CHAPTER 1

THE SCIENCE OF TAXONOMY

The most impressive aspect of the world of life is its diversity and the uniqueness of its components. No two individuals in sexually reproducing populations are the same, nor are any two populations, species, or higher taxa. Wherever we look in nature, we find uniqueness, and uniqueness means diversity. To sort all this and determine its nature is the task of taxonomy.

More than 1 million species of animals and half a million species of plants and microorganisms have been described, and estimates on the number of undescribed living species range from 3 million to 10 million and even higher. An estimate of at least half a billion for extinct species is consistent with the known facts. Each species may exist in numerous different forms (sexes, age classes, seasonal forms, *morphs,*[1] and other *phena*). The diversity of faunas has numerous dimensions. There are rich faunas not only on land but also in freshwater and in the oceans down to the greatest depths. Every organism has its fauna of parasites, many of them species-specific. Evidently, the amount of diversity is immense.

The important biological discipline concerned with the scientific study of diversity is often indiscriminately referred to as systematics or taxonomy. There is a broad overlap in the application of these terms, but there is also a subtle difference. The term *taxonomy* is derived from the Greek

[1]Consult the glossary for unfamiliar terms.

words *taxis* ("arrangement") and *nomos* ("law") and was first proposed in its French form by de Candolle (1813) for the theory of plant classification. It agrees best with current thinking to define it as follows: *Taxonomy is the theory and practice of classifying organisms.*

The term *systematics* stems from the latinized Greek word *systema* as applied to the systems of classification developed by the early naturalists, notably Linnaeus (*Systema naturae*, 1st ed., 1735). We follow Simpson's (1961:7) modern redefinition of the term: "*Systematics is the scientific study of the kinds and diversity of organisms and of any and all relationships among them.*" More simply, *systematics is the science of the diversity of organisms*. The word *relationship* is not used here in a narrow phylogenetic sense but is broadly conceived to include all biological interactions among organisms. This explains why such a broad area of common interest has developed between systematics, evolutionary biology, ecology, and behavioral biology.

Systematics deals with populations, species, and higher taxa. No other branch of biology occupies itself in a similar manner with these levels of integration of the organic world. It not only supplies urgently needed information about these levels but, more important, cultivates a way of thinking, a way of approaching biological problems that is important for the balance and well-being of biology as a whole (Mayr 1968*a*, 1982*a*).

One of the major tasks of systematics is to determine by means of comparison what the unique properties of each species and higher taxon are. Another is to determine what properties certain taxa have in common and what the biological causes of the differences or shared characters are. Finally, systematics is concerned with variation within taxa. In all these concerns systematics holds a unique and indispensable position among the biological sciences. Classification makes organic diversity accessible to the other biological disciplines. Without it, most of them would be unable to give meaning to their findings.

THE CONTRIBUTION OF SYSTEMATICS TO BIOLOGY

A consideration of the contributions of systematics to other branches of biology and to humankind as a whole adds to an appreciation of its scope.

Before the rise of genetics, the study of evolution was carried out almost entirely by taxonomists. From Lamarck and Darwin on, nearly all the leading evolutionists were practicing systematists, and the names Chetverikov, Dobzhansky, Simpson, Mayr, Stebbins, and Grant prove that this is still true in modern times. Virtually all the major evolutionary problems were first pointed out, and often solved, by systematists. Even today, the study of organic diversity as practiced by systematists continues to reveal new evolutionary problems. No other branch of biology has made a greater contribution to our understanding of evolution.

Leaders in many other fields of biology have acknowledged their dependence on taxonomy. Elton (1947:166) made this statement regarding ecology:

> The extent to which progress in ecology depends upon accurate identification, and upon the existence of a sound systematic groundwork for all groups of animals, cannot be too much impressed upon the beginner in ecology. This is the essential basis of the whole thing; without it the ecologist is helpless, and the whole of his work may be rendered useless.

No thorough ecological survey can be conducted without the most painstaking identification of all species that are of ecological significance. A similar dependence on taxonomy is true in other areas of science. In the delimitation of geological strata, key fossil species have played a decisive role. Even the experimental biologist has learned to appreciate the need for sound taxonomy. There are many genera with two, three, or more very similar species. Such species often differ more conspicuously in their physiological traits or cytology than in their external morphological characters. Every biologist can recall examples in which two workers came to very different conclusions concerning the physiological properties of a certain "species" because, in fact, one specialist had been working with species *a* and the other had been working with species *b*.

