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Stability or stasis in the names of organisms: the evolving codes of nomenclature

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Nomenclature, far from being a dry dusty subject, is today more relevant than ever before. Researchers into genomics are discovering again the need for systems of nomenclature—names are what we use to communicate about organisms, and by extension the rest of their biology. Here, we briefly outline the history of the published international codes of nomenclature, tracing them from the time of Linnaeus in the eighteenth century to the present day. We then outline some of what we feel are the major challenges that face the codes in the twenty-first century; focusing primarily on publication, priority, typification and the role of science in the naming of organisms. We conclude that the codes are essential for taxonomists in the pursuance of their science, and that the democratic nature of decision-making in the regulation of the rules of nomenclature, though sometimes perceived as a potential weakness, is in fact one of its great strengths.

Keywords: history of nomenclature; naming; taxonomy; zoology; botany; microbiology

> There will come a time when all [organisms] in existence will have been described; when [collections] will contain indubitable material of them; when [biologists] will have made, unmade, and remade, raised, lowered, and above all, modified, several hundred thousand groups, from classes to simple varieties, and when synonyms will have become much more numerous than accepted taxa. Then science will have need of some great renovation of its formulae. This nomenclature, which we now strive to improve, will appear like an old scaffolding, laboriously patched together and surrounded by a heap of somewhat embarrassing rubbish that has arisen from the accumulation of successively rejected structures. The edifice of science will have been built, but the rubbish incident to its construction not cleared away. Then perhaps there will arise something wholly different from Linnaean nomenclature, something so designed as to give certain and definite names to certain and definite groups.
>
> That is the secret of the future, a future still very distant.
>
> (de Candolle 1867, pp. 10–11; translated by S. Knapp)

1. INTRODUCTION

The names by which organisms are known are the basis for communication about them. That all biologists, from taxonomists to ecologists to geneticists, can talk about an organism called *Drosophila melanogaster* or *Caenorhabditis elegans* and be sure they are talking about the same thing seems a trivial and rather mundane fact—a by-product of modern science. Names, however, have always been important. In the classical, pre-Linnaean past, the correct application of the names for medicinal plants could mean the difference between life and death. This need for stability in names of important organisms or concepts was in part the basis for the copying and recopying of the classical works of early scholars such as Dioscorides or Theophrastus through the Middle Ages in Europe.

The forms of scientific names we use today were invented by the Swedish botanist Carl von Linné (Carolus Linnaeus) as 'nomina trivialia'; binomial (or binominal) in structure, these names were composed of two words only, in sharp contrast to the 'nomina specifica' or long phrase names that were, for him and his scientific predecessors, the correct names of the organisms in question. The longer phrase names were in effect short descriptions of the plant or animal, and were constantly changing as knowledge increased about them and other species because the phrase names acted as key characters, allowing similar species to be distinguished from one another. The new trivial names, with just two words, served a dual purpose. First, they made the name different from the actual diagnosis or description, and second, they minimized classification. Essentially, the binomial naming system as set out by Linnaeus, first in *Species plantarum* (Linnaeus 1753) and later in various editions of *Systema naturae* (Linnaeus (1758), the 10th edition, is the starting point of nomenclature for zoology) was intended to help the practising scientist memorize the names of organisms.

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The binomial names were a modification of the common 'noun adjective' (or adjective noun) naming system used in most human societies for objects.

Linnaeus and his students and contemporaries focused on replacing the past methods of naming organisms with a new easy-to-use method of naming. By no means all authors used Linnaeus's binomial system, but it eventually 'won' the day and became the standard for biological naming, in part because of its logicality and ease of use. Well into the nineteenth century, alternative systems of naming were being proposed and used; one of the most novel of these was the late eighteenth century French botanist Jean Bergeret's system, in which each name was composed of 15 letters, each representing a character of the plant, thus *Belladonna* became *leglyabiajisbey* (Bergeret 1784). This has been characterized as the worst of all possible systems (Nicolson 1991) and it is perhaps not surprising that it did not catch on.

Names of organisms are without doubt important, and users of organism names often complain about changes to familiar names of well-known species. In general such changes occur for two principal reasons. First, scientific research often leads to improvements in the understanding of relationships. As a result, a taxon, for example a species, may have to be transferred from the group in which it was originally described to where it is more correctly placed. Such transfers result in changes to the name of the taxon, and are the result of increases in scientific understanding, not merely the application of the rules of nomenclature. Second, the same species may be described more than once, for example, when it is discovered independently in different countries. When scientists realize that this has happened they generally apply the principle of priority, using the name that was given first, treating the more recent names as synonyms. Sometimes an older name is overlooked or only comes to light when the species limits are reassessed. In such cases, strict adherence to the rules can lead to changes to long-established names for well-known species. These name changes have to do with the application and use of the rules of nomenclature.

Today, all biologists use Linnaean names—binomial in construction—but they no longer really adhere to the Linnaean world view (Stevens 2002). The coining of these names is governed by the international codes of nomenclature, semi-legalistic documents (Minelli 2002) that have evolved in fits and starts since the mid-eighteenth century, changing bit by bit to accommodate new knowledge, preserve common usage and provide a framework in which scientists can work. Nomenclature is often characterized as dry and boring—a non-science that is the province of those biologists with nothing better to do. Nomenclature is certainly not science, it is convention—one great strength of today's codes is that they are scientifically neutral (see Forey 2002) and are a set of rules and recommendations for the naming of organisms that allow biologists to objectively decide what name to use, independent of the scientific opinion used to arrive at the concept of the taxon concerned. The world changes, however, and with it the codes have changed over the past several centuries.

The challenges facing nomenclature today might appear to be quite different from those that faced Alphonse de Candolle in the mid-nineteenth century, but a closer examination reveals that nothing is as constant as change. Here, we provide a short history of the international codes of nomenclature (those interested in more detail should consult Nicolson (1991, 2002) and Melville (1995) in particular) to set the stage for a discussion of just a few of the challenges facing nomenclature in the twenty-first century. We broadly characterize these challenges as stemming from:

(i) publication;
(ii) priority;
(iii) typification; and
(iv) maintenance of scientific neutrality.

