BIOLOGICAL SCIENCE FUNDAMENTALS (SYSTEMATICS)

Giancarlo Contrafatto
School of Life and Environmental Science, University of Natal Durban, Durban, South Africa

Alessandro Minelli
Department of Biology, University of Padova, Padova, Italy

Keywords: systematics, multicellularity, life-cycles, cell, adaptations, individual, colony, species, population, society, communities, life-forms, taxonomy, biodiversity, growth, development.

Contents

Summary

Earth is the only planet known to bear intelligent life as well as a great diversity of biological forms. Our planet's origin is dated to 4.6 billion years before the present day and, during the first 1 billion years or so, its prevailing conditions favored the formation of living organisms, starting from inanimate organics to pre-biontic structures such as proteinoids, spherules, and others. The first unicellular organisms lived in the pre-Cambrian oceans, 3.5 billion years before the present day, and from that time life on earth differentiated into a variety of biological forms through the process of evolution by natural selection. Factors influencing natural selection must have included the major upheavals that characterized the recognized geological eras and periods.

The natural history of life is characterized by an increased complexity of forms, which began with the relatively simple unicellular organisms, such as bacteria, and progressed to the more complex unicellular eucaryotes such as protozoa and algae. The descendants

of algae and protozoa differentiated into multicellular organisms, some 2 billion years before the present day, and these subsequently colonized land masses and air, through major evolutionary bursts that gave rise to the lineages leading to extant forms of invertebrates, vertebrates, flowering plants, and angiosperms. Each evolutionary burst was characterized by increased morphological and species diversity. New species sometimes coexisted with their ancestors but speciation, or formation of new taxa, also occurred at relatively quiet times characterized by slow evolutionary rates. Evolution by natural selection is mediated by an intrinsic property of life: the ability to replicate spontaneously. Each new individual is not replicated with absolute precision and bears a small number of new genetic mutations that accumulate, with time, within the genetic pool of a species. Environmental factors are instrumental in allowing the survival and reproduction of new mutated forms and hence, with time, re-shape the genetic pool of species.

Systematic biology is, hence, defined as the study and description of the diversity of biological forms. It is a multidisciplinary science drawing from the efforts of all biological disciplines. As such, systematic biology has benefited, during the twentieth century, from advances in genetics, biochemistry, cytogenetics, embryology, information technology, molecular biology, and statistics as well as from advances in ecology and behavioral science. This integration of knowledge augurs well for the progress of Systematics into the twenty-first century.

1. Introduction

> For my own part, I would as soon be descended from that heroic little monkey, who braved his dreaded enemy in order to save the life of his keeper; or from that old baboon who, descending from the mountains, carried away in triumph his young comrade from a crowd of astonished dogs—as from a savage who delights to torture his enemies, offers up bloody sacrifices, practices infanticide without remorse, treats his wives like slaves, knows no decency, and is haunted by the grossest superstitions.
>
> Man may be excused for feeling some pride at having risen, though not through his own exertions, to the very summit of the organic scale; and the fact of his having thus risen, instead of having been aboriginally placed there, may give him hopes for a still higher destiny in the distant future. But we are not concerned here with hopes or fears, only with the truth as far as our reason allows us to discover it. I have given the evidence to the best of my ability; and we must acknowledge, as it seems to me, that man with all his noble qualities, with sympathy which feels for the most debased, with benevolence which extends not only to other men but to the humblest living creatures, with his godlike intellect which has penetrated into the movements and constitution of the solar system—with all these exalted powers—Man still bears in his bodily frame the indelible stamp of his lowly origin.
>
> (Charles Darwin, *The Descent of Man*)

