Classification

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Abstract: A biological classification is a hierarchical arrangement of species, subspecific units and higher taxa, with the corresponding scientific nomenclature; classification is also the part of systematic biology concerned with generating such an arrangement. Scientific classifications have ancient roots in folk taxonomies. Between the classical Antiquity and the Renaissance, major conceptual advancement were due to Aristotle and Cesalpino, but modern classifications owe mainly to John Ray and eventually to Linnaeus, who introduced binominal nomenclature. Modern classifications are increasingly aiming to mirror phylogenetic relationships, an effort that may eventually require abandoning the traditional Linnaean ranks such as the genus, the family, the order and the class. Nomenclature is disciplined by international codes – these provide rules for introducing new names and for selecting the names to be used in the case of conflict between synonymous or homonymous names.

Key Concepts:

Main steps on the way from naif folk taxonomies to modern scientific classifications initiated by Linnaeus were provided by Aristotle, Andrea Cesalpino and John Ray.

Linnaeus introduced the binomial nomenclature still in use in zoology and botany for the scientific names of species.

Georges-Louis Buffon defined the species as a reproductive community, members of which can freely interbreed, thus generating fertile offspring, whereas members of different species, even if similar, cannot breed with them.

For a classification, the equation natural=evolution-based was clearly reinforced by Charles Darwin's (1809–1882) work, especially by his *On the Origin of Species* (1859). However, Darwin also introduced into biological systematics a potentially disruptive thought: that the species, the hitherto undisputed units of biological classifications, are subject to steady change. In Darwin's own words, species differ from varieties only by matter of degree.

With Charles Darwin, evolutionary biology provided the foundation for a natural classification mirroring phylogenetic relationships, a research programme actually launched by Willi Hennig one century later.

The last few decades of the twentieth century witnessed heated debates on the theoretical foundations and methodological aspects of biological systematics among the phenetic, cladistics and evolutionary schools.

The traditional Linnaean classification of living beings has the structure of a hierarchy, with a series of ranks or categories (species, genus, family, order, class, phylum and kingdom).

The Linnaean hierarchy has been criticised as its use takes for granted a branched topology and requires acknowledging absolute ranks, rather than simple relations of inclusive nesting.

Biological nomenclature is governed by international codes whose rules are intended to provide unique and universally accepted names for any recognised taxon (species, infraspecific entity or supraspecific group).

Conflicts between synonyms (different names for the same taxon) or homonyms (same name for different taxa) are basically resolved by application of a principle of priority.

Motivations and History

Humans attitude toward nature classification

The very act of classifying natural kinds is well rooted in the prescientific attitude of humans towards nature. Ethnolinguists have gathered detailed information about folk taxonomies, the classifications and nomenclatures developed by illiterate people about the plants and animals they daily come in contact, such as edible and poisonous plants and mushrooms, dangerous predators, poisonous snakes and animals valuable for food or fur. The Hanunoos of the Philippine Islands have different names for each of c. 1600 plant species. A New Guinea tribe, living in a forest area where Western ornithologists have identified 137 species of birds, have 136 names for these. Thus, the taxonomic skills of this indigenous people are similar to those of their scholarly colleagues. See also [[a0003093]] **History of Taxonomy**

Recognising and naming species, however, does not exhaust the performance of folk taxonomies. Explicitly or not, these also include an element of hierarchy. That is, the basic named units (let us say, the species) are grouped into more general kinds, for example, winged animals, scaly animals, etc., or legumes, lilies, etc. These 'genera' may be grouped, in turn, into still more general kinds, for example, land animals, aquatic animals, or herbs, trees, mushrooms. Up to five hierarchically nested ranks can be recognised in the most developed folk taxonomies.