2. THE LINNAEAN PAST

Linnaeus and his students changed the diagnoses (phrase names) as new information became available, but they also occasionally changed the binomials if it suited them. This accords well with the idea that these new binomial designations were really not so much a complete replacement for the proper phrase names, but were instead merely a set of labels by which names could be traced and identified (Melville 1995). Johann Christian Fabricius, a pupil of Linnaeus who studied butterflies and other insects, published a set of precepts about naming in which he paid more attention than Linnaeus had done to the trivial (what we now call specific) names (Fabricius 1778). His precepts are no more than a guide to good manners, as were Linnaeus's aphorisms on the generic naming of plants some 40 years earlier (Linnaeus 1737).

Stability was not a hallmark of the early implementation of the binomial naming system. Only 50 years after the first introduction of binomial nomenclature, the French zoologist Jean Baptiste de Lamarck was lamenting the lack of rules for the naming of organisms. He railed against Linnaeus's own name changes, stating 'These two kinds of names [generic and specific] ought to be subject to rules that cannot be set aside without prejudicing the science that they aim to facilitate' (de Lamarck 1798, p. 498). His is one of the first explicit pleas for stability, with the erection of rules, in the naming of organisms. It is important that his plea also includes the concept that the science is facilitated, not ruled, by the names of organisms.

3. THE NINETEENTH CENTURY

By the early nineteenth century, knowledge of the great diversity of organisms was increasing as exploration of the tropics began. It became clear that Linnaeus's system of classification, devised not from an essentialist view of the world, but as a practical mnemonic tool to enable scientists to easily memorize all organisms (see Stevens (2002) for a discussion of the philosophical basis underpinning the structure of Linnaeus's works) needed to be governed by adherence to a set of good practices. Earlier practices of changing trivial (specific) names meant that a given plant or animal might have several different binomial designations, confusing rather than simplifying the task of remembering the names of organisms. In a discussion of what might today be termed best practice in nomenclature, Augustin Pyramus de Candolle, a Swiss botanist working in Geneva, introduced the concept of priority; the use of the oldest name (de Candolle 1813). He was certainly not the only scientist concerned with maintaining usage (see remarks by Lamarck in § 2), but he argued that usage should be maintained from the time of Linnaeus by the principle of priority. He allowed only five exceptions to the priority of the oldest name; all but one of these are part of today's international codes of nomenclature. de Candolle, although writing a botanical treatise, dealt with all names, whether of plants or animals. His code of good practice therefore can be seen as an early 'biocode'. By the mid-nineteenth century zoologists felt the need to reform the naming of animals.

> ...we conceive that the botanical nomenclature of the present day stands in much less need of distinct enactment than the zoological. The admirable rules laid down by Linnaeus, Smith, de Candolle, and other botanists ... have always exercised a beneficial influence over their disciples. Hence, the language of botany has attained a more perfect and stable condition than zoology ... [in] its present backward and abnormal state.
>
> (Strickland *et al.* 1843, p. 105)

Clearly, something had to be done! Although lamenting the sorry state of zoological nomenclature at the time, the members of the Strickland Commission (including Charles Darwin) were ultimately concerned with the establishment of a set of rules of good practice covering all of natural history 'for the establishment of an uniform and permanent language among naturalists of all nations' (Strickland, quoted in Melville 1995). Stability of names was also an important consideration of the members of the Commission, and their deliberations led to the publication (in various British scientific journals) of what could be called the first formalized code of nomenclature (Strickland *et al.* 1843), although it was realized that it could not be binding upon current and past practice. Their good intentions and admonitions to the use of best practice, however, were not widely received, and by 1865 revisers of the first version were lamenting that nomenclature was not at all improved (Melville 1995). Over the subsequent few decades and concurrently with the efforts of British zoologists, other attempts to standardize nomenclature were produced in Germany, the USA and France (see Melville (1995) for a history). Controversy surrounding the application of the principle of priority—introduced by de Candolle and incorporated into the Strickland Commission's rules—meant that, rather than developing in concert, these early attempts at codification were competitive, rather than complementary.

At approximately the same time, Alphonse de Candolle (son of Augustin Pyramus de Candolle, following in his father's footsteps in Geneva) was formalizing his laws of nomenclature for presentation at the IBC of 1867 in Paris. His publication (de Candolle 1867) contains not only laws (as 'Sections' or articles) but also extensive commentary with examples of both good and bad practice. General acceptance of these rules was not, however, universal, resulting in a situation like that in the zoological community, where many competing systems were proposed and vigorously defended (see Nicolson 1991). Again, debate hinged upon the strict or not so strict application of the principle of priority, and upon the date from which this principle was to be applied (either 1737 or 1753 in the case of botany). In both communities, the realization that usage could be overturned by correctness began to crystallize into support for pragmatic application of the emerging rules. Essentially the taxonomic community—in both zoology and botany—could be divided into two principal factions; one that emphasized the rules themselves, never mind the consequences to usage of names of organisms, and the other which was concerned with the maintenance of stability in naming, never mind the complexity of the (relatively unimportant) rules (Nicolson 1991). Many other minor differences were hotly debated in the last years of the nineteenth century—some of these continue to cause strife today.

4. EMERGENCE OF NOMENCLATURAL RULES

The need for a body overseeing the establishment of rules of nomenclature (or rules) resulted in the establishment in 1895 of the International Commission for Zoological Nomenclature (ICZN) as an outcome of the First International Congress of Zoology in Paris. The ICZN was composed largely of zoologists from Europe and the USA and was charged with the goal of reuniting in a single 'codex' the rules of nomenclature then used in different countries (Melville 1995). The Commission was associated with the International Congresses of Zoology, but shortly after became separated from them and began its life as an independent and permanent body, albeit not in the form in which it is constituted today. The early twentieth century saw the establishment of international congresses as the venues for the discussion and revision of the emerging rules of nomenclature, and in zoology, the Commission carried on working with nomenclatural issues permanently, preparing documentation for each subsequent congress.