Darwin’s sentiments about the evolution of humans, albeit somewhat tainted by nineteenth-century gender-naming customs, epitomize the evolutionary thread that runs through this article on Biological Science. Although humans (the species *Homo sapiens*) appear to be the most successful species that nature has yet put on the planet, they cannot lose sight of the fact that their presence on earth is the result of billions of years of evolutionary strife and the development of countless life forms. Indeed, humans share more than a passing affinity with all other forms of life. They share with all other organisms, the very essence of life: the molecules and structures that make the hallmark of life. Rising to the summit of the organic scale, as Darwin put it, carries with it a responsibility to understand the events leading to this rise. Darwin arrived at the theory of evolution by natural selection, through careful and insightful observations of patterns of evolution (variation in forms), because the scientific information available in the first half of the nineteenth century was mostly limited to the observation of morphological features. The laws of heredity, elucidated by the nineteenth-century monk G. Mendel, had yet to be published; chromosomes, the carriers of the genetic molecule DNA, had yet to be described by the German biologist T. Boveri; and the molecules of life, the structure of nucleic acids (DNA and RNA), would only be elucidated a century hence by the American and British biochemists J. Watson and F. Crick. These, and other developments in the science of biology (Gr. *bio* = life; *logos* = discourse, study) that occurred during the twentieth century, led to the development of a new synthesis and fostered a more profound understanding of evolution and its processes. Refinements of this nature continue to this day, aided by a steady supply of new findings in all biological disciplines. Thus, evolution is best understood through a multidisciplinary view of its mechanisms; all biological disciplines have contributed and continue to contribute to this. The converse is also true as highlighted by the geneticist T. Dobzhansky in his often quoted aphorism, “Nothing in biology makes sense unless in the light of evolution.”

Of all the biological disciplines, systematic biology is perhaps the one that benefits the most from an integration of a multidisciplinary input and, thus, can be assumed to represent a springboard to evolutionary biology. Systematic biology is here defined as the description and study of the diversity of biological forms. Although the description of biodiversity was traditionally accomplished by the study of anatomical (and micro-anatomical) features, modern systematics takes into account all developments in the biological science. An analysis of biodiversity that did not include genetic, biochemical, molecular, cytological (Gr. *cyto* = cell), physiological, anatomical, reproductive, developmental, behavioral, and ecological characteristics of life forms would fail to fulfill its descriptive obligations.

Hence, this is the path to our understanding of life: a multiform acquisition of all information pertaining to life forms and their relationships with the planet. As humans go about discharging their responsibility to understand life and its evolution, this very understanding carries with it a promise: the promise of sound stewardship of the planet and the life it supports.

2. Life on Earth

Although the exploration of the solar system is still in its infancy and the search for extraterrestrial intelligence has yet to bear fruits, the information presently available indicates that earth is the only planet known to support life: countless forms of it, including intelligent life. Knowing what we do about the solar system and the processes of water-based chemistry, we are justified in believing that the presence of life on our planet is due to, besides a suitable gravitational force, earth’s enviable location: an appropriate distance from the sun. These circumstances have allowed favorable conditions of temperature and pressure for water to be present in its liquid state. This, in turn, allowed for the development of water-based chemical reactions that gave rise to water and carbon-based life. Time, as well as geological and climatic events, saw to it that simple life differentiated into a multitude of life forms on the planet.

We may eventually discover the existence of other life supporting planets, and some of these may bear intelligent life but, at present, we are still facing the obvious question: why has life developed only on earth? The key to penetrating this problem may rest with another equally obvious but, certainly older question: what is life?

Humans are inherently adept at distinguishing living creatures from inanimate objects, but they experience intrinsic difficulties when faced by the task of providing a definition of life. Vague qualities immediately come to mind and these inevitably lead to circular definitions such as, “the state or condition of being alive” or “animate existence.” There seems to be no single property that adequately defines life. One way out of the quandary is to provide lists of attributes, an activity indulged by many authors of modern biology textbooks and encyclopedias. However, these lists are often elaborate and, ultimately, unsatisfactory as they inevitably include features also shared with other complex systems. To date, the most sound and most concise of such lists was that introduced by Jacques Monod in his landmark philosophical essay *Chance and Necessity* (1970). According to Monod, one may recognize living things by the following properties.

Autonomous teleonomy: the existence of a purpose or design implicit in organism morphology. Teleonomy in an organism can be inferred by detecting morphological regularity, or symmetry, and the repetition of the organism’s morphology in large numbers of copies. Provided that such teleonomic property is internal, that is, it does not imply a purpose applied from outside, it can differentiate natural entities from artifacts of human industry, which generally do display geometric symmetry. Teleonomy in living organisms can, eventually, be identified with the “need” to replicate their own structure over indefinite time or, what is popularly known as the *purpose of reproducing and propagating the species*. Monod cogently argued that this “purpose” is determined by the constraints of entropy, chemical bonding, and bond energy that are dictated by the macromolecular components of living matter.

