblike rake near the mouth of insects has been utilized to get microorganisms e.g. Simulium larvae. Certain heptageniid mayfly and glossosomatid caddisfly have developed specialized scrappers, whereas common phytophagous scrappers are utilized in

most mayflies. First pair of prehensile legs are utilized for holding and then piercing and sucking their prey as in *Ranatra*, *Nepa*, etc. (Hemipterans). Dragonfly larvae have developed a unique system of throwing with speed their protrusible prehensile labium for holding and engulfing.

Applied Aquatic Entomology

There are several instances among aquatic insects which are related to applied aspect. It is obvious that detailed taxo-ecological knowledge of these insects is essential to utilize these in the best way. Certain important aspects of applied aquatic entomology are as follows :

Aquatic Insects as Fishfood and its Predator

Aquatic insects as fishfood occupy quite an important role. Aquaculture is in practice since the dawn of history and has been a source of protein in India and China. Insects constitute an important element in fishfood in ponds and lakes. These insects, in their turn, are dependent on phytoplankton and other organic matter for their existence. Many orders of aquatic insects serve as fishfood. Mayflies as fishfood is of great significance. Practically all littoral and benthic mayfly larvae are readily consumed by fish. Emerging subimago, ovipositing female and 'Spentmale' imago are also used as fishfood. Odonate larvae are also predated by fish (Percidae, Centrarchidae, Salmonidae), besides aquatic birds. Fish also consume larvae of Perlid stonefly, caddisflies (larvae, pupae and freshly emerged adults, ovipositing female, both male and female spent and lying on the surface of water), Midges, Crane fly, Brinefly, Beetles (Dysticids, Haliplids) etc.

On the other hand fish are also predated, when they are young, by a number of insects. Important among them are Odonata (dragonfly and damselfly larvae) and Hemiptera (Notonectids, giant *Bellestoma*, *Nepa*, *Rantara*, etc.

This makes it, therefore, imperative that insect taxonomists, bioecologists and fish culturists should work in close collaboration. It also indicates that a pure negative approach is not adequate for proper management of insects in pond fish culture.

Aquatic Insects as Fish Bait

Certain aquatic insects are readily taken by fishes. Artificial flybaits are in use for angling since quite some time. There are two types of artificial fly viz. dryfly and wetfly. Former are imitations of adults of insect which fall on water surface e.g. adult mayflies, caddisflies and trueflies. Later are imitations of larvae, which are consumed by fishes under the water, including adults which descend down for oviposition e.g. larvae of mayflies, caddisflies, stoneflies, etc. Harris (1952) has listed 45 species of mayflies, 18 caddisflies, 13 stoneflies, 5 dipterans and a single Sialid, imitations of which are used as bait.

Perfect taxonomic knowledge of above mentioned aquatic insects and their biology is felt desirable for making precise, realistic duplicates to serve as a surebait.

Aquatic Insects as Bio-indicator of Pollution

Increasing use of relative tolerance in insects towards various kinds and levels of pollution has been utilized as bio-indicator of pollution. Presence or absence of certain groups of aquatic insects in freshwater ecosystem, specially benthic forms and more particularly in streams has been fixed as criteria of the extent of pollution.

Mayflies have been found as very significant bio-indicator of pollution. Many pollutants have a marked effect on mayfly larvae. Srivastava (1986) has shown relative tolerance, in increasing order: Baetidae; Ephemeridae; Leptophlebiidae; Palingeniidae; Polymitarcyidae; Prosopistomatidae; Heptageniidae; Caenidae and Ephemerellidae.

Caddisflies, stoneflies and dipterans are also used as bio-indicator of pollution. *Culex*, *chironomus*, *cristalis*, *simulids* among dipterans are most tolerant aquatic insects.

Aquatic Insects of Medical and Veterinary Significance

Aquatic insects, specially members of the order Diptera are most significant to human and cattle welfare. the pathogenic organisms of some of the most virulent diseases, such as malaria, filaria, dengue, sleeping sickness, encephalitis, yellow fever and certain other diseases are transmitted to man through the intermediary of blood sucking dipterans. Of these, former 3 diseases are prevalent in India. Certain other dipterans of economic significance are Simuliidae causing *Onchocercia* (eye blinding) and *Leucocytozoonsis* (malaria of veterinary importance) in Africa, Syrphidae causing *Myiasis* in India and Tabanidae causing Surra in horses and cattle in India.

Biological Control

Certain predatory insects (Odonata larvae, Hemipterans : Notonectids, Belostomatids, Nepidae, Hydrometridae, Coleopterans: Gyrinids) have potential which may be explored and utilized for biological control of vector of above diseases. This may be most suitable method from futuristic viewpoint as chemical control is expensive, increases toxicity and also leads to growing immunity of target vector.

It, thus, becomes imperative that insect taxonomists and bio-ecologists should work in close collaboration. Former to make accurate identification and systematic recording of species distribution, which are essential for potential assessment, prediction and control; and the latter to gain more accurate knowledge of biology, lifecycle, microniche, seasonal fluctuation, etc, so as to

properly manage their population, specially prior to any major impoundment projects.

References

- Ananthakrishnan, T.N. (Ed.) 1980. *State of Art Report*, Zoological Survey of India, Calcutta.
- Arun Kumar & Khanna V. 1983. A review of taxonomy and ecology of odonata larvae from India, *Oriental Ins.*, 17: 127-157.
- Burghele, A. 1959. New Rumanian species of Dacnusiini (Hymenoptera: Brachonidae) and some ecological observations upon them. *Entomol. mon. Mag.*, 95: 121-126.
- Fraser, F.C. 1933. *Fauna British India*, Odonata I., Taylor & Francis, London.
- Fraser, F.C. 1934. *Fauna British India*, Odonata II., Taylor & Francis, London.
- Fraser, F.C. 1936. *Fauna British India*, Odonata III., Taylor & Francis, London.
- Fraser, F.C. 1957. A reclassification of order, Odonata. Handbook 12 : 133 ; *Royal zool. Soc. N.S.W.*, Sydney.
- Hagen, K.S. 1956. Aquatic Hymenoptera, In : *Aquatic insects of California*, 289-292. (Ed.) R.L. Usinger, Univ. Calif. Press, I Berkley.
- Harris, J. R. 1952. *An Anglers Entomology*, Collins, London.
- Hubbard, M.D. & Peters, W.L. 1978. A catalogue of the Ephemeroptera of the Indian sub-region. *Oriental Ins., Suppl.*, 9, 1-43.
- Merritt, R.W. & Cummins, K.W. 1984. *An introduction of the aquatic insects of North America*, Kendal Hunt, Iowa, U.S.A.
- Nayar K.K., Anathakrishnan, T.N. & David, B.N. 1976. *General and Applied Entomology*, Tata McGraw Hill Publishing Company Ltd., New Delhi.
- Pennak, R. W. 1953. Aquatic Lepidoptera. In : *Freshwater invertebrates of the United States*. 585-587. Ronald Press Co., New York.
- Rapport F.H. and Sanchez, L. 1963. On the epineuston or superaquatic fauna, *Oikos*, 14: 96-109.
- Richards, O.W. & Davies, R.G. *A general text book of ecology* (10th Edition) 2 vols, Chapman & Hall Ltd., London.
- Ross, H.H. 1956. *A text book of Entomology*, 2nd Ed. John Wiley and Sons Inc., New York.
- Srivastava, V.D. 1980. Collection and Preservation of Aquatic insects. *Training course on Survey and Identification of insects and mites of economic importance*, 25-35. Z.S.I., Calcutta.
- Srivastava, V.D. 1983. An analysis of the faunal component of Indian Ephemeroptera and their role in aquatic ecosystems. *Proc. Sym. Ins. Ecol. & Resource manage.*, 153-168. Muzaffarnagar.
- Srivastava, V.D. 1984. High altitude Ephemeroptera of India, *Proc. Wkshp. High Alt. Ent. & Wildl. Ecol. Zool. Surv. India*, 137-149. Solan.
- Srivastava, V.D. 1986. Collection and preservation of Aquatic Insects, *Manual, Collection, preservation and identification of insects, and mites of economic importance*, 211-226. Z.S.I. Calcutta.
- Srivastava, V.D. 1986. Ephemeroptera larvae as component of aquatic environment and their role as bio-indicator of pollution. *Proc. sym. Pest. Resid. & Environ. Pollu.*, 206-218. Muzaffarnagar.
- Srivastava, V.D. Fauna of West Bengal, Insecta : Ephemeroptera, *State Fauna Series: Rec. zool. Surv. India, Calcutta* (In press).
- Srivastava, V.D. Sinha, C. Fauna of West Bengal, Insecta : Odonata, *State Fauna Series : Rec. zool. Surv. India, Calcutta*. (In press).
- Usinger, R.L., 1956. *Aquatic insects of California*, Univ. California Press, London.

Taxonomy in Conservation of Indian Butterflies

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Taxonomy is an observational science and a part of the age-old field of natural history. It is concerned with knowing animals as individuals, kinds or groups. It is historical in large part, studying the work of the past. It is modern as day to day knowledge is being added to it to reorganise it to yield new insights. The science itself is important to systematize the knowledge by further observation and analysis. In fact the increasing demands upon taxonomists for identification, classification and analysis of available data including the list of species of the concerned group, inter and intraspecific variations, distribution, biology, and other ecological parameters are much because taxonomy helps other branches of biology to work upon. Therefore, E.O. Essig made a comment, *Taxonomists must precede all other forms of biological investigation and furnish the foundation and frame upon which may be built the results of researches of all the natural sciences.*

Certain groups are sufficiently well known taxonomically and ecologically and may be of great value both for conservation planning from biogeographical analysis and for environmental planning in local scale. The butterflies have great potential for inclusion in the faunistic analysis and environmental monitoring due to the colour and pattern of the wings, wide range of habitat, existence of numerous locals and widespread species, subspecies and forms, specific requirements for food plants, etc. Herein lies the importance of taxonomy without which the informations pertaining to the above aspects are impossible.

The butterflies often with fabulous colours have aesthetic value. The most rewarding pleasure is to observe them flying in a forest or to see them in dry and pinned condition in a museum repository. Besides their aesthetic value, they are of great importance bringing about the pollination of a large number of plants. Generally, butterfly larvae are vegetable feeders and the food plants cover a very wide range from grasses to trees, with the exception of certain lycaenids which are carnivorous and devour coccids, aphids, membracids, etc.

Before proceeding to the conservation aspects of butterflies it is important to mention the biological diversity including the classification, biology and distribution of the group in a nut shell.

Classification

The butterflies are included in the suborder Rhopalocera under order Lepidoptera on the basis of clubbed antennae. The Rhopalocera is divided into two superfamilies Papilionoidea and Hesperoidea. The former includes five families namely, the swallowtails or Papilionidae, the whites and yellows or Pieridae, the largest family Nymphalidae containing tigers, crows or danais, browns or satyrids, and also amathusids, nymphalids and acraeids. Other two families are the Riodinidae and the Lycaenidae which are popularly called as blues or coppers. The latter superfamily includes a single family Hesperiidae popularly called as skippers due to their darting flight. Generally, the wings of papilionids are marked with red, yellow, green or blue and the hindwings are provided with tail-like prolongations. In pierids, the wings are white, yellow or orange coloured with black markings. The nymphalids are brightly coloured; forelegs in both sexes are useless for walking and the short tibiae are covered with long hairs. The riodinids are small butterflies with legs reduced in males but functional in females. The lycaenids may be characterised by the abbreviated tarsi of forelegs in males and absence of one or both claws. In hesperiids, the antenna is apically prolonged beyond the club and in most cases, the very tip is pointed and recurved like a hook.

There are about 1136 species of butterflies known from India of which *Troides minos* (Cramer), popularly called as bird wing, with the wing expanse of 140-190 mm., is the largest of all known butterflies of India and the common peacock, *Papilio (Princeps) polyctor* Boisduval secured maximum points in the beauty contest of butterflies in India (Wynter-Blyth, 1957).

Biology

The adult butterfly is only the last of four distinct phases in the life cycle; the early stages being the egg, larva and pupa. The eggs are generally dome-shaped and sculptured. The caterpillars are elongate with soft integument and have three pairs of true legs and five pairs of prolegs. The pupa has a hard, smooth integument with its appendages completely soldered down and covered by external plates and it is generally fixed to the substrate usually by its tail end. The adults of the butterflies may be characterised by the clubbed antennae, large and prominent eyes, expanded base of hindwing and also by the wings held erect or spread out flat, while sitting.

Predation and parasitism of butterflies are high at all stages of development and only a small proportion will survive to adulthood. The cockroaches feed upon the eggs, birds upon the larvae, and the birds, lizards, mantids and spiders are the enemies of the imaginal (adult) stages. The eggs and larvae of many species are either attacked by parasitic Diptera or Hymenoptera. Pupae of swallowtails are severely predated by small mammals.

The adults generally take nectar from flowers though several species feed upon decaying animal matters and excrement, but the caterpillars are usually vegetable feeders except some lycaenids which are carnivorous. The food plants on which the larvae feed and grow upto quiescent pupal stage are extremely variable not only in different families but also in the genera of a family. Let us take the examples from the family Papilionidae. The food plants of *Teinopalpus* is Thymeleacea while *Bhutanitis* are found abundantly on the Aristolochiaceae. *Troides* and *Atrophaneura* are found on Aristolochiaceae but *Papilio* (*Chilasa*) mainly feeds on Lauraceae and some on Rutaceae.

The butterflies generally fly in the day and there are some striking examples of swift flight of papilios and weak flight of pierids and danaiids.

The protective resemblances are found in different stages of life cycle. The larvae sometimes harmonise with the surroundings by their colour. The colour of the pupae sometimes resemble broken twigs, stones or rocks. A classical example of protective resemblance is found in some species of *Kallima* where the colour on the underside of wings resembles leaves. Mimicry is a form of protection against predators amongst butterflies. Some of the striking examples as mentioned by Talbot (1939) are *Prioneris sita* (C&R Felder) resembling *Delias eucharis* (Pieridae), *Hypolimnas missipus* (Linnaeus) female mimicking *Danais chrysippus* Linnaeus (Nymphalidae), and female form of *Papilio* (*Princeps*) *polytes romulus* Cramer mimicking *Atrophaneura* (*Pachiliopta*) *hector* Linnaeus (Papilionidae).

Sexual, seasonal, individual and geographical variations are found amongst butterflies. Polymorphism in females of *Papilio* (*Princeps*) *polytes* Linnaeus, dimorphism in both the sexes of *Papilio* (*Chilasa*) *clytia* (Linnaeus), variation in *Melanitis* spp. between dry and wet season forms, individual variation with respect to colour and markings of the form *dissimilis* of the species *Papilio* (*Chilasa*) *clytia* (Linn.) and geographical variations in some papilios are the striking examples of variations.

Distribution

The ecosystems and biomes and the distribution of the species are necessary to be considered to define the geographical units of conservation. Though North-east India is enriched with maximum number of species of butterflies yet quite a large number of species are found in Northwest India, western Himalayas, peninsular and insular parts of India. In this context it may be mentioned that out of a total of 1136 species of butterflies represented in India, 853 species are found in Northeast India, 421 in western Himalayas, 285 in Northwest India, 315 in Peninsular India and 265 in the Insular areas (Evans, 1932). The analysis of distribution of the rare and threatened butterflies shows that there are some endemic species in India. The rare and threatened swallowtails of the family Papilionidae may be referred to here as examples of endemism. There are five endemic species namely, *Parnassius maharaja* Avinoff in Northwest India,

Papilio (Princeps) mayo Atkinson in Andamans, *Papilio (Princeps) liomedon* Moore, *Papilio (Princeps) buddha* Westwood and *Papilio (Princeps) dravidarum* Wood-Mason in southern India (Collins & Morris, 1985).