In 1900, at the so-styled First IBC in Paris, botanists too saw the need for community-wide agreement and decided to appoint someone to revise the 'Candollean Code' for the next Congress (Nicolson 1991). Rather than unifying the community, this attempt to produce agreement was a prelude to another major split, this time the fracture was across the Atlantic and lasted more than 20 years. As before, disagreement was largely over the application of the principle of priority—the Americans, led by N. L. Britton, advocated strict application of priority, whereas many Europeans were more pragmatic and advocated stability of usage over strict applications of the rules. The resultant review, although not universally accepted, led to the first imposed international code of nomenclature, voted on at the Second IBC in Vienna in 1905. In zoology, the 1901 decision to strictly apply priority with no exceptions also created problems (Melville 1995).

Just before World War I, the ICZN was given plenary powers to suspend the rules—a compromise that was stimulated by the ongoing controversy over priority. The post-war years saw personality conflicts dominate the nomenclatural scene in zoology, and the meeting of the First International Congress of Entomology in 1935 meant that no longer were all animal taxonomists meeting regularly at a single international event. In botany, the first half of the twentieth century was a time of compromise and consolidation. Compromises over publication in Latin (still a contentious issue, see Greuter *et al.* (2000*a*)) and the combination of the best features of the competing codes meant that the code produced in 1935 (the 'Cambridge Botanical Code') was the first truly international code of nomenclature that was 'universally' accepted. The first International Code of Zoological Nomenclature (Zoological Code) was not published until 1961 (International Commission on Zoological Nomenclature 1961). A committee of botanists elected at the Cambridge Congress was charged with collating and presenting proposed modifications to the published code, a process that was similar to the role of the ICZN, but which lacked the permanency of the Commission. The establishment of the *Bulletin of Zoological Nomenclature* in 1942 meant that zoologists had a single place in which to present applications to resolve problems that could not satisfactorily be resolved under provision of the code. The ICZN subsequently publishes and votes on these applications. In 1953, the International Association of Plant Taxonomy was established and with it a similar venue for publication of proposals to modify the code, the journal *Taxon* (although today the journal is devoted to much more than just nomenclatural issues).

In addition to the establishment of formalized systems for discussion of nomenclatural matters, the mid-twentieth century also heralded the solidification of the use of the type method for the application of names. A type is the objective basis to which a name is permanently linked. What is a type then? Under all of the international codes of nomenclature, a type is defined as one of the elements, or in zoology a group of organisms, on which the description associated with the original publication of the name was based—often, but not always, a specimen (see Jeffrey (1989) for a discussion of the differences in conception of elements between the codes; for example, in the International Code of Nomenclature of Bacteria (Bacteriological Code) the type must be a culture, see § 5). It is certainly not a 'typical' (in the sense of average) specimen, or an illustration of a typical member of the species. The purpose of the type is to provide a fixed point of reference (usually a physical specimen) associated with any particular name. As the type is a single point in the range of variation, no matter where taxonomic (family, genus, species) boundaries are drawn, the application of a name can be objectively and unequivocally decided. The details of the application of the type method differ subtly between the codes, but the concept of the type is critically important for the correct application of names.

Current procedures and methods for the use and modification of the international codes of nomenclature (see § 5 for a brief description, and Web sites or the codes themselves for details) were largely solidified in the early twentieth century, but two major innovations really created the nomenclatural climate in which we now operate as taxonomists. First, after the 15th International Congress of Zoology no country offered itself as host for the 16th Congress, and the era in which the entire zoological community came together at one venue was clearly over. The 16th and last International Congress of Zoology was eventually hosted by Monaco in 1972. The General Assembly of the IUBS was there identified as the logical successor to the Congress as the parent body of the ICZN. By the 1990s, however, it became clear that the meetings of the ICSEB were a more appropriate place for the nomenclature of animals to be discussed than the General Assembly of IUBS, as a more representative community with nomenclatural interests attended the former. The IUBS, however, is still the official parent body for the ICZN.

Bacteria were traditionally named using the rules and recommendations of the International Code of Botanical Nomenclature (Botanical Code), largely because bacteria had been considered to be fungi in the nineteenth century. Because living cultures (of critical importance to bacterial taxonomy, see Oren (2004)) were not allowed as type material under the Botanical Code, microbiologists began formulating a separate code in the early part of the twentieth century. Between the 1960s and 1970s bacteriologists found that many of the published names in their groups could not be reliably used, owing to lack of descriptions or lack of living cultures upon which a description could be based. The traditional starting date used by the rest of botanists was unrealistic for the bacteria. In the 1980s taxonomists working on prokaryotes established separate rules for the naming of their groups (see Sneath 2003). This involved publication of all new names in a single scientific journal (*International Journal of Systematic Bacteriology*, now published as *International Journal of Systematic and Evolutionary Microbiology* (*IJSEM*)). All previously published names were reviewed and the naming of bacteria effectively began again in 1980 with an approved list of some 20 000 names. All new names in prokaryotes must be published in the *IJSEM* or, if published elsewhere, cited in a Validation List in the *IJSEM*; however, valid publication of a name is no guarantee of either its legitimacy or its priority of publication (Tindall 1999).

Various special cases of standard nomenclatural practice have resulted in a variety of different responses from the communities involved. These range from modifications of the rules, such as the exclusion of hybrids from the Zoological Code but their inclusion in the Botanical Code, the use of the category 'form-genus' for fossil plants known only in parts in the Botanical Code (see Forey *et al.* 2004), to the establishment of semi-autonomous (e.g. the International Code of Nomenclature for Cultivated Plants (Cultivated Plant Code), see § 5) codes for domesticated organisms (see Jeffrey (1989) for other special cases). Other communities have seen the need for rules governing naming and have established a variety of mechanisms, albeit with different criteria and not as formalized as the international codes, to maintain stability (for viruses see Matthews (1983), Van Regenmortel *et al.* (2001) and § 6d; for genes and proteins see White *et al.* (1999), Burgers *et al.* (2001), Pearson (2001), Wain *et al.* (2002)). The rapidly emerging field of genomics has thrown into stark relief the need for names (White *et al.* 1998), and has highlighted the chaos that can result when no rules exist. Interestingly, nomenclature also seems to arouse passions in both the long-established (see final paragraphs of the Preface in Greuter *et al.* (2000*b*)) and the newer communities. Sue Povey of the Human Genome Organisation remarked that '[a]nyone attempting to reconcile different view of genes and gene products must be prepared for robust exchanges of a nature that one of us (S.P.) has not previously encountered in 30 years of primary research, even at its most competitive.' (Povey & Wain 2002). Rather than becoming less relevant, nomenclature is emerging into the spotlight.