Autonomous determinism or internal morphogenesis: because organisms are complexes of organic components, assembly of such components is a prerequisite of integrity, so long as this does not occur through the agency of external forces (e.g. self assembly).

Invariant reproduction: the ability to reproduce and transmit the information corresponding to its own structure. Provided that this information (genetic information) is stored in organic molecules capable of self-replication (nucleic acids), this property alone has the potential to identify life.

Commonly such lists include, as a feature, the organism’s potential to undergo evolution.

Although this quality, in itself, can also apply to inanimate or inorganic natural objects (earth's physical environment) that are likewise subject to evolutionary changes dictated by climatic variation and planetary movements, only life is able to record evolutionary changes in its invariant reproductive system.

As inadequate as this answer may be, it prompts other questions. Where did life on earth originate? How did it come about? When did it come about?

Like all historical studies, the study of evolution is inevitably inexact, since it depends on the existence, reliability, and interpretation of the records of the past. Hence, the documentation of earlier life and the steps undertaken in its evolution into modern forms is, of necessity, a process of inference that rarely enjoys the luxury of direct evidence. Nevertheless, most biologists would answer the first question by stating without hesitation, that life must have emerged in the "primordial soup," the vast ocean reservoir of water, inorganic chemicals, and coalescent organic compounds that came into existence relatively shortly after planetary formation. Earth oceans are the most serious candidates for the status of relatively stable environments and sources of matter, because they existed for billions of years and because living matter depends on water-based chemical reactions. Deep ocean vents, for example, might have been suitable cradles for the emergence of life because they contained the necessary organic matter, sources of chemical energy, and protection against hazards of extra-planetary origin (ultraviolet radiation etc.). An alternative means of seeding earth with primordial organic monomers can be panspermy. There is, as a matter of fact, mounting evidence to the effect that a source of organic compounds might be represented by extra-planetary bodies, such as comets and the meteorites known as chondrites, which are known to contain many organic compounds in significant quantities.

The initial steps in the emergence of life, through abiotic mechanisms, were experimentally modeled in the first half of the twentieth century. These experiments documented the availability of physical factors and chemical mechanisms capable of explaining the appearance of biochemical molecules or macromolecules. Since these modeled conditions are presumed to have occurred frequently in the primordial soup, it is conceivable that the formation of many different biochemicals could have occurred repeatedly in many parts of the ocean. Because many macromolecules have morphogenetic properties, it is also possible to suggest that macromolecular structures (protobionts) such as proteinoids, membranes, spherules, and liposomes would have appeared as a series of concurrent events leading to a multi-threaded emergence of living cells. Following from the properties of life listed above is the conclusion that, regardless of our inability to document it, life began at the time when a system of coding, storing, and decoding all the information necessary for replicating life (the nucleic acids popularly called "molecules of life"), was incorporated into the protobionts. This marked the emergence of the cell and from then on, life's own biological laws of natural selectionfrom, but rooted into, those of chemical interactions—regulated the progress of life on earth and influenced much of the planet's evolution.

3. The Geological Scenario and the Major Evolutionary Transitions

We have pointed out earlier that evolutionary biology is a historical study and hence, must rely heavily on inference rather than direct evidence. However, the closest evolutionary biologists can get to direct evidence is the study of the fossils of biological forms. As mentioned earlier, the oldest stromatolites are dated at 3.5 billion years before the present day (BYBP), but more recent fossils of many biota can be found in the geological strata. Why is it, then, that we do not have a clear and definitive picture of evolutionary events as constructed from the fossil records? The reason is an obvious one and was pointed out by Darwin: the fossil record is imperfect. In order to appreciate what this imperfection entails, however, we may want to briefly examine the type of rocks and fossil beds that are available on earth.

3.1. Some Fundamentals of Geology

Three types of rocks are usually recognized: igneous, sedimentary and metamorphic rocks.

Igneous rocks are those formed from the cooling of molten material (magma) extruded from deep within the planet. Some of this is of volcanic origin but some must have solidified shortly after the planet's formation.

Sedimentary rocks are those formed by the solidification and compression of sediments originated from older rocks or precipitation from waters.

In turn, igneous and sedimentary rocks may be subjected to conditions of high pressure and temperature thus undergoing physical modifications that produce *metamorphic rocks*.

