The Scope of Zoology

Denis Bellamy's Inaugral Lecture on taking up the Chair of Zoology and Headship of the Department of Zoology, University College, Cardiff, 1969

Introduction

We are living organisms, vitally interested in our own nature and in the living things which surround us. The study of life is the literal meaning of the term 'biology', and 'zoology' is taken as being synonymous with 'animal biology'. The study of animal life is a natural human activity. for man himself and can be fully understood only in his setting within the entire range of animal life. Also, whether the object of study is a jelly-fish, an elephant or a dinosaur, any progress in understanding one sheds light on all.

Zoology is primarily concerned with defining the nature of each kind of animal and its interactions with plants and microbes, as well as with other animals.   It is concerned with the relationship of animals and communities of animals to the environment. It also deals with the past history of animals in conjunction with the history of Earth. In addition, it is concerned with the origins and development of each individual animal. Modern zoology has no strict limits in that animals may be studied in all their manifestations from the 'invisible' to the 'gigantic'; as individuals and as infinitely complex webs of interrelated forms; as life now present and as life of the past. It includes a study of the properties of matter because all living things are made up of Earth's common chemical elements. At this level of organisation, the physics and chemistry of individual cells can be investigated and taught without regard for the boundaries between the plant and animal kingdoms. This is the true province of 'biology'. At a higher level, however, whole organisms and their component tissues, botany and zoology are at least as different as physics and chemistry. However, no matter how difficult it may be to define in practice, modern zoology ranges from the analytical study of cells, to the study of the organs, and the growth/maintenance activities of all members of the animal kingdom.

Zoology is a 'home' for physiologists, biochemists, and medical scientists who wish to fit their discoveries into the panorama of a past reaching back to a time when the earth was young, and relate to an unfolding story of the emergence and evolution of animals in relation to the changing Earth.

Because we are animals, zoology has a universal warmth of appeal that is not found in other sciences. This is because the goal of the zoologist is to understand his own nature. His aim is to understand the history and origin of life, and ultimately to provide sufficient self-knowledge to control the destiny of human beings who are dependent on a world of finite resources.

We alone among the animals are consciously aware of space and time and to be curious about our place within them and why we exist. Zoology is simply the outcome of our irrepressible urge to find the answers to these questions

History

Fifty years ago zoology was available, together with botany, as a school subject to those wishing to enter university and specialise in the study of living things. These two subjects also existed in every university at departmental level, and the preferred pathway for students interested in the study of animals was the undergraduate Honours course, where zoology was explored in depth over a period of two or three years. Few schools now offer zoology as a sixth form subject; along with botany it has been replaced in our public examination system by the subject biology. Reflecting this, many universities offer only biology as a very broad-based degree syllabus to students with a prime interest in the life of animals. It is usually studied as a cafeteria system where courses may be chosen in any order within the degree period, each studied to a non-stretching elementary level.

Within those universities that still have a zoology department, the preferred undergraduate pathway is gradually shifting towards a combination of zoology with one or more subjects, or parts of subjects. University College, Cardiff follows these international trends in that, although there is still a department of zoology, with a special honours syllabus, general schemes pair this subject with others such as chemistry, geology, botany, psychology, biochemistry and archaeology. Also, in Cardiff zoology has teaching links with a range of other departmental subjects from mineral exploitation to economics mainly through participation by the department in an integrated course on environmental studies which may be offered with zoology as half of a general degree scheme. These changes in undergraduate teaching clearly indicate that there have been important changes in the body of knowledge associated with the subject zoology during the past 50 years which can only be appreciated by examining the development of zoology alongside that of all other science subjects. The task is really beyond the scope of this lecture. What follows is an attempt to trace some of the major historical developments in research which distinguish zoology as a separate subject whilst at the same time emphasising links which zoology must now have with other subjects for a balanced view of animal life. It also points out the dangers of ignoring future needs for experts with knowledge to distinguish one species from another.

Traditionally, zoology is that branch of science dealing with all animals including ourselves. About half a million different sorts or species of animals have already been described and named, each breeding true to its own special characteristics and each different from all others. Over a hundred fresh species are discovered, described and named every year. This number is at present increasing annually and it is obvious that any study of all these creatures, their structure and mode of working, their habits and their history, will soon yield an enormous body of overwhelming facts unless we classify them properly.

From the beginning, botany and zoology have been concerned with classification. Both disciplines arose during the sixteenth century as applied sciences attached to medicine. Botany began as a broadened study of medicinal herbs, and early botanical gardens were herb gardens. With but one or two exceptions, all the great botanists and herbalists from the sixteenth to the eighteenth centuries were either professors of medicine or practising physicians. Zoology arose, in a similar way from medicine in connection with human anatomy and physiology. Until recently, a first year zoology course was obligatory for intending medical students. When botany and zoology became independent sciences, the first concern of the two fields was to bring order into the diversity of nature. Classification was, therefore, their dominant concern and indeed, in the eighteenth and early nineteenth centuries, botany and zoology were virtually coextensive with the science of classification termed 'taxonomy'. Moreover, by sheer necessity, classification at that period was essentially a vital part of the technique of identification required to put order into the vast inflow of new species into universities and museums.

Classification, or taxonomy, is the science of the orderly arrangement of animals according to some scheme of likenesses and differences among the various groups. At first, cataloguing animals was for convenience so that their names could be easily found, very much as one would classify an odd assortment of letters. Animals were grouped in various ways, such as those that were harmful or useful, those that lived on land or in water, and those that dwelt in trees or on the surface of the land. How they were classified depended on the whim of the taxonomist, but as knowledge of the rules of diversity of life increased, classification took on another fundamental purpose. Anatomical differences and similarities were carefully noted and it was found that despite great diversity, there were patterns of similarity between groups.

It was obvious to the early taxonomists that living nature was not planless, although the lines of the plan were obscure. It was through studies of the structure of living things that the plan began to emerge, especially through the work of Linnaeus, who made a classification of all known living forms of his day. Linnaeus over-emphasised the distinctions and barriers between species, which he thought of as immutable. The Linnean plan was that there are just so many species as there were forms created in the beginning.

With the establishment of the theory of evolution in the latter part of the l9th century, which stressed temporal changes in the organisation of living things, taxonomy gradually became concerned with the relationship or kinship of animals to each other. During this period, taxonomy began to express not merely a convenient cataloguing of animals according to structural differences and similarities, but also took into account the ancestral relationships between them. Study of the diversity of organisms with a view to establishing relationships between them is termed 'systematics' and at this time the terms 'taxonomy' and 'systematics' were generally considered to be synonymous, and dealt mainly with the progressive evolution of the anatomical features of animals.