5. CURRENT PRACTICE

Today nomenclature is regulated by three principal international codes of nomenclature: the International Code of Botanical Nomenclature (Botanical Code; Greuter *et al.* 2000*b*), the International Code of Nomenclature of Bacteria (Bacteriological Code, 1990 revision; LaPage *et al.* 1992) and the International Code of Zoological Nomenclature (Zoological Code; ICZN 1999). In addition, the International Code of Nomenclature for Cultivated Plants (Cultivated Plant Code; Trehane *et al.* 1995) governs the naming of plants whose origin or selection is primarily due to human intention (Spencer 1999); cultivated plants are covered by both the Cultivated Plant Code and the Botanical Code. Both virus and gene nomenclature have 'rules', but as yet no formalized published codes with explicit rules and recommendations analogous to what we are terming the three principal codes of nomenclature. Approach and format differ slightly between the current international codes of nomenclature, but the general principles of naming are the same (Jeffrey (1989); see Greuter *et al.* (1996) table 1 for proposed unified terminology across biology); the three operative principles are publication, typification and priority. Naming thus involves three main steps:

(i) establishing whether or not a new name is necessary (checking the literature);
(ii) publication; and
(iii) designation and deposition of type material.

In general, the codes consist of rules or articles, which are supplemented by recommendations. These rules have no status in international law, despite the perceived status of taxonomic publications as 'legal' documents (Minelli 2002). Enforcement depends only upon the voluntary agreement of practising scientists to observe the provisions of the codes; the only sanction for non-compliance with the rules is the disregard of one's peers. Widespread non-observance of the codes would also lead to great instability in the names of organisms. The ever-increasing user communities for the names of organisms (Godfray 2002) mean that instability now has wider implications than it did in the past. But just because biologists are governed (however voluntarily) by the codes, it does not mean that these rules are set in stone and unchangeable. Each of the codes is subject to review and is not a final document, but rather a temporary pause until the next review. The codes are governed and managed in slightly different ways and recent attempts to introduce a BioCode (see Greuter & Nicolson 1996; Greuter *et al.* 1996) have met with resistance, in part because of these cultural and philosophical differences.

Differences in how the codes are governed also contribute to the culture surrounding nomenclature. The Botanical Code can only be modified by the decision of a plenary session of an IBC, held every 6 years. The IBC endorses resolutions made by the Nomenclature Section of the Congress, which generally meets in the week preceding the Congress. These assemblies of hundreds of practising botanical taxonomists can become rather contentious meetings of minds (see Greuter *et al.* 2000*a*,*b*). Proposals to modify the code are published in the journal *Taxon*, and a postal ballot is sent to all members of the International Association for Plant Taxonomy before the Congress. The results of the postal ballot are not binding, however: it is the vote at the Nomenclature Section that is sent to the Congress as a whole. Various Committees are responsible for a wide variety of nomenclatural matters; the Editorial Committee is charged with the publication of the modified code after each IBC. The Cultivated Plant Code is drawn up and maintained by the IUBS Commission for the Nomenclature of Cultivated Plants, made up of appointed members representing the interests of agriculture, forestry and horticulture. The Editorial Committee for this code is a subset of the Commission members and includes representatives who participate in the Nomenclature Section of each IBC to ensure consistency between the plant codes.

Both the Bacteriological Code and the Zoological Code are also modified through international commissions. The Bacteriological Code can only be modified by the action of the ICSP (formerly the International Committee on Systematic Bacteriology, see http:/www.the-icsp.com) on proposals made to it by its Judicial Commission. The Judicial Commission is elected from among the membership of the ICSP, and proposals to modify the code are fed through the Editorial Secretary of the ICSP, who is also the Secretary of the Judicial Commission. As in the botanical world, an Editorial Committee is responsible for the production of versions of the code. The code is modified at regular intervals by the International Congresses of Microbiology, and as in zoology, the code can be modified between major irregular revisions through decisions published by the Judicial Commission in the *IJSEM* (see § 4).

Modifications to the Zoological Code are made by the IUBS, acting upon recommendations made by the ICZN. These recommendations are presented through and approved by the Section on Zoological Nomenclature of the IUBS, usually meeting at an international congress such as ICSEB (see § 4). The code is prepared on behalf of the ICZN by an editorial committee and is commented upon, during preparation, by the zoological community. Community participation is an important component of modification of all three principal international codes for the nomenclature of naturally occurring organisms. In addition to the modifications ratified by the international community at congresses, the Zoological Code can be provisionally modified by means of 'declarations' of the ICZN; these declarations can be overturned at a congress, but this rarely happens.

In practice, new editions of the various international codes tend to appear at intervals of five or more years. This seemingly ponderous pace of change to the codes, coupled with the requirement for widespread community agreement, means that the codes are in large part immune to fads in science. It also means that innovations take time to implement and sometimes can be pushed forward or stopped by vociferous groups who attend any given congress. The seemingly labyrinthine methods for modification are both strengths and weaknesses of the current codes, but we feel the stability resulting from community-wide consultation and discussion far outweighs any irritation due to the slowness of change. No one wants to spend decades undoing well-intentioned but destabilizing changes that were not debated thoroughly and by a broad cross-section of the taxonomic community (see Filgueiras *et al.* (1999) for an example of broadening the consultation process)!