Throughout geological times, strata of sediments accumulate on top of one another and can provide, by their physical and chemical properties, a record of the planet's history through time. Fossils are normally found in sedimentary rocks, never in igneous rocks and, when found in metamorphic rocks, they are usually modified or distorted as to become of little value to evolutionary studies. Hence, paleontology (the study of natural history through fossils) is limited to searching for evidence in the available columns of sedimentary strata (stratigraphic column) and few other peculiar situations, such as insects trapped in amber (fossilized plant resin) and mammals trapped in glaciers and polar ice caps. Further, the planet can be visualized as being made of a surface crust or lithosphere, composed of these three types of rocks and floating on a semifluid asthenosphere. This picture, however, is not static, since the lithosphere has been shown not to be monolithic but to be composed of eight major plates drifting over the underlying layers. The underlying hot magma produces convection cells within the asthenosphere with the consequence that some magma rises to the surface, along some flaw lines such as the ridge in the mid-Atlantic Ocean, spreads out and forms new crust. This new material added to the crust, pushes pre-existing tectonic plates aside causing them to shift laterally. The plates move at a yearly rate of 5–10 cm and, occasionally, may come together or "collide" with one another. At the points of collision, the edge of one of the plates may slide underneath the other, thus forming a subduction trench, and penetrate the underlying asthenosphere. The pressures caused by these collisions are thought to have been the major cause of the orogenetic events responsible for the formation of the major mountain ranges of the world. Plate tectonics and their associated orogenesis, therefore, would represent the major forces responsible for shifting the relative positions of sedimentary strata making them discontinuous and inconsistently distributed.

3.2. Geological Changes, Evolutionary Transitions, and Extinctions

Although no consensus has yet been reached on a unifying theory of cosmology, an expanding universe hypothesis is consistent with an age of the universe of 14 billion years, as measured by red light shift. The age of the solar system and earth, as measured by radioactive isotope decay, is in the region of 4.6 billion years. Evolution on earth began from the moment the planet started to cool off and the geological changes representing this evolution have, traditionally, been arranged into the eras, periods, and epochs shown in Table 1, where the major five mass extinction events gleaned from the fossil records are also indicated.

Era	Period	Epoch	Beginning at MYBP	Taxa	Extinctions
Cenozoic	Quaternary	Holocene	0.01		
		Pleistocene	1.8	Hominins	
	Tertiary	Pliocene	5.2		
		Miocene	23.8		
		Oligocene	33.5		
		Eocene	55.6		
		Paleocene	65.0		
Mesozoic	Cretaceous		144		≺ KT boundary
	Jurassic		206	Birds, angiosperms	
	Triassic		251	Early mammals	≺ end Triassic
Paleozoic	Permian		290		≺ end Permian
	Carboniferous		354	Early vascular plants, winged insects, reptiles	
	Devonian		409	Amphibians, insects, ferns, seed plants	≺ late Devonian
	Silurian		439	Jawed fish	
	Ordovician		500		≺ end Ordovician
	Cambrian		543	Earliest vertebrates	
Proterozoic			2 500	Eucaryotes and first multicellular plants and animals	
Archaean			3 800	Procaryotes	

Table 1. The time scale of evolution (MYBP = million years before present)

Plate tectonics appear to be responsible for much of the difficulty experienced by paleontologists: stratigraphic columns extracted from relatively distant sites, may be in different temporal sequences and thus yield conflicting information. Other problems also confound the field: fossilization depends on many environmental variables. Some environments have not been, at times, conducive to fossilization. In many taxa, the absence of a hard skeleton has meant that fossil remains formed only under very rare and special conditions. Relatively reliable dating methods exploiting polarity inversions of magnetized particles have been developed since the 1970s and have been utilized with increasing frequency since. However, the more traditional dating methods by radiometric isotope are not always pitched to the required resolution and can only be used on igneous rocks because the other types of rocks derive, indirectly, from older igneous rocks. Carbon dating (using decay of ^{14}C with half-life of 5,730 years) is most useful in studies over short time-scales up to a maximum of 40,000 to 70,000 years. Potassium-argon decay (half-life of 8.4 billion years) tends to be reliable mostly in long time periods measurements. Finally, pseudo-extinctions can introduce a further problem of a taxonomic nature to paleontological studies. Pseudo-extinctions may appear in lists of species names from successive geological time periods. In such cases, a name may disappear from the list of recorded species, because its lineage has undergone a morphological change and bears a different name in the records from a successive period. Hence, the living beings have left descendants, albeit of different form, but these are recorded as a new species since the ancestral–descendant relationship has gone unnoticed and the ancestor species declared extinct.

