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Unitary or unified taxonomy?

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Taxonomic data form a substantial, but scattered, resource. The alternative to such a fragmented system is a 'unitary' one of preferred, consensual classifications. For effective access and distribution the (Web) revision for a given taxon would be established at a single Internet site. Although all the international codes of nomenclature currently preclude the Internet as a valid medium of publication, elements of unitary taxonomy (UT) still exist in the paper system. Much taxonomy, unitary or not, already resides on the Web.

Arguments for and against adopting a unitary approach are considered and a resolution is attempted. Rendering taxonomy essentially Web-based is as inevitable as it is desirable. Apparently antithetical to the UT proposal is the view that in reality multiple classifications of the same taxon exist, since different taxonomists often hold different concepts of their taxa: a single name may apply to many different (frequently overlapping) circumscriptions and more than one name to a single taxon. However, novel means are being developed on single Internet sites to retain the diversity of multiple concepts for taxa, providing hope that taxonomy may become established as a Web-based information discipline that will unify the discipline and facilitate data access.

Keywords: unitary taxonomy; Web revisions; taxonomy; Internet; multiple classifications

1. INTRODUCTION

If taxonomy were ever to be funded in proportion to the amount it is discussed, there might be less concern about its purported decline. In the past decade or so, taxonomy (or systematics) has been the subject of inquiries twice over 10 years by the House of Lords Select Committee on Science and Technology, a Natural Environment Research Council initiative and clusters of articles and correspondence in prominent journals—notably *Nature*, *Science* and *Trends in Ecology & Evolution*. The concern for the decline of taxonomy applies mainly to that side of the subject dedicated to taxonomic monography, which is the very area of the discipline engaged in cataloguing and describing biological diversity. Rather more support has gone into evolutionary research and into developing new methods in taxonomy.

Yet the various pleadings of taxonomists do not seem to have led to significant increases in funding for this element of systematics, although recent developments in the National Science Foundation in the USA are refreshing. Taxonomists' fondness of meetings and reports might indeed be counterproductive, as was suggested by Ashburner (2002). A better future for descriptive taxonomy, and a wider appreciation of its value, would seem more likely to be gained by conspicuous achievements from the taxonomic community generated, to start with, from the level of resources available now.

Improvement of the situation will almost certainly require a greater commonality of purpose—'balkanization' of 'the field of taxoinformatics' was another of Ashburner's concerns. Progress will surely need continued and much expanded engagement with the Internet as *the* fast evolving medium for providing access to information currently distributed across the published paper-based literature, in unpublished archives, in curated collections, and, increasingly, in personal or institutional databases.

The approach taken in this paper is as follows. Unitary taxonomy (UT) is considered in its generality and in the particular sense of Godfray (2002*a*,*b*). Two questions are then examined: the extent to which UT exists, including in an incipient form, and the degree to which taxonomists have used the Internet for posting taxonomic data. Examples of the data taxonomists are making Web-available are illustrated. Special mention is made of the international codes of nomenclature—particularly the various attitudes to electronic means of publishing data, and the unitary elements that they accept or promote. Besides the regulations, which largely constitute the codes, much opinion is expressed in these (necessarily) legalistic documents. Arguments for and against UT are addressed and the paper is concluded with an attempt at a resolution.

2. UNITARY TAXONOMY

Users of taxonomic information are typically attracted to the idea of having available a single, authoritative (preferred) classification to which the relevant specialist taxonomic community largely subscribes. Key elements of such classifications are to promote a stable nomenclature and to provide wide accessibility, with the most obvious medium for improving data accessibility being the Internet. But although many taxonomists have adopted this medium as a means of providing data, taxonomic

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information remains largely dispersed across 250 years' worth of printed publications. And although examples of single, authoritative classifications exist, a consensus classification for many groups is often difficult to achieve (Vane-Wright 2003).

The marriage between consensus classifications and the medium of the Internet was explored recently by Godfray (2002*a*,*b*) under the name of UT. Similar ideas were expressed by Thompson (1993) and some have been loosely considered within the taxonomic community over many years. The main points made by Godfray are expressly discussed here because their publication has provided a focus for recent debate.