Threat to Butterflies

The butterflies are the best known of all insect groups. Documentation of the conservation and biology of threatened and rare butterflies are relatively sparse in India though the threats on these insects come from different sources. The most severe threat is the destruction of entire biotopes and habitats which destroy plants and animals indiscriminately. Several ecosystems in India are changing too quickly due to excessive human interference through commercial exploitation, industrialisation, urbanisation, agricultural conversion of lands and intensification of agriculture, deforestation, etc. Industrial effluent and extensive use of pesticides are serious threats to all forms of wildlife including the butterflies. Accelerating demands of charcoal and wood, high level of human population, widespread agriculture cause deforestation and thereby causing great depletion in species existence (Collins & Morris, 1985). The degradation of pastures are reducing the butterflies species. Trade in butterflies is a flourishing business throughout the world. Butterfly trading in India is extensive. Some enthusiasts collect the butterflies as their hobbies. Illegal traders earn huge sum of money through exports and the scientists, sometimes, unnecessarily kill butterflies in the name of research.

Taxonomists play a major role in conservation of these magnificent creatures adding richness to the environment not only by identifying the species but also to identify the changing ecosystems, to inform about the relationships between plants and animals, to study the biology of threatened and rare butterflies, to prepare a document of rare and threatened species alongwith distribution without which protection of the species meant for conservation is impossible. However, the task of protection and preservation of wild fauna and flora depend largely on the politicians, legislators, scientists, conservationists and also individual campaigners (Collins and Morris, 1985).

Legislation for the Protection of Butterflies

Convention of International trade in endangered species of wild fauna and flora (CITES) controls and monitors imports and exports of listed species. Appendix I contains no insects and Appendix II contains only some species of Papilionidae. But National legislation to protect the butterflies has been enacted. Several species and subspecies of butterflies are protected by law in India under the Revised list of Schedules to the Wild Life Protection Act, 1972 as amended upto 1986. Under Schedule I, altogether 128 species and subspecies of the families Amathusiidae, Danaidae, Satyridae, Nymphalidae (all the first three families presently considered as Nymphalidae) Pieridae, Lycaenidae and Papilionidae have been included; 306 species and subspecies of butterflies

belonging to the families mentioned above in addition to the families Riodinidae (Erycinidae) and Hesperidae and 19 species and subspecies of the families Pieridae, Lycaenidae, Hesperidae and Nymphalidae including Danaids and Nymphalids have been included in Schedule II & IV respectively. As the threats to butterflies become more intense there is a need for careful management studies in India with particular reference to those species which have been threatened.

Suggestive Conservation Measures

- (1) The human interference in habitat destruction through deforestation, urbanisation, agricultural extension should be resisted and measures should be taken to control pollution through industrial effluents or extensive use of pesticides.
- (2) Where natural forests are severely depleted the plantation forestry should be initiated as a conservation tool. However, more attention should be given on the food plants where the larvae of butterflies feed and grow.
- (3) Farming of butterflies is to be implemented on a large scale so that the recolonization of the depleted areas with the butterflies facing extinction or being threatened to be extinct is possible.
- (4) Ranching of butterflies to meet the demands in the trade may be used.
- (5) The biology of threatened and rare species including those endemic should be studied in detail and further scientific studies are necessary to establish the population sizes of each species.
- (6) Preventive measures may be taken to avoid the collection of large number of specimens of a particular species bringing the population below the threshold of recovery.
- (7) More public awareness is necessary about the conservation needs of butterflies and effective implementation of legislation is required.

Taxonomists play a major role in identification, of species, their distribution, in elucidating species composition of the concerned geographical units and their identification of food plants and habitat on which the conservation basically depends. So the direct and indirect use of taxonomic concept are virtually universal among Biologists whether they are working on systematics, applied aspect or on conservation.

References

- Collins, N. M. & Morris, M. G. 1985. *Threatened swallowtail Butterflies of the world*. The IUCN Red Data Book. IUCH, Gland and Cambridge.

- Evans, W. H. 1932. *The identification of Indian Butterflies*. Second revised ed., Bombay Natural History Society, Bombay.
- Talbot, G. 1939. *The Fauna of British India-Butterflies*, 2nd ed., 1; Taylor and Francis Ltd., London.
- Wynter-Blyth, M. A. 1957. *Butterflies of the Indian Region*, 1st ed., Bombay Natural History Society, Bombay.

Taxonomy, Control and Environmental Management of Parasitic Protozoa

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Long before man acquired knowledge about the parasites themselves, the diseases caused by them were known to him. Gradual increase in knowledge on the taxonomy of parasites, specially parasitic protozoa, necessitated more information about their vectors as also their modes of transmission. These, in turn, demanded their control measures to be visualised in a multidimensional way. Growing global awareness towards a cleaner environment during the past several decades has warranted that the control of parasites should also be envisaged through environmental management programmes.

Man and his livestock are considered as integral parts of the environment. With rapid increase in human population, man has had to increase his livestock to meet up the ever increasing demand of protein and milk. A number of parasitic protozoa are found in man and his livestock causing several diseases. Some of these pathogenic protozoa are transmitted through vectors and others are spread through faeco-oral route by ingestion of cysts. Usually the parasites/vectors are properly identified and suitable therapeutic measures are applied for controlling these diseases. To achieve this goal, the principles of environmental management should be practiced more frequently. In the present context both the control measures have been discussed with reference to the role of taxonomy of these parasites.

Protozoan Parasites and Man

Malaria and Leishmaniasis are the two most important vector-borne parasitic protozoan diseases of man in India. Other noteworthy diseases caused by protozoa in this country are Amoebiasis and Giardiasis which are spread through the faeco-oral route.

Out of the four species of parasites of human beings, *Plasmodium vivax* and *P. falciparum* are common in India. These, as is well known, are transmitted through female anopheline mosquitoes. Of the two species of the genus *Leishmania* which are found in man, the one called *L. donovani* causes a dreadful

disease, Kala-Azar, and the other, *L. tropica* is responsible for Dermal Leishmaniasis. These are transmitted through sandfly.

Entamoeba histolytica causes Amoebiasis and *Giardia intestinalis* causes Giardiasis in man.

In addition, the peculiar disease Toxoplasmosis which is produced by *Toxoplasma gondii* is zoonotic, and has a complicated cycle involving rat, cat and man.

Protozoan Parasites and Livestock

Vector-borne protozoan diseases of the livestock in India are Babesiasis, Theileriasis, Anaplasmosis and Surra in cattle, buffaloes, sheep and goats. *Babesia bigumina* and *B. bovis* are the predominant species causing Babesiasis in cattle and buffaloes. *B. motasi* is common in sheep while *B. surgenti* is found in goats. *Theileria perva* and *T. motasi* cause Theileriasis in cattle, and *T. hirci* in goats. *Anaplasma* sp. causes Anaplasmosis in cattle. These are all transmitted through ticks. *Trypanosoma evansi* causing Surra in cattle is transmitted through tabanid fly. Coccidiosis is the other noteworthy protozoan disease of the livestock in India. This is transmitted directly through the faeco-oral route. Coccidiosis in the livestock is caused by several species of *Eimeria*. Thirteen species of *Eimeria* are responsible for coccidiosis in cattle and buffaloes while ten in sheep and goats.

Importance of Parasitic Protozoa in Relation to the Control of Diseases

It is well known that the specific drug of malaria is quinine or its synthetic substitute. It, therefore, follows that a person clinically diagnosed as suffering from malaria is to be treated with quinine/its synthetic substitute. Unfortunately, it may so happen that even after administering usual dose of the drug, the symptoms subside, but without reinfection the disease relapses. Under these circumstances the most logical conclusion would be that proper dose of the drug has not been administered. Because of the two common species of human malarial parasites, *P. falciparum* is more virulent and the dose of the drug required for the cure of this type of malaria is different from the dose required to cure *P. vivax* infection. Therefore, specific identification of the pathogen is absolutely necessary to determine the dose of the drug and the course of treatment. Specific identity of *Plasmodium* can be established only by a competent taxonomist by examining the blood smear. Similarly, the services of competent taxonomists are essential in establishing specific identities of some other pathogenic protozoans and their vectors, and also in controlling these parasitic diseases. Therefore, the importance of taxonomy in relation to the control of parasitic diseases can be properly emphasised.

Man and Environment

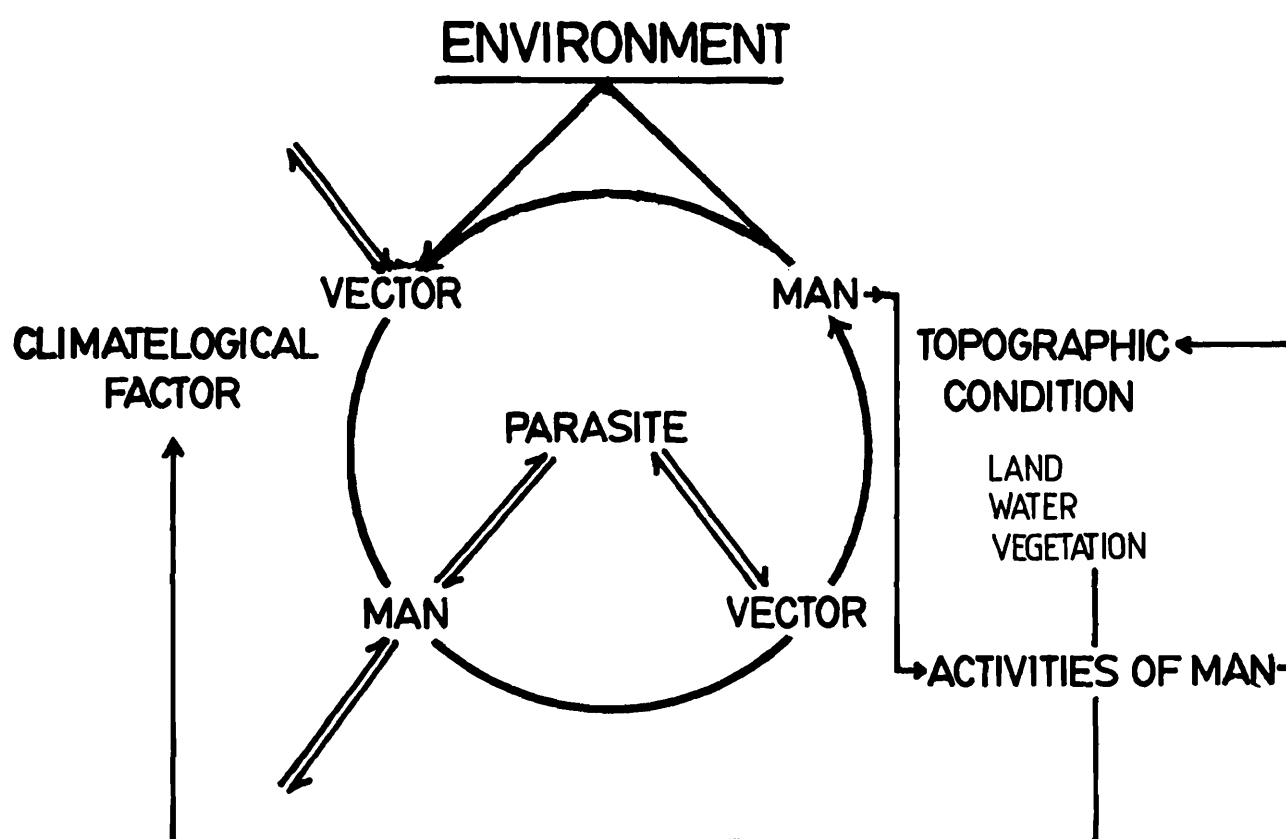
In order to fulfill the immediate needs of the ever increasing population, man

has overexploited the environment. The parasites associated with man and his livestock have also increased to such an extent that instead of attempting to eradicate them completely it is easier to have a natural harmonious equilibrium amongst themselves. This tolerable equilibrium can be acquired through environmental management as also by applying suitable therapeutic measures.

As indicated by Mather and Trinh (1984) environmental management covers three aspects - (1) permanent or long-term modification of land, water or vegetation; (2) recurrent manipulations to produce temporary conditions unfavourable to vector breeding and (3) modification or manipulation of human habitation or behaviour. The ultimate aim of environmental management is to handover this globe we live in with all its life forms and the capacity of sustaining growth and development, to the future generation.

Conclusion

The close circuit among man, parasite and vector or the one among domestic animals, parasite and vector (Fig. 1) existing in the environment can be modified by the modification or manipulation of environment through which the prevalence and virulence of manifestation of the diseases caused by these



parasites can be controlled to a great extent. The improvement of shelter, their site selection, etc., can be treated as environmental modification. The improvement of food, drinking water, etc., are treated under sanitation and Public Health and Hygiene. The utilisation of the refuge and keeping the area clean, indicate to some extent, the environmental manipulation (Faryvogel, 1968). The

breeding of vector can be controlled through environmental modification. Particularly, the proper programme of Public Health and Hygiene, a part of the environmental programme, is very much effective in controlling the spread of diseases, especially when the increase of exploitation and consequent degradation of environment has already taken place. On the other hand, when the situation deteriorates to such an extent that the use of drug for a particular disease caused by a parasite is necessary, proper diagnosis is very much needed which is only possible by the identification of the parasite. It is not possible to initiate therapeutic measures without the knowledge of taxonomy of these parasites. As has been stated earlier, even the quantity of the drug or the dose normally given for the two species of *Plasmodium* are different. Until the correct identification of the species is done, the effective therapy is not possible which may even lead to near fatal side effects to the patient.

Complete eradication of any disease caused by the protozoans is not known so far. Therefore, in the 'loosing battle' between man and the parasites, both environmental management programme and the effective therapy will help to maintain a tolerable equilibrium among man, his livestock and their parasites. According to the situation and condition of the disease, both the processes can be taken up simultaneously or one is to be followed by the other. Keeping this in view, the person who knows taxonomy should be included for the implementation of the environmental management programme which will not only be beneficial to the human welfare but also be helpful in maintaining the ecosystem as a whole.

References

- Mather, T.H & Trinh, T. T. 1984. Environmental management for vector control in rice field. *FAO Irrigation and Drainage paper*.
- Freyvogel, T.A. 1986. Environment management for the control of parasitic protozoan diseases. *Insect Sci. Applic.*, 7(3) : 297-304.

Environmental Impact Assessment

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Historically, one may trace the genesis of alternative technology for environmental protection in the introduction of terraced agriculture, contour cultivation, irrigation canal system, storm water sewers, etc. Decades ago, William Blake castigated England's dark "Satanic mills"

However, it is admitted that incorporation of environmental protection' as a component of administrative, planning, legislative and executive arms of Government' is a recent phenomenon. In general, the hypothesis of environmental control carries the negative connotation of preservation and rather costly measures for protection, conflicting with urgent need to develop; hence it is viewed as 'an inappropriate extravagaza for developing countries' (Escap, 1985). The apparent conflict between those who view resource exploitation as serving the basic human needs and the ones who consider wasteful use of resource will only lead to decreasing productivity in future.

As such, the system of Environmental Impact Assessment orginated from the concept that better method and more organised information flow, if generated in a timely, accurate and complete manner and presented in useful format will help decision makers balance the demand for immediate gain from exploitation of resources with the necessity to maintain ecosystem for sustainable development.

The EIA differs from conventional cost benefit analysis aimed at reviewing economic parameters, including the ones with pollution control measures. A host of environmental parameters are "intangible" and no monetary price-tags are available for such parameters; (e.g. social disruption resulting from relocation, destruction of rare habitat or environmental impact over a long time-scale or in geographical location remote to a particular project area.)

By designing a scheme which may include (i) statement of development objectives (ii) techno-economic feasibility (iii) vetting by agency on economic and technical ground (if necessary with corrective measures), (iv) proposed action and alternatives (v) identification of impact (vi) alternative technical/engineering plan (vii) reidentification of impact (viii) Environment Impact Assessment arrive at the point of understanding. that primary role of EIA is to efficient

utilization of natural and human resources in economic development (Evans, 1980).

Since, EIA requires input from different disciplines/sectors, under the coordination of an agency, it provides a unparallel ground for inter-agency cooperation, EIA, has also been widely adopted as an information gathering and analytical tool to aid economic development (Sammy, 1982).