Notwithstanding these difficulties, the data broadly outlined in Table 1 clearly indicate that paleontologists have done remarkably well in documenting the variety of biota that made their, sometimes temporary, appearance on earth. The evolution of some taxa is remarkably well documented and allows detailing of the major evolutionary transitions that are outlined below. Some of these have been confirmed by phylogenetic studies carried out on extant taxa and we are thus able to confirm some evolutionary events by independent lines of investigation.

3.2.1. Major Evolutionary Transitions

Paleontological endeavors have made available a wealth of information that has made plain a number of major events. The “Cambrian revolution” is perhaps the most frequently cited aspect. It is quite evident, from the fossil record, that the Cambrian period (543 MYBP), in its later part, witnessed an impressive burst of diversification of animal phyla. Although a few representatives of modern animal phyla are recorded from the late Precambrian and early Cambrian, virtually all of extant marine phyla with skeletons made their relatively abrupt appearance about 530 MYBP, probably within a time frame of 10 to 30 million years. Some 100 million years later, during the late Silurian and early Devonian, plant life invaded the landmasses. These were in the form of early bryophytes and tracheophytes: by the late Devonian some large vascularized trees were already present and these became dominant during the Carboniferous. This invasion was accompanied by a colonization of land by arthropods of two major groups: chelicerates and mandibulates. The Mesozoic era (251–65 MYBP) was characterized by extensive plate tectonic movements.

The large continent Pangaea began fragmenting in the late Jurassic with the formation of the Tethyan Sea between the northern continent, Laurasia, and the southern Gondwana. The final separation into the modern continents was, however, only completed during the Eocene epoch of the Cenozoic. The Mesozoic flora was dominated by gymnosperms, especially cycads and conifers and most orders of modern insects emerged in this era. This was, undoubtedly, the era of the dinosaurs that are well represented in the fossil record and whose diversity appears to have been declining throughout the late Cretaceous. Only a few families of dinosaurs were still in existence by the end of the Cretaceous when this group of reptiles became extinct. The redistribution of landmasses and oceans that occurred in the Mesozoic may have been responsible for climatic changes that influenced biotic distribution and radiations during the Cenozoic. The Eocene was typified by the differentiation of most modern angiosperms and insects whereas, during the Oligocene, much of the forested area was replaced by grasslands. Grasses and herbaceous plants underwent a significant adaptive radiation and some of the largest extant families (i.e. *Compositae*) differentiated at this time. This radiation of grasses was accompanied by a differentiation and radiation of grassland adapted animals. The Pleistocene saw the emergence of hominin primates and the beginning of human evolution, which proceeded into present times and was probably significantly influenced by the 100,000 year cycle of glaciations (pluvials and interpluvials in much of the Southern Hemisphere) that characterized the Quaternary period.

A phenomenon that punctuated most of the scenario described above, was that of extinctions: events whereby many existing taxa disappeared from the fossil record without leaving descendants. Some authors recognize as many as twenty-seven extinctions since the Cambrian “explosion” but most of these were of local scope and did not seem to fundamentally alter the biodiversity recorded for those times in the stratigraphic column. However, five of these extinctions, those listed in Table 1, were wide and severe enough to affect biotic diversity worldwide and are thus referred to as “mass extinctions.” The most severe took place at the Permian–Triassic boundary but all five appear to have occurred at, or close to, a periodic boundary. Perhaps this observation alone should alert us to the direction to be taken in investigating the possible causes of such extinctions. Nevertheless, the causes of extinctions remain somewhat obscure.