From Antiquity to Middle Ages

More formal arrangements of plant and animal species have been developed by different civilisations, mostly in relation to agriculture or medicine. Five main kinds of animals (insects, scaly animals, shelly animals, animals with feathers, animals with fur) were recognised by the Chinese pharmacologist Li Che-Chen (1518–1593). Aristotle (384–322 BC) deserves mention here both as a philosopher and a naturalist. As a philosopher, he formally established the binary logic upon which the Italian botanist Andrea Cesalpino (1519–1603) developed, in his *De plantis* (1583), the first comprehensive distribution of known plants according to a cascade of binary (dichotomous) choices among alternative sets of characters (e.g. herbs versus trees). As a naturalist, Aristotle provided suggestions for a classification of c. 500 species of animals, his primary distinction being between the Enema (with blood: i.e. more or less, our vertebrates) and Anema (without blood). To modern eyes, this distinction looks more scientific than those in the best arrangement of plants provided later by Dioskorides (first century) who, in *De materia medica*, organised some 500 species according to their medicinal use. See also [[a0002348]] **Aristotle of Stagira**

The limited knowledge of organism affinities embodied in these old classifications is evident in the work of Albertus Magnus (1193–1280), arguably the most knowledgeable natural history author during Medieval times. In his *De animalibus*, whales were still classified with fishes and bats with birds.

From the Renaissance to Linnaeus

Among the zoological books produced in the Renaissance, a prominent place is occupied by the enormous encyclopedias of Konrad Gesner (1516–1565) and Ulisse Aldrovandi (1522–1605) (4500 and 7000 pages, respectively), but more valuable are some monographic works such as Pierre Belon's (1517–1564) book on the natural history of birds, and the books on fishes and other aquatic animals written by Guillaume Rondelet (1507–1556) and Ippolito Salviani (1514–1572). Most remarkable in Belon's ornithological book, the drawings of a human and a bird skeleton are printed side-by-side, with the individual bones (e.g. humerus, femur, etc.) labelled with the same letters in both figures. This offered a first example of comparative anatomy, more than two centuries before the conventional beginning of this discipline. The species described in these works were often arranged alphabetically, or distributed according to tenuous and often inconsistently applied classificatory criteria, such as broad similarity, or practical use. See also [[a0002347]] **Aldrovandi, Ulisse**

Efforts to describe plants resulted in a tremendous increase in the number of known plant species: from the 500 species illustrated by Leonhart Fuchs (1501–1556) in De *historia stirpium* (1542) to the more than 6000 described by Gaspard Bauhin (1560–1624) in *Pinax theatri botanici* (1623) to the 18655 listed by John Ray (1627–1705) in *Methodus plantarum nova* (1682). See also [[a0002523]] **Fuchs, Leonhart**, and [[a0002462]] **Ray, John**

Ray, who worked extensively on both plants and animals, made a valuable contribution by noting that classificatory work should proceed upwards, rather than downwards, that is, the naturalist should begin by describing and diagnosing species, then grouping these into genera, and finally grouping genera into still more extensive groups. This is opposite to the downwards procedure exemplified by Cesalpino's use of Aristotelian logic in dividing the whole of plants first into two major mutually exclusive groups (herbs and trees) and then progressively subdividing each of these groups into smaller and smaller units, down to the species level. This downward process has affinities with a modern procedure of identification of a specimen (the assessment of its belonging to a given species) rather than to the way a classification is built

The first half of the eighteenth century was dominated by the classification of plants offered in his *Institutiones rei herbariae* (1700) by Joseph Pitton de Tournefort (1656–1708), who arranged 698 genera in 122 sections in 22 classes. This classification was later overturned by Carolus Linnaeus (1707–1778), whose major treatises were *Species plantarum* and *Systema naturae*. Both works went through many editions, but the first edition of *Species plantarum* (1753) and the 10th edition of *Systema naturae* (1758) were eventually adopted in the nineteenth century as the starting points of modern botanical and zoological nomenclature, respectively. The success of Linnaeus did not simply derive from the sheer number of species he dealt with, but primarily from his straightforward use of a clear and uniform hierarchical arrangement of species and groups (Fig. 1) and his systematic adoption of binomial nomenclature. The latter was a simple and compact way of naming plants intended to replace the unmanageable sentence-long Latin names of plants then in use For example, in this work Linnaeus renamed *Laurus camphora* the camphor tree (known today as *Cinnamomum camphora*), a plant species he had himself called *Laurus foliis ovatis utrinque acuminatis trinerviis nitidis,* *petiolis laxis* in his 1737 work *Hortus Cliffortianus*.). Limited examples of binomial nomenclature are present in some prelinnean works by G. Bauhin and August Quirinus Bachmann (Rivinus) (1652–1725). However, Linnaeus was the first author to adopt binomial nomenclature systematically, especially for animals. See also [[a0002767]] **Tournefort, Joseph Pitton de**

Figure 1 [new figure]

Schematics of the Linnaean hierarchical system of classification. On the left are the main ranks of the system. As an example, the position of the wolf in the classification is traced down from the kingdom to the species.