Although a single, preferred classification can be created as a printed document, it was suggested that only by making taxonomy wholly Web-based would the discipline be effectively transformed into 'a twenty-first century information science...'. Indeed, given the relative inaccessibility of printed publications, it was suggested that the very survival of descriptive taxonomy is likely to depend on systematists adopting the Internet for publishing the results of their work. Preliminary (pre-publication) posting on the Web would enable a draft revision to be subjected to an agreed period of peer review. At present, publication on the Internet is disallowed by the international codes of nomenclature (e.g. the International Code of Zoological Nomenclature (Zoological Code), International Code of Botanical Nomenclature (Botanical Code) and the International Code of Nomenclature of Bacteria (Bacteriological Code)). Even in bacterial (prokaryote) taxonomy, where a new approved list of names (now Web-available) was adopted in 1980, and where registration is required for new names, publication on paper is still necessary. The taxonomic community, however, is clearly actively exploring the role of the Internet in improving data access in systematics.

It was also proposed, controversially, that once the author(s) of the revision had addressed and incorporated the results of the review by the taxonomic community, those names should be adopted formally. The 'principle of priority', a fundamental tenet of biological nomenclature, would be followed during the construction and peer review of unitary taxonomies. However, older names, identified as such subsequent to the accepted version of the Web publication for any given taxon, would fall into disuse (be 'unavailable' in zoological terminology). Adopting lists of names (making them official) would, it was believed, liberate taxonomists from spending excessive amounts of time on abstruse and largely purposeless issues of nomenclature, allowing them to concentrate on the more important function of classifying organisms. While fixing names is an expectation of the specific UT proposal, a lack of acceptance of such a convention would not undermine the idea of providing a Web-based revision on a single Internet site.

The UT proposal was made in response to a concern for the future well-being of descriptive taxonomy (the very part involved in cataloguing biodiversity), where funding is declining. The great unifying and standardizing strengths acknowledged to have been achieved by universal adoption of the international codes of nomenclature had, suggested Godfray, reached the point at which they were restricting the development of taxonomy.

Descriptive taxonomy, it was believed, fails to attract large-scale funds for three main reasons. First, taxonomists lack clearly achievable goals that are realistic and relevant. Second, the discipline suffers from the 'dead hand of 200 years of legacy and its interpretation'. Third, most taxonomic output is on paper rather than the Web, making it both expensive to publish and restricting it largely to specialist libraries. The classification of any group is, currently, 'an ill-defined integral of the accumulated literature on that group'. In the alternative unitary model it would reside in one place (on the Internet), be administered centrally, and be self-contained. Thus, all future work would refer only to the set of species in the first Web revision and, later, to those in the *n*th (or then current) Web revision. This suggestion implies that the decision on what names to accept would lie entirely with the taxonomic community and its peer review system: no role was proposed by Godfray (2002*a*,*b*) for the various international commissions to be the final arbitrators in, say, adopting lists of existing names or registering new ones. A final and essential requirement was that Web revisions should be free at the point of access.

Were such a unitary system to be adopted, management would be required both physically (servers and networks) and intellectually (taxonomic/editorial). Large museums and herbariums, those institutions associated with holding substantial collections, would be the natural administrative bodies.

Several advantages were cited for UT. Its development would be evolutionary rather than revolutionary, and its impact and wide availability might render it more attractive to funding bodies. A Web revision would also serve as an information hub by means of its inherent content and links to other sites. Species names cited in electronic journals of any discipline could be hot-linked to details of the species in the appropriate Web revision, and connections from the revision to Web-available legacy literature could also be made. A very practical advantage would be the extent of cheap space on Web servers compared with costly paper publication. Greater space would help taxonomists to be more expansive in their information, encouraging users less familiar with taxonomic terminology and protocols to be provided with a better explanation. More space would be available for illustrations, particularly colour where printing remains expensive—even if costs are easing. Free access to the information would, it was suggested, raise the profile of taxonomy and increase the number of readers.

Disadvantages noted were the extra costs associated with administration of the UTs. Special software, which is technologically demanding to produce, would need to be written to handle the complex Web sites and to support the Web taxonomies. Two sociological problems noted were the risk of cliques of taxonomists imposing their collective will on the broader community of workers, and the disenfranchisement of those without access to computers or Internet connections.

As is the case for revisions published on paper, Web revisions would be expected to include descriptions, keys or other means of identification, images of whole specimens, natural history and phylogenetic information. They would also provide links to a much greater range of biological work.