This approach also dominated British zoology in the first quarter of the 20th century when it was almost wholly occupied with problems of phylogeny and comparative anatomy; that is with the apportioning out of evolutionary priorities and the unravelling of relationships of descent. Comparative anatomy has many brilliant discoveries to its credit; at best, exemplified by the deduction that the bones in the mammalian ear, which transmit vibrations from the eardrum to the organ of hearing, are cognate with bones of ancestral organisms which had formed part of the articulations of the lower jaw. These discoveries and others equally dramatic showing modifications with evolution, were the product of the l9th century.

Studies in the early 20th century were concerned with refining and correcting basic discoveries made earlier. All of the great successes of comparative anatomy were achieved before the turn of the century and nearly all of the great dynasties in the evolutionary history of animals were established in the l9th century. Unfortunately the continuation of this well established approach, increasingly pre-occupied with "gap-filling", had led by the end of the first world war to a sterile form of teaching and research concerned wholly with minutia of anatomy, and tedious arguments about the direction in which evolution was progressing.

It is only in recent years that there has been a resurgence of interest in classification. This development has brought about the rise of the system of objective taxonomy based on the premise that it is only possible to devise a satisfactory classification to distinguish very similar organisms if a large number of characters are available for analysis. The more varied the characters available for comparison, the more effective will be the classification. It is not necessary or even permissible to restrict the characters investigated to those that have been in the past listed as diagnostic. Theoretically, the whole of an organism's evolutionary history is contained within the molecules of a single cell, and we are now beginning to discern something of this molecular key to an organism's past in its macromolecules. Chemotaxonomy, dealing generally with chemical differences and serotaxonomy, dealing specifically with differences in proteins are two recent developments in this field of 'numerical taxonomy'.

Systematic zoology when considered as a discipline apart from taxonomy, is clearly devoted to the study of the evolution of different shapes and varied sequences of movement, which together broadly distinguish the different kinds of animals from each other. Early zoologists dealt only with the description of shapes. It was not until the second and third decades of this century that they turned to the description of sequences of movement, or the 'behavioural structures' of animals. It can be argued that zoology has distinction as a subject only when dealing with the building of three-dimensional shapes, and the assembly of patterns of movement. That is to say, what is distinctly animal is found only in the evolution of communities of cells to form organ systems and the establishment of behavioural structures by which animals interact with each other and with their environment. The motivation of zoologists is summarised by the questions "What is the use in having a particular shape and mode of behaviour? Does it contribute to the animal's success? If so, How?" and "What makes it happen?"

Questions on the origins of shape and size are still central to modern zoology. The most original approach to escape the anatomist's method of comparing shapes piecemeal was to view all changes in relative dimensions simply as the topical expressions of some comprehensive and pervasive change of shape through development taking place mainly in one direction. At the turn of the century, D'Arcy Thompson developed this approach to grasp evolutionary transformations as a whole, viewing the change of shape as analogous to that produced by distorting a sheet of rubber on which has been drawn a house or a face. Every single aspect of the drawing changes but the transformation as a whole might be defined by some quite simple formula describing the way the rubber had been stretched. Thompson's methods were later developed by J.S. Huxley into more usable quantitative relationships between the rate of reproduction of one part of the organism to another. This quantification of ideas in comparative anatomy that began in the late l9th century came to an abrupt end at the outbreak of the second World War. In 1945 a new generation of zoologists was in command of research, and it was the comparative experimental approach to physiology that surged forward. The achievements of the D'Arcy Thompson/Huxley school were left behind as a blind end to a particular research philosophy. It is only now, with a marriage between biochemistry and developmental biology that we are beginning to understand the operation of growth mechanisms during development, and to some extent to explain the precise mathematical analyses of the organism in relation to its parts that were carried out between 1900 and 1939.

Current approaches to the study of size and shape can be traced to the beginnings of experimental developmental biology. Historically, the study of development as a process began, not with the final product of ontogeny, which was the mainstay of dynastic zoology, but with the developing embryo. In the 1930's experimental embryology had much the same appeal as molecular biology has today, in that students felt it to be the most promising advancing front of biological research. This was partly because histological analysis in early development showed that unity existed between animal dynasties previously separated in terms of gross anatomy. Further, differentiation proceeded uniformly through the mobilisation and deployment of similarly structured cellular envelopes, tubes and sheets in all animals. Chemical unity of evolution was also apparent in the topical organiser theory, which postulated that differentiation in development is the outcome of an orderly sequence of limited but specific chemical stimuli. The underlying assumption of the theory was that an understanding of the chemical properties of the inductive agent would reveal why the amino acid sequence of proteins should differ. Unfortunately the rapid rise of experimental embryology tended to segregate various aspects of the life-cycle as distinct topics within the zoology syllabus, such as differentiation, growth, maturation and ageing, which is only now being overcome. For example, it is currently felt that life should be viewed more as a continuum at the chemical level; ageing and embryonic growth have a unity.

In retrospect, it is clear that embryology in the 1920's lacked the broad background of genetical reasoning which would have made it possible to formulate a correct theory of development. Also, the necessary analytical techniques for testing chemical theories involving interactions between unstable mixtures of proteins had not been invented. It is not now generally believed that a stimulus external to the system on which it acts can convey instructions that amino acids shall be assembled in a given order at a certain time and place. Only in the 1950's and 60's could embryonic development be viewed at the level of molecules as the unfolding of pre-existing capabilities in genetically encoded instructions. The growth of biochemistry and microbiology has allowed the zoologist to see something relevant to embryology in the induction of adaptive enzymes of bacteria. It is by this analogy that embryonic development is explained. That is to say the 'organiser' of the 20's is now identified as an agent that selects or activates one set of genetic instructions rather than another.

This very broad approach to systematics has only developed during the last 30 years with the growth of genetics, gathering momentum in the late 50's with the centenary of Darwin's 'The Origin of Species'. During those years biology has advanced more rapidly than at any other time in the history of science. The most telling discoveries have been concerned with our knowledge of the part played by molecules in living systems. The turning point came with the demonstration in the early 1950's of the Watson-Crick structure of DNA and later the identification of the genetic code. The rise of this viewpoint occurred within the field termed molecular biology. This field was concerned in its early stages more particularly with structure; this was part of the description or taxonomic phase of biochemistry. Today, molecular biologists are more interested in the evolutionary history of the molecules they study. In this respect it may be said that biochemists will gradually enter zoology when they study not just substances, but the evolutionary events that reject or retain them. Comparative studies of chemical structure led to comparative biochemistry as one of the first developments in modern biochemistry, but this broad-based approach rapidly lost ground to the preferential laboratory use of rats, mice, and the bacterium Escherichia coli. Now, systematic biochemists are rare because evolution is not an integrated part of the biochemistry syllabus, which instead stresses the chemical unity of living things. Zoologists are more interested in the ecological origins of chemical diversity.

