

## PHYLOGENY AND NOMENCLATURE

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## Linnaean nomenclature in the 21<sup>st</sup> Century: a report from a workshop on integrating traditional nomenclature and phylogenetic classification

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As a follow-up to the 2001 Smithsonian Botanical Symposium, in late June of 2002 a group of 15 taxonomists took part in a Workshop entitled “Linnaean Nomenclature in the 21<sup>st</sup> Century” at the Hunt Institute for Botanical Documentation in Pittsburgh to discuss integrating phylogenetic information into the current systems of naming plants, animals, and microorganisms. The Hunt Group included a diversity of taxonomists, including traditional and phylogenetic practitioners as well as authorities on the current codes and end-users of nomenclatural rules. The discussion ranged from identifying problems and possible solutions to devising strategies for implementing change. It was concluded that the central problems revolve around the concepts of (1) circumscribing taxa, (2) hierarchical ranking, and (3) the use of binomials. In a critical article-by-article examination of the current edition of the *International Code of Botanical Nomenclature* it was found that only 14 of the total 62 articles (plus appendices) are relevant to whether or not classification is phylogenetic. Furthermore, each of these potentially problematic articles is either amenable to conveying phylogenetic information or neutral to phylogenetic considerations. There is nothing in the current Linnaean nomenclature that prevents cladistic information from being incorporated into the naming procedure. We suggest that a major effort is needed to educate the botanical community as well as lay persons on the implications and use of these pertinent articles in phylogenetic nomenclature.

### BACKGROUND

The participants in the Workshop were brought together to consider how best to integrate the needs of phylogenetic classification given our current system of naming the world's biota. The Workshop was developed as a follow-up to the 2001 Smithsonian Botanical Symposium held in Washington, D.C., the results of which were published in *Taxon* [volume 51(1), 2002]. The Smithsonian symposium was attended by 190 scientists from numerous countries. At that meeting issues concerning the Linnaean naming system and the needs of an emerging phylogeny-based classification were discussed.

Participants in this follow-up Workshop at the Hunt Institute in Pittsburgh were selected on the basis of their response to a widely distributed announcement about the

planned workshop. In addition, several individuals were specifically invited because of the particular perspective they would bring to the discussion. It is recognized that the results of the workshop have predominantly American and botanical perspectives. Although the discussion centred on the *International Code of Botanical Nomenclature (ICBN)* (Greuter & al., 2000), many of the comments are also applicable to the Zoological and Bacteriological Codes as well. This report is offered for discussion and critique with the hope that it will be useful to the community of taxonomists and biologists at large in understanding and formulating a workable system of nomenclature and classification.

Attendees at the workshop included co-moderators Robert W. Kiger (Hunt Institute) and W. John Kress (U.S. National Herbarium), and participants Theodore M. Barkley (Botanical Research Institute of Texas), Richard K. Brummitt (Royal Botanic Gardens, Kew),

Paula DePriest (U.S. National Herbarium), Kristian Fauchald (Invertebrate Zoology, National Museum of Natural History), Vicki Funk (U.S. National Herbarium), John McNeill (Royal Botanic Garden, Edinburgh), Brent Mishler (University of California-Berkeley), Gerry Moore (Brooklyn Botanic Garden), Dan H. Nicolson (U.S. National Herbarium), J. Mark Porter (Rancho Santa Ana Botanic Garden), Peter Stevens (Missouri Botanical Garden), Dennis W. Stevenson (New York Botanical Garden), and Quentin D. Wheeler (U.S.A. National Science Foundation).

Early in the discussion it was recognized that, in reality, taxonomists have been moving toward a phylogenetic classification system since Darwin. For much of the 20<sup>th</sup> Century, taxonomists described their work as “phylogenetic” or “evolutionary,” but it was an intuitive phylogeny based upon a general knowledge of the organisms and not rigorously assembled. The advent of cladistics (an outgrowth of Hennigian Phylogenetic Systematics) has changed the face, or rather the roots, of taxonomy and produced conflicts, both real and misconceived, with the Linnaean system of nomenclature. The participants in the workshop were asked to define these conflicts on the first day and to suggest solutions during the second day.

In general the three major questions that a taxonomist must answer in constructing a classification are: (1) What is the best way to incorporate current understanding of relationships into a classification? (2) How does one confront the perceived problem of ranking? and (3) What does one do with paraphyletic groups? Discussion of these issues and finding answers to these questions were the main focus of the workshop.