3. EXISTING ELEMENTS OF UNITARY TAXONOMY

The process of rendering a classification unitary is not, in principle, dependent on the medium of the Internet—unitary elements in taxonomy existed before the presence of the Web. To promote stability of nomenclature, taxonomists have long subscribed to certain basic and major standards. Despite divergence of the various international codes of nomenclature, these standards help unify the discipline. Two of them, the binomial system and the type concept, are followed universally. The third, the principle of priority, is fundamental to the Botanical Code and the Zoological Codes (Greuter *et al.* 2000; ICZN 1999, respectively), but requires a caveat when considering both the Bacteriological Code (Sneath 1992) and the less formal regulations for the nomenclature of viruses (Francki *et al.* 1990). Much discussed by the taxonomic communities, but by no means universally accepted, are proposals to consider new names validly published only when they have been registered, and to establish existing names by adopting lists of those already available (see Nic Lughadha 2004).

(a) *The binomial system*

The most profound and durable of these standards (notwithstanding the 'PhyloCode' www.ohiou.edu/phylocode/), is the binomial system of nomenclature. It did not, as is often tacitly assumed, appear suddenly, with Linnaeus (1753) for botanists, or Clerck (1757) and Linnaeus (1758) for zoologists, but evolved over many years (see, for example, Koerner 1999). Before Linnaeus's system, species had been referred to by brief diagnostic phrases, or 'phrase names' (Blunt 1971), which were both a cumbersome means of communication and combined description with nomenclature. Although Linnaean binomials often have a meaning (frequently cryptic) that applies to the species described, the strength of the system and the reason it has endured for 250 years lies in the separation of the processes of description and naming. It was suggested by Koerner (1999) that the binomial system was developed, at least in part, in response to the unsatisfactory use of *ad hoc* systems of abbreviations used by Linnaeus's collectors (typically his students) to communicate with their master. Information about specimens collected by these students, from parts of the world often far distant from their native Sweden, was relayed with reference to a small travelling library and by using a system based on words, numbers or both. Linnaeus was certainly not the first person to describe species; but we acknowledge his importance as the founding father of taxonomy because he was the initiator of an information system for the discipline.

(b) *Types*

Type specimens bear the names of species (and taxa of lower rank and, in botany, also of higher taxa). Although the rules about types and their designation are extensive, the working system is simple and practical. Type specimens are the physical means by which taxonomists arbitrate in cases of disputed species identity. As with the binomial standard, types would remain integral to UT. Anyone doubting the value of the type system need only study what occurred in bacterial taxonomy where the absence of type cultures meant that numerous names had no meaning (see below).

(c) *Priority*

The principle of priority, which states that the earliest name prevails, was adopted by convention, and later became established as one of the foundation stones of the international codes of nomenclature. Priority remains a powerful and straightforward means of stabilizing names, and communicating their original underlying taxonomic concepts, even if searching for older names has sometimes become an obsession. In fact, priority is not mandatory but can be overridden when nomenclatural stability is threatened. Large sections of the codes (particularly the Zoological Code) deal with exceptions to the principle of priority. Names in a refereed UT Web revision would be those in existence plus any that are new: there is no suggestion that existing names should be replaced (other than to meet nomenclatural requirements). Changes in subsequent Web revisions of a taxon, however, would establish the names accepted in that later revision.

(d) *Nomenclatural databases*

Databases of names may be treated as (unitary) standards provided that they are widely accepted as authoritative within the relevant taxonomic communities. Such standards are provided by the Global Species Databases (GSDs) of the Species 2000 initiative and the Electronic Catalogue of Names of Known Organisms (ECAT) programme of the Global Biodiversity Information Facility (GBIF). A limitation of such universal lists is that a single name may and often does subtend more than one taxonomic concept (Geoffroy & Berendsohn 2003). The issue of multiple classifications is discussed in § 6.

(e) *Adoption and registration of names*

Of particular significance to the UT proposal are the adoption of stabilized lists of current names and the mandatory registration of new names. Both mechanisms are requirements of bacterial taxonomy, although, unlike the UT position, names of bacteria are not validly published until they appear in an approved journal. In neither the Zoological Code nor the Botanical Code is the formal registration of new names required. Indeed, recent attempts made to emend the botanical code by incorporating mandatory registration were met with fierce resistance (Greuter & Hawksworth in Greuter *et al.* 2000, Preface). With regard to registration, in the latest (fourth) edition of the Zoological Code (ICZN 1999, article 79) a facility exists, albeit highly qualified, to allow international groups of specialists to compile lists of extant and known available names in major taxonomic fields, and to have these lists adopted by the Commission so that names absent from such a list would not be available (validly published).