However, the most commonly voiced objections to EIA are the prohibitive cost and also that idea that this practice retards development (Sammy, op.cit). A summary, based on response to an international questionnaires which was distributed to 139 developing and 25 industrilized countries, indicate the EIA invariably increase project cost but enhance national development and project planning, (Table 1, source Sammy, op.cit).

Table 1. Effect of EIA on Project Cost, National Development and Project Planning

Region or group	Percentage of respondents giving each answer					
	Effect of EIA on project cost		Effect of EIA on national development		Effect of EIA on project planning	
	Increase	No effect/ decrease	Enhance/ retard		No effect/ retard	
<i>Developing :</i>						(%)
Africa and the Middle East	84	16	79	21	80	20
Americas	71	29	88	12	81	19
Asia and the Pacific	83	17	60	40	78	22
Europe	100	0	20	80	33	66
<i>Industrialized :</i>						
United States	75	20	41	59	71	29
Canada	70	30	44	56	70	30
Europe	63	34	41	59	57	43
Developing	80	20	74	26	78	22
Industrialized	70	30	42	58	66	34

Environmental Concept and Impact Assessment

Coming back to the basic parameters of EIA, lets look at the concept of environment. In the broadest sense 'the environment is the sum of all social, biological and physical and chemical factors which compose the surrounding of the man. The natural environment of man consists of soil, water, solid waste,

noise, biotic components, habitat for wildlife, while the self (man) made environment include work environment, housing, technology, disposal system of noxious air, effluent and garbage, aesthetics, etc. One can therefore, rationally expect that EIA should consider all the parameters cited above along with objectives to minimise the impact on shortterm and longterm perspectives.

Limitations on EIA arise from complexities of data collection resulting in the delays in implementation and lack of manpower and expertise for assessing the impacts (in developing countries). EIA become more expensive in developing countries due to limited technical and social data-base available at present (Evans, 1982). Large amount of base line data collection become imperative and 'this is perhaps the single most expensive and time consuming endeavour' In order to cut down the time and expense, it is often advocated that EIA should be incorporated into the overall development plan of a region (Ludwig, 1984).

The impact assessment procedure can only be based on data presented in the project feasibility report and Environmental Impact Statement (EIS) both to be submitted by the proposer of the project. The substantive content of the EIS may be comprehensive but resulting documents often appear to be long on description but short on analysis and becomes of little use in decision making. US Council of Environmental Quality recognised the term "Scoping" (in 1978) to 'describe the process used to determine in an EIS and to what detail' Earlier, issues and choice of alternatives were largely completed outside the public view but now, the process in USA, has been open to public, affected federal agencies and government.

EIS, as such, forms an integral part for assessment process by the authorised agency (such as Department of Environment in India).

The base line data required for EIS, as mentioned earlier, are to be collected, in most of the cases, in developing countries, a new, from the proposed site and its surroundings.

Impact Assessment Studies in India

In India, such data are being asked from identified agencies (Table 2) directly by the Project authorities. When preparation of the report [for submission of Department of Environment] is assigned to a consultant, group/individual the agencies identified may not always be forthcoming considering the role of private profiteering scope of the consultant. But a major question remains, can the identified agencies reply to the questions on the impact statement without any field visit/data collection? If not, will the agencies be interested to comply with the requests of number of public-sector clients (without charging any fees for such service) to generate essential data and suggested mitigative measures? Since each of the identified agencies listed in (Table 2) have their own programme of work and priorities, the man-month/days required for such data generation are to be met by deviating a part of expertise from departmental work.

Table 2. India : Agencies responsible for input to EIS

	<i>Agencies</i>	<i>Area</i>
1.	State Forest Department	Forest data
2.	Indian Meterological Deptt.	Climatological data
3.	State Fisheries Deptt.	Fisheries - data
4.	Zoological Survey of India	Faunal data
5.	State Wildlife Deptt.	Wildlife data
6.	State Health Deptt.	Health data
7.	Botanical Survey of India	Floral - data
8.	Geological Survey of India	Geological - data

The conceptual framework (Table 3) for conduct of EIA in developing countries indicate that Environmental Status and Environmental Impact Statement, are to be prepared by an 'Environmental Team' This team has featured from the very beginning to the last but two steps, of the 9 steps in the framework scheme.

Table 3. Conceptual Framework for the conduct of EIA in Developing Countries

Assessment step	When ?	By whom ?
1. Preliminary activities	During feasibility study	Project management and environmental team
2. Impact identification (scoping)	Between feasibility study and preliminary design	Environmental team
3. Baseline study	During preliminary design	Environmental and engineering teams
4. Impact evaluation	Between preliminary and final design	Environmental team and technical specialists
5. Mitigation measures	Between preliminary and final design	Environmental team with input from engineering team
6. Comparison of alternatives	Before final design	Environmental team
7. Documentation	Before final design	Environmental team
8. Decision-making	Before final design	Project management
9. Post audits	After the start of operation	Project O & M

It is evident that no such teamwork functions in India in the impact evaluation, mitigation-measure steps. However, once the project document, preliminary questionnaire for initial environmental examination (IEE) and / or Environmental Impact Statement (EIS) are received (in part from different agencies and compiled by the client department) the Department of Environment (DOEn) takes up the responsibility of Environmental Impact Assessment and clearance/or rejection. DOEn has provision for constitution of expert team for actual field visit if necessary. At this stage, it must be mentioned that, for each of the six sectors of development project for which environmental clearance has been made compulsory in India, separate committee (with fixed tenure), constituted by DOEn function independently. Recommendation (EAC) is put up to the Secretary, DOEn, for his consideration.

The demand for development in each of the six sectors from almost every state and union territory, *vis-a-vis* the time-frame proposed by concerned client department, can really put pressure to each individual nodal organisations. Above all, in the absence of environmental team at the first 5 steps and variable methodology adopted by different organisation, the assessment procedure may not be an easy exercise at EAC level.

On the other hand, alternatives are difficult to find out. The efforts on the part of national government to register consultant firms or data generating laboratories often end up in specialised agency list. There is hardly any centre in India, either at non-governmental/governmental level, who can undertake total responsibility of generation/compilation of data (if available) interpretation for impact statement and suggestion of mitigative measure. Many of the consultant group may be qualified to prepare report on socio-economic-geotechnical/geochemical parameters but then again, most of these group lack expertise in fisheries/flora/fauna/wildlife/ecology. As such, functioning of multi-disciplinary "environmental team" appears remote, but not impossible if such teams are formed by drawing experts from different discipline as a routine matter. Some statement can be made for the case where a "Environmental Management Plan (EMP)", it to be submitted along with other documents, detailing out reclamation process (e.g. mining). Three vital questions crop up, *viz*, as to the credibility of data on which present status is based and thereby possible impact assessed; secondly, as the workability of the management plan and thirdly as to the implementation of monitoring system. Specially, identification of expertise/agencies with proven credibility for undertaking reclamation and monitoring work appears to be most difficult, at least at present.

Having the brief overview of the genesis of EIA, its scope and limitations problem of its application and implementation in developing countries, especially in India, one can now look at the detailed requirement for preparation of status report and EIS, prescribed for each of the six sectors (Table 4) by Government of India.

Table 4. Environmental Impact Assessment : Requirement for**Name of the Sectors**

1. River valley Development Project (Hydel Power)
2. Industrial Project
3. Mining Project
4. Thermal Power Project
5. Shipping, Harbour Project
6. Irrigation Project.

Before concluding, it would be worthwhile to mention that the cost involved for EIA in other developing countries has been estimated to vary between 0.01 to 0.48 of the total project cost depending on project size and nature (Escap, 1985). In India no such data is available to this author but it has been noted that in order to implement environment management plan (say for instance in coal-mining sector) 5% of the total project cost may be sufficient.

It can also be stated that while, more than 100 methods are reported to be available for carrying out EIA (Ludwig, 1985) most of these can be divided into 8 broad classes as listed below.

- (1) Check-list
- (2) Environmental evaluation
- (3) Matrices
- (4) Network
- (5) Overlays
- (6) Environmental indices
- (7) Cost benefit analysis
- (8) Simulation modelling

The Indian system incorporates at least 5 of the 8 classes (*viz*, 1,2,3,6,7) in different sectors. Ideally speaking, the review agency should use critical assessment criteria. Typical questions for such exercise may include (Davies and Müller, 1984) the following:

1. Will the project result in environmental issues that are likely to be highly controversial and if so, how will this be managed?
2. Will the project result in loss of precious/ irreplaceable natural resources, and if so, is this justified?

3. Will the project sacrifice important long-term environmental resources and values in favour of immediate gains?
4. Does the project fit into the regional development plan of the region in which the project is to be sited, if such a regional development plan exists?
5. Will the project endanger species survival, and if so, how is this justified?
6. Will the project establish a precedent for future actions involving sensitive environmental issues?
7. Whether the project, while in itself not exercising serious impacts, will be related to other actions where the total accumulated effects could be serious?
8. Whether the project is consistent with the national policies?
9. Whether the project is consistent with national foreign exchange policies?
10. Whether due consideration has been given, to alternative projects which could realize the desired development objectives, and whether any of these alternatives might represent a better overall solution including consideration of all applicable project constraints including environmental effects?

It is advocated that in case of big project, where the effects of the environment affect many sections of populations, public hearing should be organized and views of various interest groups should be heard. This may expose the decision makers to the views of diverse interest group on one hand, educate the public opinion and stimulate public awareness on the other hand.

Role of Taxonomy

In the context of impact assessment, the biological resources play one of the most significant role; it has been realised that sustainable development can only be ensured through maintainance of biological diversity (McNeely, 1988). The entire foundation for such study of bio-diversity invariably is based on taxonomy and systematics. (Ghosh, 1990)

The Association for Systematic Collections"and Smithsonian Institute, in USA in a recent report (January, 1989) entitles "Systematic collection resources for 1990's pointed out that "We are at a turning point in which biodiversity mapping and comparative studies will play a central role; a total of 1.4 million species of all kinds of organisms have been described to date" The actual number of species is certainly much higher largely because the tropics are biologically so rich and so poorly known: a widely accepted minimum figure is 10 million and nearly three fourth of the invertebrates are believed to be unknown as yet; some zoologists, including the authors of the above mentioned reports and experts

opining in the report on "World Resources" (1986) suggested that there could be as many as 30 million insect species in the tropical forests alone (Erwin, 1983).

Due to demand of development processes and ever growing population in the tropical countries, it is estimated that 80,000 square km., of tropical forest is being converted to other uses, annually. At the same time few scientists are qualified to describe new tropical species and a 1986 report states that worldwide, only 1600 taxonomists and systematists study tropical organisms, whereas 66 percent of all species occur in the tropics which occupy 42 percent of earth's surface.

The environmental impact assessment study demand precise knowledge of taxonomy related to plants and animals and specifies that the scientists reporting on the proposed site must opine as to whether the area harbour any rare or endangered species, or whether it supports such biodiversity which should be given a shelter under wildlife sanctuary. Ecological condition underline the basic concept of animal diversity, including biology and other phenomenon like annual migration etc. The impact assessment study, therefore, also demand information on possible migration route of terrestrial animals (e.g. elephants), birds and fishes. As such the entire exercise need a serious scientific study by competent taxonomists and biologists.

Interestingly, while it is acknowledged that systematics appeared early in biological research, the number of specialists, the training facilities, importance of reference collections and funding for systematic research based on taxonomic principles follow a downward trend in recent decades. And this trend continues even at a time when a huge demand for conservation data base and check-lists is evident. The 'old' science of systematics becomes synonymous with "out of date".

The danger that may arise due to inappropriate survey and identification of resources in land area or waterbody is never fully appreciated. But the finding of 16 new rice varieties in silent valley area of Kerala (which would have been submerged had the proposed hydelpower project been implemented), amply demonstrate the point.

The present system of environmental impact assessment putting only 20 percent weightage on assessment of living natural resources (wholly dependant on taxonomic knowledge), in the matrix analysis calls for a change; specially in view of the fact that both physical environment (45%) (surface water, hydrology and quality, ground water quality, physiography, etc.) and human environment (35%) (agriculture, water supply, health etc.) largely depend on ecology and environment *per se*. But for the present, the question remains as to how many taxonomists in a country like India, are available to identify and assess the fauna and flora, that are likely to be affected due to various developmental projects. The pace of such projects being very fast and the number of experts being too inadequate, such exercise of impact assessment remain highly unsatisfactory in many cases. One is inclined to agree with Bramwell (1988) that "We are

allowing a major impoverishment of both ecological and biological diversity to take place under our noses with the inventory incomplete and with probably millions of unknown and undescribed species in the tropics. We have allowed planners and grant committees to ignore, for example, the need for both basic taxonomic training, for taxonomic research, in favour of more glamorous, sophisticated trivialities".

Even, the "International Biological Programme (IBP) when emphasising on the conservation of terrestrial biological communities, pointed out to the urgent need for extensive taxonomic training to meet the demand (Worthington, 1975) of development.

In summary, the study of biological diversity provide the base line data for genetic resources on which human society 'depends for virtually all its food, nearly half of its medicines much of its clothing and in some regions virtually all its fuel and building material" (Fitter, 1982). Much of such diverse genetic resource remain in the yet unexplored, unmapped areas (biologically) but being continuously converted for other uses. Without appropriate support for taxonomic work, a close estimate of the country's total number of species can never be attained. The pursuit for a basic truth will sadly suffer from lack of empathy in an world of esoteric concepts.

References

- Anon, 1989. Systematics Collections Resources for 1990's. A Report to the National Science Foundation. *Association of Systematic Collections* : 1-5.
- Bramwell, D. 1988. Are botanical garden doing the right Conservation Research. *Species*, II: 30-31.
- Davies, G.S. & Muller, 1984. *Handbook on Environmental Impact Assessment for use in Developing Countries*, UNED, Nairobi.
- Erwin, T.L. 1983. Tropical Forest canopies: The last Biotic Frontier. *Bull. ent.Soc. Am.* 29(1): 14-19.
- Escap, 1985. *Environment Impact Assessment*. United Nations. ESCAP. Bangkok, Thailand.
- Evans, J.W. 1980. *Summary Report of the Environmental Impact Evaluation*. National Environment Board, Bangkok.
- Evans, J.W. 1982. *The use of Environmental Impact Assessment for Development Project Planning in ASEAN Countries*, UNEP, Bangkok.
- Fitter, Richard. 1982. "Wildlife for Man": Excerpts in "How and why we should conserve species" IUCN Special Report 18(1-3) : 8-9.
- Ghosh, A.K. 1990. Biological diversity in India. An appraisal of programmes and strategies for conservation. In : *Man and Ecology*, 6-21 (Ed.) S.P. Dasgupta, School of Fundamental Research, Calcutta.
- Ludwig, H.F. 1984. *Environmental Parameters in Planning Economic cum Environmental development*. National Environment Board, Bangkok.
- Ludwig, H.F. 1985. *Guidelines for preparing Environmental Impact Assessment for Water Resources Project in Developing Countries*. PEEM, Geneva.
- McNeely, Jeffrey. A. 1988. "Economics and Biological Diversity Executive Summary and Guidelines for using Incentives IUCN. Gland Switzerland.

- Sammy, G.K. 1982. Environmental Impact Assessment in Developing countries. Ph.D. Thesis. Univ. Oklahoma, USA.
- World Resources, 1986. *A report by the World Resources Institute and the International Institute for Environment and Development*, Basic Books Inc., New York.
- Worthington, E.B. (ed) 1975. *The evolution of IBP*. IBP Synthesis Series 1. Cambridge University Press.

Taxonomy in Biological Monitoring

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Biological monitoring includes varied monitoring techniques that in turn further rely on use of different parameters. Thus, there are physiological and cytological parameters (used occasionally in biomonitoring), parameters at the organism level and at population and community levels. Over the years, living organisms have come to be regarded as good indicators of environmental pollution. The organisms selected as also their representative species, should invariably possess the following properties: high susceptibility to pollution stress, abundance or productivity, physical community structure or regulatory properties in the system, and the species is supported by previous ecological and physiological data. In short, the merits or limitations of the indicator organisms or species should be well documented so as to help draw conclusions.