Systematic zoology in the 1920's was based upon dynastic evolution, which was taught largely in the form of anatomical pedigrees or family trees. Students were encouraged to consider the evolution of the dogfish, the horse, the elephant and man. This dynastic conception influenced the training of zoologists long after the revival of Darwinism had made it altogether inappropriate.

A new dynamic kind of Darwinism arose with theories of genetics from the early 1900's. According to the old ideas, the outcome of an evolutionary episode was the appearance of a new genetical formula which conferred the greatest degree of adaptiveness in the prevailing circumstances. Gradually this new solution of the problem of remaining alive in a hostile environment was seen to become a general characteristic of the majority of the members of the population. A new character would be stable except insofar as it might be modified by further evolution; members of the population would be predominantly uniform in genetic make-up, and would necessarily breed true. Genetic diversity was thought of as being maintained by mutation, which was for the most part non-adaptive, and bad mutations were converted into harmless recessives by natural selection. When evolution was not in progress, natural selection made on the whole for uniformity. Polymorphism, the occurrence of a stable pattern of genetic inequality within populations, was recognised as an interesting but somewhat unusual phenomenon, each example of which required an explanation peculiar to itself.

These ideas were superseded through the impact of genetics, which was far from departmental status in the universities of the 1920's. Natural populations are now known to be highly diverse, and even chemical polymorphism has been found wherever it has been looked for. Today it is no longer possible to think of the evolutionary process as the formulation of a new genotype or the inception of a new type of organism. The raw material of evolution is itself a diverse population, and the product is a new and well-adapted pattern of genetic inequality, shaped and actively maintained by selective forces. An important modern viewpoint is that the population, as a whole breeds true, not its individual members, so that we can no longer draw the old distinction between an active process of evolution and a more or less stationary end product. Evolution is constantly in progress and the genetical structure of every population is diverse and dynamically sustained.

As yet, nothing is known about the genetic specification of order at levels above the molecular level, and this is probably where the next major developments in systematic zoology will occur. Already, it is possible to observe new ideas on the relationship between cellular and organ function emerging at the interface between developmental biology and cell biology, which may allow new insight into the way in which organs exist as integrated cellular systems in their own right.

Cell biology had its origins in the two decades before the second World War coincidentally with the rise of biochemistry. Urease and pepsin were crystallised respectively in 1926 and 1930. Tobacco mosaic virus was crystallised in the 1930's, when it was thought to be a pure protein. Other portentous discoveries were those arising from X-ray diffraction, which revealed an essentially crystalline orderliness in common biological structures.

The first electron micrographs were published in the 1930's with a resolving power of one micron. This was the time at which the old concept of the colloidal organisation of matter was being replaced by ideas of precise compartmentation of cells. The view of protoplasm as a fragile colloidal slime, permeating otherwise inanimate structures was already obsolete in the thirties, but the colloidal conception was still used with an allowance made for heterogeneity, and for the existence of what were termed liquid-crystalline states and cytoskeletons. The substitution of the structural for the vague colloidal conception of the physical basis of life was one of the great revolutions of modern biology. The change was very gradual, and was only finally completed in the late 1950's when the electron microscope became a routine instrument.

One of the most recent developments of the electron microscope enables chemical analysis to be carried out with a high degree of precision within the sectioned specimen. With this instrument, the biochemist and the zoologist may realise the long-sought integrative goal of their respective disciplines as they sit, side by side and discuss the implications of molecular events in a multi-molecular, highly compartmented structure. Biochemists, by destroying this compartmentation, destroy the regulating systems which they wish to study, and so can only study the 'nuts and bolts' of the organism.

Other important interactions between biochemistry and zoology are now widespread at the physiological level. Although comparative studies of function have always taken place alongside anatomical investigations, it was in an effort to escape from the fruitless arguments of descriptive systematic zoology that a group of zoologists deliberately broke away from this mainstream in the 1920's in order to augment description by experiment. Two aspects of this new school of experimental zoology can be observed in modern zoology encompassed by the fields of comparative endocrinology and comparative neurophysiology. At worst, the experimental school has carried through a systematic philosophy to a less complex level of physiology and biochemistry without adding anything new to a phylogeny already established on morphological grounds. At best, it has unravelled the workings of new organ systems. This is particularly true for the structure and functions concerned with homeostasis or self-regulation, which was a concept clarified in the 1920's from many old ideas concerning the immediate resistance of animals to environmental change. Some of the greatest achievements of physiological analysis have been performed on material that in 1926 was known only to zoologists, but the exploitation of these structures, such as the giant axon of the squid, has been in the hands of workers trained in other fields. This probably reflects different attitudes towards biological modelling, where a system is chosen for study simply on the grounds that it shows in an exaggerated or uncomplicated form a mechanistic phenomenon of particular interest. Biological modelling is commonplace in physiology and biochemistry but not in zoology, where there is a tendency to study a particular animal long after it has ceased to yield important data. Also, because much comparative zoology has to await the development of techniques and principles in other fields before data can be obtained, there is a natural reluctance on the part of zoologists to initiate chemically orientated research. Too often, the uncritical application by zoologists of ideas and methods of chemistry, originating outside zoology, has led to a great deal of wasted research effort. Set against this are the great achievements of zoologists who have entered other fields and through bringing the holistic viewpoint of zoology to bear, have obtained unique insight into diverse problems. Medical research in particular has gained much from systematic zoology.

If we regard systematic zoology as the comprehensive analysis of evolutionary processes at all levels that lead to the building of new organs and behaviours, animal ecology is a complementary study of the building of spatial relationships between animals. Unlike systematics it is a subject area that <u>must</u> forge links with other disciplines, particularly botany for even a superficial understanding to be obtained. Because of its essential interdisciplinary aspect, in recent years ecological research has tended more and more to rely on techniques of mathematical modelling which enable the flow paths between plants, animals, soil and water to be quantified. A mathematical model in biology is a device used to describe what are believed to be essential features of a natural process, such as the development of sequential events, or the distribution in space of certain phenomena. Compartment or box models originated in the physical sciences, but are now widely used in zoology. They are essentially integrated diagrams of natural processes designed to describe temporally defined spaces. The property of interest in each space is conceptually described in terms of a volume integral of that property, such as mass, number or energy. The advantage of box building is that it avoids to a large extent the complexity of detailed processes within each box. Because it is an approximation, a compartment model with flow paths between boxes is a crude picture of reality, which means that when it is used for prediction, errors may be amplified and augmented because of a lack of precision with regard to mechanism. Nevertheless it is the only way to handle physiological and ecological data that require integration for a full understanding. The technique is becoming widely used in these branches of zoology.