Biological systematics after Linnaeus

As soon as theoretical thoughts began to accompany and eventually to guide taxonomic practice, systematists became aware that classifying animals or plants involves two different tasks: (1) grouping species or other taxonomic units according to criteria such as overall similarity or the shared presence of derived characters; and (2) ranking the resulting groups at conventional levels, such as the genus, the family and the class, or just recognising them as bigger and lesser branches of the tree-like system of living beings. The conceptual history of biological systematics is largely based on the evolving attitudes towards grouping and ranking.

Debate developed about the possibility of obtaining a natural, that is, nonarbitrary, system of living beings. This possibility gained support with the development of evolutionary thought, that resolved the otherwise mysterious 'affinities' between species by explaining them as the result of common descent. In due course, the reconstruction of phylogeny (the pattern of common ancestry) become the necessary background for any serious systematic endeavour.

A critical contribution towards the future developments of biological systematics was provided by Georges-Louis Leclercq, comte de Buffon (1707–1788), who defined the species as a reproductive community: members of this community can freely interbreed, thus generating fertile offspring, whereas members of different species, even if similar, cannot interbreed or, if they can, only generate sterile hybrids, such as mules and hinnies. See also [[a0002378]] **Buffon, Georges Louis**

Valuable developments were also provided by the French school of comparative anatomy, in particular by Georges Cuvier (1769–1832) and by Etienne Geoffroy Saint-Hilaire (1772–1844). In theyr works, we find the foundations of the modern concepts of homology and analogy, which were later defined in formal terms (1843) by Richard Owen (1804–1892). See also: Cuvier, Georges Le´opold Chre´tien Fre´de´ ric Dagobert Baron de; Owen, Richard

The evolutionary philosophy of Jean-Baptiste Monet de Lamarck (1744–1829) displayed in his *Histoire naturelle des animaux sans vertèbres* (1815–1822) reversed the traditional arrangement of zoological treatises (from 'higher' to 'lower' forms), beginning instead with the simplest invertebrates and progressively moving towards the most complex ones. From Lamarck's perspective, in nature there are no discrete groups of organisms, a view already defended by the French botanist Antoine-Laurent de Jussieu (1748–1836) in his important monograph *Genera Plantarum* (1789). As a consequence, all genera and higher taxonomic groups in a classification must be regarded as arbitrarily circumscribed. This is exactly the opposite to Cuvier's embranchments, which were introduced as major divisions fixed by nature, a view whose validity would soon be shaken by the development of evolutionary thought. It is important to note that if the circumscription of taxonomic groups is arbitrary, it will be just a matter of tradition, or practical advantage, to put hundreds of related species in one genus, or to divide that genus into a number of smaller genera, according to the opposite attitudes of practitioners known as 'lumpers' and 'splitters', respectively. See also [[a0002468]] **Jean-Baptiste Lamarck**

For a classification, the equation natural=evolution-based was strongly reinforced by Charles Darwin's (1809–1882) work, especially by his *On the Origin of Species* (1859). However, Darwin also introduced into biological systematics a potentially disruptive thought: that the species, the hitherto undisputed units of biological classifications, are subject to steady change. In Darwin's own words, species differ from varieties only by matter of degree. The new-born evolutionary biology thus provided the foundation for a natural classification of living beings, based on descent from a more or less distant common ancestor, but at the same time it shook the established faith in the solidity of the classification's units. See also [[a0002397]] **Darwin, Charles Robert**

In the 1930s, biological systematics had a primary role in the development of the 'evolutionary synthesis', as witnessed by *The New Systematics*, edited in 1940 by Julian Huxley (1887–1975). Prominent during this phase was the development of a populational, nontypological notion of species, mainly owing to Theodosius Dobzhansky (1900–1975) and Ernst Mayr (1904–2005). See also [[a0002473]] **Dobzhansky, Theodosius**

Late twentieth century debate

The last few decades of the twentieth century witnessed a burst of debates on the theoretical foundations and methodological aspects of biological systematics. Three main schools were initially recognised.