The Cretaceous–Tertiary (KT boundary) event has been investigated more intensively than others and some hypotheses have been presented: periodic meteorite impacts, climatic and sea level changes, and changes of continental profiles. Some experimental evidence, such as the detection of worldwide iridium anomalies in rocks (iridium is found in high concentrations in extraterrestrial objects) and shock quartz (a sign of high energy impacts) applies to the KT boundary extinction but does not correlate with other mass extinctions. This hypothesis needs a meteorite impact crater, of the appropriate age, of large enough diameter (100–200 km) and this has been described from Chixulub, in Mexico. On the other hand, the fourth largest impact crater on earth, the Morokweng crater in South Africa (*c*. 145 MYBP or K/C boundary), does not appear to correlate strongly with an extinction of biota, as seen in the fossil records. Hence, the meteorite impact hypothesis may explain some, but not all, extinction events and is not the only possible mechanism. The climatic change hypothesis and the continent shape hypothesis have not yet been fully tested and hence we still lack a general mechanism to explain extinctions.

Typically, the fossil record is not very informative regarding detailed processes such as modes and mechanisms of origin of taxa. On the other hand, when taxa are abundantly represented and widely spread amongst biota, fossil remains tend to be abundant and readily excavated thus providing many details that are not commonly available to evolutionists. Such is the case of early vertebrates and the wealth of fossils from relatively well resolved stratigraphic records allows the detailing of the transition from the lobe-finned fish (*Sarcopterygii*) to the earliest tetrapods of the amphibian type. Besides some fossil groups (*Osteolepiformes*), the Sarcopterygii include the extant lungfishes (*Dipnoi*) and the coelacanth. As opposed to the other bony fish, which have fins supported by bony rays, the Sarcopterygii only have a ray-finned caudal fin whereas their paired fins are fleshy and supported by several large axial bones homologous to the vertebrate limb bones (fibula, tibia, and femur). The fibula is attached to a large number of bony branches that support the rim of the fin.

The femur of Osteolepiformes, like that of modern Sarcopterygii, articulated with the pelvic girdle, as is the case in tetrapod vertebrates. Hence we observe here, a structure that differs markedly from the equivalent structure of ray-finned fishes and shows conspicuous homologies with the limbs of vertebrates. This anatomical structure, intermediate between fishes and four-limbed vertebrates, is strongly suggestive of a trend. If so, we should be able to observe other features that place the Osteolepiformes in an intermediate evolutionary position between bony fishes and tetrapods, thus documenting a relatively gradual change from a biological form to another. Such features are indeed available and are as follows:

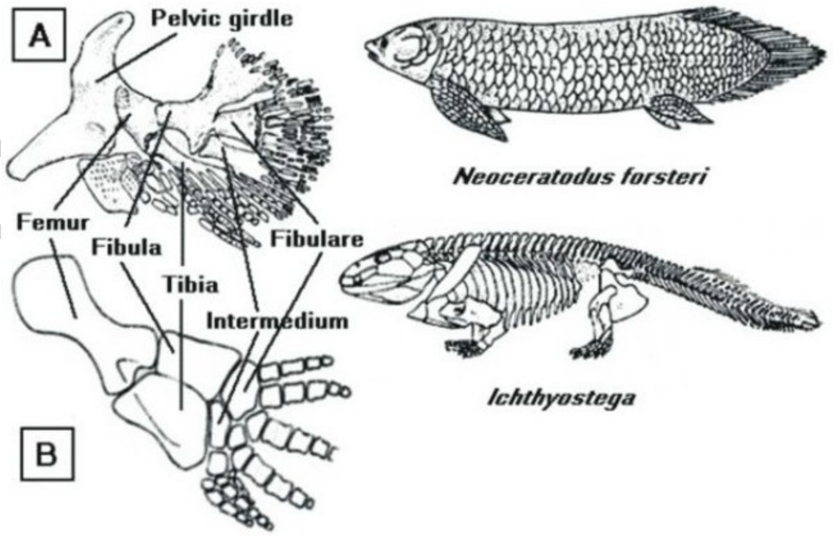

Figure 1. From fish to amphibian: some osteological features illustrating the evolution of the forelimbs of tetrapoda (B) from the fins of lungfishes (A)

- A notochord running trough a canal below the brain cavity.
- A hyomandibular bone, a gill-bearing arch forming a brace between the ear (otic) region of the skull and the jaw.

- Dermal bones not only surrounding the brain case but also in the region of the nostrils (nares) and the snout.
- The bones of jaw and maxilla bearing teeth.
- Labyrinthine infoldings of the teeth surface.
- External nares connected to internal ones (choanae).
- The presence of lungs, which are also found in modern Sarcopterygii.