Molecular biologists are vitally interested in sound classification. The evolution of molecules, an increasingly important area of research, can be understood only against the background of a sound classification. It is only in consultation with the taxonomist that the biochemist can determine what organisms may supply the key to important steps in the evolution of molecules. In turn, molecular biology continues to make valuable contributions to the classification of organisms and the discovery of *sibling species*. Let us single out some specific areas to which taxonomy has made noteworthy contributions.

Applied Biology

The contribution of taxonomy to the applied sciences—medicine, public health, agriculture, conservation, management of natural resources—has been both direct and indirect. Taxonomic breakthroughs have often supplied the key to the solution of previously perplexing problems in economic entomology. The famous case of the epidemiology of malaria is a good example. The supposed vector in Europe, the malaria mosquito, *Anopheles maculipennis* Meigen, was reported throughout the continent, yet malaria was restricted to local districts. Large amounts of money were wasted because no one understood the connection between the distribution of the mosquito and that of malaria. Careful taxonomic studies finally provided the key. The *maculipennis* complex was found to consist of several sibling species with different habitat preferences and breeding habits, only some of which are responsible for the transmission of malaria in a given area. This new information allowed control measures to be directed to the spots where they would be most effective.

With biological control of insect pests again receiving increased attention, the determination of the exact country of origin of insect pests and their total fauna of parasites and parasitoids has been restored to the great importance it had prior to the brief period in which at least some applied entomologists thought that they could completely control insects with pesticides.

Pemberton (1941) cites an outstanding instance of the value of insect collections assembled for taxonomic study in the solution of a problem involving biological control. Some 20 years earlier the fern weevil, *Syagrius fulvitarsis* Pascoe, had become very destructive to *Sadleria* ferns in a forest reserve on the island of Hawaii, and control measures became necessary. The entomological literature failed to reveal the occurrence of this weevil anywhere outside Hawaii except in greenhouses in Australia and Ireland. These records gave no clue to the country of origin. However, while engaged in other problems in Australia in 1921, Pemberton had an opportunity to examine an old private insect collection at Sydney; among the beetle specimens was a single *S. fulvitarsis* bearing the date of collection—1857—and the name of the locality in Australia from which it had been obtained. This provided the key to the solution, for a search of the forest areas indicated on the label revealed a small population of the beetles and, better still, a braconid parasite that was attacking the larvae. Collections were made immediately for shipment to Hawaii, and the establishment of the parasite was quickly followed by satisfactory control of the pest. The data borne on a label attached to a single insect specimen in 1857 in Australia thus contributed directly to the successful biological control of that pest in Hawaii 65 years later.

For a while it appeared that biological control had become obsolete owing to the success of chemicals. Recently, however, applied entomologists have had to revert increasingly to biological control because of the development of resistant strains among insect pests and the adverse effects of many of these chemicals on human health and the well-being of the entire ecosystem.

Theoretical Biology

The service functions of taxonomy are often stressed to such a degree that the important contributions of systematics to the conceptual structure of biology are overlooked. *Population thinking*, for instance, has come into biology through taxonomy (Mayr 1963), and indeed, one of the two roots of population genetics is taxonomy (Chapter 3). The problem of the multiplication of species was solved by taxonomists. They have made the greatest contributions to our understanding of the structure of species and the evolutionary role of peripheral populations and were important contributors to the evolutionary synthesis (Mayr and Provine 1980). It was taxonomists who continued to uphold the importance of natural selection when the early Mendelians thought that mutation had eliminated the role of natural selection as an evolutionary factor. Taxonomists such as H. W. Bates and F. Müller made significant contributions to the understanding of mimicry and related evolutionary phenomena and thus provided the first clear proof of natural selection. Taxonomists and naturalists in close contact with taxonomy were instrumental in the development of ethology and the study of the phylogeny of behavior. Taxonomists have consistently played an important role in counteracting the *reductionist* tendencies dominant in so much of functional biology. They have thus contributed to a healthy balance in biological science (Mayr 1974*a*, 1982*a*).

The Role of Taxonomy

The erroneous view is widespread among laboratory biologists that systematics consists merely of the pigeonholing of specimens. In this view, the taxonomist should be content with identifying material and devising keys. Beyond that, the taxonomist should keep collections in good order, describe new species, and have every specimen properly labeled. According to this view, systematics is a more or less clerical activity.