Subdivisions of biology

The ultimate goal of science is to devise and explain conceptual schemes about the nature of the universe in which we live. Science used to be divided into Natural Philosophy and Natural History, thereby suggesting a single subject - Nature - and a dichotomy of method. In today's usage, we have a division into the Biological and Physical Sciences, implying a revised attitude - a unity of method - Science and a diversity of subject. However, differences between the biological and physical sciences are clearly a feature of the specialist viewpoint and the diversity of subject matter disappears when we take a broad view of science and detect a basic unity.

Unity is most obvious at the elementary level of biology. Here we see the fundamental particles of matter about which physics is still unable to make positive statements. At this sub-atomic level are the familiar particles of the atom. A second level comprises the atoms of the ninety odd elements which belong partly to the non-living and partly to the living world. It is at this level that we see the beginning of a dichotomy between biology and the physical sciences, because only a small proportion of the elements are important constituents of living matter. At a third level, atoms join to form molecules. Separation of biology from chemistry is complete when we consider the special aggregations of these molecules to form living systems, giving rise to the fourth level of organisation - the cell. There are two further levels of organisation peculiar to biology: a fifth level is presented by multicellular systems, organs and organisms; and the existence of super-individual systems which display the characteristics of mutual inter-dependence and self-regulation is the basis for the sixth level of organisation - the community consisting of inter-dependent populations.

It is worthwhile stressing the fundamental differences between the physical and biological sciences, because it is these differences which form the basis for the undergraduate's choice of courses at the university. For him, physics, chemistry and mathematics differ profoundly from biology in both their subject matter and methodology. He sees that the laws of chemistry and physics are general and wide enough to embrace both the actual and the possible, whereas the laws of biology are strongly bounded by the actual. This diversity in approach can best be seen by contrasting mathematics with biology. The mathematician is busy making deductions from general, well founded propositions; the biologist is more especially occupied with observation and comparison, and those processes which <u>lead</u> to general propositions. However, it is misleading to think that these differences within science depend on fundamental distinctions between the disciplines themselves. They depend simply on accidents of subject matter and the relative complexity and consequently the relative perfection of concepts.

Unity in science comes when we see that all the laws of nature, whether they apply to physical or to biological systems, are of a statistical kind. They are statements made about the average behaviour of collectives. To put it another way, science as a whole appears to be a hierarchy of statistics. At the level of physics and chemistry, statistical fluctuations in the behaviour of atoms are levelled out because we always deal with very large numbers of interacting particles. A biologist never deals with such large numbers of organisms at one time and consequently has to cope with much variability and unpredictability in his results.

The list of separate subjects at universities at any one time is due in part to historical accident and a good many of the present lines of demarcation may be regarded as purely provisional. The demarcation of an area of study in universities termed 'Biology' is of relatively recent origin. Despite this, the term Biology has been in use as a general descriptive term for over a century. Biology defines the science of living things. The word 'biology' is one of those all-embracing terms which are often too general to have much meaning. It is derived from the Greek 'bios', meaning life, and 'logos' - the study of. Historically, knowledge about living things was developed somewhat independently by students of plants and students of animals. As a result, many biologists think of two main sub-divisions of biology: botany, the study of plants; and zoology, the study of animals. Other biologists feel that there are really three types of organisms - plants, animals and microbes - and consider microbiology to be a third major division of biology. This system operates in University College, Cardiff.

Another method of subdividing biology is based on what is termed an operational/ functional approach which cuts across the divisions of animal, plant and microbe. This scheme is sometimes referred to as the horizontal method of organisation. It works because, particularly at a research level, the scope of biology has no boundaries. Many of the important advances, particularly in the past few years, have been made by workers who defy categorisation into a particular branch of biology. However, because workers have become specialised in various branches of biology, many horizontal investigations are carried out by team research in which zoologists, botanists, microbiologists, chemists, physicists and mathematicians collaborate.

The horizontal categories include molecular biology, cellular biology, developmental biology organismal biology and population, or comnunity biology. Several undergraduate curricula have been developed using one or more of these categories as the main theme and this makes the important point that there are many legitimate ways of introducing a student to the biological sciences at the university.

Molecular biology encompasses biochemistry and biophysics and mainly includes all of those aspects of biology which take a molecular approach to problems and their solution. It is obvious that there is a considerable overlap among the various subdivisions of molecular biology. All of the subdivisions include investigations at the molecular level and all involve the flow of chemical information in biological systems; the term Molecular genetics is often used to refer to these latter aspects of biology because their expression depends on chemical information passed on from one generation to another. Cellular biology includes all approaches to structure and function of cells, such as chemical and physical organisation, the production and utilisation of energy, transport of materials within the body, and the mobility and stabilising mechanisms of cells.

Developmental biology is much broader than traditional embryology; it includes development from the molecular level to gross structural levels. The phenomena of regeneration, wound repair and ageing are also included in developmental biology.

Organismal biology focuses on whole organisms. It is concerned with such matters as the evolution of the main groups of living things, functional and developmental anatomy, comparative physiology and behaviour. Population and community biology are concerned with the structure, maintenance and dynamics of populations or communities and with the process of natural selection, whereby whole populations change their character with the passage of time, due to the influence of a gradually changing environment. Biology also has applied aspects ,in space sciences, earth sciences, physical sciences, social sciences and humanities.

Sub-divisions of zoology

Despite this apparent maze of sub-units of biology, there are basically only two kinds of zoology which are divided in terms of the approach used by the investigator. One - functional zoology - investigates the immediate causality of biological functions and processes; the other evolutionary zoology - has its roots in natural history and deals with the historical causality of the organic world. Functional zoology takes much of its techniques from physics and chemistry and a functional zoologist is happiest when he can reduce observed biological phenomena to physicochemical processes. Evolutionary zoology, dealing with highly complex systems operated by the historically evolved programme of heredity, must pursue a different strategy of research in order to provide explanations. Its most productive method is that of making comparisons and its most famous exponent was Charles Darwin. It is no coincidence that Darwin wrote the 'Origin of Species' after encountering problems of classification of a diversity of facts during the voyage of the Beagle and, in particular, after eight years' concentrated work classifying the world's barnacles.

To express the two approaches in a different manner, at one extreme, zoology is preoccupied with the ultimate building stones and ultimate unit processes that are the common denominators throughout the living world. This has largely been the concern of biochemists who study animals and deal with the structure of macromolecules and such functional unit processes as the chemical pathways for food utilisation. This reductionist methodology when applied to functional problems, quickly carries us down to a level where we leave behind most of what is typically zoological. This is surely true for the chemistry and physics of the ultimate building stones; at this level it would be quite legitimate to equate zoology with chemistry and physics.