This report is not a transcript of the workshop, but rather a distillation of the discussions and conclusions. For this reason the arguments presented below are not always exhaustive, but rather exemplary of the issues. Because of the extent of discussion and similar views often expressed by more than one person and because much of what was said has been suggested previously in one context or another, no attribution is made as to who said what. Note that the term “Linnaean nomenclature” as used here generally refers to the naming systems as defined by the various current codes of nomenclature, e.g., the *ICBN*. The discussants were particularly aware that a system of naming taxa is not synonymous with a classification system, i.e., nomenclature and classification should not be confounded.

## NOMENCLATURE AND PHYLOGENETIC CLASSIFICATION, AS TO TAXA ESPECIALLY.

Questions were raised and discussions ensued about why biologists recognize “groups” of organisms. Much work has been done on folk taxonomies, which often seem to work without the need to specify the characters upon which they are based. Why do we classify? We classify so that we can communicate. Why do we make groups within groups? We make groups because humankind appears to have an innate ability to discern patterns. Humans are good at seeing “patterns,” but sometimes the patterns are illusory in that they are not necessarily congruent with the natural relationships among taxa.

Questions facing taxonomists include: how do we perceive what is real and what is not, and how do we communicate this knowledge effectively? All agreed that life occurs in series of continua and that if we had a record of all organisms that had lived it would be difficult, indeed, to develop a classification that accurately reflected the diversification of life. Furthermore, we agreed that the history of science is loaded with instances of how humankind’s understanding of things or events is extensively modified by the incorporation of new knowledge and by new schemes for understanding that knowledge. It was also recognized that while one general-purpose classification is needed, special classification systems also may serve various important purposes, such as one that is strictly based on phylogeny or on taxa of hybrid origin. There was a sense that the general-purpose classification system should rest upon a dominant theoretical basis, must be “practical,” and should work under a variety of circumstances.

After a discussion of patterns and hierarchies, real vs. not real perceptions, and the communication of information, it was concluded that “a general classification should be maximally predictive and that this classification is best based on the theory of descent with modification”. Most participants agreed that it was quite possible to use basic Linnaean nomenclature with a few modifications to accommodate all of phylogenetic taxonomy, although several attending felt that a whole new system must be put into place. Much of the remaining discussion centered on the changes that could be made in Linnaean nomenclature.

An exercise in listing the exact conflicts between Linnaean nomenclature and phylogenetic classification led to two major topics: ranking and monophyly. The current cladistic philosophy is that all taxa at all ranks should be monophyletic. However, some taxonomists feel that the recognition of paraphyletic groups is unavoidable unless one wishes to choose between large meaningless groups or many small difficult to define

**GOAL #1: TO ASSESS THEORETICAL AND PRACTICAL INCOMPATIBILITIES BETWEEN LINNAEAN**

ones. It was agreed that ranking has some negative aspects and can convey unintended scientific implications and misinformation.

It was emphasized that the distinction between nomenclature and classification is important, i.e., “nomenclature” is a method of labelling taxa while “classification” is a system of ordering taxa. The system embodied in the *ICBN* (regardless of whether it is characterized as Linnaean) is one of nomenclature. This system in no way limits how a taxonomist may circumscribe a particular taxon (beyond inclusion of its type). It was also pointed out that the system in use today has been substantially modified since Linnaeus’ time. Examples include the incorporation of the type-based method, an expanded set of rank-denoting terms, and detailed rules for binomials. Concerns were raised by many about any system of nomenclature that would constrain circumscriptions of taxa beyond the inclusion of the type specimen. Such systems will be particularly problematic with regard to stability when ideas about relationships of taxa are changed.

## GOAL #2: TO ASSESS THEORETICAL AND PRACTICAL INCOMPATIBILITIES BETWEEN LINNAEAN NOMENCLATURE AND PHYLOGENETIC CLASSIFICATION, AS TO NAMES ESPECIALLY.

