HISTORY AND SCOPE OF BIOLOGICAL SCIENCES

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Contents

Summary

This contribution briefly outlines the history of the main fields of the biological sciences, with special attention to their theoretical aspects. It also outlines the significance that the main fields of research and the current debates have for the broader development of biological sciences and sketches some of the practical applications of such researches. It considers as the underlying scopes of all biological research both the understanding and reconstruction of the history of evolution, and the understanding and consequent management of the networks of interactions at work in the different environments.

However, it considers that such basic and broad scopes are, in fact, operationally subdivided into groups of closely related disciplines, and therefore the actual development of research is considered under these headings.

1. Ancient and Medieval Times up to the 16th Century

Since the dawn of humanity, every culture has accumulated experiences concerning the broad field of biological sciences: knowledge of animals and plants, whether useful, dangerous, beautiful and so on, on disease, reproduction, behavior. However, with all peoples, except with the Ancient Greeks, and thence, following in their steps, the Romans and later Western Europe, this wealth of information has been organized in traditions, myths, well-tested and standardized practices, but not in such a manner that we would qualify it as "science".

Also, with the Greeks the transition from such common lore to the rigorous tests of unbiased experience, investigation for the sake of investigation, logical analysis and development into a philosophical framework was quite a slow process. Something approaching scientific medical practices appear with the Hippocratic texts, most of them undoubtedly due to Hippocrates (c460-c380 BC), while pure biological studies were the single-handed creation of Aristotle (384-322 BC), even if it must be allowed that shortly before his times, Democritus of Abdera (c455 BC) and Anaxagoras of Clazomene (c500-c425 BC) had advanced some shrewd hypotheses within the framework of a philosophy which may well be described as a "scientific philosophy".

Aristotle, his pupil Theophrastus (c380-c-286 BC) and a few others, whose writings are, however, unfortunately lost, so that we barely know that they studied animals and plants, pursued biological investigations for the sake of understanding nature, that is as a philosophical enquiry However, their attitude soon vanished from the record of the development of philosophy and sciences during the Roman empire, to leave room for compilations, such as the *Naturalis Historia* by Pliny the senior, the sort of book aimed at rounding up the education of the learned gentleman. Meanwhile, the anatomical and medical studies continued at a steady, albeit slow advance. Considerable advances were made in anatomy during Hellenistic times, and are mainly credited to Herophilus (c.290 BC) and Erasistratus (c.275), but still greater advances were made during Roman times, these being illustrated by treatises such as those by Soranus (98-117 AD), Celsus (25 BC-50 AD), Oribasius (326-406 AD) etc. or by the famous herbal by Dioscorides (probably late 1st century AD), in fact a treatise covering all aspects of pharmacopoeia. A place apart, during this period, was Galen: his medical treatises were to become almost standard for over a thousand years, and he, having no opportunity to practice anatomy on human corpses, made extensive and quite accurate investigations in the anatomy of a variety of animals (and, unfortunately, often assumed that his findings would also apply to humans) and, moreover, opened new pathways into physiology through admirable experiments on animals. However, such were the merits of Galen and his self assurance, that he came to be assumed as a certain guide: he was the unchallenged authority much more than was Aristotle. This became even more apparent with the final triumph of Christianity, as the philosophy and religion of Galen could easily be reconciled with Christian religion, while that of Aristotle could not.

During early medieval times there were no advances in biology in its broad meaning, and what advances were made, mainly through the introduction of new drugs, were the result of the development of Arab, or rather, Moslem culture, which had dutifully appropriated most of the Classic science and gave it new impulse. Treatises such as those of Avicenna, Rhazes and others were to become standard in later European universities.

All this changed when, around 1100 AD, the economy of Western Europe began to develop at a quick pace and, at the same time, European armies began to advance in Spain, where the "re-conquest" was achieved some four centuries later by the elimination of the last Moorish kingdom. In the East, as well, the temporary establishment of so-called Latin or Frank states of Syria and Palestine in the 12^{t} century, as well as the, equally temporary, capture and partition of the Byzantine empire had a great cultural impact. They were all conducive to intensive cultural exchanges, and Greek scientific treatises, both in their original Greek, or in Arabic or Jewish translations poured into Western Europe. It is estimated that between 1150 and 1350 some 5,000 scientific orphilosophical treatises were translated into Latin and were discussed in the new Universities, which began to develop at the same age.