At the other extreme is preoccupation with the level of zoology that deals with whole organisms, with uniqueness and systems. In this connection, it has been stated that, just as architecture is more than the study of building materials, so is biology more than the study of macromolecules. To carry this analogy further, the architect has to learn a lot about the properties of bricks, but the brickmaker can function without any knowledge of architecture. Although no zoologist would hold the extreme reductionist view that it is always possible and desirable to explain happenings at one level of integration in terms of events at a lower level, it is informative and often essential to refer back to a lower level in order to understand better the workings of a higher order. Thus, an adequate understanding of zoology is impossible without a good working knowledge of chemistry, but chemistry can be understood without reference to Zoology.

However, it is still often said that the only way to understand life is to start with the molecules and work upwards. The absurdity of this viewpoint is clear when we examine the approach of the naturalist. The natural historian's way of handling data is well illustrated by Darwin's observations on a group of small land birds in the Galapagos Islands. These islands are a compact group lying about 600 miles off the coast of Ecuador. They were visited by Darwin when he was serving as a naturalist aboard the exploration ship H.M.S. Beagle in 1832. His observations on these islands strongly influenced Darwin's later thoughts about evolution.

The zoologist's interest in the Galapagos stems from the fact that they are oceanic islands thrust up by volcanic action from the ocean floor. They have had no connection with the mainland at any time in their history. Coming into existence late in the history of life, they initially constituted a completely unoccupied environment.

When Darwin arrived, he found that there were fourteen distinct finches inhabiting the islands, all of a type similar to a less varied variety on the mainland of South America. The island birds can be grouped in various ways according to various similarities and differences; in terms of habitat, i.e. ground dwelling, cactus dwelling or tree dwelling; in terms of food, i.e. insect eaters or seed eaters; in terms of habit, i.e. warblers, woodpeckers and finches; and in terms of size, i.e. small, medium and large. Not all islands contained birds and some had a restricted distribution. These simple observations, which could have been made by anyone with a sharp eye, were assembled by Darwin into the following pattern. Some time after the islands were formed, finches from the mainland arrived as the first terrestrial birds and began breeding on the islands. The mainland finches are ground birds feeding on seeds and it is assumed that the ancestors of the Galapagos finches had the same habits. Subsequently, the ground finch changed in form and habits and became diversified in terms of size, habitat and food. Three finches appeared still feeding on seeds, but differing in size, whilst others developed feeding mainly on cactus and one combined ground and cactus feeding. Others became tree dwellers, where the majority took up the habit of feeding on insects.

This historical picture, built up from simple observations of present day geographical distribution, form and habits, has given rise to the important zoological principle of adaptive radiation. The principle states that descendants of an ancestral species that was itself adapted to a restricted way of life have radiated out into a diversity of new habitats. The radiation of the Galapagos finches is trivial in extent, even if beautifully clear in detail. However, using the same simple method of natural history, it has been established that other radiations have occurred on a more massive scale with far-reaching importance to the history of life in general. Not least of these followed the exit of the vertebrates from water. It is important to understand that it was not necessary to know the inner working of animals, nor was it necessary to conduct any experiment, in order to deduce the principle of adaptive radiation.

This example demonstrates that the working levels of the naturalist and the chemist are different; they each produce a picture of the living world which could not be produced in any other way. At this point, it is worth stressing, once again, that there is no difference in the methodology of the physical scientist and the biologist. Both must first obtain facts, either by observations of natural phenomena, or obtain artificial facts, through experimentation. These facts are next grouped together according to similarities by the procedure known as "comparison" or "classification". Results of this process are termed 'general propositions'. A general proposition is used to predict the facts about an unknown situation - a form of reasoning known as deduction. Finally, there is the process of verification which gives information as to the validity of a particular deduction. A mathematician deals with two properties of objects only number and extension; all the inductive reasoning to provide general propositions was carried out long ago. He is occupied now with nothing but deduction and verification. A biologist is still concerned with assembling a vast number of facts relating to the properties of living objects which will eventually give rise to general propositions. Only when this phase has been completed will biology be as deductive and as exact as mathematics.

Zoology has never been synonymous with taxonomy. Its province has always been that of animal biology in its widest context. For example, a zoologist may want, first of all, to find out how a particular animal works, considered as a piece of living mechanism, and to compare the ways of working of various other animals. This is the field of animal physiology with the emphasis on comparisons. Secondly, he may want to know all he can about the structural plans of animals, to know how that structure develops and to compare the structure of different animals. That is animal morphology - the science of form. Finally, he may want to understand how and why it is that different individuals and species of animals are what they are; their history and as much as possible about the causes of their history. That is the field of animal heredity and evolution.

The uniqueness of the zoologist as he stands amongst other biologists is that he seeks to interpret findings about the life of animals within the framework of the theory of evolution. Evolution is the term used to describe the process by which man arose, by an infinitesimal slow progression, from a level of organisation similar to that of present-day micro-organisms. As far as we know, the most important mechanism in the evolution of living species is that of natural selection. Natural selection suggests that if any form of stress is put on a population of living creatures, those which most effectively respond to the stress will survive and those which respond less effectively will die. Survivors pass on their successful characteristics, which we term 'adaptations', to their descendants. Unsuccessful characteristics are eliminated through a failure in reproduction and the nature of the population changes. This leads the zoologist to examine the adaptive significance of his findings, whether they be at the population or molecular level. In other words, he wishes to know how the structure or function he has discovered has been advantageous in promoting the evolution of the animal possessing it. In answer to the question "Why does the tiger have claws?", the molecular biologist would say that physico-chemical conditions exist at certain point in the embryo which make it inevitable that certain living cells there will produce the special hard substance of claws and that because of the spatial pattern of the cells this will inevitably be laid down to give a pointed curved structure. This does not satisfy the zoologist; he sees that if the tiger did not develop claws, it would not survive. Also, the ultimate in evolution is man himself and in so far as zoology is more than a branch of mere idle curiosity, it is the overall aim of the zoologist to explain the phenomenon of man through the detailed study of all animals.

Evolution manifests itself in varied aspects of the living world, particularly in the manner in which animals are distributed over the earth and adapted to differing environments.

Animal geography may be taken as a good starting point to show the essence and scope of zoology. Indeed, it does not require a course in zoology to generate an awareness that most animals have a restricted distribution. At first glance, it would appear that it is the physical characteristics of the earth which limits the spread of the majority of animal types. There is an obvious restriction of many animals to an aquatic environment, either the sea or fresh-water. Also, the temperature appears to limit severely the distribution of both aquatic and terrestrial forms, particularly the cold-blooded animals, which are clearly dependent upon radiant energy from the sun for all of their activities.