6. CHALLENGES

(a) *Publication*

Once the need for a new taxon name has been identified, the next step is publication. Traditionally done in paper media, it has been suggested that in future, all taxonomic publication should be done on the World Wide Web (Godfray 2002). In general, publication must fulfil two basic conditions; a name must be accompanied by information and must be in a medium that conforms to the requirements of the code in question. The former condition is rarely violated by today's taxonomists; it is about the latter that opinions differ. Neither the Botanical Code nor the Bacteriological Code allow publication in other than paper journals or books. The Bacteriological Code requires all names to be published in the *IJSEM* (see § 4), a paper journal that is also available online; names published elsewhere must be included on Validation Lists in the *IJSEM* to be available for use. The lists of all validly published bacterial names available on the Web (see http://www.bacterio.cict.fr/) are published by J. P. Euzénby, a professor of Microbiology-Immunology at the École National Vétérinaire in Toulouse, France, and are not a compulsory central registry, nor do they have any standing in nomenclature beyond that of being composed of names published in the *IJSEM*. Like the IPNI (see Nic Lughadha 2004), the bacterial lists are a service to the community at large. The ICZN requires that for a work produced after 1999 by a method other than printing on paper to be accepted as published within the meaning of the code, it must contain a statement that copies (in the form in which it is published, e.g. on read-only laser disks) have been deposited in at least five major publicly accessible libraries which are identified by name in the work itself (Article 8.6). Text or illustrations distributed by means of electronic signals (e.g. by means of the Internet) do not currently constitute published work under the Zoological Code.

Electronic journals, however, are beginning to be used for taxonomy; a sterling example is the journal *ZooTaxa* (http://www.mapress.com/zootaxa). The journal is published online, with separates lodged in public libraries to satisfy the requirements of the Zoological Code. The speed with which new taxa are rigorously peer reviewed and published in this journal is astonishing: a look at recent issues shows receipt dates of only a week or so before publication dates; market forces will surely stimulate more such efforts in the very near future. But this is not solely an electronic, Web-only available publication: the paper version has a different ISSN number and is distributed as a traditional paper journal such as the *Novitates* of the American Museum of Natural History (which also appears in fascicles of various sizes).

The ephemerality of Web sites has been cited as an additional disincentive to electronic publication solely on the Internet, with the half-life of Web pages now averaging *ca.* 2 years (Koehler 2002). The necessity of storing taxonomic work essentially indefinitely and in multiple copies has meant that large, publicly funded libraries are the primary resource for such information. That multiple copies are kept is critical—the destruction of libraries (and collections too) as a result of natural disasters or wars is all too common. Single copy information carries huge risks. The journals database JSTOR, in which electronic copies of entire runs of increasing numbers (in December 2001 totalling some 9 million pages) of scientific journals are archived and made available over the Internet, is mirrored on three servers in two countries (USA and UK) to ensure reliable data access. JSTOR is a subscription service with a relatively large infrastructure (Schonfeld 2003); a similar system for names in taxonomy would be complex to establish, and access for those unable to pay (as is currently done for JSTOR) would need careful regulation. Like JSTOR, the data used to construct the human, mouse or tomato genome are not stored in single sites or in single institutions. The assembly of the human genome through sections (by AGP files, which are the archived pieces of information) can be likened to the building of a jigsaw whose pieces are stored in multiple copies in different houses (A. V. Cox, personal communication). The individual pieces, bits of DNA sequence, are stored in large, publicly funded databases such as GenBank and European Molecular Biology Laboratory (but see caveats about such databases in Harris (2003)).

Registration of all names has been suggested as a way of not only keeping track of all new names published, but also as a way of increasing the status and visibility of the taxonomic literature (Minelli 2002). Registration can mean many different things to different people: from the compulsory centralized registration advocated by Minelli (2002), through the registration of cultivar names administered by voluntary international registration authorities for over 300 genera of cultivated plants, to distributed, community-based initiatives such as the IPNI. Issues of registration also intersect broadly with those of priority.

Widespread discussion of modifications to the nomenclatural codes with the aim of enhancing stability of names began in the late 1980s. The proposed innovations were of two broad types: registration systems for newly published names and the adoption of lists of NCUs. The latter is treated under 'Priority' below. Both the botanical (emphatically) and the zoological communities recently rejected mandatory registration (see Nic Lughadha 2004). The grounds for rejection by the botanical community focused largely on the fact that the potential increase in stability likely to result from the new system was negligible compared with the great increase in bureaucracy involved (Eggli 1998; Turland & Davidse 1998). For the zoologists, the primary concerns were threefold: coverage, availability (validity of publication) and access issues (Thorne 2003). Some of these issues have since been addressed in part through the provision of the Index to Organism Names (ION; see www.biosis.org.uk/free_resources/ion.html), a freely accessible view of names in the *Zoological record*. Although the Bacteriological Code is widely perceived to include a requirement for online registration, this is not in fact the case (see under § 5), although the publication of all new names in prokaryotes in the *IJSEM* (either through original articles or in the Validation Lists) effectively makes that publication a central register, as it is an author's responsibility to send a name in for inclusion in the Validation Lists.

Thus, the current situation for registration and the organismal codes can be summarized as follows: outright rejection by the botanists (the Article about registration provisionally included in the 1993 'Tokyo Botanical Code' was voted out by the 1999 St Louis Congress: see Greuter *et al.* (2000*a*)); provisional rejection by the zoologists (the registration requirement was included only as a recommendation in the fourth edition of the Zoological Code but the matter continues to be discussed: see Scoble (2004)); parallel evolution in the prokaryotic community with the publication of Validation Lists in the *IJSEM* and Notification Lists having been published since 1991 (see LaPage *et al.* 1992). The experiences of the past two decades suggest that if 'registration' is to be successfully introduced at some time in the future it must be:

(i) easy—involving no significant additional workload for most taxonomists, editors or institutions;
(ii) accessible—offering a register that is freely and immediately open to all (electronic provision offers the obvious solution here); and
(iii) broadly community based—with buy-in from the community of practising taxonomists who see the system as useful and worthwhile.

(b) *Priority*

History shows that finding the appropriate balance between pragmatism and correctness in the application of rules of priority has been a constant challenge that has dogged taxonomic practitioners for almost two centuries. Times have not changed at all! In theory, application of the principle of priority, finding and using the oldest acceptable name, should in the long term serve the interests of nomenclatural stability. It also has the advantage of following established scientific custom in crediting the earliest originator of an idea, even though others may independently discover the same phenomenon (or taxon) at a later date.