Medical studies immediately profited from the new intellectual interests, and these were joined with a revival of pure studies. So, while new compilations aiming to collect all known evidence were successfully produced (such as those of Adelard of Bath, Vincent of Beauvais or Thomas of Cantimpré for general natural history and the many medical and surgical handbooks), also some new investigations were made, for instance by the Emperor Frederic II or by his contemporary St. Albert the great.

The requirements of surgery soon prompted, first in Italy, fresh developments in anatomy. The anatomy that had been practiced previously, as training for surgery, had been made on swine; when chartering the University of Naples, emperor Frederic II had recommended the dissection of human corpses. There is good evidence for human dissection being made in the late 13th century, for instance by Guglielmo da Saliceto, who died in 1277 or 1280, and an autopsy for suspect murder was ordered by four physicians in Bologna in 1302. Anyway, the first certain instance of human dissections by a master of anatomy was performed by Mondino de' Luzzi in 1315. Mondino made several dissections and wrote a little treatise, which became immensely popular, but which does not include anything new. The real development of the new anatomy had to wait for another full century, although dissections were regularly made in Italian universities, usually twice per year.

By the middle of the 15th century, the practice of human dissections was common in Italy (even the corpse of a Pope was dissected to find the cause of death). Both artists and physicians were practicing it and Leonardo, who had made over 30 autopsies and made hundreds of wonderful drawings, planned an immense treatise in co-operation with a brilliant young professor of anatomy, Marcantonio della Torre. Unfortunately, the project collapsed because of the sudden death of Della Torre.

However, a junior contemporary of Leonardo, Berengario da Carpi (c1460-1530) published a treatise which was both well illustrated and which included a number of new discoveries and improvements on previous descriptions.

In fact the introduction of printing soon prompted not only the printing of traditional texts, but also the production of a number of new books on all kinds of subjects. Among the scientific texts, herbals were among the first and *De virtutibus herbarum* by a Macer Floridus without figures was printed in 1477, an illustrated edition of the herbal by the Pseudo-Apuleius platonicus, a text which had enjoyed a considerable repute since late Roman times, was printed in 1482/3, soon followed by a number of medical and anatomical texts both in Latin and vernacular editions.

2. Post-Renaissance Developments

Thereafter, the development of biological sciences was a steady one and is outlined in another section of this Encyclopedia (see *History of Biological Sciences*). Therefore, rather than attempt to summarize it and mention a few names of outstanding scholars, it may be worthwhile to trace the development of what are nowadays the main scopes of biology.

It would be easy and at the same time quite correct to say that the biological sciences are, indeed, a single science with a single scope: the understanding of the mechanisms of life and how they worked through the ages to make the biosphere as it presently is; with the complementary aim of being able to control biological factors for the maximum benefit of mankind. This latter may well be considered as part and parcel of the broader scope, as a comprehensive understanding is the prerequisite for control. Yet the enormously varied range of phenomena investigated has, unavoidably, caused specialization, and each one of these specialized branches of biology has, to some extent, further scope of its own.

As we have seen, biological studies developed through Antiquity and the Middle Ages, first with the aim of improving medical treatments, and to a much lesser degree in order to gain a philosophical understanding of living beings.

However, while medical research remained the background for the advances in descriptive anatomy and in physiology, it also showed a remarkable tendency, in post-Renaissance times, to appropriate and further develop for its own purposes new fields of research which were opened either for purely scientific purposes or to meet the needs of other human activities. So, for instance, microbiology, in the broad sense of the study of microscopic organisms, was primarily the result of the fortuitous discovery of these organisms and, though the belief that epidemic diseases were due to material agents had been standard for centuries, and the hypothesis that these were living beings had been mooted since the 16th century, it was first developed for quite different purposes. Indeed, the first systematic investigations on micro-organisms for practical purposes were done with the aim of controlling diseases in the breeding of useful animals, such as silkworms, or of agricultural products such as wines, beers etc. So, the significance of microbiology for medicine was first systematically advocated by Henle in 1840, basically on the evidence of Bassi's studies on silkworm's muscardine and Schwann's studies on fermentations.

Likewise, genetics was first developed by botanists for what we would label as purely academic purposes, though physicians were prompt to see its potential significance in order to understand several human diseases.

