Biodiversity

Christian Lévêque
Centre National de la Recherche Scientifique, France

Jean-Claude Mounolou
Université d'Orsay, France

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Centre National de la Recherche Scientifique, France

Jean-Claude Mounolou
Université d'Orsay, France

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Introduction

In less than a century, our perception of nature and the living world has changed profoundly. Ample evidence of this shift is found in social behaviour and in schoolbooks.

In the early 20th century, the world population was primarily rural, and survival was its top priority. Predators and crop pests abounded, and harvests were uncertain. In Europe and the tropics (this was still the colonial era), humans were seriously threatened by diseases. The natural and animal worlds were often perceived as hostile. Thus, up until the mid-20th century, schoolbooks classified animals as 'harmful' or 'useful.' There was a national economic stake in destroying 'harmful' species in order to foster agricultural development. As one French schoolbook taught children, in preparation for adult life: 'Almost all insects are harmful and must be fiercely combated.'

This attitude was entirely legitimate at the time. In daily life, humankind suffered unbearable attacks, especially in the agricultural domain (crop pests) and to health (malaria, for example). Given this psychological context, it is not surprising that people sometimes went too far. Attitudes towards birds of prey, for example, manifest an ignorance of nature and how it operates, a psychotic relationship to wild species, and an exaltation of human supremacy over nature. 'Birds of prey, bandits! All such birds are bandits worse than bandits. If they are only the slightest bit harmful, that is reason enough for me to eradicate them' (extract from *The French Hunter*, 1924).

What were scientists doing during this time? They were collecting, inventorying, and drawing up lists of animal and plant species in different regions, in the tradition of natural history cabinets. They were also actively involved in the national battle against crop pests.

After the Second World War, behavioural patterns slowly began to change: urbanization and industrialization progressed. Many citizens became distanced from the rural world. The development of insecticides

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encouraged people to believe that sooner or later it would be possible to control harmful insects such as the Colorado beetle, the locust, the cockchafer, as well as mosquitoes. DDT, later decried for causing ecological damage, was initially hailed as a miracle product that would finally liberate humans from certain natural constraints and give them better control over agricultural production. This was also the time of the 'Green Revolution', of intensive farming based on high-yield crops, but at the same time requiring intensive use of fertilizers and insecticides.

In the early 1970s, the epithets 'harmful' and 'useful', as applied to animals, disappeared from schoolbooks. The whole idea behind such classifications was called into question. The 1960s also saw the beginnings of the science of ecology. Henceforth, knowledge was no longer structured around species, but rather based upon the functioning of natural systems and the relationships between different animal and plant species that constitute 'ecosystems'.

By the 1980s, the human populations of the western hemisphere had come to dominate most of their predators (or so-called predators . . .) and had acquired technologies for controlled and intensive farming. They had finally achieved their ends, as defined by the prevailing mentality at the beginning of the century; i.e. they were well on the way to overcoming natural constraints. And yet the situation today is far from idyllic, and a new perception of nature has taken shape in Western society. Under the pressure of conservation movements (who represent conservationism, not ecological science), there is a growing sense of guilt over the destruction of species that was encouraged in preceding decades. The large NGOs for nature conservation have played an important role in sharpening public awareness for the disappearance of charismatic species, especially mammals and birds. On the other hand, citizens see nature as a place of repose, of recreation and resources. They want 'nature' to be attractive (beautiful landscapes), welcoming (not too many mosquitoes) and full of life (animals and plants to look at). Intensive farming, with its immoderate use of pesticides and fertilisers and destruction of hedges and trees, has been increasingly called into question for its ecological consequences.

People began to talk about the environment in the 1970s. The farmer, once considered the mainstay of the national economy and gardener of 'natural' spaces, was marginalized and accused, sometimes rightly, of destroying landscapes, fauna and flora. At the same time, in the tropical world, scientists and conservationists are concerned by the large-scale destruction of forests regarded as hotspots of living nature. Humans stand accused: they are held accountable for the erosion of biological

diversity on the face of the Earth as a result of their uncontrolled activities. The term 'biodiversity' was invented to qualify this impact of human activities upon natural environments and the species that inhabit them. Biodiversity became a global concern, culminating in the Rio Conference on Sustainable Development in 1992. In the process, the debate shifted from the scientific to the political arena.