The phenetic school. It found its manifesto in *Principles of Numerical Taxonomy* (1963) by Robert R. Sokal (1926– 2012) and Peter H. A. Sneath (1923–2011). This school, putting aside as incorrigibly subjective all efforts to interpret similarities and differences among species in terms of descent, pleaded for an objective evaluation of phenotypic traits at face value and started developing numerical methods for obtaining tree-like representations of similarity (dendrograms) from matrices of descriptive data. The dendrograms are eventually segmented at arbitrarily chosen levels of overall phenotypic similarity, to obtain hierarchically ordered taxa at arbitrary ranks.

The phylogenetic (or cladistic) school. It originated with the publication of *Phylogenetic Systematics* (1966) of the German entomologist Willi Hennig (1913-1976). If the phenetic school completely neglected phylogeny, opposite is the approach to biological systematics developed by Hennig. Here, the reconstruction of phylogeny, expressed in tree representations called cladograms, becomes the primary goal of the systematic. For this purpose, only shared derivative traits (synapomorphies) are informative, while shared primitive traits (symplesiomorphies) are not. Synapomorphies identify natural groups (monophyletic taxa or clades), while symplesiomorphies identify "incomplete" groups (paraphyletic taxa), which must instead be rejected. Methods have been developed by Hennig and later authors to identify the polarity of the states of a character (primitive or plesiomorphic vs. derived or apomorphic state).. See also [[a0001522]] **Cladistics**

The evolutionary school. The impact of this phylogenetic approach on biological systematics was decisive, although at the beginning it was strongly opposed by representatives of the so-called evolutionary school, such as Ernst Mayr and the American paleontologist George Gaylord Simpson (1902-1984). These authors agreed on the principle that classification must be based on a reconstruction of evolutionary events; in their view, however, evolution was not to be understood only as phylogeny, but also as adaptive change. This is the reason why systematic evolutionists defended paraphyletic taxa. For example, birds are rooted phylogenetically within reptiles, but have evolved in an original way, with the development of their conspicuous apomorphies (wings, feathers, etc.); this should be sufficient to guarantee them class status independent of that of reptiles. According to phylogenetic systematics, instead, Reptiles should include Birds, this more inclusive clade being often called Sauropsids; Figure 2a–c); similarly, among the flowering plants, Dicotyledons should include Monocotyledons, thus virtually becoming the same as Angiosperms. See also [[a0001776]] **Homology in Character Evolution**, [[a0002482]] **Simpson, George Gaylord**, and [[a0003337]] **Systematics: Historical Overview**

In recent years, these school-to-school conflicts are fading away. Cladistics, in its multiple expressions, dominates the scene, but it has adopted to its purposes many numerical techniques originally developed in a context of phenetic systematics. At the same time, the defense of the paraphyletic groups decreases in strength, even if it is far from extinct.

Figure 2 **[fg001.eps]**

(a) A traditional classification of the Tetrapoda. The structure is hierarchical and formally acknowledges two ranks, the Superclass and the Class. (b) A phylogenetic tree of the Tetrapoda with names for each internal node (diamonds). The taxon Reptilia of the traditional classification has disappeared because it results paraphyletic, as it contains all the Sauropsida to the exclusion of Aves. (c) A phylogeny-based classification. Only monophyletic taxa are admitted, not all nodes needs to be represented, taxon ranking is still in use. (d) A rank-free phylogeny-based classification. Indentation represents clade nesting.

Linnaean Hierarchy and Categories

The traditional Linnaean classification of living beings has the structure of a hierarchy, with a series of ranks (categories) to which more or less extensive groups (taxa; singular, taxon) are allocated (Fig. 1). The number of ranks in the classification is not strictly prescribed. However, tradition has consolidated the use of a few main ranks - the species, the genus, the family, the order, the class, the phylum and the kingdom, listed here from the lowest to the highest.

Below the species level, tradition is not uniform. Botanists are generally more inclined than zoologists to recognise and name infraspecific entities. As for zoology, only one rank below the species is officially recognised (the subspecies); this rank is extensively used in some groups (e.g. mammals, birds, butterflies), but virtually ignored in others (e.g. most marine invertebrates). As for botany, multiple infraspecific categories are recognised, but lower-level units, for example, forms, are often named within a species that has not been articulated into higher-order species subunits such as subspecies. Peculiar categories such as the cultivar are extensively employed for the cultivated plants.