However, in the short to medium term, applying the principal of priority all too often results in name changes that the users of organism names find irritating and senseless. In the interests of stability, options to limit the application of the principle of priority in particular cases have been introduced in all three principal codes. These include options to reject a little-used name which, if adopted might overturn a long-established but younger name and options to conserve a long-established name for application in a particular sense. Each case for conservation or rejection of a name or a group of closely related names is separately judged and its merit is assessed in the light of its effect on stability of usage. Fear has been expressed that widening the options for conservation or rejection would open floodgates such that the communities would be swamped with trivial proposals. This has in fact not happened; opening the options for conserving usage has improved rather than decreased stability of names. List of conserved and rejected names form appendices to the Botanical Code; in zoology, these names and their status are published at various intervals as lists of conserved names and indexes of rejected names in the *Bulletin of Zoological Nomenclature*. Both the Zoological Code and Botanical Code have provision for the rejection of entire works; however, the option is not used often and is used with great care (see Melville (1995), p. 72 and Appendix V 'Opera Utique Opressa' in Greuter *et al.* (2000*b*)).

The concept of protecting lists of NCUs or Lists of Available Names was widely promoted in the 1980s. Application of this concept would be equivalent to conservation of established names on a grand scale, involving the preparation of lists of currently accepted names for the world's organisms. These lists could then be recommended to be preserved over any potential threat from names not on those lists. In effect, the adoption of such a list for a particular group would represent a new starting date for the nomenclature of that group. Proposals for development and adoption of lists went hand in hand with registration—the latter being designed to address the potential problems caused by future names while the NCU approach addressed the (greater) problem of extant names. Both were strongly supported by the IUBS (Greuter 1991) but not so well received by the community of practising zoological and botanical taxonomists. The NCU concept was by no means new (Greuter 1991); lists of protected NCUs were already included in the Botanical Code in the form of lists of conserved family names for mosses and seed plants. The furore over the radical changes to lepidopteran names arising from the publication of the checklist of Miller & Brown (1981) of the butterflies north of Mexico in part arose because of the suggestion of Ehrlich & Murphy (1981) that nomenclature be retrospectively frozen to an earlier work (Howe (1975); see Johnson & Quinter (1984) for a discussion of the case). Enhanced stability and certainty in the application of names and a greatly reduced requirement for extensive bibliographic and nomenclatural searches were cited as major benefits of the implementation of the NCU concept. Considerable time and effort was invested by the botanical community in the preparation of a list of generic names in common use (see Greuter *et al.* 1993). The most fervent advocates of NCU in the botanical community hoped that a thoroughly vetted and reliable list might be available by early 1993 and that this would increase the probability of the NCU principle being passed at the XV IBC in Tokyo later that year. However, the draft lists circulated in the botanical community were heavily criticized and at the Congress the NCU proposals were variously defeated or withdrawn.

A more recent and radical suggestion would in effect result in new starting dates for particular groups on a group-by-group basis (Godfray 2002). The pros and cons of unitary taxonomies are discussed by Scoble (2004), and he touches on some of the nomenclatural issues surrounding a move to such a system. A unitary taxonomy implies many of the same issues as does registration (discussed in § 6a and Nic Lughadha 2004), but additionally brings with it a unique nomenclatural twist in having potential different starting dates for each group. Discussions of the BioCode proposals at the 1999 IBC in St Louis often centred on a widespread concern that a multiplicity of starting dates would confuse rather than clarify nomenclature. That same issue holds with unitary taxonomies, with the additional twist that should a group with, let us say, a 'first web revision' of 2003, later be found to be included in a monophyletic group with a 'first web revision' of 2005 by another taxonomist (or group of taxonomists), what does the correct starting date become? One strength of our current codes is their relative simplicity (although it might not seem simple to an untrained user!). The beguiling simplicity of systems of registration and so-called unitary taxonomies are attractive, but as was abundantly clear at the rather acrimonious discussions during the Nomenclature Section of the 1999 IBC, failure to discuss thoroughly the ramifications of proposals to amend the codes can lead to problems later on (see Greuter *et al.* 2000*a*).

(c) *Typification*

Specimens are the evidence upon which names are based, for all taxonomic levels in botany and at the species level in the other two codes. It seems logical to assume that type specimens should be deposited in public institutions that will care for them in perpetuity—they are held in trust for future generations of biologists. Strangely, none of the codes specifies the deposition of all types in public institutions. Recommendation 7A of the Botanical Code 'strongly recommends' that holotypes be deposited in public and open-access institutions and Article 37.6 requires that for names published after 1990 that the 'single herbarium or collection or institution in which the type is conserved' must be specified (Greuter *et al.* 2000*b*). It is required by the Zoological Code that neotypes (newly designated types when the original type specimen is lost) be deposited in public institutions; why should the same not be mandatory for other primary types (holotypes, syntypes, isotypes, lectotypes)? Type specimens deposited in private collections (personal herbaria or museums) often are lost, either temporarily or permanently, when the owner of the collection dies or the collection is broken up. This is particularly problematic for zoological holotypes or for botanical holotypes based on unicate (single specimen) collections and for difficult-to-maintain bacterial cultures. The Bacteriological Code now requires new names to be typified with living cultures maintained in two registered collections (De Vos & Trüper 2000). Authors must also provide evidence as to the deposition and availability of the strains. This sort of deposition of specimens and declaration of the open accessibility of the specimens would be a logical and welcome step for the other two codes to follow, modified of course to conform to the specifics of the sorts of specimens involved.

In practice, most new taxa described under the Botanical Code are in fact based on material deposited in public institutions (K. Challis, personal communication). When problems of access to type material occur they are most often attributable to temporary but extended closure by such public institutions or to abuses of the inter-institutional loan system by researchers who borrow all the type specimens of a particular taxon and retain the material for years (sometimes for decades) beyond the agreed loan period. Although such problems can scarcely be legislated for by the nomenclatural codes they do have serious implications for stability of names, because examination of type material is the single most reliable means to avoid misapplication of names and superfluous redescription of taxa already known to science. Recent initiatives to create and disseminate digital images of type material have greatly enhanced access to type material for particular groups and areas (see for instance the New York Botanical Garden's Vascular Plants Type Catalog, http://www.nybg.org/bsci/hcol/vasc/).