One thing leads to another; it is urgently necessary to take action to preserve biological diversity, if we do not want to be the agents and witnesses of new mass extinctions. Planning and realizing the appropriate measures requires both scientific knowledge and political will. Conventions are being signed, reserves created, and efforts are underway to implement a somewhat simplistic application of the principle of sustainable development. Some people are driven by ethical considerations: we must preserve the world as we inherited it for the benefit of our children. Others need to be convinced by more pragmatic reasoning; biological diversity is presented as an economic resource of the first order – as a reservoir of genes and molecules useful to agriculture, pharmaceutics and industry. The commercialization of the living world creates new economic prospects with biotechnology and patents on living things. Given the stakes, it is logical to take measures to conserve a source of wealth that has so far been only partially turned to profit.

Within the scientific community, research directions and foci of interest are diversifying. Genetic sequencing and molecular biology are affording ever deeper insight into the living world. The old question of the origin of life has resurfaced, but accompanied this time by knowledge and tools that may deliver concrete answers. Biotechnology offers new prospects for using the living world through genetic engineering of organisms. The economic stakes are huge, but new ethical and scientific questions arise as to the limits of genetically modified organisms (GMO) and the conditions for their use.

Thanks to advances in genetics and new knowledge derived from palaeontology, the great adventure of evolution has once again captured the public interest. At the same time, the inventory of species is continuing with new methods and tools (ecology, physiology, molecular biology, databases, etc.). For a long time, life was considered to be constrained by its physical and chemical environment; however, recent studies in ecology and palaeontology have shown that life actually contributes extensively towards modifying and shaping its environment. The living world plays an active role in the dynamics of the major biogeochemical cycles that are partly responsible for climate states and changes.

In practical terms, the conservation of biological diversity raises both technical and social questions. To implement the principles of sustainable development, the central concern of all conservation policy, it is necessary to find compromises between species protection and development.

In less than a century, the behaviour of western societies towards nature has changed profoundly. They have gradually moved away from their initial impulse to control a hostile natural world towards a more respectful approach to life, seeking a balance that meets the demands of humanity without destroying the diversity of the living world. Nature is still seen as useful, but there is now also concern for protecting nature so as to improve future prospects of exploiting resources yet to be discovered. This change in attitude springs from motivations that are both ethical, aesthetic, commercial and ecological. All these aspects work together, such that it is difficult to evaluate their respective import.

At the same time, we are experiencing an exhilarating period in science. Never before has our knowledge about the living world advanced at such a pace. On the one hand, we are extending the frontiers for the infinitesimally small; on the other, we are developing tools for exploring our planet in its entirety and searching for traces of life in the Universe. Seen through the prism of biological diversity, the debate over humans versus nature and the origins of humanity acquires a new dimension. In the search for solutions to the future of biological diversity, of which humans are a component, it is important to transcend the barriers of academic disciplines and relate the social with the natural sciences. The future of biodiversity cannot be reduced to a technical problem; it depends upon the economic and social choices facing societies in coming decades. In some sense, it depends upon the attitude of each and every citizen.

The aim of this book is to illuminate some perspectives of this issue by giving the reader an overview of current knowledge about the diversity of the living world and the various problems entailed in its conservation and sustainable use.

1 Brief History of a Concept: Why be Concerned by Biological Diversity?

The term 'biodiversity' is perceived differently, depending upon the sociological group involved. Taxonomists, economists, agronomists and sociologists each have their own partial view of the concept. Biologists tend to define biodiversity as the diversity of all living beings. Farmers are interested in exploiting the manifold potential deriving from variations over soils, territories and regions. Industry sees a reservoir of genes useful in biotechnology or a set of exploitable biological resources (timber, fish, etc.). As for the general public: its main concern is with landscapes and charismatic species threatened by extinction. All these points of view are admissible, since the concept of biodiversity effectively refers to a variety of different concerns. Moreover, these different approaches are not independent of one another; they implicitly pursue the same objective, namely the conservation of natural environments and the species which they harbour.

Biodiversity emerged as an environmental issue in the early 1980s, culminating in the Conference on Sustainable Development held in Rio in 1992. Towards the end of the 20th century, humankind grew conscious of its unprecedented impact upon natural environments and the danger of exhausting biological resources. At the same time, biological diversity was recognised as an essential parameter, in particular for the agro-alimentary and pharmaceutical industries. This raised ethical questions about the conservation of biological diversity and patenting of living beings.

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Thus, biodiversity became a framework for considering and discussing the whole range of questions raised by human relationships with other species and natural environments – a kind of 'mediator', as it were, between ecological systems and social systems. Independently of this new role, biodiversity remains one of the major concerns relative to global environment.