Two criticisms may be levelled with respect to the Linnaean hierarchy. The first criticism is that its use takes for granted a branched topology of relationships. This may be true for very large segments of the tree of life, but it is not universally true. First, the very origin of the eukaryotic cell, hence an event at the root of a disproportionately major branch of the phylogenetic tree, is currently explained as a symbiotic event, that is, as an event determined by a fusion among the oldest branches of the tree of life. Second, fusions of branches of the phylogenetic tree are produced by any successful event of hybridisation, which is possibly rare in animals but is certainly common in plants. In some cases, as in the sunflower genus *Helianthus*, the two small genomes associated with the chloroplast and the mitochondrion, respectively, may trace a history of recent hybridisation other than the one recorded in the nuclear genome. In all these instances, reducing the real topology of phylogeny to the conventional branched topology of the Linnaean hierarchycan hardly be considered ‘natural’.

Another criticism of the Linnaean hierarchy comes from cladistics. The problem is that a phylogenetic reconstruction may only allow for the identification of nesting relationships, but cannot offer any ground to the recognition of absolute ranks. For instance, the brown bear (*Ursus arctos*) will turn out to be a terminal twig of the bear family (Ursids), this being in turn a branch of the Carnivores, which are part of a larger branch Mammals, and so on. However, nothing justifies giving the same rank (say, order) to Carnivores and Rodents, or – outside Mammals – to Galliforms and Coleoptera.

Names for Taxa

For all taxonomic entities we recognise, as for all scientific concepts, we need an adequate nomenclature, that is, a system of universal and stable names. With the discovery of increasing numbers of previously unknown species and with progress in understanding their relationships, new names are continuously required both for species and higher taxa. To avoid confusion, the introduction and use of names must be clearly controlled.

The codes

No rule seemed to be necessary at the time of Bauhin, Ray or Linnaeus, but this soon changed after the proliferation of systematic works directly or indirectly inspired by Linnaeus. In zoology, early serious efforts towards a stabilisation and internationalisation of nomenclature were the so-called Strickland Code (1842) and the *Règles internationales de la nomenclature zoologique* issued in 1905; in botany, Alphonse de Candolle's (1806–1893) *Lois de la nomenclature botanique* (1867).

Today, biological nomenclature is governed by the following codes:

- International Code of Zoological Nomenclature, 4th edition, 1999 [ICZN]
- International Code of Nomenclature *for Algae, Fungi, and Plants (Shenzhen Code)* adopted by the Nineteenth International Botanical Congress, Shenzhen, China, July 2017 [ICBN]
- International Code of Nomenclature of Bacteria, 1992 [ICNB]

There are also an International Code of Nomenclature for Cultivated Plants (current edition, 2009) and an International Code of Virus Classification and Nomenclature (2002). See also [[a0000452]] **Codes of Nomenclature**, and [[a0000440]] **Viral Classification and Nomenclature**

Several times, beginning with the 1840s, there have been efforts towards devising a single code, which would rule the nomenclature of all living beings, but no fixed result has been achieved. The two major problems that such a universal BioCode should possibly solve are (1) cross-kingdom homonymies (names of animal genera identical to names of plant genera, for example, *Pieris*, both a butterfly and a plant of the heather family) and (2) the nomenclature of 'ambiregnal' organisms, that is, of such groups of unicellular eukaryots ('protists') that have been dealt with both as animals (protozoans) under the ICZN and as plants (algae) under the ICBN, thus giving rise to cumbersome problems of nomenclature (Greuter et al., 2011). One of the differences between the ICZN and the ICBN is that the goal of scientific botanical nomenclature is to have but a single name for any taxon with a particular circumscription, position and rank, whereas this principle of uniqueness is somewhat less strict in zoology. Within the ICZN, a specific epithet is retained if a species is moved from within a genus into another genus. For example, *Libellula puella*, Linnaeus' (1758) name for a little European damselfly, became *Agrion puella* and later *Coenagrion puella*, when the species was moved from the genus *Libellula* to *Agrion* to *Coenagrion*, prompting new combinations of its specific epithet *puella* with new genus names. Under the ICBN, however, the tomato was originally called *Solanum lycopersicum*, but the specific epithet '*lycopersicum'* was replaced by *esculentum* when the species was considered to belong to a genus other than *Solanum*, thus becoming *Lycopersicum esculentum*.