Although viewing an image is not always an adequate substitute for examining the type material itself, in many cases high-quality images suffice for most typification or application queries. Thus, the trend towards digitization of type specimens for Web dissemination is very much to be encouraged and one can envisage a time in the not-too-distant future when scientists describing new taxa routinely cite Web sites where the type material can be viewed, much as those publishing research based on DNA sequences publish an accession number to a sequence deposited in GenBank or EMBL.

Although molecular sequences are often used in the characterization of new species of prokaryotes, DNA sequences on their own are not allowed as types by the Bacteriological Code, nor are they used on their own in viral taxonomy, but in conjunction with a broad suite of other characteristics (Van Regenmortel *et al.* 2001). The sole use of the DNA sequence of a particular gene (see Tautz *et al.* 2002), perhaps using different genes for each taxonomic group, seems to us a retrograde step, tantamount to throwing away good data. The checks and balances of the morphology of an actual specimen on which a taxonomist can examine additional characters are critical for the best taxonomic practice; the more data the better.

(d) *Flexible rules for changing knowledge*

Both gene and virus nomenclature first wrestle with the definition of that to be named. Debates on naming or not naming genes usually begin with 'what is a gene?' (S. Povey, personal communication), and the International Committee on the Taxonomy of Viruses (ICTV) has established a standard definition of a virus 'species' (Van Regenmortel 1990) which forms the basis for the universal virus taxonomy (see www.ncbi.nlm.nih.gov/ICTV). The nomenclature of organisms does not have such a basis: in all three of the principal codes naming is independent of taxonomic opinion. This fact is often not appreciated. Tindall (1999) cogently remarked that the 'principle of the "freedom of taxonomic thought and action" is not fully appreciated and the scientist is required to make an evaluation of the data presented before making a taxonomic judgement, rather than just opening an appropriate reference book and slavishly following what has been published before'. The independence of naming and taxonomic judgement can be a source of frustration for users of names; for example, species can be found to belong in another genus, necessitating a change of name (see § 1). Different taxonomic opinion can also lead to several names being in use, reflecting that we can never 'know' the truth, only estimate it from empirical data (Vane-Wright 2003). The codes do not legislate on what is a species, genus, family or any other taxon.

Proposals to introduce a PhyloCode (http://www.ohiou.edu/phylocode/ or www.phylocode.org) cut to the heart of how naming is done by introducing a scientific truth to the naming of organisms. The PhyloCode and its pros and cons have been debated in many fora (see de Queiroz 1994; Forey 2001, 2002; de Queiroz & Cantino 2001; Godfray & Knapp 2004), but essentially the point of contention is whether the naming of clades rather than taxa will increase stability of names. Anything likely to increase stability has immediate appeal, but closer examination of the PhyloCode shows that claims about increases in stability are not held up (Forey 2002), and wholesale adoption would immediately cause widespread name changes—a decrease in stability. It has been suggested that cladistic methodology necessitates naming using something like the PhyloCode (Brummit 2002; but also see Nelson *et al.* 2003) whereas the traditional codes are only applicable to taxonomy done non-cladistically. This is a gross oversimplification of how science proceeds; there is widespread acceptance of the utility and desirability of naming monophyletic groups, but we still have far to go to really understand the shape of the tree of life. Naming can go on in the absence of knowledge of monophyly, the named taxon can then be used by others in phylogenetic analysis. Almost two centuries ago, the dipterist C. R. W. Wiedemann said '[n]ames carry value like coins, the sound of the name, not its contents, is to remind us of the named' (Wiedemann 1817, translated by M. Spies, see http://www.sel.barc.usda.gov/Diptera/wied1817.htm). Our codes are the stronger for their neutral stance on the continuing scientific debates on what is a species, or how groups are related.

Perhaps the most formidable challenge to biological nomenclature comes from the so-called 'ambiregnal' organisms (Patterson 1986), that is, those whose nomenclature falls simultaneously under the jurisdiction of more than one code (typically the Botanical Code and the Zoological Code) owing to a combination of historical, cultural and biological reasons. At the time of the origin of the codes, the delimitation of their respective fields of applicability must have been quite straightforward because there was then little doubt as to what constituted a 'plant' as opposed to an 'animal'. However, with the development of microbiology as a modern science in the twentieth century it became clear that within the protists (the unicellular eukaryotes) in general and flagellate protists in particular (the ambiregnals *par excellence*), the concept of being a plant versus an animal loses much of its meaning owing to the nutritional heterogeneity of these organisms—protists can feed either photosynthetically or heterotrophically, or a combination of these two feeding modes depending on environmental conditions. Thus, biologists have for a long time been faced with a dilemma deciding in which category to place the nutritionally heterogeneous protists—plants or animals—for nomenclatural purposes. A striking example is that of the dinoflagellates, which botanists have traditionally considered as plants with few concessions to their animal nature despite the widespread occurrence of heterotrophic nutrition within the group. Firm evidence that as many as 50% of dinoflagellate species may be heterotrophic or mixotrophic (Larsen & Sournia 1991), with entire genera relying on a single nutrition mode, certainly reinforces the argument against the dinoflagellates as 'plants'. However, just designating the dinoflagellates as 'plants' is not a way of resolving ambiregnal nomenclatural issues because the possibility of considering the dinoflagellates *en bloc* as 'animals' is just as unsatisfactory. Other famous examples of ambiregnal flagellates include the euglenoids, of which several cases are illustrated in Larsen & Patterson (1990) and the cryptomonads (Novarino & Lucas 1993, 1995).