1.1 What does 'Biodiversity' Refer to?

The term 'biodiversity' – a contraction of biological diversity – was introduced in the mid-1980s by naturalists who were worried about the rapid destruction of natural environments such as tropical rainforests and demanded that society take measures to protect this heritage. The term was adopted by the political world and popularized by the media during the debates leading up to the ratification of the Convention on Biological Diversity.

The expression actually covers a number of essentially different approaches, orientated around four major issues.

- Due to technological progress and the need to occupy new spaces to meet the demands of a rapidly growing population, humankind is impacting natural environments and the diversity of living resources to an unprecedented degree. The questions raised by this tendency vary considerably, as do the possible responses, depending upon the behaviour and choices of particular societies in their approach to economic development. Ultimately, it is a matter of implementing strategies for conservation so as to preserve the natural patrimony as the heritage of future generations (Figure 1.1).

- To understand the causes and conditions that have led to the diversity of the living world as we know it today, we need a new perspective on evolutionary processes. What are the biological mechanisms that explain species diversity? What are the interactions between changes in the biophysical environment and in the phenomena of speciation? Our knowledge of such matters remains fragmentary. While it is still important to continue with the process of making an inventory of species that was initiated by Linnaeus in the 18th century, we must also exploit modern methodological advances to penetrate the world

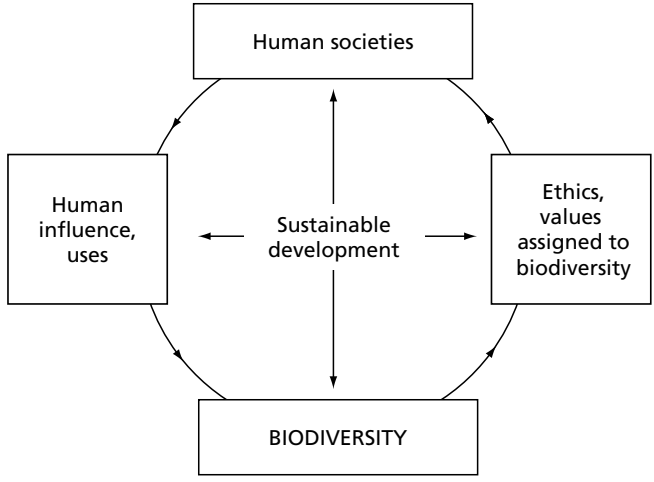

Figure 1.1 Interactions between human societies and biological diversity

of the infinitely minute and the molecular mechanisms involved in the diversification of life.

- Advances in ecology are also redefining our approach to biological diversity as the product of dynamic interactions among different levels of integration within the living world. We are now aware that the living world acts upon and modifies its physical/chemical environment. The functional processes of ecosystems, such as the flows of matter and energy, are subject to the twofold influence of both physical/chemical and biological dynamics. This realization constitutes a major paradigm shift, challenging the customary tendency to consider only the influence of the physical/chemical context upon the dynamics of the living world, to the exclusion of other interactions. This integrated approach leads to new concepts such as functional ecology and biocomplexity (see box).

- Finally, biodiversity is seen as 'useful' nature – the set of species and genes that humankind uses for its own profit, whether they are derived from natural surroundings or through domestication. In this context, biodiversity becomes a natural form of capital, subject to the regulatory forces of the market and a potential source of considerable profit to countries possessing genetic resources. The

economic valuation of biodiversity also provides powerful arguments for the cause of natural conservationists.

Biological diversity, biodiversity, biocomplexity

Indiscriminate usage of the word 'biodiversity' may generate indifference or even aversion to the term. We propose a more specific application that focuses on questions of interactions between humankind and nature. Traditionally, the term biodiversity has been used with regard to the depletion of the living world as a result of human activities, or activities undertaken for its protection and conservation – whether through creation of protected areas or by modifying human behaviour with respect to development (the concept of sustainable development).

Here, the term biodiversity will be used to refer to the whole range of activities traditionally connected with inventorying and studying living resources.

The term biological complexity, or biocomplexity, belongs to the new scientific vocabulary of biodiversity. Biocomplexity is the result of functional interactions between biological entities, at all levels of organization, and their biological, chemical, physical and social environments. It involves all types of organisms from microbes to humans, all kinds of environments from polar spheres to temperate forests to agricultural regions, and all human activities affecting these organisms and environments. Biocomplexity is characterized by non-linear, chaotic dynamics and interactions on different spatiotemporal scales. Integrating social and economic factors, it deepens our understanding of the living system in its entirety, rather than in bits and pieces.