Nowadays, the prevention and cure of diseases are to most people one of the main purposes of biological studies, sometimes to the annoyance of non-medical biologists, who complain that their medical colleagues get too big a share in the available resources for research.

Indeed, important as medical research is, the claim by other biologists that, quite apart from the purely scientific significance of research in any other field, even considering only the applied aspects of biology, the progress in environmental sciences management and development of resources promise, in the long run, such lasting benefits that they should deserve greater investments than they get.

Apart from medical science, the different branches of biological sciences may, perhaps, be grouped under two main titles: "The history of the biosphere" and "The conservation and management of the biosphere". In addition, the significance of biological sciences for the development of philosophy and ethics may well be considered as a distinct scope in itself.

It must be stressed that all the various distinctive branches of biology: morphology, physiology, genetics, ecology, paleontology etc. impinge on each one of the three major scopes of biological studies that we have just outlined; though, obviously, in different manners and with different significance. Thus, for instance ecology is the very foundation of environmental conservation, while applied paleontology, though much less critical, is still of considerable relevance because of its significance in the discovery of deposits of petrol, coal etc. The significance of the two is reversed when we consider the evolutionary history of Earth.

3. Paleontology and Evolution

None of the scholars of antiquity or of the early Middle Ages suspected that fossils might belong to organisms different form those presently living. By the 13th century, opinions were divided as to the nature of fossils: some assumed that they were either some sort of causal resemblance of rocks to living beings, *lusus naturae*, or that they were aborted attempts of the inanimate Earth to produce living beings or, finally, that they were the remains of animals that had died during the Biblical Flood. A few scholars, like Boccaccio (the author of the "Decameron"), suspected that the fossils could be much older than the "Flood". Leonardo da Vinci was unquestionably the first to clearly understand the great antiquity of fossils and, in a rather obscure page describing how the body of a monster became entombed in the rocks, may even have guessed that these belonged to organisms different from the present ones. While Leonardo never published anything, Fracastoro apparently took from him and advocated these ideas, so that they were, somewhat later, published and credited to Fracastoro himself.

The debate on fossils and on their antiquity continued through the 17th and the early 18th century, and by the end of the 17th century it also begun to be recognized, at least in England and Italy, that the most common fossils appeared to belong to tropical faunas, thus pointing to considerable environmental changes.

By the end of the 18th century, and the first two decades of the 19th, paleontology became a well- established branch of science. While an increasing number of fossils were being described by many scholars all over Europe, the outstanding contributions to this transition came from Lamarck, Cuvier and Geoffroy St. Hilaire, who were then working at the Museum d'Histoire Naturelle of Paris. While Lamarck, studying invertebrates, advanced his evolutionary theory in full in 1809, Cuvier, still held by a rigidly fixist stand, admitting that a number of species had vanished and that their antiquity was very much greater than had been previously been considered as possible. Geoffroy became a true evolutionist after 1830, during a long argument with Cuvier. Such advances, and a new and enlarged scope for the study of fossils, were possible because these three scholars were firmly establishing the practice of comparative morphology.

As soon as a sound evolutionary theory was advanced by Darwin and Wallace in 1858

(Darwin's basic "origin of Species" being published in 1859), comparative morphology of fossils took a new turn in the minds of almost all the best anatomists and paleontologists. While paleontology has since been developed as the reconstruction of the actual history of the evolution of living beings, it is becoming more and more integrated with all the other disciplines of biology, as well as taking advantage of the advances in geology, paleoecology etc., as well as providing these disciplines, including their applied branches, with a rich feed-back.