An extensive discussion on the concept of ranking demonstrated two opposing viewpoints. Some held that ranks mean nothing and are in fact misleading in that they imply that all families (or genera, species, etc.) are biologically comparable in some way. It was noted that “comparability” is often assumed by non-taxonomists to be the case in Linnaean nomenclature. Others held that ranks are useful in several ways, not the least of which is the principle of exclusion, i.e., if something is in one family (genus, species, etc.) it cannot be in any other group of the same rank. Linnaean nomenclature, as currently employed, does not permit having “families inside of families,” and traditionally it is sometimes necessary to change a taxon’s rank when the concept (or circumscription) of the group is altered. It was claimed, therefore, that a system of strict hierarchy with nested and symmetrical rankings can lead to instability. A common misconception is that ranking creates a particular problem for phylogenetic classifications because Linnaean nomenclature requires the creation of autonyms, i.e., when a group is erected at a certain rank the remaining taxa are automatically placed in another group of equal rank, thus sometimes creating paraphyletic groups by

default. However, this requirement is indeed not the case: the autonym rule creates the autonymic name only and does not automatically lead to the circumscription of a parallel taxon (see Barkley & al., 2004).

It was the general consensus of the group that rank-denoting terms, indeed, may be ontologically meaningless (e.g., a family of bacteria is in no significant way comparable to a family of vascular plants), but still they may be highly useful, especially regarding information retrieval. For example, under a rank-based system someone seeking information on the names *Fagus* and *Quercus* can recognize that these labels are names of genera because they are uninomials with none of the standardized higher level endings. The user can then conclude that the circumscriptions of the two taxa are mutually exclusive, and any information obtained on one taxon is not necessarily applicable to the other. No such conclusions could be drawn in a rankless system. It is important to remember that while many use scientific names for communication purposes, many (especially non-scientists) use them for information-retrieval purposes. Any changes to the current system must carefully evaluate how they will affect this process.

The summary session for the discussions of Goals #1 and #2 focused on the fact that Linnaean nomenclature has proved to be both useful and enduring. The compromise between the system’s flexibility for incorporating new knowledge while retaining connections with the past is important. It was agreed that Linnaean nomenclature cannot be summarily abandoned. The final conclusion of the session was that, because the current system does not impinge on how one circumscribes a group, the fundamental incompatibility that has been perceived between the current system of nomenclature and phylogenetic classification does not exist. The current system does not force one to circumscribe non-monophyletic taxa, nor for that matter monophyletic taxa. The claimed incompatibilities with phylogenetic classification are perhaps best characterized as “inconveniences” that are simply costs that in other contexts have very real benefits. For example, ranks lead to name changes when new information alters our ideas about relationships; however, these ranks play a valuable role in information retrieval by the users. The implication that binomials and ranks are nothing more than holdovers from Linnaeus’ time when they were believed to have ontological force is simply not true. We must now provide a unified, general-purpose classification system that offers the traditional utility of Linnaean nomenclature with accurate phylogenetic representation.

**GOAL #3: TO SEEK SOLUTIONS TO ACHIEVE FUNCTIONAL CONGRUENCE OF LINNAEAN NOMENCLATURE AND PHYLOGENETIC CLASSIFICATION, AS TO TAXA ESPECIALLY.**

All agreed that nomenclature should not constrain science, but some disagreement arises with the reverse, i.e., should science constrain nomenclature? The predominant feeling was that current science should not force taxonomists to classify in a particular way and that any system must be flexible enough to accommodate different philosophies. Even those who said that they did not accept and would not use non-monophyletic groups in classifications, still supported the legitimacy of others doing so as long as it is justified on some cogent rationale and so indicated. One individual who opposed the recognition of paraphyletic groups did recognize that a monograph including taxa circumscribed in a paraphyletic manner was still immensely valuable in that it could contain extensive and useful information on species (e.g., descriptions, ranges, keys, etc.) regardless of how the higher taxa were delimited. The general feeling was that groups are proposed and vetted by the scientific community and eventually accepted or rejected based on merit. This philosophy has the great benefit of leaving the door open for new scientific paradigms to be accepted without radical changes in nomenclature. On the other hand one person felt that science should constrain nomenclature and that individuals should be forced to recognize only monophyletic groups; this perspective was rejected by the group at large.

It was also noted that within groups where hybridization is common (e.g., Poaceae tribe Triticeae) or where lateral gene transfer is frequent (e.g., prokaryotes and some single-celled eukaryotes) the concept of a branching tree of life must be modified to one of a “net”, making the monophyly/paraphyly debate inconsequential.