1.2 The Origins of the Convention on Biological Diversity and What is at Stake

The ratification of the Convention on Biological Diversity by a majority of nations marks a new chapter in our consciousness of the risks pertaining to the erosion of biological diversity. Today, the issue is seen as an environmental concern of global dimensions demanding urgent solutions. To a certain extent, the approach to this question resembles that to climate change. Both discussions converge upon a similar statement –

humankind is exerting a collective impact of unprecedented magnitude upon the Earth as a whole. Nothing will remain exempt from its effect!

The Preamble to the Convention addresses the role of biological diversity in the biosphere, humankind's responsibility for the depletion of biological diversity, the lack of knowledge needed to undertake appropriate measures for its conservation, the preference for preserving ecosystems and natural habitats rather than resorting to *ex situ* measures. At the same time, the Preamble also acknowledges that economic and social development are priorities for the developing countries and that nations have sovereign rights over the exploitation and conservation of their biological resources. Altogether, the Convention represents a political compromise among diverse concerns and communities of interest.

1.2.1 The 'conservationists'

People have long been concerned by the extinction or near-disappearance of species such as the aurochs and bison in Europe, the dodo on the island of Mauritius, the emperor penguin of Antarctica and the American migrant pigeon. The depletion of these emblematic species is largely the result of intensive hunting by humans.

In recent decades, the magnitude of human impact upon natural environments has attained unprecedented dimensions. Significant population growth, utilization of previously untouched territories and increasing efficiency of technological means of exploitation are given as the major causes. Biodiversity loss no longer means only the extinction of isolated species but rather the modification of entire ecosystems, with all their floristic and faunistic components. Towards the end of the 1970s, naturalists drew attention to the rapid destruction of certain environments such as tropical rainforests. The American zoologist E.O. Wilson declared that humankind was the cause for species extinctions on a par with the mass extinctions of the past. Others have gone so far as to prophesy the end of life on Earth, with humankind disappearing along with the rest, if nothing is done to reverse the process.

Since the 1970s, scientific discourse has been considerably amplified and effectively propagated by the non-governmental organizations (NGO) for natural protection (IUCN, WWF, WRI, etc.), which rallied public opinion around endangered charismatic animals (elephants, whales, pandas, etc.). In the beginning, NGO gave priority to species conservation. Since 1989, they have been collaborating with UNEP

(United Nations Environmental Programme) to develop a global biodiversity strategy based upon the premise that Nature has an intrinsic right to existence and must be protected from human actions.

1.2.2 'Useful' nature

Ethical and emotional considerations have proven inadequate to rally countries to the cause of biodiversity conservation. Other arguments have been more effective in motivating politicians and policy makers to enact changes. One such approach seeks to demonstrate the utility of biological diversity for the well-being of humankind by citing, for example, the range of cultivatable plants or the therapeutic substances derived from biological diversity. In this context, the term used is 'useful nature', denoting a genetic library that must be preserved to enable the improvement of domestic species.

The Food and Agriculture Organization (FAO) has contributed to this debate with its efforts to promote 'farmers' rights' and recognition of their work in domesticating and improving local varieties of plants and animals. In the fight against famine in the world, the FAO would like to see biodiversity treated as the common heritage of all humankind with free access to resources. But in practice, such initiatives have had little effect. They have been overtaken by the development of biotechnologies and the powerful new roles of industry and national groups, who have their sights on different goals.

1.2.3 Nature has its price

Another consideration, akin to the notion of 'useful nature', is acquiring major significance: the economic interest in biological diversity. On the one hand, naturalists and NGO are enlisting the help of economists to formulate convincing arguments based on the goods and services rendered by biodiversity. On the other hand, the countries involved are beginning to see that industrial interest in biodiversity constitutes a potential source of revenue for patents on forms of life. At the time of the conference in Rio in 1992, the debate polarized around the economic stakes involved in exploiting the value of nature. The first Article of the Convention emphasizes the 'fair and equitable sharing of the benefits arising out of the utilization of genetic resources, including by

appropriate access to genetic resources and by appropriate transfer of relevant technologies, taking into account all rights over those resources and to technologies, and by appropriate funding'. Thus, biological diversity is considered as a primary resource for many different kinds of production processes (pharmaceuticals, cosmetics, agricultural foods, etc.). This resource is natural capital that can be exploited and turned to profit.