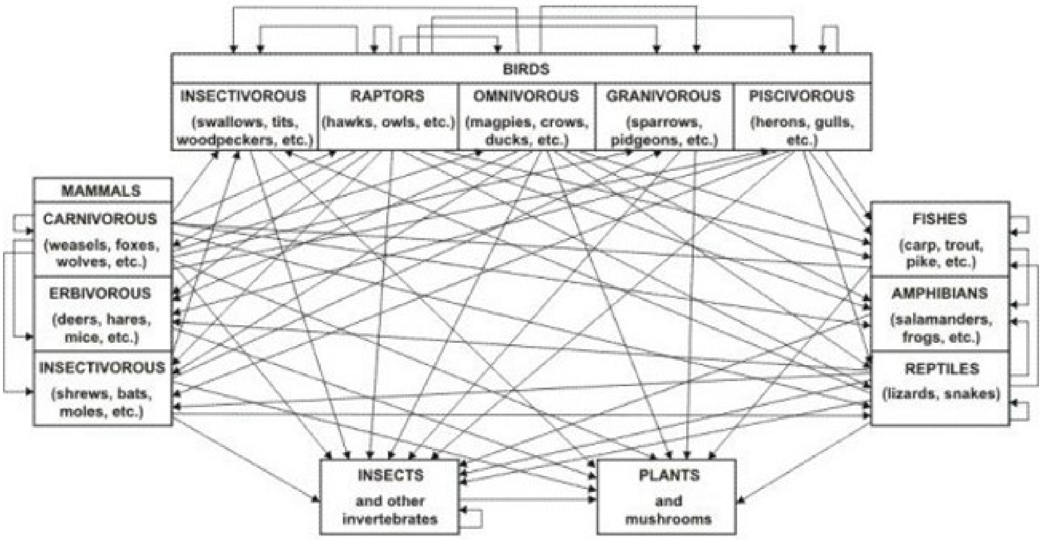

Figure 1. A tentative scheme of the phylogenetic relationship of eukaryotes.

Nowadays, apart from the more traditional challenges of the reconstruction of the morphology, phylogeny and biology, including ecology, of the different post-Cambrian and later organisms, the most exciting advances are in the field of the early Cambrian and of the pre-Cambrian organisms as, most of these are so remarkably different from later organisms, as to still defy the identification of their evolutionary connections with them. There is also the feeling that a better understanding of them will uncover critical evidence for the understanding of the origin of life itself, and for such critical developments as the origin and relationships of multi-cellular organisms.

Quite apart from the immediate significance of applied paleontology in the location of mineral resources, the basic significance of this branch of biology in the understanding of the evolution of the different organisms will naturally impinge also in the field of ethics, even if its use is still debated. Its significance relates to two different problems:

On the one hand, it provides the backbone to be able to reconstruct the evolution of mankind, and the precise placing of man in his proper phylogenetic relationships offers the (controversial) justification for using comparative behavioral data in the discussion of the behavior of Man.

On another hand, it provides evidence of past environmental changes and, possibly, some of the keys needed to foretell the risks that our familiar environments are now sustaining.

The development of evolutionary studies, taken as the development of general theories as to the possible mechanisms of evolution, underwent four or, perhaps, five major phases. Some hypotheses, as we have seen, about the possible transmutation of species had been sporadically advanced rather early. Vague evolutionary ideas had been advanced by Vanini (burnt at the stake in 1619); in the 17th century, and a first organic evolutionary hypothesis was advanced by Father Athanasius Kircher S.J. in 1675 in order to account for the fact that, even allowing for spontaneous generation for a large number of animals, such as most invertebrates (a thesis that he staunchly advocated even in front of Redi's evidence to the contrary), Noah's Ark was not big enough to hold all the diverse animals that had been discovered around the world! So the Reverend Father, suggested that the Ark actually preserved just a few hundred species and that all the present species evolved from these after the 'Flood' by adaptation to local environmental requirements.

Again, the idea of limited transmutation was advanced by Linnaeus in some of his later books, by Buffon, by Bonnet whose ideas are at the root of Cuvier's theory of catastrophes (he envisaged repeated crises which each time had made some substantial improvements in all beings, and foresaw a final crisis in which apes and elephants and other mammals would become so intelligent as to take the place of mankind, which, having attained perfection would presumably leave this world and migrate to the heavens). The first organic theory which may be considered of real significance was developed in the first place by Lamarck, who envisaged the combined action of an innate trend of all organisms towards an increasingly complicated and specialized structure, this being actually molded by environmental factors. In the meantime, in Germany several scholars, including Goethe, had advocated the thesis that all organisms, and even their individual parts, were the result of the adaptive transformations of a few basic structures; such was the idea, usually credited to Goethe, but in fact older, that the various parts of the flower are actually modified leaves, or that all parts of a vertebrate are actually modified repetitions of a model segment built around a vertebra (a theory claimed by both Oken and Goethe!). Whether this so- called 'idealist morphology' can be taken as being an evolutionist attitude is debatable, although it certainly produced some excellent comparative anatomy, and prepared the ground both in Germany and in England for the prompt acceptance of evolutionary theories when Darwin, finally, produced a really satisfactory theory.