Biologists believe that life originated in a stable watery environment and that early life evolved in the seas, where many kinds of animals are still only to be found. This environmental system is and has been very stable. Despite its chemical complexity, the composition of sea-water remains remarkably constant, while the vertical and horizontal circulations of oceanic water tend to reduce temperature differences between one climatic region and another. Uniformity and stability are particularly evident under deep-sea conditions. Below about 300 fathoms, light and heat from the sun hardly penetrate. The main trend in the evolution of life has been for animals to move away from the relatively stable conditions of the oceans to inhabit first fresh-water and then terrestrial habitats, both of which are less stable and more varied than the sea. All freshwater and land animals show clear indications of an ultimate origin from marine ancestors and progressive adaptation to these secondary habitats has been accompanied by steadily increasing specialisation. A large number of animals have returned from both freshwater and land to a marine life. Whales, dolphins and porpoises all display a degree of differentiation in both structure and function, which no zoologist believes could have developed unless their ancestors had been terrestrial. A porpoise may, to the untrained eye, look like a fish, but in its lung structure, its nervous system, its method of reproduction, the way in which its young are nourished and so on, it affords clear proof of descent with appropriate modifications from land forms. Some of these features derived from terrestrial ancestors are very obvious, such as the hairy coat which is present from birth. All of these adaptations to a different habitat occur through inherited variations in morphology, physiology and biochemistry and it is the role of the zoologist to pursue these variations at any level and to make deductions as to the pathway and mechanism of evolution.

Dynamic aspects

Within a well-developed science, it should be possible to reduce the varied subject matter to order. In biology, this means we have to show that all differences can be understood to have arisen by the influence of specific factors operating to modify some original scheme. Nothing less than the establishment of a general scheme and simple set of factors to include many special circumstances should be the aim of biology as a science. That is to say, in order to know life, what it is, what it has been and what it will be, we must look beyond the details of individual ' lives and try to find the rules governing all our findings.

In our efforts to elucidate the rules of life, we use relatively simple-minded concepts derived from man-made objects and processes which we can understand because we made them. Most obscurity in biology comes from the ill considered use of these analogies. We have a science of anatomy, which we are told is concerned with the 'structure' of animals. Physiology is the study of 'function'. In both cases, we take implied analogies from man-made machines which have both structure and function. However, further examination of living things has made these classical viewpoints of biology much less clear than they have seemed in the past.

This simple view fails when we ask: What is the life of an animal? What is passed on from generation to generation to provide continuity? What is it that changes through time by the process we call evolution?

The answer to these questions cannot be given by either the anatomist or the physiologist. It has gradually become apparent that the body is not a fixed, definite structure, as it appears to casual observation or when dissected. In life, there is ceaseless activity and change going on within the apparently constant framework of the body. The essence of life is not a particular substance or substances, but a particular kind of dynamic organisation. Sometimes, this belief is expressed by likening the organism to a candle-flame. Just as in a quiet atmosphere, the flame keeps its shape despite the fact that new particles of wax are being constantly fed into it while the burned remains of the wax are leaving the flame as smoke, so the living organism keeps its shape in spite of the constant replacement by synthesis and degradation of the molecules that compose it. The continuous movement of blood was one of the earliest examples of this activity, examined by Harvey in the 17th century. We now know of innumerable others. Skin is continually being renewed by growth from below and many other types of tissue are similarly replaced.

This phenomenon is described as the process of turnover and is a reflection of events at the chemical level. The concept of chemical turnover is now the mainstay of biology.

There is a constant flow of energy and materials into, through and out of the cells. Nevertheless, the cells persist as a whole, despite the continual turnover of materials which compose them. At successive times, the cells may look the same and they may contain the same numbers and kinds of molecules and atoms. But the individual components are not the same ones; some have moved out or have broken down, and others have moved in or have been newly formed. Components at all levels, atoms, molecules, cells and organisms are appearing and disappearing, but continuity of properties is conserved nevertheless. Like a candle-flame or a waterfall, living substance endures despite the continuous replacement of components. Furthermore, killing an organism in order to make it fit our inadequate analytical methods is like putting out a candle-flame in order to study the process of burning.

If the matter of the body is continually changing, we cannot expect to be able to describe the characteristics of life in terms of the properties of particular substances. However, specification of chemical units ranging in organisation from organs to pure chemicals is our only means of studying the systems of living things. As yet, we have no means of studying the enormous complicated network of activities that constitutes a single life and we can only attempt to do this by bringing together information collected by various specialists: the morphologists, geneticists, embryologists, physiologists, biophysicists and biochemists. Put another way, when making any observations, whether by dissection, with a microscope, a test-tube, an oscilloscope or respirometer, it is necessary continually to think back to the time when the tissue was active in some living body and to frame the observation so that it shall reveal something significant of that activity. This means that every worker in the biological sciences should know as much as possible of the life Or the whole organism with which he deals and must certainly be aware of the nature of the population from which the specimen was taken. This latter point is often ignored by many biologists, particularly those working with molecules. It is true that each living thing is defined by its own chemical pattern, but the specific pattern of life is not necessarily to be found in any one individual, still less in the parts of an individual. The unit of life is that which tends to be preserved through time and is, therefore, the whole interbreeding population, and it is in his dealings with populations that the biologist is distinguished from other scientists.

To summarise, the way to study wallflowers, rats or men is first and foremost, to examine them whole, to see how their actions serve to meet the requirements of the environment and so allow the preservation of the life of the individual and race. Then, with this knowledge of how the animal 'uses' its parts, we are able to make more detailed studies down to the molecular level and show how, together, the activities form a single scheme of action.

Action is the characteristic feature of living, compared with lifeless, matter. To most people, animals are generally more lively than plants. Even when asleep, an animal is breathing, its heart is beating and brain pulsing. The waking life, of course, shows this restless action even more clearly. It is at this level of 'animals-alive' that we see the side of biology that is most interesting to the bulk of humanity. However, to make sense of animals alone or in groups is very difficult and it is no accident that it is more often found that the easier path is taken and we spend our time examining the structure and chemistry of the dead.

Animals versus plants

Following the line of defining zoology, there remains the problem as to the fundamental difference between plants and animals. Why do we call this organism a plant and this an animal? Most people would not hesitate, but would say that the animal moved, whereas the plant did not; that the animal was conscious, while the plant was not; that the animal devoured its food while the plant absorbed its nutriment from its surroundings. None of these criteria, however, are absolute.

Many animals, like corals or sea squirts are as rooted to the spot as most plants, while some undoubted plants move about. With regard to consciousness, no-one could assert with confidence that a sponge, an undoubted animal, possessed a higher level of consciousness than a mushroom or a wallflower. On the point of nutrition, many animal parasites absorb their food from the medium which surrounds them. The only valid distinction between plants and animals is concerned with the type of foodstuffs which they can utilise.