Biological surveillance as a means of monitoring water quality relies on detecting change in natural communities or distribution of species. In short, biological methods of assessing water quality increasingly rely on indicator species. Traditionally an indicator species has been defined as an organism that by its presence in a biotope also helps to denote particular characteristics of the environment that were otherwise difficult to determine. In the field of water quality, potentially every aquatic organism can serve as an indicator of water quality. However, any group of organism to be useful as indicator species should primarily possess the following attributes: easy identification even by non-specialists, abundance in distribution over large geographic area, possess relatively long life span, be relatively sessile and unable to avoid stressed environment.

Biological Monitoring Studies in India

The upsurge of interest in environmental surveillance and biomonitoring in recent past have triggered quite a few Indian studies in ecological evaluation of riverine and lacustrine water quality. As a result, we have studies that rely on the whole gamut of freshwater invertebrates - Protozoa to Mollusca, and indeed fishes too as 'facies of indicator species' for evaluation of inland water quality.

Unfortunately, in India there is still no general consensus on the use of

Biological Indicators of Environmental Pollution despite the growing importance of biomonitoring and bioindicators in the field of environmental surveillance. The classic saprobien system has been indiscriminately applied and extended to tropical situations despite wide geoclimatic differences, and attendant high biotic diversity and seasonal variability in the tropics. Most qualitative studies are patchy and therefore less reliable. Quantitative studies are few and far between. Further, the most commonly used diversity indices in Indian studies are Shannon & Weaver and Margalef's index of diversity (Trivedy 1981; Someshwar 1985 and Rao *et al.* 1985). A number of other methods based on *biomass pigments* (chlorophyll a, b & c) and *metabolism* of organisms have also been introduced though not widely used, especially in Indian studies.

The basic lacunae in wide acceptance of the saprobien system as also the biotic and diversity indices may be traced back to poor awareness of the state of art of taxonomy of many faunal groups, chiefly inland water faunae-riverine and lacustrine groups, and the equally poor knowledge of their 'normal' ecology, not to talk of the 'pollution ecology' of various groups. The high temporal and seasonal variability of the biota in the tropics, the high incidence of *cyclomorphoses* or polymorphic forms in many lower faunal groups-Protozoa, Rotatoria, Cladocera, etc. as also wide *temporal* and *spatial patchiness* (cf. zooplankton groups) compounds the problem. Above all, there have been no attempts on the part of biologists/ecologists on the development of a few standard biological methods for evaluation of water quality and or environmental monitoring. As a result, biological methods have not found as wide adherents and applications as the physicochemical and bacteriological methods in environmental monitoring.

Thus, the primary role of taxonomy and taxonomists in documenting the biotic diversity (*faunal resource inventory*) in an ecosystem, the "normal" ecology of the organisms, and changes, if any, due to pollution needs no emphasis. In short, firm inferences based on pollution ecology should have a reference to "normal" ecology. Further, taxonomic endeavour should aim at elucidating species enjoying a cosmopolitan distribution so that the same could be used with greater precision/certainty as 'ecological indicator' of environment. Biomonitoring studies, to be more meaningful, should be based on year long studies to account for high variability and seasonal fluctuations characteristic of tropics. Biological monitoring, then could meaningfully be applied to the bigger role of successfully protecting the water resources on a global scale.

Only then, can it be said safely the biomonitoring or biological monitoring, as a means of assessing water quality or the toxicity of chemicals employing living organisms as sensors, has come of age, like the physico-chemical monitoring.

References

- Rao, K. S., Das N. K. & Pandya S. S. 1985. Community structure of Benthic Macroinvertebrates and their utility, as Indicator of pollution in River Khan (Indore) India. *Bull. Bot. Soc. Sagar*, 32 : 114 - 149.

- Someshwar, R. K. 1985. Studies on Water Pollution of River Cauvery. *Bull. Bot. Soc. Sagar*, 32 : 145 - 149.**
- Trivedy, R. C. 1981. Use of Diversity Index in Evaluation of Water Quality. WHO Workshop on Biological Indicators and Indices of Environmental Pollution. *Cent. Bd. Prev. Contr. Water Poll./Osm. Univ.*, 175 - 188.**

Taxonomy and Ecology - A Twin of Biology

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Many zoologists, are apparently averse to taxonomical studies and only some accept taxonomy as an avocation that too probably for some impelling reasons. Presumably many zoologists do not consider taxonomy as glorious and glamorous as physiology and molecular biology. On the contrary, they judge it to be dry, monotonous and uninteresting to a degree. Very often the museum taxonomists are ridiculed as technicians, bristle counters as well as fin and scale counters. There is also a funny feeling that the taxonomic profession is a routine job and does not satisfy the personal ego of being a proud scientist. A curious impression also prevails that 'one should not think much about taxonomy but just do it'

A. J. Cain, an acclaimed evolutionist and taxonomist posed a very strange question (Quoted by Simpson, 1961) :

"Is it not extraordinary that young taxonomists are trained like performing monkeys, almost wholly by imitation and that in only the rarest cases are they given any instruction in taxonomic theory ?"

Keeping the above statement in view a few questions arise.

Has taxonomy nothing to contribute to the entire gamut of biology ?

Does it have no excellence of its own ?

Or, is taxonomy just doing a nagging and mechanical exercise having no sound theoretical as well as philosophical basis to feel proud of ?

In order to answer the above questions it is imperative to make an introspection of the historical perspectives of the discipline.

Retrospect of the Perspective of the Past

Perhaps none can refute that at the onset, taxonomy was limited only to the job of identification of taxa, preparation of key and description of the new species. All these activities may be colourless but are important and indispensable steps for making any kind of taxonomic study on any organism. It is a bare fact that at the very beginning no discipline could claim to have developed excellence. Excellence grows with the travel of time and with the

contributions of eminent scientists through sustained interest and productive research. Of course, the sole purpose of taxonomy does not necessarily end with the initial exercises as mentioned above. However, the need of proper identification of taxa may be well understood from the following paragraph.

A student of wildlife wrote to some museum people : "I have all my voluminous field notes ready and only await the names of the [specimens] which I sent you long ago. I can publish nothing until I get the names."

Behold the helplessness of a conscientious wildlife biologist !

It is no denying the fact that there have been some very serious snags in the concept and practice of taxonomy which made the scope of the subject quite narrow and dragging. Consequently, taxonomy during latter part of nineteenth century and early part of twentieth century 'fell into some disrepute' as Mayr (1969) has pointed out.

Obviously, if taxonomy remains circumscribed within the domain of identification of dead specimens without considering their mode and manner of life and living, the very charm of studying biology is probably lost. In such an instance the concerned taxonomist is no better than a sorter in the postal service who only minds the pigeonholing of letters according to pin code totally ignoring the sense and sentiments embodied in the letters. Of course, sorting is an important job but taxonomists will never remain satisfied with the mechanical sorting of biota. Mayr (1969) prudently pointed out that :

"If systematics [taxonomy] were satisfied with merely pigeonholing the diversity of the living world, it would be a technology but not a science."

Although the celebrated 'doctrine of descent' developed by Darwin revolutionised the concept of species by establishing, contrary to Linnaeus' view of typological species concept (which ordains the fixity of species), that species are in continuum and not a static entity as well as by providing an apt philosophical parlour to taxonomy, yet it could not come up to the desired level that taxonomy to-day demands and deserves. Many practising taxonomists remained preoccupied mainly with the 'tedious job of describing, diagnosing and classifying the seemingly endless number of species' and the others remained complacent very often with the game of unnecessary cleavage as well as clubbing of various taxonomic categories. Some taxonomists remained busy with the 'unearthing of long forgotten synonyms' which aroused 'the ire of general biologists who complained quite rightly that this defeated the basic objective of nomenclature as information retrieval system'.

Genesis and Utility of Taxonomy

Tracing the genesis of taxonomy Blackwelder (1966) stated that :

"Historically, the fields of Zoology appeared in about this order : taxonomy (the recognition of kinds), natural history (the life history in

general), comparative anatomy, classification, cytology, evolution, embryology, genetics, ecology, speciation, and biochemistry."

The indispensability of taxonomy in zoological inquiry has unequivocally as well as convincingly been highlighted by Simpson (1945) :

Taxonomy is at the same time 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 taxonomy in its various guises and branches gathers together, utilizes, summarises and implements everything that is known about animals, whether morphological, physiological or ecological.

Blackwelder (1966) further emphasized that both evolution and genetics were made possible by the ability of the taxonomists to identify species and relate them to classification. That taxonomy has got immense importance in the domain of biology and may be considered as an independent and self-reliant discipline is explicitly evident from the statement made by Corliss (1962). He stated that :

'Rather than occupying the subservient position of handmaiden to other biological disciplines - by merely providing convenient sets of names arranged in order - systematics is to-day recognized in its own right as an independent and respectable field, one of the broadest of all among biological sciences'

Some biologists also consider that 'taxonomy is the mirror of evolution' Huxley denoted that the objective of taxonomy should be 'detecting evolution at work' and one taxonomist twisted this to read 'detection of the work of evolution' However, one question troubles me a lot. Should taxonomy need an attestation to the effect that it is an essential discipline of biology ? Although taxonomy should not claim that it is more important than other branches of biology but undoubtedly there cannot be any branch of biology which is not related to taxonomy at certain level at least tangentially. Systematisation of knowledge which taxonomy brings in the field of biological diversity, is an invaluable component of science.

Rennaisance in Taxonomy

During the last fifty years, there has been a qualitative improvement, so to say a quantum jump in the arena of taxonomic concepts and applications which could remarkably bring emancipation of the discipline from parochial philosophy.

'The New Systematics'* (Huxley, 1940), the *magnum opus*, which contains a volume of 'heuristic papers' authored by a number of distinguished doyens among taxonomists and evolutionists, has brought renaissance in the province of taxonomy. It has been described by Mayr (1969) 'as a view point an attitude, a

* 1990 is the Golden Jubilee Year of the publication of 'The New Systematics'

general philosophy'. Simpson (1961) feels : 'it [The New Systematics] did make clear that there was a ferment working in the field and did point, a general direction that taxonomy was to follow'.

Three other outstanding publications, one by Mayr (1942), the other by Dobzhansky (1951) and the third by Simpson (1961) provided the solid conceptual background to taxonomy which remarkably elevated the status of the subject making it pragmatic and intellectually inspiring.

Taxonomy in Ecology

Perhaps it is incontrovertible that taxonomy can hardly afford to be an isolated arena of investigation but is rather entwined intimately with other subdivisions of biology in far-flung avenues of interdisciplinary research. It is axiomatic that an ecologist is concerned primarily with the biota and their environment while a taxonomist with the biota. Of course, taxonomists in their study can neither spare nor part with the environment, the abode of the biota. Both taxonomy and ecology are essentially field sciences and basically observational in operation. Therefore, because of common concern and interdependence both taxonomy and ecology can be profitably coupled together as a unitary science in many spheres of biological enquiry. Perhaps it will not be difficult to find such an episode when some naturalist-taxonomists in course of their study developed an ecological fervour and ultimately converted to ecologists; and conversely many enthusiastic ecologists being impressed with the boundless organic diversity may develop respect for taxonomy and finally become talented taxonomists. Such a viaduct between taxonomy and ecology will invigorate both the disciplines and this is possible only due to their propinquity.

But it is utterly surprising that some biologists failed to find out the articulate relationships between taxonomy and ecology. Simpson (1961) was absolutely aware of this attitude which is evident from his statement that 'the pertinence of ecology [in taxonomy] is less generally noted and has, indeed, been denied by some systematists' Blackwelder and Boyden (1952) although had comprehensively overwhelming view of systematics but even they excluded ecology from taxonomy. The astounding or rather a devastating comment of Thorpe (1940), a proponent of the concept of 'New Systematics' deserves a special mention in this context. He in his article 'Ecology and the future of systematics' expressed an unaccordable judgement that :

'[Synecology] has in itself had relatively little effect on the studies of systematists beyond giving them a great deal of identification work and taking much valuable time and energy which might in many cases have been more usefully employed'

What a curious conjecture !

It is now widely known that synecological studies can neither be conceived nor conducted without due involvement of taxonomic cognition.

Simpson (1961) very rightly realized the role and relevance of systematics in ecological studies. He stated that :

"Synecology is the study of multispecific communities, as opposed to autecology which is the study of the relationships between particular kinds of organisms and their environments. It would appear that in reality synecology is not only pertinent to but is a branch of systematics as here conceived, because it is the study of some sorts of relationships (various associations of contiguity) among diverse organisms."

The validity of this maxim has subsequently been appreciated.

Many leading biologists, ecologists in particular, unambiguously admitted their dependence on taxonomy at least in certain phases of their study. According to Charles Elton (1947), an eminent ecologist, 'the ecologist is helpless and the whole of his work may be rendered useless' without accurate identification of the taxa he comes across. I am confident that this contention is ubiquitously applicable to anatomists, biochemists, cytologists, endocrinologists, geneticists, toxicologists or any other expert on any branch of zoology. Elton also pronounced seemingly a word of caution probably to the ecologists confronting a taxonomic dilemma.

it is much more sensible to get animals identified properly by a man [surely a competent taxonomist] who knows them well, than to attain a fallacious sense of independence by working them out oneself - wrong."

Mayr (1969) also echoed almost the same voice that 'no scientific ecological survey can be carried out without the most painstaking identification of all the species of ecological significance'.

While highlighting the outline ideas of biological species concept Mayr (1969) professed that the members of a species form (1) a reproductive community, (2) a genetic unit and (3) an ecological unit. This view point of Mayr enjoys general acceptance of the biologists. If that be so, it is incontestable that species which form the core concern of taxonomy, has got essential ecological attribute in its marrow. How can taxonomy then be dissociated from ecology and *vice versa* ?

Moreover from ecological standpoint each species is niche specific. It is well established that no two species with identical niche requirements can continue to coexist for long and this diction is designated as Gause's principle or competitive exclusion principle. Keeping this principle in view, an introspective study of niche requirements of very closely allied species may profusely help in taking taxonomic decision when morphological identity is either deceptive or not decisive.

A very interesting example of similar inclusiveness of taxonomy and ecology may be relevant here. It has been observed that the members of the same species of certain molluscs inhabiting different habitats in the same region produce

nongenetic ecophenotypic forms. The taxonomic identity of such forms at the species level becomes obscured due to differential shell forms caused by ecological factors. Depending on the shape of the shell, malacologists 'split up the few well known species into countless new ones' As many as 251 species of *Anodonta* were recorded from France. Subsequent study proved that all those species are the habitat forms of two species and 'the other names have been sunk into the synonymy of the two valid species' This 'absurd systematics' is undoubtedly the result of taking no cognizance of ecological factors which caused the variations in shell morphology. Plastic species very often are amenable to morphological variations caused by ecological factors. Such variations may be temporary, cyclic or permanent. Cyclomorphosis – a succession of shapes probably due to succession of seasons, is a remarkable aspect of cladoceran biology. Undoubtedly, therefore, ecological data in such cases will supplement taxonomic decision. Likewise the concern of taxonomy in many aspects of ecological enterprise is not only useful but also obligatory. As for example, in biomonitoring programme precise taxonomic knowledge is vital. In such programmes instead of entirely depending on the physico-chemical parameters for the assessment of environmental quality, either species or community is utilised as indicator. Such an indicator whether it is a single species or a community is expected to determine qualitatively the pollutional status of any segment of environment under consideration. The correct identification of the indicator species, whom I like to call the culprit species, or all the species comprising the community is very essential otherwise any prediction on the quality of environment will entirely be an exercise in futility.