The orthodox Darwinian wave was over by the time of Darwin's death. By then, almost every scientist accepted the fact that evolution had occurred and was, possibly, still occurring. However, for a number of different reasons, Darwin's theory based on more or less random variability and selection by environmental requirements, met with increasing criticism and for the next fifty years or so, a number of alternative, and usually short lived, theories were advanced.

At this point, as genetics had made sufficient advances to be fully recruited into evolutionary theories, came the development of the 'New synthesis' or 'Neo-Darwinian synthesis'.

Neo-Darwinism soon became the dominant theory in the middle of the last century, and is still the one most familiar to biologists, there being, however, some significant varieties stressing different models for the evolution and selection of characters (classic neo-Darwinism, neutralism etc).

However, the rather chaotic and unpredictable aspects of evolution implicit in any of the typical Darwinian theories, is considered unsatisfactory by a number of taxonomists, their main criticism being that it allows for too big a margin of subjective assessment in the significance of the evidence available and its low predictive value.

Thus, beginning in the late 1960s, a new wave started to spread, sparked by the publication of the English translation of Hennig's cladistic theory of taxonomy. Cladistics developed in a fair number of varieties, and has not directly challenged the basic neo-Darwinian models of evolution. Its challenge is, however, implicit in the regularities they presume.

Thus we can consider that presently, on one side, there is a steady progress in the understanding of the different ways by which the variability, distribution, etc., of populations develop, and of the mechanisms that bring about selection, or of the effects that may result by the lack of such selection. There is no question that such progress is generating the identification of an increasingly complicated pattern of interactions of different possible mechanisms. On the other hand, while almost everyone pays lip service to the goal of attaining the best possible reconstruction of phylogenies, and to the desirable role in the improvement of classifications, the different schools are increasingly at odds.

4. Morphology and Physiology

Since early in the 19th century, comparative anatomy and comparative physiology have always been closely linked with the development of the reconstruction of the history of life, for obvious reasons. Evolutionary morphology and physiology have largely been the main trend in these studies, but gradually the scholars interests have been increasingly attracted by functional morphology, and the related aspects of comparative physiology in connection with adaptation to different environmental requirements. Nor should the great significance that reproduction and development have in the understanding of the overall biology of the different living beings be overlooked. Indeed, all the different aspects of development have an undoubted significance for the correct interpretation of morphology and evolution (though certainly not by the simplistic assumption that 'ontogeny repeats or summarizes phylogeny', as advocated by Haeckel and sometimes still repeated in popular texts), but they are quite often significant for the understanding of the functioning of genetic mechanisms, and even have relevant practical significance, which promises great rewards especially in the field of transplants and other therapeutic practices.

If we consider all the various purposes to which morphology and physiology may contribute significant advances the list is a fairly long one:

First comes the traditional scope of understanding the phylogenetic significance of the special features of the different structures: the different structures may be either homologous or analogous, but these are relative concepts, which must be understood in

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Bibliography

Barbieri M. (2000) I codici organici. Pequod: Ancona [A monograph expounding the evidence for the existence of additional 'codes' besides the genetic code of nucleic acids].

Mayr E. (1982) *The Growth of Biological Thought*. Harvard University Press, Cambridge, MA. [An excellent account of the development of evolutionary theories].

Minelli A. (1993) *Biological Systematics, the state of the art*. Chapman and Hall: London [A most useful reference, to appreciate the various approaches to systematics]

Simonetta A. (in press) *A Short History of Biology*. Backhuys Publishers: Leiden [A comprehensive history of biology since its origin to the beginning of the 20th century].

Sober E (1991) *Reconstructing the Past, Parsimony, Evolution, and Inference* [A still standard and balanced book on the theoretical problems of modern methods in evolutionary taxonomy]

Strickberger MW (2000) *Evolution*. Jones and Bartlett:Sudbury, Ma [A good textbook on the evolutionary mechanisms and the main lines in the development of the history of life].

Biographical Sketch

Alberto M. Simonetta, born 1930, is full Professor of Zoology at the University of Florence (Italy). He studied in Florence, where he had his first appointments as 'assistant' and was appointed as full Professor of Comparative Anatomy at the University of Camerino in 1969. His major research interests are the comparative anatomy and evolution of vertebrates and of arthropods, including fossils, theoretic aspects of evolutionary taxonomy and the history of biology.