The current biological nomenclature deserves the name of Linnaean nomenclature, in that it derives the following basic features from the work of Linnaeus:

- Names are provided for hierarchically nested taxa. The classificatory hierarchy acknowledges a series of nested categorical ranks (see above).
- Names have a generally Latin form (although quite a number of 'barbaric' names have crept into the current classifications).
- Names of genera comprise one word only, the genus name. For example, *Homo, Canis, Rosa* and *Bacillus*.
- Names of species comprise two words, the first being the genus name and the second the specific epithet; this is in agreement with the already mentioned principle of binomial nomenclature. For example, *Homo sapiens*, *Canis lupus*, *Rosa rugosa*, *Bacillus subtilis*.
- Names of families are formed by adding a given termination (-idae for animals, -aceae for plants and bacteria) to the grammatical stem of one of the included genera (the type genus). For example: Hominidae, from *Homo*; Canidae, from *Canis*; Rosaceae, from *Rosa*; Bacillaceae, from *Bacillus*.

Available names

Leaving aside minor differences in terminology, all current codes recognise two main criteria to which names must satisfy. In ICZN wording, these criteria are availability and validity. The botanical equivalents for available and valid names are, respectively, validly published and correct names. The basic traditional foundation of availability is publication.

A new name is not available (or validly published) if only circulated in manuscript form, or only used to label a specimen in a museum. Several additional requirements are specified by the individual codes, in order to make a published name available. A general requirement, although with different qualifications in the different fields, concerns type specimens (see below). In this context it is worth remarking that, as a consequence of being ruled by the codes of nomenclature, taxonomic papers containing the description of new species and other classificatory acts are a kind of legal documents, to some extent independently from their significance as scientific works (Minelli, 2003).

Valid names: priority versus usage

Within the scope of each code, two available names may be in conflict, in terms of either homonymy or synonymy. There is homonymy between two identically spelled genus names, or between two species of the same genus to which the same specific epithet has been attributed. On the contrary, there is synonymy whenever two different names have been given to what is, either subjectively or objectively, the same genus or the same species. The basic requirements of biological nomenclature, uniqueness and universality of names, require a solution of these conflicts. To this aim, the basic principle acknowledged by systematists and embodied in the codes is the principle of priority. According to it, of the synonyms available for the same taxon the oldest is the valid name; of homonyms, the oldest, again, is the valid name of the corresponding taxon, whereas each of the younger ones must be replaced by a younger synonym, if available, otherwise by a new name. Sometimes, however, there are problems with an automatic application of this principle. These matters are solved by two specific organs: the *International Commission on Zoological Nomenclature* and the *International Congress of Botany*. For example, there are cases of well-known species, often with an extensive literature record outside taxonomy (e.g. species of agricultural or medical interest, or extensively reared in the laboratory, so called model organisms), of which an overlooked senior name is discovered. Reintroducing this name would easily destabilise nomenclature, owing to conceivable delays in accepting the change and the likely resistance to it. In such circumstances, strict priority clearly conflicts with established usage. In zoology, similar cases (as well as any other case where there may be reasons for suspending a provision of the code) are offered to public discussion through publication of a relevant application in the *Bulletin of Zoological Nomenclature* and subsequently submitted for a ruling to the International Commission on Zoological Nomenclature. In botany, corresponding matters are published in the journal *Taxon* and ruled by the International Congress of Botany.

Type specimens

Types are reference entities around which the concept of a taxon will be permanently evaluated. There are two kinds of types. Species and subspecies have material types (type specimens), whereas supraspecific taxa (genera and families) have subordinate taxa as types. That is, every genus has a type species, and every family has a type genus. Type specimens are thus, the permanent vouchers of the characters of a named species or infraspecific taxon.

In zoology and in botany, unique status is accorded to the holotype, officially defined in ICZN's glossary as 'a single specimen designated as the name-bearing type of a species or subspecies when established, or the single specimen on which such a taxon was based when no type was specified'. If no holotype was originally selected within the original type series comprising more than one specimen (syntypes), a lectotype may be subsequently selected from among the syntypes. If no holotype, lectotype or syntype is believed to exist, a neotype may be selected, the greatest care being thus required in selecting a specimen best suiting the original description. In principle at least, type specimens must be deposited in public collections.