In community ecology various indices such as the index of dominance, variety index, evenness index, Shannon's index of general diversity, etc., are utilised for analysing the species structure in the community which may even detect the degree of stress in the environment. In all these exercises not only very accurate and unmistakable taxonomic decision at the species level but also an intimate knowledge of the response of the species towards ecological factors will be essential. One will have to know which particular species or a group of species are sensitive (intolerant), facultative or tolerant to a particular kind of ecological stress. What are the species that inhabit the polysaprobic, mesosaprobic or oligosaprobic zones of the polluted environment. If the taxonomic purport is erroneous, the entire finding and the decisions made therein will be redundant. Certainly in this area of investigation taxonomy and ecology are confluent.

The developmental activities such as installations of industries, superthermal and nuclear power projects and construction of dams and barrages, are said to cause ecological degradation of great magnitude in space and time. Such deterioration of the environment will generate physical as well as physiological stress on the fauna and flora making their existence and perpetuation vulnerable. This necessitates Environmental Impact Assessment which is supposed to make prognosis of the possible adverse impacts (ecological, socio-economic and cultural) before any project is permitted for inauguration.

Taxonomists and ecologists can happily confederate in this enterprise for the conservation of biological diversity in the interest of mankind.

Conclusion

With the passage of time emphasis changes, new needs emerge and older outlook becomes outdated. In consonance with the advent of new outlook and emerging scope both taxonomy and ecology are advancing remarkably. But taxonomy in practice, may be due to obvious reasons, is perhaps not able to utilise the results of the recent developments in biology. I apprehend that if this trend continues it will be subversive. The boundary of taxonomy should be broadened enough to incorporate ecological as well as ethological traits of the taxa along with morphological, genetical, biochemical, statistical and experimental input so that the approach may be holistic. If it could be appropriately done, alleged monotony of taxonomy will be on the wane, morbidity will vanish, and vivid and erudite taxonomy will flourish. We look forward to seeing taxonomy as a science of synthesis providing the sense of pride to its ardent devotees.

References

- Blackwelder, R. E. 1966. *Taxonomy*. John Wiley & Sons, Inc. New York, London, Sydney.
- Blackwelder, R. E. & Boyden A. 1952. The nature of systematics. *Systematic Zoology*, 1: 26-33.
- Corliss, J. O. 1962. Newer Paths in Taxonomy. In : *Frontiers of Modern Biology*, 37-45. (Ed.) G. B. Moment, Houghton Mifflin Company, Boston.
- Dobzhansky, Th. 1951. *Genetics and the origin of species* (3rd ed.). Columbia University Press, New York.
- Elton, C. 1947. *Animal Ecology*. Sidgwick & Jackson Ltd., London.
- Huxley, J. S. 1940. *The new systematics*. Clarendon Press, Oxford.
- Mayr, E. 1942. *Systematics and the origin of species*. Columbia University Press, New York.
- Mayr, E. 1969. *Principles of Systematic Zoology*, McGraw Hill, Inc., New York.
- Simpson, G. G. 1945. The principles of classification and a classification of mammals. *Bull. Amer. Mus. nat. Hist.*, 85: 1-350.
- Simpson, G. G. 1961. *Principles of Animal Taxonomy*. Columbia University Press, New York.
- Thorpe, W. H. 1940. Ecology and the future of systematics. In : *The new systematics*. 341-364 (Ed.) J. S. Huxley . Clarendon Press, Oxford.

Species Diversity in Environmental Management and Conservation

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Species diversity is a measure of the number of species present in a community and can be used to compare environmental conditions between habitats. In general, habitats with congenial environmental conditions will have more number of species, each represented by small populations whereas, habitats afflicted by severe environmental factors will show reduced number of species, but each with much larger population (Thienemann's first law; Dajoz, 1977). Environmental factors are those components of the environment capable of acting directly on living organisms during at least one state of their life cycle. These factors act on living organisms in mainly three ways: (1) by eliminating some organisms from unsuitable regions and thus determining their geographical distribution; (2) by influencing population density through varying the factors of population dynamics like fecundity, mortality and dispersal; (3) and by encouraging development of adaptive features. The species diversity of a region is the end product of all the above processes.

Causes of Species Diversity

While the environmental factors are the proximal causes of species diversity, it could also reflect the results of factors independent of present environment. Thus, geographical and historical factors could give shape to the conformation of species diversity displayed by a region.

Geographical Factors : The geographical location of a region may itself form the cause of the number of species found in it. The arctic region is relatively much poorer in number of species than tropical region and a gradation in the number may be found in the regions as one proceeds from arctic to tropics. (Table 1).

However, while the number of species may vary widely between arctic, temperate and tropical regions, the total population of species in these regions may remain about the same. Bird fauna is a case in point: a hectare of tropical forest may contain about a hundred species compared to that of a temperate forest containing only ten species, but in both forests the total number of individuals of all species may add up to closely similar figures. Another gradient of difference

Table 1. Decrease in Number of Species with change of Latitude in N. America (Dajoz 1977)

Animal/plant	27°N*	42°N	54°N	70°N
Beetles	4000	2000	169	90
Terrestrial snails	250	100	25	0
Littoral molluscs	425	175	60	0
Amphibians	50	21	16	0
Freshwater fish	–	75	20	1
Shore fish	650	225	75	–
Reptiles	107	21	5	0
Higher plants	2500	1650	390	218
Mosses and ferns	–	70	31	11

* Florida is seacoast

of a geographical nature is the altitudinal one, brought out by Simpson (1964) who found that the species diversity increases along with altitude in the case of mammals. A third gradient of difference may be seen in island fauna when compared to the fauna of mainland, the former being less diverse in species, and displaying a graded difference depending on the distance of the islands from the mainland, the farthest and the smallest showing the least diversity. (Table 2).

Table 2. Numbers of Species of Animals and Plants in some Islands of varying distances from Mainland. (Dajoz, 1977)

Area/Fauna/Flora	Distance (km) and islands		
	1100 (Cocos)	350 (Christmas)	35 (Durian)
Arca (km ²)	110	110	79
Total animal species	141	480	889
Total vascular cryptogams and mosses	1	43	?
Total flowering plants	22	136	?

Historic Factors : Communities of greater antiquity are more diverse than recent ones. This is another reason for paucity of species in temperate countries, as having been subject to a series of glaciations in the past, their faunas are recent. On the other hand tropical communities are generally stable and mature being of more ancient lineage. Ancient faunas are characterised by higher number of endemic and relict species. An example is the biota of Western Ghats, which is estimated to possess about 2100 species of endemic flowering plants (Nayar, 1982)

out of an estimated total of 4000 species (Nayar and Daniel, 1986). In fauna, Blanford (1901) lists 28 genera of birds that are endemic to W. Ghats out of a total of 275 genera. According to Jayaram (1974), 41.6% of the genera of Amphibia of W. Ghats are endemic there. As regards relict species, Kurup (1974) lists two mammalian families, four genera and three species as relict forms, while 3 genera of butterflies (Holloway, 1974), six genera of fishes, five genera of Amphibia, four genera of lizards, and six genera and one family of snakes (Uropeltidae) (Jayaram, 1974) relict forms in the Ghats. Kurup (1974) and Mani (1974) stress the ancient derivation of the Western Ghat fauna and flora.

Environmental Factors : Both biotic and abiotic environmental factors influence species diversity. The chief abiotic factor is, of course, that of climate.

The climate is said to be rather stable when the mean daily temperature range is greater than mean annual range and the rainfall is regular. Regions of such climatic stability will have stable food supply also which, in turn, encourages specialisation and narrow adaptation. Reduced daily food requirement in regions of higher temperature could also bring about the same processes. One result is the reduction of niche-size of species enabling more species to coexist in the same space, producing ultimately more species diversity. Conversely, broader adaptation is associated with greater niche-size, restricting species diversity but producing more abundance (of individuals) owing to their increased survivability in less stable climate. Thus, there is greater abundance of passerine birds in temperate countries than in tropical one (Klopfer, 1962).

The seasonality of the climate also produces species diversity. Both tropical and temperate regions have seasonality of a kind, one of rainfall and temperature respectively (MacArthur, 1972). Thus fruiting season in temperate region being narrow and restricted, there is a paucity of fruit-bats in temperate countries; all north American bats are insectivorous. Then again annual winter migration of birds could considerably enhance the species diversity in tropical countries albeit seasonally.

Important biotic factors having decisive bearing on species diversity are those of spatial heterogeneity, competition and or predation, and productivity.

Spatial heterogeneity can be brought about by topographical and vegetational variability. According to Mayr (1963), topographic variability plays an important role in increasing habitat diversity and resultant speciation. This is true in areas where other factors are similar. Floral variability directly produces spatial heterogeneity in habitats. Pianka (1967) found a clear correlation of number of species of lizards present and the growth season of plants in areas extending along north-south for 2500 km. in west American deserts. Text figure 1 shows the climatic-floral-faunal model of interaction representing the result. MacArthur and MacArthur (1961) similarly found a linear relationship between plant density and species diversity in tropical forests.

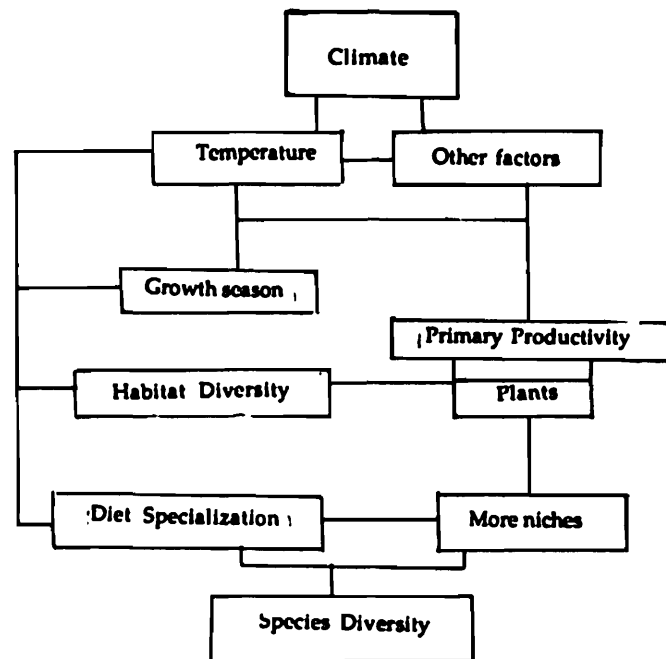


Fig. 1. Effect of temperature on lizard species diversity.

Interspecific competition takes place when an increase of one species harms the other and predation occurs when one species derives its nourishment from, and at the expense of another (MacArthur, 1972). Gause's principle states that two species can coexist only in different niches, but according to MacArthur (1972) niches overlap. In any case, species compete either behaviourally or by reducing resources. The behavioural competition involves either open combat or interspecific territoriality but according to MacArthur (1972) behaviour competition is a modification of underlying resource competition. Although contradicting Gause's principle, MacArthur cites evidence which suggests that behavioural competition can eliminate the zone of overlap. He is also of the opinion that evolution will super-impose aggression onto resource competition if it benefits either species, and it need not necessarily benefit both.

Predator-prey interactions cause oscillations in both predator and prey populations. These oscillations are prevented from causing extinction of prey species if either the predators have a low ceiling of their population or the prey have a sufficiently large refuge. A high degree of complexity of an environment will also ensure continued predator-prey existence (Huffaker, 1958). According to Paine (1966) predators and parasites play an important part in reducing competition in tropics.

Habitat productivity is another determinant factor of species diversity, high productivity resulting in high species diversity (Connell and Orias, 1964). Stable environment economises on energy by reducing losses and storing it up in the form of living material. This enables most species to produce large populations, which eventually split into smaller semi-isolated demes that might give rise to new species. But conversely, the kind of higher productivity exhibited in polluted waters as evidenced by population abundance of certain organisms will actually reduce species diversity. The few species, there are, will be common, compared to

many but less common species characteristic of unpolluted waters (Patric *et al.*, 1954).

Classification of Species Diversity

Whittaker (1972) has classified species diversity into what are called Alpha, Beta and Theta diversities (Southwood, 1978). The alpha diversity is of the species within a community and beta diversity is the rate and extent of change in species along a gradient from one habitat to others, while theta diversity is the species diversity of a range of habitats in a geographical region. Latter is a result of alpha diversity coupled with the magnitude of beta diversity. It is the alpha and beta diversities that might be encountered usually for managerial requirements and therefore the methods of analysis of these are briefly sketched below. Theta diversity in most cases can be treated on the same lines as for alpha as both are scalars (having only magnitude and no direction).

Analysis of Species Diversity

A number of indices have been devised for measurement of species diversity of which the first and also the most widely adopted is the log series proposed by Fisher, Corbet and Williams (1943). The hypothetical total number of species of a habitat is the Species equilibrium (ST). During the course of a survey the relationship between cumulative sample of individuals (ΣN) and the number of species (ΣS) is variable depending on sample size. If the form of relationship between S and N is found then the parameter(s) of this allow the characterization of slopes of the curves from any sample size (Southwood, 1978). The log number of individuals of each species is plotted against the rank (species sequence) to get a plot that will approximate to a straight line. The index of diversity is therefore represented as: $ST = \alpha \log_e (1 + N/\alpha)$. Here the relationship between species number(s) and abundance of individuals (N) has two features: (1) species richness: the total number of species present in the area (ST), (2) equitability or evenness: pattern of distribution of individuals between species (100 individuals can represent 10 species of 10 individuals each (equitable) or 91 of one (dominant) species and one each of other 9 species). By comparing indices such as this, we can differentiate the habitats where environmental changes have taken place. If the data do not fall in a straight line, there has been some departure from normalcy and the species which have caused this also could be identified. Log series index is said to provide the most comprehensible result in such studies of alpha diversity. Some other useful indices may also be briefly mentioned (see Southwood 1978 for details).

Log normal distribution index : Based on the assumption that distribution of individuals among species is of the normal or Gaussian type and population growth is geometric, Preston (1948) proposed to plot the frequency of species against abundance classes (population) on a log scale. Index is represented as: $R_i = \log_2 (N_i / N_o)$, where N_o is the abundance of species at the mode of the

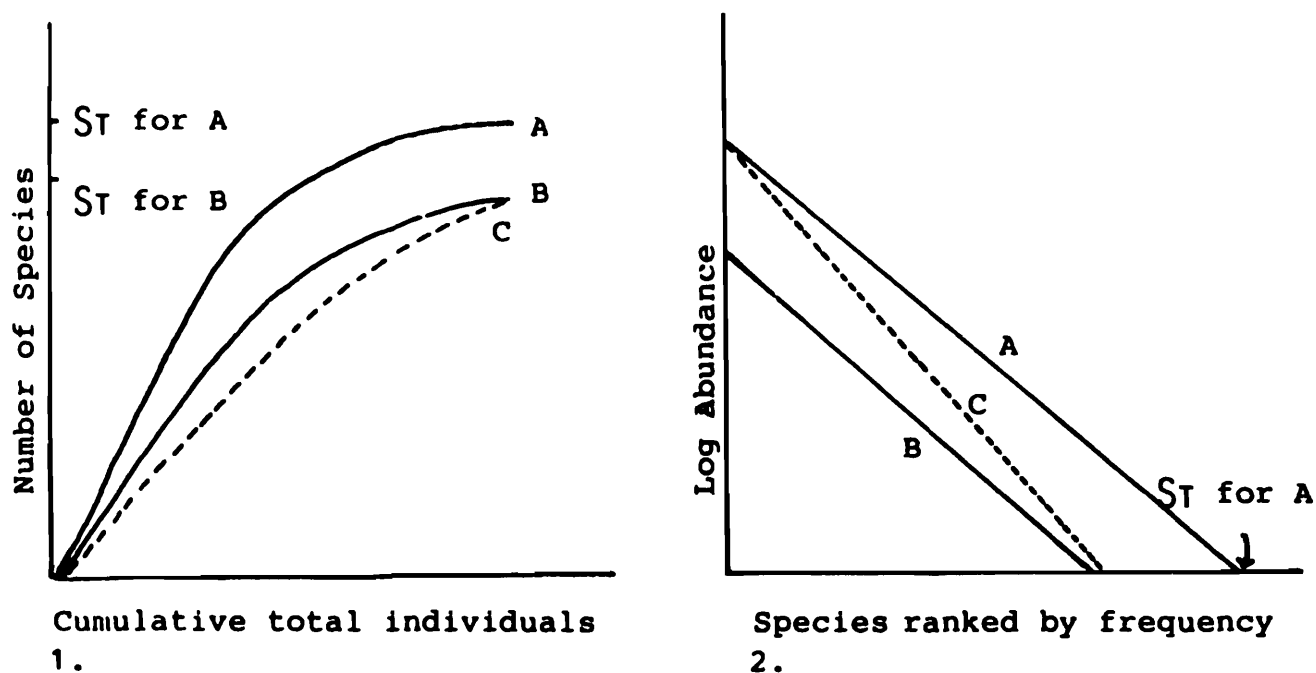


Fig. 2. Species richness and equitability. Of habitats A, B and C, and A and B have similar equitability but different richness; B and C have similar richness but different equitability. No.1 gives the rate of accumulation of species against cumulative total of individuals collected during a survey and No.2 shows log total. Individuals per ranked species, most common species towards the left. (Southwood, 1978).

distribution. The index is said to give a good description of species abundance pattern.