The nomenclatural difficulties raised by the ambiregnal status are too numerous to list here; they have been explored in detail by Patterson (1986), Taylor *et al.* (1987), Patterson & Larsen (1991, 1992), Corliss (1992, 1995), Hawksworth (1994) and Hawksworth *et al.* (1994). Briefly, they range from small clerical issues arising from minor inter-code differences (e.g. spelling; name endings), to more serious matters in relation to cultural differences between respective backbone provisions of the codes (e.g. ranks of taxa covered by each code, 'available' versus 'valid' publication in the Zoological Code and the Botanical Code, respectively; starting dates for compulsory holotype designation in the original publication of a taxon name; kinds of types allowed by each code), to veritable nomenclatural conundrums arising on a case-by-case basis, the latter usually involving instances of priority, homonymy, synonymy or any of these simultaneously (in any combination), under one, the other, or both codes at the same time. Complexity of individual cases falling under the remit of ambiregnal nomenclature can be quite daunting (see Larsen & Patterson 1990; Novarino 1996). The most extreme consequence of the ambiregnal status is that a given taxon may be known by two different names, each one in accord with the provisions of its respective code (Novarino (1996), and references therein). As a result, in the more recent taxonomic works on ambiregnal protists (Larsen & Patterson 1990) it is becoming customary to specify the correct name of taxa under each code.

What is needed urgently is a general solution to the ambiregnal dilemma. The way forward has attracted a good amount of discussion and there have also been suggestions for formal revisions of the Botanical Code and the Zoological Code to deal specifically with ambiregnal protists (Taylor *et al.* 1987). However, the situation is still largely unresolved. This is very undesirable at a time when, thanks to the combined achievements of ultrastructural and molecular investigations, the study of protistan evolution, systematics and taxonomy is experiencing a true *renaissance*. Perhaps the most critical issue is that of the existence of taxa with 'double' (under both codes) names, a 'non-partisan' solution to ambiregnal questions whose laboriousness has attracted some criticism (Corliss 1995). It is clearly undesirable to have two different but equally correct names for one and the same taxon, and to avoid this it may be sufficient to use what suitable tools are legally available under each code—for instance, making a proposal to conserve or reject a name under one code only (Novarino & Gilbert 2002). However, such fortunate cases are the exception rather than the rule and in the current nomenclatural legislation the existence of taxa with double names is usually the least of all possible evils. There also exists a view whereby in selected cases the adoption of double names could be avoided by accepting the coexistence of ambiregnal homonyms as long as these refer to systematically distinct taxa and the respective systematic positions of the taxa to which they refer are clearly stated. The risk here is that of contravening the fundamental requirement of biological nomenclature that taxon names are univocal. Furthermore, if the trend of referring to the higher-rank protistan taxa using informal names also in a formal scientific context (Patterson 1993) will prevail over the well-established custom of formally typified scientific names (as perpetuated most recently by Cavalier-Smith (2002)), the systematic position of protistan taxa with homonymous names might not be all that clear after all. Another alternative to double names could be that of deciding on a case-by-case basis to which particular code should ambiregnal taxa be applied to the exclusion of the other. The danger with this approach is that by abandoning nomenclature under a given code there could result a loss of precious bibliographical information, which could be detrimental, not only nomenclaturally, but also taxonomically, systematically, biologically or—last but not least—historically. Furthermore, case-by-case decisions would almost certainly generate undesirable controversy within the scientific community—the well-known precedent of the Cyanobacteria speaks for itself (see Oren 2004).

7. CONCLUSIONS

In this paper, we have attempted to draw out some of the challenges facing, not taxonomy itself, but the long-established codes governing nomenclature that help taxonomists do their jobs effectively. Many of the challenges facing taxonomy have to do with science or with the presentation of information; but underpinning all of the taxonomy we do are the codes, with their changeable flexible rules and recommendations for how to assign names to organisms so we can continue the science of finding out about them consistently. Although we are clearly in a time of great change in how we do taxonomy, we think the codes, with their broadly democratic processes, provide an anchor of stability in a time of change. Peter Raven, in his address to the Nomenclature Section of the 1999 IBC, stated the position clearly: 'the real importance of these sessions is that all listen to one another, that they recognise and respect the others' points of view and thereby gain a broader appreciation of [plant] systematics and of the whole range of different attitudes held by colleagues around the world. As is so wisely said in the Preface to the 'Tokyo Botanical Code', it is only by the willing acceptance that results from understanding, that the system of laws we are now going to discuss and vote will then govern our activities' (Raven, in Greuter *et al.* (2000*a*), p. 12). The codes will certainly evolve in the next century, as they have evolved over the past centuries, but several points are clear looking back at history and considering how the codes might evolve to help taxonomy progress into the twentieth century.

(i) Priority is the oldest challenge: getting the balance right is always going to be difficult, but if more taxonomy is done to a high standard, these problems will eventually diminish (but never completely disappear!).

(ii) The codes are essential for taxonomists and for good taxonomic practice—the splintering of the community into groups governing each little piece is counterproductive and will lead to problems, not only within, but also between, groups.

(iii) Keep the science out of nomenclature! It has served its purpose well for centuries, despite ups and downs and minor internal squabbles. Give it a chance to come into the twenty-first century and show how it can serve us for a bit longer, until we have the 'perfect knowledge' predicted by de Candolle in 1867, and still so elusive today.

Stability in names—whether of genes, viruses, micro-organisms, plants or animals—is a goal to be desired and we should all strive to achieve it. It is best done by the highest quality science, not by arbitrary stasis in which names are set in concrete or frozen—our real goal as taxonomists should be true and lasting stability, not artificial stasis.

> Meanwhile, let us perfect the system introduced by Linnaeus. Let us try to adapt it to the continual and necessary changes in our science…; let us attack abuses and negligence; and let us come to understanding on debated points, if possible. We shall thus have paved the way for the practice of science for many years to come.
> (de Candolle 1867, p. 11; translated by S. Knapp)

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GLOSSARY

IBC: International Botanical Congress

ICSEB: International Congress of Systematic and Evolutionary Biology

ICSP: International Committee on Systematics of Prokaryotes

ICTV: International Committee on the Taxonomy of Viruses

ICZN: International Commission on Zoological Nomenclature

IPNI: International Plant Names Index

IUBS: International Union of Biological Sciences

NCU: Names in Current Use