All these features in slightly modified form, but nevertheless plainly homologous, are also found in the earliest definite amphibian fossils from the late Devonian: the ichthyostegids. Perhaps the most striking feature concerns the limbs of the fossil labyrinthodonts *Ichthyostega* and *Acanthostega*, which show fusion of the fin bony branches into seven and eight digits, respectively. This indicates that the ancestral tetrapod condition was not pentadactyl (five fingers) and that this condition was probably still in a variable evolutionary stage.

This is not the only major transition that can be documented by the fossil record. Equally crucial transitions have been demonstrated from amphibians to amniotic vertebrates (reptiles, birds, and mammals), from dinosaurs to birds and from early amniotes to mammals. Within the mammals, perhaps the best documented path is that of the horse evolution (see "Diversity of form, function, and adaptation in animals," EOLSS on-line, 2002).

-
-
-

Bibliography

Auderisk, T.; Auderisk, G. 1996. *Life on Earth.* Upper Saddle River, N.J., Prentice Hall. 654 pp. [A basic biology textbook with concept maps.]

Baltimore, D. 2001. Our Genome Unveiled. *Nature*, No. 409, pp. 814–16. [Overview of the human genome report.]

Black, J. G. 1999. *Microbiology: Principles and Explorations.* 4th edn. Upper Saddle River, New Jersey, Prentice Hall. 786 pp. [A well presented microbiology textbook dealing with bacteria, viruses, and health.]

Bork, P.; Copley, R. 2001. Filling the gaps. *Nature*, No. 409, pp. 818–20. [Draft sequence overview from the human genome report.]

Brock, T. D.; Madigan, M. T.; Martinko, J. M.; Parker, J, 1994. *Biology of Microorganisms.* USA, Prentice Hall. 909 pp. [A wide scope microbiology textbook also including microbial ecology and microbial systematics.]

Futuyma, D. J. 1998. *Evolutionary Biology*. 3rd edn. Sunderland, Mass., Sinauer. 763 pp. [A very informative and exhaustive account of evolution and biological forms.]

Goldsmith, T. H.; Zimmerman, W. F. 2001. *Biology, Evolution and Human Nature.* New York, Wiley. 370 pp. [A unique textbook discussing the evolution of the brain and human behaviour.]

Jeffreys, M. J. 1997. *Biodiversity and Conservation.* London and New York, Routledge. 208 pp. [A rarely encountered synthesis of biodiversity as a tool for conservation.]

Margulis, L.; Schwartz, K. 1998. *Five Kingdoms: An Illustrated Guide to the Ohyla of Life on Earth.* 3rd edn. New York, W. H. Freeman. 520 pp. [A classic systematics book reinterpreted according to modern taxonomic thinking by the proposer of the endosymbiosis theory.]

Minelli, A. 1993. *Biological Systematics: The State of the Art.* No. 16. London, Chapman and Hall. 387 pp. [An overview of concepts, tools, and current awareness in different sub-disciplines within biological systematics.]

Monod, J. 1970. *Chance and Necessity.* London, Collins/Fount. 187 pp. [A phylosophical essay on life and evolution.]

Ridley, M. 1993. *Evolution.* Boston, Mass., Blackwell Scientific. 670 pp. [Popular textbook of evolutionary biology.]

Sagan, C. 1978. *The Dragons of Eden: Speculations on the Evolution of the Human Intelligence.* Sevenoaks, UK, Hodder and Stoughton. 263 pp. [An informative essay on evolution eminently readable by the non-biologist.]

Biographical Sketches

Giancarlo Contrafatto, born 1948, is a graduate in Biological Sciences from the University of Turin (Italy) and obtained his Ph.D. from the University of Natal Durban (South Africa). His research interests are isolation mechanisms related to speciation of small mammals. Recipient of the 1976 British Association Medal from the South African Association for the Advancement of Science. G. Contrafatto has been on the staff of the University of Natal since 1983, and is responsible for the courses of Microbiology, Immunology, Comparative Immunology, Systematics and Evolution.

Alessandro Minelli, born 1948, is full professor of zoology at the University of Padova (Italy). President (1995–2001) of the International Commission on Zoological Nomenclature. His major research interests are the evolution of arthropods and the evolutionary developmental biology of segmentation, together with theoretical and historical aspects of systematic biology.