It has been suggested that Linnaean nomenclature is fundamentally incompatible with a system based strictly on monophyletic groups. However, most participants felt that with Linnaean nomenclature a taxonomist can lump or split without phylogenetic constraints, so the perception of incompatibility is false; it was agreed that it may be inconvenient to name every node, make constant rank changes, and create autonyms. Indeed, devising a classification system that includes the whole “tree of life”—all ancestors as well as descendants—is exceptionally difficult with a rank-based system. Neontologists are fortunate that extinction provides some amelioration of the difficulty, but eventually palaeontological information must be integrated into contemporary classification schemes. After some lengthy discussion it became clear

that there was no “perfect solution” to classifying and naming all of Life due to the inherent conflict between practicality and reflecting such complexity.

To date, Linnaean nomenclature has been flexible enough to accommodate new scientific paradigms. However, do expectations exist for classifications that are not compatible with Linnaean nomenclature? A careful examination of Linnaean nomenclature, as embodied in the *ICBN*, showed that no special knowledge of relationships is required, and that the naming process can operate equally well with or without a phylogeny. Taxonomists know that meaningful biological comparisons can be made only between sister taxa and not across unrelated groups of taxa. It was asked if it must be possible to reproduce the evolutionary history of a group from the classification scheme. The preferable answer is yes and the converse should (or at least could) also be true, i.e., the classification should be derived from knowledge about evolutionary history. Implied in this is the notion that Linnaean nomenclature has a utility that extends beyond the reflection of evolution, and that other proposed solutions to the ranking problem, e.g., abandoning ranks and insisting on monophyly, are in reality special-purpose classifications.

Ranking was discussed again. To some researchers Linnaean nomenclature appears to allow only rank equivalence. However, scientists who use ranks as equivalent entities for biological comparisons simply need to be better educated as to the uses and misuses of nomenclature. We should not abandon our system of nomenclature because of this misunderstanding.

In summation of the discussion concerning Goal #3, it was noted that the Linnaean system is flexible and of continuing utility, but many misunderstandings exist as to exactly what is and is not possible under the rules of the *ICBN* and other codes. An operational clarification and illumination of the pertinent parts of the *Code* clearly needs to be prepared.

**GOAL #4: TO SEEK SOLUTIONS TO ACHIEVE FUNCTIONAL CONGRUENCE OF LINNAEAN NOMENCLATURE AND PHYLOGENETIC CLASSIFICATION, AS TO NAMES ESPECIALLY.**

The suggestion has been made to use rank-free classifications in which clades are named with uninomials and the hierarchical concepts are communicated through cladograms, as has been proposed in the *PhyloCode* (<http://www.ohiou.edu/phylocode/>). Such a scheme would be put into place by abandoning ranks and naming

taxa based on circumscription (e.g., phylogenetic histories) rather than types. Some opposition to this approach was voiced: most important is that cost versus benefit must be considered in any revision of the classification and nomenclature systems. Discussions among proponents of various “schools of thought” would be more productive if the costs of altering a given component of a nomenclatural system were reviewed with respect to the benefits of the proposed changes. Serious cost-benefit analyses usually have not been carried out in proposing new systems. Although these costs and benefits were discussed within an intellectual framework, the actual monetary costs of changing the nomenclatural system, for example in the U.S.A. Endangered Species Act, could range in the millions to billions of dollars.

Some changes to current methods of classification are essential and the general feeling of the participants was that Linnaean nomenclature is adaptable enough to accommodate most revisions required for reflecting phylogenetic information. A comprehensive examination of Linnaean nomenclature is called for in order to explicate its nature and applications, and to clarify exactly what the codes do and do not permit.

The concepts of species and higher-level taxa and the application of the type method were discussed at length. It was noted that taxon names may be applied by the type method (the current system) or by circumscription in the context of a given phylogeny (the *PhyloCode* system). Taxon names that depend on circumscription, for example, are names based on some particular biological criterion; names that are fixed by type specimens simply provide a starting point for circumscription. The ensuing discussion led to a conclusion that although conceptually a “species” must be based on the biological nature of the organisms, it must also include an associated name as a practical device for dealing with it. Agreement was by no means total, but a consensus supported the notions that uninomials at the species level are impractical and that ranking in classification is useful. Also favourably supported by most was the belief that Linnaean nomenclature is sufficiently flexible for present and future purposes. There is nothing in the current Linnaean nomenclature that prevents cladistic information from being incorporated into the naming procedure. It was suggested that a taxonomist can recognize and give names to as many higher groups as necessary to convey his/her understanding of the group. It was further noted that abandoning the type method would be giving up the hard-won benefit of many years experience in biological classification. The type method augmented the simple description in Linnaeus’ system of naming taxa and no compelling reasons have been presented for reviving description or circumscription as the basis for a nomenclatural system.