At a chemical level, it has been found that the pathways by which the primary products of photosynthesis, the sugars, are utilised are identical in both plants and animals. Plants differ from animals in possessing chlorophyll and the pathways for turning carbon dioxide into sugar.

All of the differences with which we are familiar, between higher plants and higher animals, are purely secondary to the difference in nutrition. The fact that green plants can obtain food from water and air without special search has led to their developing great feeding surfaces such as the leaves and roots. The fact that animals have to find their food ready-made has led to their developing mouths and stomachs to catch and hold the food, and limbs to move from place to place in search for more.

The fact of locomotion has, in its turn, made necessary the development of sense organs, nervous system and brain. But all hinges on the first difference in nutrition.
Contrasting animals with plants, we see that it is not immaterial where one takes one's cells from, to put into the test-tube. At the levels of cells, organs and organisms, botany and zoology are as distinct as

chemistry and physics. Despite this natural cleavage between departmental subjects we must ask whether the separation goes deeper than it should.

Although biology is not a well-defined body of knowledge, it is possible to write an elementary curriculum which, with minor changes, could be studied with reference to either plants, animals or microbes. This has been realised in schools and the single subject, biology, is gradually replacing botany and zoology as two separate subjects at A-level. This emphasis on the similarities of living things has also been used to bring biology into the universities. However, for most people, the interest of biology lies in its diversity. Universal similarity is limited and makes the diversity more remarkable.

Certain broad laws have a general application throughout both the animal and vegetable worlds, but the ground common to these kingdoms of Nature is not of very wide extent and the multiplicity of details is so great that the student of living things soon finds himself obliged to devote his attention exclusively either to one or the other. So, although animals, plants and microbes may be unified through their chemistry and biochemistry is a major and active field of discovery, biochemistry is not synonymous with the whole of biology. The mathematical crystallographer and the endocrinologist cannot contribute to biology until a problem is posed at the level of the whole organism. Also, the results of molecular biology are sterile until ploughed back into botany or zoology. Because of this, we must strengthen the classical regimes for themselves alone, and also because they hold problems awaiting solution at a chemical level.

Despite this plea for the maintenance of the major working divisions of botany, zoology and microbiology, there are great dangers where these divisions are established in the university departmental system. The greatest failing is that departments prevent the spread of ideas. They also often impede the development of co operative teaching. If these academic disadvantages were not enough, the departmental system generates a
'them and us' mentality which shows the academic at his very worst - intent on fending off other departments in terms of space and students. It is unlikely that these social difficulties can be completely eliminated. They arise from the institutional-professional organisation of modern science, where motivation chiefly involves question of status and financial reward, and where inter-personal relationships may easily come to dominate the co-operation at the personal level, through joint teaching and research, and also the communal sharing of lecture and laboratory facilities.

The value of ‘ologies’

We are constantly exposed to the term 'science' and, in general, science is highly regarded. It is an inextricable part of our lives and impinges on our comfort. At the same time, although science is the most influential of the forces shaping our world, the aims and limitations of science are little understood by most people. This lack of understanding is disquieting because we are an integral part of a biological world which is increasingly dominated by man's scientific activities. The best way to understand the scope and aims of science is to become immersed in it for a time, providing sufficient reason for anyone taking a university science course and reading a biological subject in particular.

Zoology is a well-defined academic pursuit which impinges on many other disciplines. But what is the use of studying zoology at the university? A student wonders, and properly so, how the subjects taught can have personal significance. Many students who enrolled in a course of zoology have different interests, purposes in enrolment and goals. In teaching students science, we have not to debate whether we should produce specialists or the educated man. An essential function of the university involves the production of both. In general, we should aim at an education which sets out to present the basic ideas that express the civilisation of our time. These days, in any career which involves making decisions or the prediction of future events, a deep understanding of the scientific method is likely to be as helpful, if not more so, than an academic knowledge I gained in the arts faculty. The intellectual processes required to understand science are no different from those needed to follow a course, say, in history, but the scientific method offers a more powerful tool for controlling the human environment than the historians method. If only from this viewpoint, we must try to find ways to giving a deep appreciation of science to an increasing number of students who will never be scientists themselves, but who will be living in a world shaped in many ways by the ideas of science, as well as by the material products of scientific technology.

Two hundred years ago, the age of Newtonian physics had reached its zenith. This was to be followed by the age of chemistry and science was rapidly elevated to a dominant prestigious position in human society simply because it offered ways of controlling the environment for the benefit of most people.

It is not generally appreciated that science cannot be studied as a so-called 'pure' intellectual pursuit without at the same time opening up possibilities for applying the new knowledge for good or evil. This is particularly true for discoveries made by the experimental method. Consider a scientist from another planet faced for the first time with a working petrol engine. He asks the pure disinterested question 'How does this object work?'. He sees three tubes carrying different fluids into the engine, water, oil and petrol. The first question is framed in a more specific form 'Are these fluids essential to the working of the engine ?' Scientists generally ask questions on a day-to-day basis rather than frame hypotheses. An appropriate hypothesis would be 'these fluids are not essential to the working of the engine'. To answer the question and test the hypothesis, the machine has to be tampered with; in turn, the flow of each fluid has to be stopped and the machine observed for evidence of failure. To safeguard against failure occurring due to reasons other than the scientist's specific manipulation, a second engine identical in all respects to the first and running alongside it must be observed during the same time interval. By comparing the operation of the latter 'control' engine with that of the 'test' engine, it would be concluded that petrol in some way provides the motive power. The question has been answered, the hypothesis has been tested and the scientist's curiosity satisfied. However, the way is now open for anyone with access to this new knowledge to exploit the discovery; the scientist has provided a way of controlling the working of the engine through regulating the flow of petrol into it. It is easy to demonstrate the applied aspects of 'pure' research in the physical sciences.

Biological knowledge offers greater potential for controlling the lives of all organisms on this planet. Birth control pills originated in fundamental discoveries motivated by the question 'How is it that reproduction is a cyclic phenomenon?' This question has been largely answered by endocrinologists and 'the pill' is now influencing the social and economic aspects of our society. How will our lives be affected when questions such as 'What is the nature of the ageing process?' and 'What is memory?' have been answered.

In a healthy society, we can neither stop the questions of fundamental research being asked nor disallow the acquisition of certain kinds of because knowledge/of its possible social consequences. Scientific activities are an important part of Man' s biological heritage . presumably the capacity for scientific thought, which relies on unique' information - acquiring 'and 'information - organising' processes, evolved with man, enabling him to adapt successfully to the environment. Science is increasingly becoming the principal means of adaptation for civilised man. We can and should prepare the ground for the assimilation of new knowledge and it is here that education plays a major role. We are now so much enmeshed in socialised science that a universal understanding of the basis of science, particularly as it bears on animals, is necessary so that man may adapt to the results of his scientific enterprises.