MacArthur's Model ("broken stick") : This is used to find the abundance of the most abundant species on the assumption that niche boundaries are drawn at random when a resource spectrum is over occupied and is represented as

$$= N_i = \frac{NT}{ST} \sum_{n=1}^{ST} \frac{1}{n}$$

Shannon-Weaver Function : Also used to describe species abundance relationship; the index is given as

$$H = \sum_{i=1}^{ST} p_i \log_e p_i$$

but criticised as rather insensitive being dominated by abundant species.

Simpson-Yule Index : This calculates the probability of the individuals of same species being encountered consecutively in a population and represented as

$$1/\left(\sum_i^{ST} p_i^2\right)$$

the latter part of the equation or static is referred to C, and 1-C (instead of 1/c) gives the probability of the next encounter being with another species.

Berger-Parker Dominance Index : This simple index calculates the proportion of dominant species in the total sample of population (NT) and is: $d = N_{\max}/NT$ where $N_{\max}$ is the abundance of the dominant species.

Analysis of Beta Diversity

As already mentioned, beta diversity is a measure of change of species diversity (difference or similarity) from habitat to habitat. The most widely practised index for studying beta diversity is that of Sorenson Coefficient as modified by Bray and Curtis (1957) which particularly reflects similarity in individuals between habitats: $CN = 2jN/(aN+bN)$ where aN = the total individuals sampled (NT), bN = the same in habitat b, and jN = the sum of the lesser values for the species common to both habitats (w). The criticism of this index is that it underestimates the contribution of common species in diversity which are truer indicators of faunal characteristics.

Ordination of Indices : Graphic methods like Trellis diagram or Dendrogram are used for sorting of sample indices estimated. In trellis diagram the sample localities are arranged in order so that highest values for similarity come on the diagonal. If there is a discontinuity the inference is that two separate communities are involved.

In a dendrogram, pairs of samples with highest value of similarity are placed on the apex line and connected at their level of similarity value, next the sample with the highest value to one or other is joined at this level and so on. It is the level of the linkage lines rather than the order on the apex line that is significant. The limitation of dendrograms is that as it utilizes only highest value and much of the information is lost. Other methods of ordination are cluster analysis, multivariate analysis and gradient description (Southwood, 1978).

Species Packing

Coexistence of species in an interaction matrix is the meeting ground of community and population ecology (Southwood, 1978). The distribution of species against a resource gradient is the species packing, in relation to that particular component of the species niche. The width (breadth) of the section of the

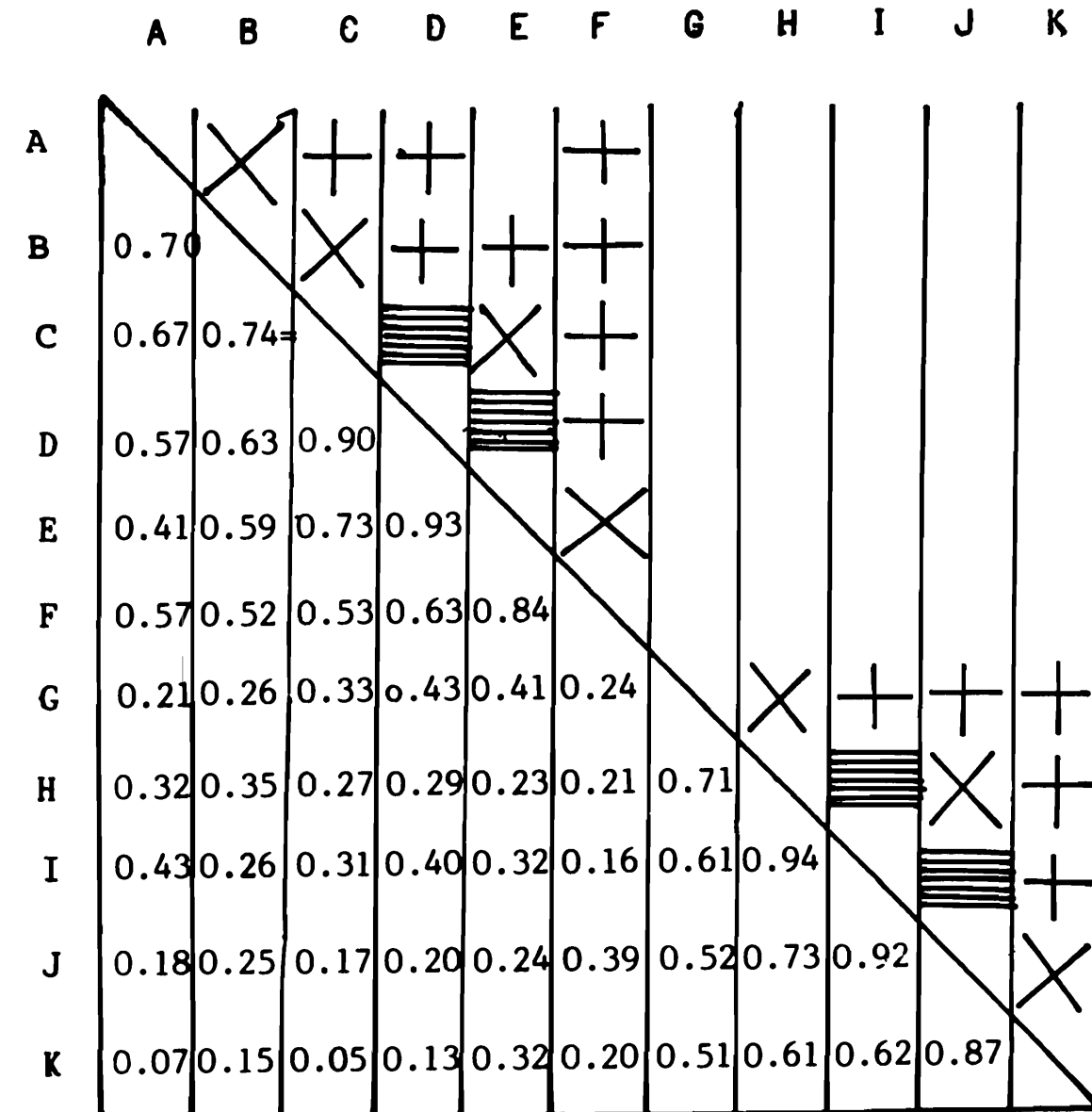


Fig. 3. Trellis diagram showing indices of species-similarity, + = 0.50 – 0.70; x = 0.70 – 0.90; hatching = 0.90 – 1.0. Data suggest the presence of two distinct communities.

gradient occupied by a species is its niche-breadth which might sometimes overlap with that of adjacent species and this is niche-overlap. Methods to study these aspects are mentioned below :

Measurement of Interspecific Association : This is mainly based on presence or absence data in a habitat and will show the extent to which the requirements of species are similar. A 2 x 2 contingency table is prepared for pairs of species where the more abundant species is placed to the right side of the table. A chi-square (X^2) value of the data is then estimated to know whether the association is significant. If X^2 is significant a number of coefficients of association (Cole, 1949; Hurlbert, 1969) can be used to get actual quantitative value for comparison with other species.

Measurement of Resource Utilization : Resource consists of a spectrum of food, space, physio-chemical factors, and time. Resource utilization measure for each species is plotted as curves which vary widely, being wide where resources are

scarce and narrow where they are plentiful. Simpson-Yule index described earlier can be used here whereby the proportion of the species using the particular segment of resource gradient is determined, the breadth of utilization or niche-breadth being equivalent to Simpson-Yule index.

The species packing in continuous resource spectrum especially in the case of seasonal and diurnal occurrence of food items or other resources defined by size can be studied through the mean and width of resource utilization range. In seasonal occurrence (migrant birds) the mean number of days of occurrence is first estimated and then the total range of occurrence is taken as twice the interval between the mean and the earliest occurrence. If the frequency is normally distributed then the total frequency range can be taken as 6 w or three standard deviations on either side of the mean. If not normal the graphical method of estimating the numbers in a stage (Southwood, 1978, p. 358) could be used. The resource separation ratio is then $p_{ij} = d_{ij}/w_{ij}$, where d_{ij} is the difference between the means of resource utilization by i th and j th species.

When different resources are proportionally utilized, the species packing can be estimated by the p_i method where the Simpson-Yule index is applied to the distribution of individuals to find out the niche-breadth or utilization. This states :

$$B = 1 \sum_i^m p_i^2 = 1 \sum_i^m N_i^2 / NT^2$$

where N_i = the number of individuals of the given species in the i th resource state, NT = the total number of individuals in all ($=m$) the resource states. Here, resource states need not be along a continuum and may be from different m of different categories of food types (eg. stomach content analysis). However, it is not advisable to apply this method to samples from heterogeneous habitats.

The niche-overlap leads to varying degrees of competition between overlapping species. In order to consider competition effect also on species packing and niche-overlap, the following competition coefficients are proposed: for that between i th and j th species for one resource axis: when the resource separation rates is known by:

$$\alpha_{ij} = \exp \left[-d_{ij}^2 / 4 w_{ij}^2 \right]$$

and when proportional utilization known by:

$$\alpha_{ij} = \sum p_i p_j \sqrt{(\sum p_i^2)(\sum p_j^2)}$$

Each term is summed for the array of resources.

Environmental Scale : Diversity can be studied at various geographic scales. The decision to adopt a particular level or unit largely depends on the objective

and logistics. However, too small a sampling unit or square is usually ruled out as it will not reveal a representative number of the individuals of any of the species present in the area. Also a unit square must be big enough to reveal most of the species if many are present. If the objective is to bring out the effect of speciation, then very large squares should be selected, of say about 2000 km on a side. Such a region will have enough topographic diversity to have geographic isolation which ultimately leads to speciation. On the other hand if the objective is to know the effect of competition for managerial purpose, then the squares should be small enough and homogeneous so that species would be coexisting. A good sample for managerial objectives would be one of an area large enough to have adequate number of coexisting species, but smaller than a region where past history and speciation still leave their dominant effects. Such homogeneous habitats usually contain only a single species of a taxon.

Ecological Succession

Ecological succession is an ordered, directed and inevitable process. It is terminated by the climax community in which species diversity and biomass are highest and where for a given flow of energy the interactions between organisms are many. The primary succession by pioneering colonists leads to the next community or series (Clements, 1916) which finally develops into a stable community of the climax type. A secondary succession is said to have taken place when organisms have been eliminated and replaced by different kinds. It produces a disclimax different from original climax. Species diversity analysis using the various methods described above, will enable one to identify the type of community present in a region and the type of succession involved. The study by Ferry and Frochot (1958) of bird fauna of forests, where trees were harvested at 40 year rotation showed that in felled plots, the number of species showed a rapid increase in the scrub stage of regeneration followed by a gradual decline and then again a marked rise. Certain species appeared immediately after the felling, increased rapidly in number only to disappear thereafter. Others maintained their increase throughout. In young communities under the process of succession the quotient Q which is the ratio of Productivity (oblique line) Biomass will be high. The quotient Q represents the turnover of the ecosystem. Q becomes smaller as the ecosystem increases in efficiency and as species diversity is increased. The serial stages of a succession show a tendency towards progressive reduction in Q while mature ecosystems are more complex, diverse and have a low value for Q . The managerial objective in naturally maintained ecosystems should be to produce an efficient ecosystem where this ratio is low, as is characteristic of stable ecosystems and in which the biomass and species diversity would be high. Agricultural systems contravene this principle where man attempts to produce high productivity with low biomass i.e. a high Q .

Ecological Efficiency

This is the ratio between energy assimilated by two trophic levels and is

estimated by the equation $A1/GP \times 100\%$ and $A2/A1 \times 100\%$ where A1 is the assimilated energy and GP is productivity of the trophic level. This ratio is always low. It is estimated that the photosynthetic efficiency of green plants is just 0.1 to 0.5% and for the entire biosphere it is only 0.1 percent. Herbivores use just one percent of the plant energy consumed for growth. Thus for a mean of 4200 KJ/day/m² of radiant energy fixed by plants only 42 KJ is assimilated by herbivores, 4.2 KJ energy fixed by plants only 42 KJ is assimilated by herbivores, 4.2 KJ by primary carnivores and 0.42 KJ by secondary carnivores (Dajoz, 1977).

The quantity of energy available is so small that the number of animals at the secondary carnivore level is very low. The low ecological efficiency of conversion from one trophic level to another necessitates that an efficient and productive ecosystem is one that consists of a diversity of species capable of exploiting different trophic levels. Homeotherms are less efficient than poikilotherms as they must use up a large proportion of their food in maintenance of body temperature. For this reason more protein can be produced per area by fish-farming than by raising cattle. Traditional fish-farming in south China further improves on this by making use of five or six species of fish having different diets, so that, by exploiting different trophic levels, highest degree of efficiency can be obtained. The rich species diversity of herbivore, in African savanna suggests that a very high degree of ecological efficiency in energy conversion has been achieved there where cattle alone will do poorly. Incidentally, the low ecological efficiency from one trophic level to the next is a strong argument in favour of adopting an entirely vegetarian diet !

Indicator Species

Species which are narrowly adapted to particular sections of habitats and with restricted ecological requirements can be used as indicators of the health of that habitat. Many species of dragonflies are restricted to particular type of water bodies. Dragonfly larvae are carnivores and therefore must find abundant prey to complete their development. The degree of abundance of dragonflies over a water body is a reliable indicator of the trophic state of that habitat. Similarly, it is possible to assess the extent of organic pollution along a river by identifying the species of saprophile organisms and their associations present in the river. Polysaprobic waters which are highly polluted, with reddish colour and offending smell are characterised by sulphur bacteria, fungus, oligochaetes, chironomid larvae, leeches and certain species of isopods. Mildly polluted waters containing ammonium compounds and nitrates and greenish in colour are characterised by mesosaprophile insects like corixids, nepids, etc., cladocera, and unicellular algae like *Spirogyra*. The disappearance of lichens from tree trunks indicates an increased level of sulphur dioxide in the air. Mosquito species and their potential breeding sites can be identified by the species of plant cover of the areas involved. Salt marshes with *Juncus* and *Salicornia* plant cover are found to be breeding ground of mosquitoes. Oviposition sites of migratory locust *Schistocerca gregaria* can also be located by characteristic plant species of the

habitat. Plant species can also be used to recognise at once the soil type of an area.

Each species is influenced by other species with which it interacts. Therefore encouragement of species diversity is a high conservation priority because the opportunity for biotic manipulation to achieve managerial objectives through interaction between species are greater when the diversity of biota is greater. Moreover, species diversity buffers the ecosystem against violent oscillations and ensures the preservation of the greatest range of genetic viability to be drawn as and when required in future. Species diversity therefore keeps the options, including the basic one of survival, open for man.