It will not be long before nations collide over this domain. Most of the resources are in southern hemisphere countries, while the main users, the biotechnology industries, are mostly multinational enterprises of the northern hemisphere. The countries of the southern hemisphere are against the appropriation of their resources without financial compensation and condemn the practice of 'biopiracy'.

1.3 What is Changing?

Since 1993, application of the ratified provisions has altered the situation. By reaffirming the sovereignty of nations over their biological diversity, the Convention confirmed the right of ownership of living things, paving the way for patents and exploitation licenses to be filed, issued and recognised. One might say that at Rio, patent rights emerged victorious over the rights of the environment. This radically transformed the altruistic attitude that had prevailed since the beginning of the 20th century. Biodiversity used to be considered the common heritage of humanity. People were at liberty to exploit the living world and appropriate its derivative forms – the processes and products of its transformation, in accordance with their social position or economic power.

At the same time, there is a heightened awareness that urgent measures must be taken to preserve biological diversity. This is apparent from the number of internet sites and journals addressing the issue, including major scientific publications like *Nature* and *Science*. But at the moment, there is no technical solution to the problem of conservation that meets the needs and is acceptable to society at large. The use and conservation of biological diversity generate fundamental conflicts of interest. Their resolution is contingent upon the choices made by society concerning economic progress and the exploitation of biological resources. For some, priorities may be ethically founded and/or inspired by religious beliefs: we must not destroy that which nature has created over eons of time. For others, the present or potential economic value of biological

diversity is sufficient justification to project and implement investments in conservation.

The debate over biodiversity has also given rise to two notions that have grown increasingly popular in recent years: risk and the principle of precaution. We have been confronted with risk in connection with genetically modified organisms (GMO) and the emergence or reappearance of certain diseases which have rekindled old fears: could technological innovations, particularly those involving the manipulation of living organisms, result in a threat to life itself? Some of the objections against the manipulation (and commercialization) of living organisms are voiced in the name of the precautionary principle. The Biosecurity Protocol, signed in January, 2000 in Montreal and ratified in May of the same year in Nairobi, acknowledges the risk that GMO might enter the environment and modify the natural ecological equilibrium. Its goal is to contain risks, even where this is not backed by scientific studies.

The biologists who first raised the issue of biodiversity are no longer the only protagonists of the debate. They are being confronted with a new situation – earlier experienced by atomic physicists in their field – involving continuous, intensive interaction between the progress of scientific knowledge on the one hand and the response of society to emerging perspectives and uncertainties on the other. The question of biodiversity should not remain the domain of one interest group or another; it should rather be regarded as a major problem for society as a whole. There can be no resolution unless all the different protagonists participate. Scientists and socioeconomists must join forces to help clarify the issues.

2 Biological Diversity: What do we Know?

Despite the attention given to biological diversity over the last ten years by both scientists and the media, we are still in no position to draw up an exhaustive inventory – especially as it is not distributed uniformly over the planet. Nevertheless, we do have a sufficiently broad global perception to be able to lay down the foundations for a conservation policy that meets the objectives of the Convention on Biological Diversity.

2.1 The Classification of Living Organisms – Underlying Principles

Classification is a way of organising information by grouping similar taxa. For centuries, we have been trying to describe, name, classify and count species. There are different ways of going about this. Aristotle, in his time, grouped human beings and birds together, because they walked on two legs. Today, classifications are based upon the degree of genetic similarity between individuals, and organisms are grouped according to their phylogenetic relationships.

2.1.1 Levels of organization in the living world

One of the characteristics of the living world is its complex structure and hierarchy: atoms organise themselves into crystals (inanimate world) or molecules, and these molecules, in turn, organise themselves into cells capable of reproduction (living world). Cells can aggregate and co-operate to form multicellular organisms. Individuals – whether single-cell or

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Classification

The scientific discipline devoted to naming, describing and classifying living beings is called *taxonomy*. This science is highly formalized and follows the rules of the international codes of nomenclature. *Systematics*, on the other hand, studies the diversity of organisms and strives to understand the relationships between living organisms and fossils, i.e. the degree to which they share a common heritage. What is now called *biosystematics* is a modern approach to systematics that draws upon information from different sources: morphology, genetics, biology, behaviour, ecology, etc.

multicellular – organize themselves into multispecific communities. Taking into account the environment in which organisms live, increasingly complex entities emerge: ecosystems, landscapes and biosphere. On this hierarchic scale, the elements of one level of organization constitute the basic units for the composition of the next, higher level of organization. At each stage, new structures and properties emerge as a result of interactions among the elements of the level below.