In the case of zoology, man is not apart from the study, but an integral part of it. An educated person should know about himself; this is one of the obvious values of a study in zoology. Man is composed of the same basic units of structure which are found in other organisms. Man also carries on the same basic functions. He starts out life in the same way and he arrives at his morphological form by the same process.

That man is composed of the same basic units of structure and function as other animals can be appreciated by studying a variety of animals as well as man. During such a study, the student will discover that although the various animals are basically alike in structure and function, they differ considerably in body form and nutritional requirements. Unity of plan and diversity of execution is the lesson of comparative anatomy. These differences have resulted in many kinds of habitat requirements and many different ways of obtaining food. As a result, the student finds that all kinds of organisms are interdependent in a series of nutritive links (predator-prey, host-parasite) and that if this were not so, life on this planet would have ceased long ago. Furthermore, the student finds that animals can be grouped into several large groups, the members of each group being obviously very much alike. But the extent of the relationship reaches beyond that found within these large groups - relationships can be seen between the large groups. Thus, the student will be introduced to the principle of organic evolution. Probably no other biological generalisation has had more effect on man's thinking than this one. Yet no person can intelligently understand and discuss the validity and implications of this concept without a broad sound base in zoology.

There can be little doubt that Darwin initiated an intellectual revolution in 1859 by publishing the Origin of Species. Historians are aware that many factors were responsible for the general public reaction to this book. However, two reasons for the reaction seem outstanding. First of all, the concept of evolution emerged as being in direct opposition to the literal interpretation of the biblical account of Creation. The second factor and one which was more fully emphasised in a later book by Darwin, 'The Descent of Man', was that man had non-human ancestors, so reducing his biological nature to the level of other higher animals.

Today, one only occasionally encounters a person who refuses to accept the animal nature of man. The evidence is held secure within zoology, where it may be examined by students without prejudice. Zoology, therefore, stresses man's close genetic kinship with other animals and sets him at one with Nature.

It is because man is an integral part of nature that he cannot, in fact, conserve nature. The consequences of everything we do from painting a house to emptying sewage into the ocean is a part of nature. Man only stands apart from Nature in this respect, in that he can observe the whole of the natural world at a particular stage and say that certain species or natural features are worth preserving for aesthetic or practical reasons, or for the addition of knowledge which can be made from their study. The integration of man with nature and the demonstration of purpose and design in living things has resulted in zoology being at the centre of the most profound revolution in man's outlook on nature in the history of modern civilisation. It also incidentally places zoologists at the centre of the modern conservation movement.

During his time as an undergraduate, it is particularly important that the student should not cut himself off from fields other than his own. Furthermore, it is very desirable that the student, in seeking a broad generalised education, should attempt to relate his several studies to each other, regardless of how much he may specialise later. Zoology holds the key to a number of inter-disciplinary doors, not least to those which open into the behavioural and social sciences.

Man is a social organism; he lives in groups. In attempting to understand the behaviour and interrelationships of men, psychologists and sociologists are gathering information from observation and experimentation. Some understanding of the nervous system, glands and other organs is necessary for the study of psychology. Some knowledge of the laws of inheritance and the principles of ecology is important for studies in sociology. Without question most inherited differences among human beings are those that produce effects of extremely low adaptive significance. Nevertheless, the mere fact that such small differences in heredity exist in abundance is of the greatest importance in human affairs. They are the basis for divisions within the human population which are made on the grounds of differences in physical and mental performance. In this regard, surely it is through zoology that a true appreciation of science will come to the so-called social sciences.

Although zoology has probably had its greatest impact upon society through the realm of ideas associated with the theory of evolution, it has always been important from the practical standpoint. Man himself is an organism and the principles and laws which he formulates usually have a bearing on his own welfare. Medical research has utilised this principle very effectively through the experimental approach based on the reactions of laboratory animals to conditions set by the researcher.

In addition, there are many other areas that have direct and practical applications in everyday life. The fields of agriculture, conservation of natural resources, public health and so forth, all of which are integral parts of our civilisation, are based on zoological knowledge.

As a specific example of the scope of zoology, consider a writer preparing a novel of social criticism of the mid-twentieth century. Such a work may involve discussions of germ warfare, pollution of the biosphere, birth control, control of the development of individuals, thought control, and psychomimetic drugs. Such a novel would fail to carry its message if the author did not understand the fundamental zoology involved in these problems. In the same way, some background in zoology is important to poets, artists, civil servants, legislators, financiers, historians and dramatists.

In summary, the scope of zoology is unlimited. No matter what is the future area of specialisation, every student will find the study of zoology valuable, not only in its application to himself as a member of the animal kingdom, but as a source of understanding in almost any field of work or study.

However, zoology, and botany are both under threat from without and within. External pressures come from those who would see the physical separation of scientists within subjects as impeding the flow of ideas, and see their departments as expensive to maintain in terms of the multiplication of top management, and administration. Pressures from within come from the younger generations of staff who see resources being concentrated on biochemical research. For example, junior staff in both zoology and botany who graduated on a diet of taxonomy and systematics are increasingly deserting this field to work on problems of function at the molecular level. Also, as knowledge of the mechanics of organs and molecular systems increases, lectures and practical classes dealing with classification of animals gives way to provide the extra time needed to impart the latest discoveries in endocrinology and biochemistry. With most of the world's plants and animals still to be discovered, a world without the 'ologies' is likely face a future manpower crisis when practical taxonomic and systematic problems have to be solved. Unknown species may suddenly appear as agricultural pests, or disease carriers. Perhaps there will be an even greater crisis with the the loss of ecosystems as yet uncharted in Darwinian terms, where unknown species will become extinct without being noticed or valued.

Postscript

In 1988, the two Cardiff colleges of the University of Wales, the institute of science and technology and University College Cardiff merged to, form the University of Wales College of Cardiff (UWCC). There was also a consequential merger of the departments of zoology, botany and microbiology in University College with UWIST's department of applied biology to create a School of Biological Sciences.

In 2009, the House of Lords Science and Technology Sub Committee on Systematics and Taxonomy held an inquiry and produced a report, criticising the fragmented responsibility for systematic biology within Government. They highlighted the importance of the specialism, given climate change and other threats to biodiversity, and recommended that the Natural Environment Research Council (NERC) carry out a study on the profession and how to ensure its sustainability. This review was published in 2011.

The NERC report address whether there should be a national strategy for taxonomy and systematics in the UK and if so how it should be developed. It affirms, and treats as a basis for action, the conclusion of the 2008 House of Lords Science and Technology Committee report that stressed the importance and cost effectiveness of taxonomy and systematics in modern biology and environmental sciences. The *report considers all aspects of taxonomy and systematics* ***except teaching at school and undergraduate level.***