Monophyly can be communicated adequately under the current codes and therefore no reason exists to change the current system based on this perceived necessity. While it is true that paraphyletic grades are sometimes left over after describing a series of monophyletic taxa, one can break such groups up into smaller units, include them in larger groups, or recognize a paraphyletic group depending on one’s philosophy of classification. One option, if paraphyletic groups are to be accepted, would be to flag these taxa in some manner, e.g., by using an asterisk, analogous to the way that we indicate hybrids with a “multiplication symbol”.

Likewise, the problem of autonyms was found to be mostly based on a lack of detailed knowledge of the *ICBN*. The *Code* requires only that a parallel name be automatically created and not a category or taxon that one must accept or use. Ranking is also not a problem under the current codes because a taxonomist is allowed to use as many informal ranks as needed and may circumscribe them as deemed appropriate.

The Workshop concluded by examining current Linnaean nomenclature for plant names (embodied in the *ICBN*) article by article for matters relevant to phylogenetic classification. The overall conclusion was that Linnaean nomenclature is very flexible, but that an explanation (i.e., a “user’s manual” or “primer”) should be prepared to guide users in its application, to clarify misconceptions, to interpret the language of the *Code*, and to provide examples. Only 13 articles of the *ICBN* are pertinent to the relationship between phylogenetic classification and nomenclature (Table 1). The workshop ended with the recommendation that an immediate effort be made to clarify each of these articles with respect to phylogenetic theory and practice (Barkley & al., 2004; Moore & al., 2004).

## SUMMARY AND CONCLUSIONS

1. Any classification system to be widely applicable must be maximally predictive; contemporary thought indicates that such a system is best based on the theory of descent with modification.

2. The Linnaean system of nomenclature has served long and well, and it continues to satisfy most of the needs of the consumers of botanical information.

3. The needs of those who wish to incorporate phylogenetic information into nomenclature should be recognized and can be accommodated by modifications to the existing Linnaean system. However, the use of rankless classifications and uninomials to name clades is seen as awkward and unnecessary.

4. The current version of Linnaean nomenclature (e.g., the *ICBN* in botany) is sufficiently flexible to per-

**Table 1. Articles in the *International Code of Botanical Nomenclature* that are pertinent to phylogenetic classification and nomenclature.**

ICBN Articles	Remarks
Article 2.1 [ranks of taxa]	Consider the deletion of “among which the rank of species is basic”.
Article 3.1 [ranks of taxa]	Clarify that it is permissible, not mandatory, to assign families to orders, orders to classes, etc.; flexibility is therefore inherent and it is not necessary to create a new system that compares non-comparable entities.
Articles 3, 4, and 5 [ranks of taxa]	Clarify that ranks are not necessarily comparable across taxa.
Articles 7 to 10 [typification]	Clarify that biological investigations are unfettered by nomenclature and that the type method applies only to the legalistic business of applying names. The method of circumscription relies on type specimens that serve simply as vouchers.
Article 16 [taxa above the rank of family]	Provide explanation of why names above the rank of family must be treated differently from names at family-level and ranks below.
Article 20 [names of genera]	Emphasize that the noun-and-adjective construction of a binomial is not a description of the species.
Articles 21 [names of genera] and Article 23 [names of species]	Clarify that the use of binomials begins below the rank of genus whereas uninomials suffice at the rank of genus and above.
Articles 22 & 26 [autonyms]	Emphasize that an autonym is defined as the automatic creation of a name and not a taxon.

mit the incorporation of evolutionarily circumscribed clades and to communicate phylogenetic taxonomy.

5. A number of misconceptions are prevalent concerning Linnaean nomenclature as embodied in the codes of nomenclature and the current versions need clarification in order to meet the classificatory expectations engendered by the advent of modern phylogenetic methods.

6. Science should not be constrained by nomenclature, but neither should nomenclature be constrained by science. It is important that a scientist be allowed to decide what is important in his/her classification. Linnaean nomenclature accommodates this need and should continue to serve as our general-purpose system.

7. The *PhyloCode* is unnecessary in order to accommodate phylogenetic principles in classification. However, it can serve as a special-purpose classification for those who wish to prohibit all non-monophyletic groups, use rankless classifications, and abandon the type concept in favour of circumscription as the basis for naming taxa.

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