References

- Bray, J.R. & Curtis, C.T. 1957. An ordination of the upland forest communities of southern Wisconsin. *Ecol. Monogor.*, 27: 325-349.
- Clements, F.E. 1916. *Plant succession: analysis of the development of vegetation*. Publ. Carnegie Inst. Washington.
- Cole, L.C. 1949. The measurement of interspecific association, *Ecology*; 30: 411-424.
- Connel, J.H. & Orias, E. 1964. The ecological regulation of species diversity. *American Naturalist*, 98: 399-414.
- Dajoz, R. 1977. *Introduction to Ecology*. Hodder and Stoughton, London.
- Ferry, C. & Frochot, B. 1958. Une methode pour denommer les oiseaux nicheurs La Terre et al Vie: 85-102.
- Fisher, R.A., Corbet, A.S. & Williams, C.B. 1943. The relation between the number of species and the number of individuals in a random sample of an animal population. *J. Anim. Ecol.*, 12: 42-58.
- Holloway, J.D. 1974. The biogeography of Indian butterflies. In : *Ecology and Biogeography in India*, 473-499 (Ed.) M.S. Mani, W. Junk, The Hague.
- Huffaker, C.B. 1958. Experimental studies on predation. *Hilgardia.*, 27: 343-383.
- Hulbert, S.H. 1969. A coefficient of interspecific association. *Ecology*, 50(1): 1-9.
- Jayaram, K.C. 1974. Ecology and distribution of freshwater fishes, amphibia and reptiles. In : *Ecology and Biogeography in India*, 517-583 (Ed.) M.S. Mani, W. Junk, The Hague.
- Klopfer, P.H. 1962. *Behavioural aspects of ecology*. Prentice Hall, New Jersey.
- Kurup, G.U. 1974. Mammals of Assam and the mammal-geography of India. In : *Ecology and Biogeography in India*, 585-613 (Ed.) M.S. Mani, W. Junk, The Hague.
- MacArthur, R.H. 1972. *Geographical Ecology*. Harper & Row, New York.
- MacArthur, R.H. and MacArthur, J. 1961. On bird species diversity. *Ecology*, 42: 594-598.
- Mani, M.S. 1974 (Ed.). *Ecology and Biogeography in India*. W. Junk, The Hague.
- Mayr, E. 1963. *Animal species and evolution*. Harvard University Press, Mass.
- Nayar, M.P. 1982. Endemic flora of peninsular India and its significance. *Bull. Bot. Sur. India.*, 22: 12-23.
- Nair, N.C. & Daniel, P. 1986. The floristic diversity of the Western Ghats and its conservation: A review. *Proc. Indian Acad. Sciences (Supplement)*.
- Paine, R.T. 1966. Food web complexity and species diversity. *American Naturalist*, 100: 65-76.
- Patrick, R., Hohn, M. & Wallace, J. 1954. *A new method of determining the pattern of the diatom flora. notulae Natura* 259. Academy of natural Sciences, Philadelphia.

- Pianka, E.R. 1967. Latitudinal gradients in species diversity: a review of concepts. *American Naturalist*, 100: 33-46.
- Preston, F.W. 1948. The commonness and rarity of species. *Ecology*, 29: 254-283.
- Southwood, T.R.E. 1978. *Ecological Methods* (2nd ed.). Chapman and Hall. John Wiley and Sons, London.
- Simpson, G.G. 1964. Species diversity of North American mammals. *Systematic Zoology*, 13: 5-73.
- Whittaker, R.H. 1972. Evolution and measurement of species diversity. *Taxon*, 21: 213-251.

Ethological and Ecological Adaptations

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In animals, structure, behaviour, and adaptation, form a biological mirror in which the different disciplines of the life sciences reflect their images directly or indirectly. Considering the rapid advancement of the life sciences in the recent times, the taxonomists are giving proper importance to the three aforesaid inter-related facts in their studies for better understanding of a taxa. So, the taxonomic inquiry is developing and expanding in finding the cause, function, evolution and development of structure, behaviour and adaptation of animals.

Generally, the taxa are characterized by a basic structural pattern laid down early in evolution, except in some very highly specialized groups having special adaptive significance due to their special ethological or ecological adaptations. Taxonomic studies reveal that not all morphological or ethological characters are equally useful. Some are powerful indicators of relationships, others are not. The usefulness of a morphological character depends on its function that is on its correlation with its particular adaptation produced by evolution. The taxonomist assigns a certain weight to each character according to its usefulness, that is, according to its ability to reveal relationship. We realize that as phenotypic manifestations of the genotype, taxonomic characters are the product of a long history of natural selection which is continually acting on instinctive activities, always favouring better adaptations to the environment, and it must be also advantageous to the animal and contribute to its survival.

The order Coleoptera is the largest group in the animal kingdom and it offers many interesting examples of structural, behavioural and adaptive diversification, affecting every type of characteristics which can be studied by most modern research techniques. As a taxonomist, during the work on some Indian fauna of coleopteran insects, it appeared to the author that in some very highly specialized groups, the structural manifestations due to ethological or ecological adaptations, provide important characteristics for taxonomical studies. Among the coleopteran insects, specially two families, Meloidae (Blister beetles) and Tenebrionidae (Darkling beetles) drew the attention of the author long ago. The author studied these insects in the field as well as in the laboratory and availed the opportunity of examining the huge collections of these insects collected from Asia, Africa and Europe represented in different

institutes of India and foreign countries. As a first Indian worker on these two families of Coleoptera, the author (Saha, 1972a, 1972b, 1972c, 1979, 1983, 1984, 1988a, 1988b and Saha & Das, in press) has published several papers and a monograph on these insects.

Ethological Adaptations in Meloidae

Several important biological characteristics of the family Meloidae are having very important impact on taxonomic studies of this taxa. The members of the family, popularly known as blister beetles, are the natural source of bio-chemical pharmaceutical product, cantharidin ($C_{10}H_{12}O_4$), and are of immense economic importance. The family has been divided into three sub-families, namely, Meloinae, Zonitinae (= Nemognathinae) and Horiinae. Some genera of the Sub-family Meloinae, namely, *Mylabris*, *Epicauta*, *Psalydolytta*, *Cyaneolytta* and *Meloe* show prolonged dominating sexual behaviour throughout the whole day. For this they manifest specific behavioural pattern and as a result of which they have developed distinct morphological characteristics which provide the most important characters for taxonomic studies. And due to these activities they have become taxonomically as well as biologically very distinct group. Certain structural features of these insects, namely, antenna, maxillary palpi, abdomen, forelegs and genitalia of males appear to have some special functional relationship with one or more of the acts comprising these behaviour. These structures have become the integral part for performing specific, stereotyped acts of display such as antennation, palpation, genital probing or rubbing, and leg rubbing. In antennation, the male grasps the antenna of the female with segments V to VII which are all elaborately modified for this purpose. Palpation is the act of rubbing the maxillary palpi on the top and front of the head of the female. In performing the act of leg rubbing, males rapidly move the legs on each side of the body up and down in opposite direction so as to brush the tarsi against the sides of the elytra and abdomen of the female. During mating the male moves backward from over the dorsal side of the female, with the genitalia extruded, and attempts to insert the genitalia in that of the female. When, during courtship, a female is ready to copulate, she typically becomes still, lowers her head and elevates the apex of the abdomen to facilitate intromission of the male genitalia. The latter has been modified like an anchor, with hooks, for prolonged period of copulation. This is one of most adaptive significance of male genitalic modification which is very rare in the insect world. Thus, in the family Meloidae, genitalia is one of the most dependable species character.

Among three sub-families, Meloinae is having the most dominating sexual instinctive activities which are supported by natural selection and having most distinct behavioural and structural characteristics than in the other two sub-families. For an animal to manifest a behaviour pattern, a specific stimulus is required. In the body of these insects belonging to the sub-family Meloinae, a sex stimulant bio-chemical product, cantharidin is produced, which is lacking in

other two sub-families of blister beetles. In many animals, hormones, as an internal stimuli, play an important role in controlling behaviour. According to Lorenz (1950) the central nervous system produces impulses which act as a direct cause of instinctive manifestation. Due to mutation, structural characteristics are manifested, which constitute the supporting frame work of behavioural pattern. This fact had been experimented in fruit fly, *Drosophila melanogaster*, the most thoroughly investigated animal from the genetic standpoint.

In most insects, the innate, "Instinctive" responses play a much larger role in normal behaviour than do the effects of experience. The most complex patterns of behaviour are usually those associated with mating and oviposition. From an adaptive point of view, the main significance of an elaborate courtship pattern is probably to minimise the likelihood of inter-specific matings, which would be biologically wasteful. A courtship can be regarded as a series of signals transmitted by the male to the sensory apparatus of the female, interspersed at times with similar signals from the female to the male. Such signals commonly involve the tactile and chemical senses. Secondary sexual characters are usually manifested in organs or part of the body involved in such signal transference actions. Cuticular surfaces of some male meloids which come in contact with the female during the courtship possess a higher density of cuticular pores. These may be instrumental in chemotactic communications. Furthermore, the ventral surface of the maxillary and labial palpi in males have greater pore concentrations than in females. The other distinct anatomical modification associated with courtship is the single curved spur at the apex of the foretibiae of males. This structure is associated with mounting behaviour.

Ecological Adaptations in Tenebrionidae

The family Tenebrionidae is a versatile group in having unique power of adaptation in desert and Himalayan ecosystems. It has extreme organic diversities and adaptive radiations in different ecological niches, and of special value in zoogeography. It plays an important role as scavengers and stored grain pests. Its vastness and extreme diversity of forms in nature exceeds those of any other families of Coleoptera. Its population has long been used in the laboratory to carry out the different biological experiments.

In a typical desert, beetles almost always represent a dominant element in the insect fauna and form one of the most important animal components of the ecosystem (Cloudsley - Thompson and Chadwick, 1964). Most of the true desert beetles belonging to the family Tenebrionidae show diverse and characteristic modifications. They belong to the Cryptonephric group, with water economizing modifications of their Malpighian tubules. The desert tenebrionids generally have thick cuticle and the epicuticular wax layer. They are almost always flightless and wingless, and have additional skeletal modifications to restrict or protect the areas of thin cuticle between the sclerites, and to occlude the spiracles. Most of them are black and nocturnal, with more or less burrowing

habit. Some of the desert living species of the tribe *Adesmini* and *Zophosini*, are active by day and are fast runners, tending to develop long legs and large almost continuous hind coxae as in *Adesmia*, (Koch, 1955). Some of the larger species of sandy desert tend to develop special modifications of the tarsus, forming ventral hairy "sand shoes". Many of *Zophosini* develop a peculiar mode of propulsion known as "Sand swimming", in which the hind legs work together instead of alternately, resulting in the modification of the metasternum like that found in Dytiscid water beetles.

The water conserving adaptation of desert beetles include the development of exceptionally thick and impermeable epicuticle and a high degree of reduction or occlusion of the connecting membranes between the sclerites. A fusion of two elytra along the suture in the modified flightless types are found in various desert tenebrionids. Thus, desert adaptation involve a combination of characteristics structural, physiological, behavioural and mode of life which manifest many interesting adaptive characteristics which are of immense importance in taxonomic studies.

Conclusion

Structure, behaviour and adaptation form an integrated triangle of animal life and these three are interrelated. These can be studied through psychology, ecology, physiology, biochemistry, genetics and evolution. So, in recent times, the taxonomy has become the science of synthesis of all these disciplines and in true sense, it has become the biological taxonomy. Thus, the studies of Blister beetles and Darkling beetles are contributing in understanding that taxonomy is part and parcel of modern biology.

References

- Alexander, R.D. 1962. The role of behavioural study in cricket Classification. *Supt. Zool.*, 11, 53-72.
- Cloudsley - Thompson, J.L. & Chadwick, M.J. 1964 "Life in deserts". Foulis, London.
- Crowson, R.A. 1955. *The Natural classification of the families of Coleoptera*, London.
- Crowson, R.A. 1981. *The Biology of the Coleoptera*, Academic Press, London.
- Koch, C. 1955. "Monograph of the Tenebrionidae of Southern Africa", Vol. 1. Transvaal Museum, Pretoria.
- Lorenz, K.Z. 1950. The Comparative method in studying innate behaviour patterns. *Symp. Soc. exp. Biol.*, 4, 221-68
- Mayr, E. 1969. *Principles of systematic Zoology*. Tata McGraw Hill Publishing Company, Bombay, New Delhi.
- Saha, G.N. 1972a. Studies on Blister Beetles (Coleoptera: Meloidae), II. Four new species of *Mylabris* Fab. from Rajasthan. *Oriental Ins.*, 6(3) : 273-280.
- Saha, G.N. 1972b. Studies on Blister Beetles (Coleoptera: Meloidae) from India : I. Two new species of the genus *Eletica* Lacordaire. *Zool. Anz.*, Leipzig, 189: 98-101.
- Saha, G.N. 1972c. Observations on a collection of Blister Beetles, *Mylabris* Fab. (Coleoptera: Meloidae) from Pakistan, with the description of a new species and a new sub-species. *Proc. zool. Soc.*, Calcutta, 25: 19-23.

- Saha, G.N. 1979. Revision of Indian Blister Beetles (Coleoptera: Meloidae) - *Rec. zool., Surv. India*, 73(1) : 1-146.
- Saha, G.N. 1983. A new genus of Meloidae (Coleoptera : Insecta) from India. - *Oriental Ins.*, 15(3) : 63-65.
- Saha, G.N. 1984. Discovery of the genus *Tentyrina* Reither (Coleoptera : Tenebrionidae) from India with description of a new species *Bull. zool. Surv. India*, 6(1-3) : 253-255.
- Saha, G.N. 1988a. A new genus of Amarygmini (Coleoptera: Tenebrionidae) from India. *Rec.zool.Surv. India*, 85(3) : 429-432.
- Saha, G.N. 1988b. Discovery of genus *Platolenes* (Coleoptera : Tenebrionidae) from India with description of the new species. *Rec. zool. Surv. India*, 85(3) : 433-437.
- Saha, G.N. & Das, B.N. 1990. Studies on the Meloidae fauna of West Bengal (In Press).
- Sealander, R.B. 1964. Comparative ethology and systematics of Meloidae (a new classification based on anatomical, ecological & bionomic characters proposed). *Can. Ent.*, 96: 1056-1082.
- Spieth, H.T. 1952. Mating behaviour within the genus *Drosophila* (Diptera). *Bull.Am. Mus.Nat. Hist.*, 99: 399-474.

Taxonomy in Conservation and Management of the Environment

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How many of us fully appreciate the environmental problems facing India as it approaches the 21st century ? Ten years is probably the time remaining for the world to avert a global disaster. It is an unfortunate fact of human behaviour that problems which cannot be seen or which have no instant or direct effect on the individual (like the thinning of the ozone layer, greenhouse effect, nuclear and toxic chemical effects, extinction of inconspicuous species) are not considered important and for many they do not exist at all. There is a need to review national goals and for the redefinition or measurement of progress and quality of life in terms of clean air, clean water, contamination-free food and sustainable use of resources (Recher and Rohan-Jones, 1981).

It is ironic that a time so filled with great opportunities should also be a time when a major fraction of the diversity of life on earth, perhaps a quarter over the next few decades, is in danger of extinction. Each species that disappears takes with it an elaborate, unique and little understood pattern of genes and gene expression that evolved over many millions of years. Acting prudently for the future, demands that biologists greatly accelerate the pace of taxonomic inventory and of charting the poorly understood contours of life on earth, especially in the tropics. Otherwise, the opportunity will be lost before biologists understand the base line conditions for many phenomena, including those that might benefit mankind (Raven, 1990). *Species do not live in isolation, they live in communities and ecosystems.* The advantage of a species based reserve system is that species are fundamental units of nature rather than artificial human constraints (Soule, 1986). These living communities react according to their own rules, although they can only exist if they also constantly store and process information on other components of their area system. The structural and energetic analysis of living communities can hence give essential information on the space in which they live. From the distribution pattern of sympatric species we obtain not only the possibility of characterizing spaces and knowledge of the evolution dynamics present there, but also an insight into their genesis. Ecological and historical information on populations and the habitats in which they live flows together in area systems. These are living subsystems of

our landscapes. Through the elucidation of its structure, function and history, every living system supplies information which gives deeper understanding of the space in which it lives.