In actuality systematics is one of the major subdivisions of biology, as broad-based as genetics or molecular biology. It includes not only the service functions of identifying and classifying but also the comparative study of all aspects of organisms as well as an interpretation of the role of lower and higher taxa in the economy of nature and in evolutionary history. It is a synthesis of many kinds of knowledge, theory, and method applied to all aspects of classification. The ultimate task of the systematist is not only to describe the diversity of the living world but to contribute to its understanding.

Modern taxonomists are far more than the caretakers of a collection. They are well-trained field naturalists who study the ecology and behavior of species in their native environment. Most younger systematists have had thorough training in various branches of biology, including genetics and molecular biology. This experience in both field and laboratory gives them an excellent background for more fundamental studies.

The multiple role of taxonomy in biology can be summarized as follows:

1 It is the only science that provides a vivid picture of the existing organic diversity of the Earth.

2 It provides most of the information needed for a reconstruction of the phylogeny of life.

3 It reveals numerous interesting evolutionary phenomena and thus makes them available for causal study by other branches of biology.

4 It supplies, almost exclusively, the information needed for entire branches of biology (e.g., biogeography).

5 It supplies classifications which are of greatest heuristic and explanatory value in most branches of biology, e.g., evolutionary biochemistry, immunology, ecology, genetics, ethology, and historical geology. A sound classification is the indispensable basis of much biological research. It is a prerequisite for the application of the comparative method. All aspects of living organisms are of interest to systematists who adopt Simpson's (1961:7) definition of the field as "the scientific study of the kinds and diversity of organisms and of any and all relationships among them." Such studies are often meaningless without a sound classification. Studies of species formation, the factors of evolution, and biogeography are unthinkable without classification. Classifications are particularly important in applied biology, for instance, agriculture, public health, and environmental biology, because the correct identification of an important agricultural insect pest, disease vector, or major component of an ecosystem depends on the availability of a sound classification.

6 In the hands of its foremost exponents systematics makes important conceptual contributions (such as population thinking) that would not otherwise be easily accessible to experimental biologists. Thus it contributes significantly to a broadening of biology and to a better balance within biological science as a whole.

SYSTEMATICS AS THE SCIENCE OF ORGANIC DIVERSITY

The diversity of the living world is one of the most interesting and challenging aspects of nature (Mayr 1982*a*:133–146; Wilson 1988). This diversity, so strikingly in contrast with the ultimately uniform world of physics, is expressed in virtually unlimited forms of variation. First, there are the five major kingdoms with their myriad lower taxa and millions of species. There are organisms with nuclei (eukaryotes) and those without (prokaryotes). Some organisms are haploid during most of their life cycle, while others are diploid. Some reproduce sexually; others, by one of

several forms of asexuality. There are primary producers; others are herbivores, carnivores, or parasites or have adopted other forms of specialization. No matter what aspect of the life history of organisms one looks at, one will find remarkable diversity.

The study of this diversity has on the whole been rather neglected in teaching. In discussions of this subject, two rather different aspects have usually been confused.

1 The teaching of taxonomy narrowly defined—that is, the teaching of proposed classifications of animals, plants, and microorganisms; the reconstruction of their phylogeny; and the methods of identifying specimens

2 The study of biological diversity in all its aspects, particularly in areas where systematics overlaps with evolutionary biology, ecology, and behavioral biology

In the teaching of systematics, emphasis has usually been placed on the description and survey of the major (and a few minor) animal types. Although at least a superficial acquaintance with the system should be part of the background of every biologist, the teaching of systematics should be much broader. It should include analyses of causations, theories of classification, discussions of the origin of diversity (speciation, adaptive radiation)—in sum, all the factors and processes that are causally responsible for organic diversity. It should also attempt to develop generalizations. Such an approach to systematics would be far more attractive to the student than are the largely descriptive surveys that are usually taught. It would permit an *organismic* treatment, a counterpart to the necessarily reductionist treatment of most of molecular biology. A modern course in the principles of systematics would provide an excellent foundation for more advanced courses in evolution, population genetics, morphology, and behavior.

The Study of Patterned Diversity

Organic diversity is not chaotic but patterned, revealing all sorts of regularities. These regularities have various causes, and it is one of the major tasks of systematics to discover the nature of the causation of these patterns. Rodents and lagomorphs (rabbits, etc.) have rootless gnawing incisors. Is this evidence of common descent or of adaptation to an equivalent adaptive zone? Under what conditions do descendants of a common ancestor diverge drastically, and under what conditions do unrelated taxa become convergently similar when invading the same adaptive zone? Similarity might have either form of causation, and it is the task of taxonomy to find out. There is perhaps not a single evolutionary