Things are understandably different in bacteriology. Here, the type of a species or subspecies is, whenever possible, a designated strain made up of living cultures descended from a first strain designated as the nomenclatural type. In zoology and in botany, however, there is a strong resistance to dispensing with traditionally preserved types, as conventional museum specimens. This is the case of the spectacular Pink Land Iguana (*Conolophus marthae*, Figure 3) from the northern Isabela Island of the Galápagos, described by Gentile and Snell (2009), whose holotype was at the time a free-ranging adult male bearing a Passive Integrated Transponder (PIT) hypodermically inserted in one of the posterior legs. The choice of avoid sacrificing a specimen to obtain a conventional museum object as the new species' holotype immediately spurred controversy (e.g. Donegan, 2009; Dubois, 2009; Nemésio, 2009). Similarly, heated controversy (e.g., Amorim *et al*., 2016) followed the description of a showy South African bee fly (*Marleyimyia xylocopae*) on the basis of photographs only (Marshall and Evenhuis, 2015). See also [[a0021999]] **Philosophy of Biological Classification**

Figure 3 **[fgz002.eps]**

The pink terrestrial iguana of the Galápagos Islands *Conolophus marthae* was described in 2009 by selecting a living specimen as the species' holotype.

(Photo courtesy of Gabriele Gentile.)

The Current Debate

During the last decade, increasing dissatisfaction has been manifested with respect to the strict dependence of traditional nomenclature on the conventional taxonomic ranks, such as the genus or the family. Due to the arbitrary nature of these ranks, efforts have been produced at developing a rank-free system of nomenclature (Figure 2d). These efforts started towards the end of the last century and eventually produced a set of rules known as the PhyloCode (http://www.ohio.edu/phylocode/). The phylogenetic system of nomenclature ruled by the PhyloCode is independent of taxonomic ranks. Despite the fact that taxa are hierarchically related (e.g. primates as a part of mammals), taxonomic rank has no bearing on the spelling or application of taxon names. The differences between the phylogenetic and rank-based nomenclatural systems also entail a different way to determine cases of synonymy and homonymy. It is important to note, anyway, that it does not seem to be sensible to name all and any node in a phylogeny. In addition to the basic condition of being monophyletic (uniquely derived), a group should only be named if it is significant for a given context. In phylogenetic nomenclature, the application of names is not fixed based on types, because a specimen or a subordinate taxon is a type only for a taxon of specified rank, be it the species or other. In this nomenclature, targeted to name rankless units, the application of names is based instead on specifiers, as in the following example: Coniferae can be defined as the least inclusive clade containing *Pinus strobus*, *Cupressus sempervirens*, *Podocarpus macrophyllus*, *Taxus baccata* (Cantino *et al.* 2007). None of the four plant species mentioned here is in any sense a ‘typical’ conifer, but the four of them, in their mutual phylogenetic positions, contribute to specify the application of the name.

End Notes

Based in part on the previous version of this eLS article ‘Classification’ (2005) by Alessandro Minelli.

Glossary

Analogy = The similarity between characters or character states in two or more organisms with different organisation. A pre-Darwinian concept and term.

Apomorphy = Derived (advanced) state of a character with respect to the state in a reference ancestor.
Cladogram = In phylogenetic systematics (cladistics), a tree-like representation of a phylogenetic hypothesis based on shared apomorphies (synapomorphies) of the included taxa. The main kind of tree-like graphs currently in use in evolutionary biology is the cladogram, specifically intended to express topological relationships of descent.
Dendrogram = In phenetic systematics, a tree-like representation of shared similarities between taxonomic units.
Homology = The relationship between characters or character states deriving from the same feature in a common ancestor.
Homoplasy = The similarity between characters or character states in two or more organisms not deriving from the same feature in their most recent common ancestor.
Plesiomorphy = Original (primitive) state of a character with respect to the state in a reference ancestor.
Taxon (plural taxa) = A classificatory unit, for example, a species; otherwise a supraspecific entity such as a genus, a family, an order, a class and a phylum, or a subspecific entity such as a subspecies.

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