One of the most interesting developments in the field of ecology and resource management is the recognition of the significance of historical review in understanding ecological patterns and developing guidelines for the management of natural areas. As individual humans, we seldom have personal experience with populations, communities or ecosystems much in excess of our 40 or 45 years of working life. Most ecological research is planned and carried out over every 2 or 3 years available for doctoral study or funded by research grants. There is the risk, therefore, of assuming that which we observe is affected only by current processes or event, (IUCN, CNPPA, 1984). Moreover, every person has a subjective, frequently idealized conception of his environment, which is not necessarily his total natural environment. In order to prevent such misconceptions, appropriate insights are necessary into the synergism of our landscapes. Evaluation of the burden on a landscape is essentially related to the load capacity of various ecological factors. This problem can only be solved if we work out imperative ecological norms for each habitat/ecosystem on the basis of detailed investigations and make them into workable rules for their inhabitants (Müller, 1974).

Environmental management and conservation programmes, must be extended to all land, regardless of tenure and despite arbitrary political boundaries or bureaucratic divisions. Government departments must work together in recognition of their primary responsibility to the community and not to some perceived hierarchy of power within the government or to an imagined obligation to industry. *Much needs to be done to guarantee the free exchange of scientific information.* Scientists of government departments are prevented from public comment by government policies and others are stopped from commenting for fear of losing research funds or being denied permission to work on areas controlled by particular government departments. As a result, the conservation movement is often forced to act with incomplete information while planners control the flow of information, information which is usually funded by the Indian taxpayer. The entrenched bureaucracy has strongly resisted any change, making the functioning of the government cumbersome, lacking the necessary expertise and may too often lack the intellectual stamina and foresight required to deal with complex events such as environmental issues.

We must encourage debate on the objectives and priorities for conservation. But debate should not be a substitute for action. Rather they need to go hand in hand. Conservationists cannot afford the luxury and the excitement of adversary science. The weakness of this parochial style of intellectual progress is that years or decades may pass before a clear resolution is reached and before timid politicians, technocrats or bureaucrats decide that action will not bring a storm of criticism. By the turn of the century most options will be closed regarding the

design, size and organization of nature reserves (West, 1989). The identification of the components of a nature conservation programme needs to be accompanied by an assessment of which components are important, and fixing priorities and making choices. Then comes building a sampling protocol and designing a system of the sampling strategy. Within these fall much of the recent advances in conservation biology, in fields such as species/area ratios, and the implications of island biogeographic theory, minimum viable populations, long term survival from stochastic events etc. When you pay real money for programmes you tend to be a little more careful that you really are getting what is not merely important or useful but what matters most (Mackinon *et.al.* 1986). The International Biological Programme (IBP) conservation survey aimed to show a way in which a national system of reserves conserving the greatest variety of plants and animals which can be achieved in the shortest period of time. They also recommended that a national conservation network should be based on major ecosystems, but for convenience, proceeded to substitute major plant communities for major ecosystems because most animals depend on particular plant communities and that plant communities are relatively better known. Interestingly IBP did not discuss or debate the underlying objectives of their conservation proposals - should it be based on species conservation, should it be community based, should it be ecosystem based or should it include both abiotic and biotic elements ?

One of the foremost and obvious effects of societal demand in any region, is its diminishing greenery - the vanishing forests resulting in shrinking animal populations. One does not need empirical data or figures to realize this, the ugly scars of unvegetated land and exposed soil dotting the once lush green landscape and the turbid waters of the once crystal clear rivers and streams are evidence enough of the malise. To facilitate adoption of remedial measures and judicious management practices for resource utilization, a base-line data - one which is reliable and periodically updated - is indispensable. Identification of factors and practices contributing towards forest degradation and destruction is undoubtedly necessary as well. Traditionally foresters have been trained to value forests for the wood they produce for people to use and the jobs they create, and not for their pristine beauty, wilderness or its precious wildlife. Despite promoting an image of 'multiple use' objectives in forest management, foresters throughout the world measure success in volumes of wood harvested. In fact all forests reserved for nature conservation or as wilderness, is land deemed worthless for other purposes including production of timber. The historical analyses of these objectives, assist in understanding why some foresters, who justifiably pride themselves as the nation's first forest conservationists, actively oppose preserving the final remnants of old growth forest and why they align themselves with the forest products industry instead of being neutral, in the debate over the allocation of forest land for competing public uses.

Some may even ask, why preserve wildlife if much of what it does can be replaced by man made systems ? In brief, there are two reasons. The first reason for conserving wildlife is in part aesthetic, part scientific. *Organisms are unique*

creations of evolutionary process. They deserve to be preserved as many artifacts which man preserves. When a species becomes extinct something unique has been lost that can never be retrieved and neither can it be brought back or bought back. The second reason is that we know so little about the interrelationships of these natural assemblages of organisms. Their study is not merely of academic value but has applied implications. Organic communities represent the outcome of millions of years of evolution. By studying the flow of energy through such systems and the utilization of chemicals by them, we have much to learn about organic production and this should prove of use to us, both in relation to food production and in the proper use of landscape. (Ward, 1970).

As a case study, many of the above mentioned plans of action fail when a unique situation as in N. E. India is faced. Most of the forest lands in N. E. India are "unclassified" forests, i.e., with no legal status, or are under private ownership. The local tribal communities claim ownership over unclassified forest lands and also enjoy excessive concession in the exploitation of the products from these forests. As a result scientific management has not been possible in most of the forests in the N. E. states. Table 1 lists some of the fauna restricted to North-East India. The list is by no means exhaustive, for only the best known vertebrate species have been accounted for - to highlight the species richness endemic to a small part of country only. There are many more faunal species which have been given protective or endangered status (Alfred *et al.*, 1989). However, population data or information about seasonal variations in number and information about their ecology and behaviour remain negligible. The effect of disturbance, specially fire (resulting from swidden agriculture, another great factor to be reckoned with in N. E. India), has a profound effect on all animals and especially soil animals (Darlong & Alfred, 1988). They have reported a decrease in faunal density to the tune of approximately 50% in Oligochaeta, Chilopoda, Araneida, 90% in Blattaria, Orthoptera, Coleoptera and cent percent in Mollusca, Diplopoda and Isopoda. It is important to note that these animals are crucial to decomposition and nutrient cycling, and hence for efficient forest productivity. These figures only serve to emphasise the fact that degradation results in disturbance of the complex web of life and a resultant destructive chain reaction sets in, effecting not only the smaller diminutive forms of life, but the well being of the whole system. The end result is depriving the capacity of the forest and its inhabitants to recoup to their original status.

The depletion of the tropical rain forests of the world at an estimated rate of nearly 2,50,000 km² per year is one of the most disturbing aspects of the present day. For although occupying less than 10% of the Earth's land surface, they harbour about half of the Earth's 5-10 million biological species, while it is estimated a net release of 4-8 pentagrams (10¹⁵ g each) of carbon annually into the atmosphere mainly from clearing and/or burning of tropical forests. Species from the moist forests already contribute a huge range of benefits to mankind. In future they may provide us with entirely new food and industrial crops, and they can certainly be extensively used to improve the genetic makeup of existing crops.

Table 1. Some Fauna restricted to North-East India

Group	Status
MAMMALS	
Primates	
<i>Nycticebus coucang</i> Bodd. (Slow loris)	Schedule I
<i>Presbytis geei</i> Khajuria (Golden langur)	do
<i>P. phayrei</i> Blyth (Phayre's leaf monkey)	do
<i>P. pileatus</i> Blyth (Capped langur)	do
<i>Hylobates hoolock</i> Harl. (Hoolock gibbon)	do
<i>Macaca nemestrina</i> Blyth (Pig-tailed macaque)	Schedule II
<i>M. arctoides</i> Blyth (Stump-tailed macaque)	do
Carnivora	
<i>Arctonyx collaris</i> F. Cuv. (Hog badger)	Schedule I
Artiodactyla	
<i>Cervus eldi eldi</i> (Browantlered or Thamin deer)	Schedule I
AVES	
Galliformes (Pheasants)	
<i>Tragopan blythi</i> (Jerdon) (Blyth's tragopan)	Schedule I
<i>Lophophorus sclateri</i> Jerdon (Sclater's monal pheasant)	do
<i>Crossoptilon crossoptilon</i> Elwes (Elwe's eared pheasant)	do
<i>Syrmaticus humiae humiae</i> (Hume's bar-backed pheasant)	do
REPTILIA	
Lizard	
Lacertidae (Lacertids)	
<i>Takydromus sexlineatus khasiensis</i> (Blgr.)	nk
Tortoises	
Emydidae (Freshwater tortoises)	
<i>Geoemyda mouhati</i> Gray (Assam Freshwater tortoise)	Schedule IV
<i>Cyclemis dentata</i> (Gray)	do
<i>Khachuga sylhetensis</i> (Jerdon) (Assam sawback turtle)	do
Testudinidae (Land tortoises)	
<i>Indotestudo elongata</i> (Blyth)	do
<i>I. emys</i> (Schlegel & Muller) (Assam tortoise)	do
AMPHIBIA	
Ranidae	
<i>Rana assamensis</i> Sclater	nk
<i>R. garoensis</i> Boul.	nk

Group	Status
<i>R. danieli</i> Pillai	nk
<i>R. mawphlangensis</i> Pillai	nk
<i>Micrixalus borealis</i> Annandale	nk
Rhacophoridae	
<i>Philautus shillongensis</i> Pillai & Chanda	nk
<i>P. garo</i> Boul.	nk
<i>P. cherrapunjiae</i> Roonwall & Kripalani	nk
Microhylidae	
<i>Microhyla berdmorei</i> (Blyth)	nk
Bufoidea	
<i>Bufoides meghalayana</i> (Yazdani & Chanda)	nk
<i>Pedostibes kempi</i> (Boul.)	nk
Hylidae	
<i>Hyla annectans</i> (Jerdon)	nk
PISCES	
Cyprinidae	
<i>Barilius tileo</i> (Hamilton)	nk
<i>Danio meghalayensis</i> Sen	nk
<i>D. deyi</i> Sen	
<i>Garra nagaensis</i> Hora	nk
<i>G. rupecula</i> (Mc Clelland)	nk
<i>Puntius shalynius</i> Yazdani & Talukdar	nk
Psilorhynchidae	
<i>Psilorhynchus homaloptera</i> Hora & Mukherjee	nk
Cobitidae	
<i>Lepidocephalus annandalei</i> Chaudhuri	nk
<i>Mesonoemacheilus reticulofasciatus</i> Singh & Banarascu	nk
Pillaiidae	
<i>Pillaia indica</i> Yazdani	nk
<i>Garo khajuriai</i> (Talwar, Yazdani & Kundu)	nk
Sisoridae	
<i>Glyptothorax striatus</i> (Mc Clelland)	nk
<i>G. shawi</i> Menon	nk

N.B: 1) *C. eldi eldi* is endemic to N. E. (Manipur); *P. geei* is also distributed over Bhutan; all the other mammals are also found in Southeast Asia.

2) nk = not known

Arguments for conserving those increasingly wonderful ecosystems nearly always emphasize the material benefits that man can derive from them, but some attention should also be given to scientific interest and beauty of these forests. Few people in the world understand the process occurring in tropical forests, or have had the opportunity to see for themselves the beautiful adaptations of plant and animal life that they exhibit in innumerable ways. If only more people could have the opportunity to experience the wonders of the tropical forests then surely demand for their conservation would be greatly increased.

The Golden langur, eg. *Presbytis geei* Khajuria is highly restricted in occurrence and distribution in the foothills of the Assam-Bhutan border. They are probably still found today fortunately because of the status their habitat has been given - first as a National Park and now as a Biosphere Reserve. Two other species which were accorded Red Data Book Category, "Endangered" status are the Pygmy hog, *Sus salvanius* and the Hispid hare, *Caprolagus hispidus* from North western Assam. The earlier and the present distribution range of both these species can be exclusively equated with the availability of the tall thatch grass or elephant grass that typically occurs along the southern edge of the Himalayan foothills. The only living ape in India, *Hylobates hooleck* occurs only on the south of Brahmaputra. In fragmented habitats or in isolated stretches, some of these species might be lost during habitat disturbances, and certain species that are critical may die off as commuting distances between diverse resources become too great (Alfred and Sati, 1990).

The history of human use of plant and animal species demonstrates that vanishing and apparently insignificant species are useful and even important. Many unexpectedly have been found useful for scientific research, whether as experimental material or as providers of clues of technical innovations. Also they are necessary as food, fibre and medicines. Armadillos are the only animals other than human beings known to contact leprosy. They are now providing to be invaluable in the search for a cure for this disease (Storrs, 1971). It is also necessary to ensure that the loss of species does not impair the effective functioning of ecological processes. It is unlikely that the particular communities of plants, animals and microorganisms that make up the ecosystems associated with so many essential processes - pollination and naturally occurring pest control - can readily be substituted by other communities. The genetic composition of such ecosystems may be crucial for their performance.

Preservation of genetic diversity is both a matter of insurance and investment. An estimated 1000 vertebrate species and subspecies are threatened with extinction (IUCN, 1975). These do not take account of the inevitable loss of small animal species - particularly invertebrates. Estimates that do attempt to take this factor into account suggest that from half a million to a million species will have been made extinct, by the end of the century (Myers, 1979). If these species disappeared, the loss to humanity could be irreparable. The most serious threat

is habitat destruction. Conservation of living species is the management of human use of the biosphere enabling the greatest sustainable benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations. Conservation is positive, embracing preservation, maintenance, management, sustainable utilization, restoration and enhancement of the natural environment. Living resources are renewable if conserved and they are destructable if not. Conservation is also an ethical imperative, expressed in the belief that *"we have not inherited the Earth from our parents, we have borrowed it from our children"*.

References

- Alfred, J.R.B. & Sati, J.P. 1990. Survey and Census of the Hoolock gibbon in West Garo Hills, Northeast India. *Primates*, 31(2): 299-306.
- Alfred, J. R. B., Darlong, V. T. & Sati, J. P. 1989. Wildlife Conservation in North-East India : Problems and realities. *Exposure*, 2(1) : 11-17.
- Darlong, V. T. & Alfred, J. R.B. 1988. Effect of shifting cultivation (Jhum) on soil fauna with particular reference to the earthworms in North-East India. *Proc. IX Inter. Soil Zool. Coll., Bangalore. (In press)*
- IUCN, 1975. *Red Data Book*, IUCN, Gland., Switzerland.
- IUCN, CNPPA, 1984. Categories, Objectives and Criteria for Protected Areas. 47-53 In : *National Parks, Conservation and Development : The role of Protected Areas in Sustaining Society.* (Ed.) J. A. Neely and K. R. Miller. Smithsonian Press, Washington D. C.
- MacKinnon, J, MacKinnon, K., Child, G. & Thorsell, J. 1986. *Managing Protected Areas in the Tropics.* IUCN, Gland., Switzerland.
- Müller. P. 1974. *Aspects of Zoogeography.* De. Hague : Verl. W. Junk.
- Myers, Norman, 1979. *The Sinking Ark.* Pergamon Press. Oxford.
- Raven, Peter, 1990. *Opportunities in Biology*, National academic Press, Washington, D. C.
- Recher, H. F. & Rohan-Jones, W. 1981. Forests and wildlife management : Conflict or challenge. *Living Earth*, 11-14.
- Soule, M. E. (Ed.) 1986. *Conservation Biology : The Science of Scarcity and Diversity.* Sinauer Associates Inc., Sunderland, M. A.
- Storrs, Eleanor, E., 1971. The nine banded armadillo : a model for leprosy and other biomedical research. *Inter. J. Lep.*, 39: 703-714.
- Ward, M. A. (Ed.) 1970. *Man and his environment.* Pergamon, Oxford.
- West, W., 1989. Substandard academics "inevitable". *Australian*, 25th October.