- The basic unit of the living world is the *individual*, each bearing its own genetic heritage. The pool of all genes belonging to one individual constitutes its *genotype*. A bacterium contains about 1000 genes; some fungi have around 10 000. Humans have slightly over 30 000.

- A *species* is the group of individuals prone to fertile and fecund genetic exchanges (cf. section 2.1.3)

- A *population* corresponds to a group of individuals of the same biological species inhabiting the same surroundings. It is at this level of organization that natural selection occurs. A species is often distributed over separate populations. Its existence and dynamics are functions of exchanges and replacements among these fragmented, interactive populations, which are called metapopulations.

- Multispecific assemblages that are restricted, usually on a taxonomic basis, constitute settlements or communities. A *biocenosis* is a group of animal and plant populations living in a given place.

- The term *ecosystem* was first introduced by Tansley in 1935 to designate an ecological system combining living organisms with their physical and chemical environment. The Convention on Biological Diversity defines ecosystem as 'a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit'. This legalistic definition is fundamentally similar to that found in ecological textbooks.

- The biosphere (*sensu stricto*) refers to all living organisms that inhabit the Earth's surface. However, biosphere (*sensu lato*) may also be defined as the superficial layer of the planet that contains living organisms and in which enduring life is possible. This space also comprehends the lithosphere (terrestrial crust), hydrosphere (including oceans and inland waters) and the atmosphere (the gaseous sheath enveloping the Earth).

2.1.2 Taxonomic hierarchies: the search for an evolutionary and functional order in the diversity of species

Classification is concerned with identifying and defining groups or taxa – sets of organisms possessing at least one characteristic in common – and giving them names. A classification of the living world must be hierarchical, because the smaller groups are completely included in larger groups that do not overlap. Initially, in the Renaissance, taxonomy was based on the notion of a descending classification system (the division of large classes into subclasses, as in the classification of inanimate objects). Later, taxonomy shifted to an ascending classification system whereby related taxa are grouped into taxa of a higher order.

> Classification of the living world is important for understanding of ecosystems and of biodiversity in general. Postulating that species belonging to the same taxon share a certain number of common biological and ecological characteristics that may differ in those of other taxa, it enables comparisons among species or among taxa of a higher order. Moreover, given that biodiversity is a structural component of the ecosystem, it may sometimes be possible to explain certain ecological functions on the basis of the phyla represented.

In the classification system proposed by Linnaeus, each level of the hierarchy corresponds to the name of a taxon. Naturalists around the world use the same system of general nomenclature – the binominal system – to designate and identify the species. This system consists of a genus name followed by a species name. The superior categories (genus, family, order, division, class, phylum, etc.) indicate the degrees of relationship between taxa (Table 2.1).

The *phenetic hierarchy* is based on the similarity of forms or characteristics among species. According to the premises of *numeric taxonomy*, organisms sharing common characteristics (homologous traits) have similar developmental histories; however, this is not conclusively indicative of their genealogy. Morphological convergences in the course of evolution may have led to possible regroupings. Thus, the Dipneusts (fish with functional lungs, such as *Protoperus*) are morphologically closer to salmon than to cows, but they have a more recent ancestral relationship with cows than with salmon. So how should Dipneusts be classified?

> Among today's vertebrates, the group of 'fish' represents a composite class. For example, Actinopterygians (such as trout) are closer to Tetrapods than to Chondrichthians (skates, sharks). As for the coelacanth, this sole known survivor of the group of Crossopterygians is much closer to tetrapods than to other groups of fish, with the exception of Dipneusts, another very ancient group currently represented by several species, such as for example, the African *Protopterus*.

The *phylogenetic hierarchy* is based on the evolutionary relationships of groups descending from common ancestors. The cladistic classification

Table 2.1 Hierarchic biological classification of three animal species

Level	Species 1	Species 2	Species 3
Domain	Eukaryotes	Eukaryotes	Eukaryotes
Kingdom	Animal	Animal	Animal
Phylum	Arthropods	Arthropods	Chordates
Class	Insects	Crustaceans	Mammals
Order	Diptera	Decapods	Primates
Family	Nematocera	Caridae	Hominidae
Genus	*Aedes*	*Homarus*	*Homo*
Species	*aegypti*	*americanus*	*sapiens*