(f) *Monographs*

The traditional printed taxonomic monograph plays a unitary role to the extent that it is sufficiently authoritative that taxonomists defer to it. The author of a monograph typically analyses critically previous classifications as part of the process of producing a revised scheme. The unitary effect of the work, however, will eventually be outlived as new species are described or new phylogenetic insights that change the structure of the classification are made. Eventually this leads to a new revision. By contrast, Web revisions have the potential to allow a gradual transformation of typical monographic content by the addition of new information as it is generated to a single site.

4. TAXONOMY ON THE WEB

The taxonomic community and its users might wish both for far more and for better-structured information on the Internet than that which is currently available. Nevertheless, many systematists have embraced the Web enthusiastically as a medium for taxonomy, and much taxonomic data exist on the Internet. Moreover, several Web sites hold, or are constructed to hold, information on a target taxon worldwide. While posting taxonomic information on the Internet does not render it unitary as such, a gradation of Web sites can be observed from nomenclatural lists to complex, information-rich sites that are close to the UT model. Like Web content generally, taxonomy on the Internet has arisen idiosyncratically, but the more taxonomy that is posted the sooner will an infrastructure emerge, simply by virtue of volume.

An important qualification to such an emergent infrastructure is the need to control quality. Anyone can publish, whether on the Internet or in print, but the content of scientific journals will typically have been subjected to peer review and thus to some restriction by editorial boards or particular societies. Although the Web sites described below have not, as far as I am aware, been subjected explicitly to external review, many of the data have been derived from peer-reviewed, printed publications. A more transparent system of peer review for Web publication is something that will be needed both to maintain quality and to give credit to authors.

To provide some idea of the range of taxonomic Web sites, I have divided those mentioned, somewhat arbitrarily, for there is no sharp division between them, into a few main categories. The examples selected mostly have components illustrating incipient or well-developed UT elements.

(a) *Nomenclatural*

This first category of taxonomy on the Web is of special interest to proponents of UT. A List of Bacterial names with Standing in Nomenclature is available at www.bacterio.cict.fr/index.html, and an Index of Viruses is posted at www.ncbi.nlm.nih.gov/ICTVdb/Ictv/fr-index.htm. The information on viruses is particularly impressive, with lists of names (complete) and descriptions (with variable amounts of detail, but often extensive) generated from the universal virus database of the International Committee on Taxonomy of Viruses (ICTVdB). The database, which continues to grow, is certainly a model for UT. It is an expressed goal of the ICTV 'to build and make available to all virologists, worldwide' such a universal database 'encompassing data that are now used in developing and managing the universal system for virus taxonomy'.

These lists have an expressly unitary role. They emerged largely through necessity because the taxonomy of these micro-organisms was so confused as seriously to effect progress in understanding their biology. Clearly the international communities working on them accept the lists as authoritative and the names as authorized. Although there are several groups of animals and plants that benefit from having much data about them Internet-accessible, their degree of authority is determined by the level of respect they receive from the international community; the names are not posted as approved lists.

An example of a high-quality eukaryote Web site is that to the orthopteroid insect orders (grasshoppers, crickets and their relatives) http://140.247.119.145/Orthoptera/, which contains information on the names, including synonyms, of over 25 000 species and genera. Although much detail has yet to be added, the authors (Otte & Naskrecki 1997) intend the site to become established as a global database for the groups, holding data beyond the current taxonomic content. Included, besides synonymy, are literature citations, distribution data, many images of whole specimens (including types) and morphological characters. There is a field for description and biology. A novelty of this site, and a decided move towards a UT for these insects, is that taxa identified as new are recorded and may be given a provisional name on the Web site, although these are of no nomenclatural standing because they are not validly published. The Web site is a cooperative initiative with the Orthopterists' Society, an international organization of the very kind anticipated to play a central role in UT. The detail provided by the site and its future scope goes well beyond a list. It could be placed in the next category, but is cited here because it has grown from a nomenclatural project.

Another ambitious project is the BioSystematic Database of World Diptera (www.sel.barc.usda.gov/diptera/biosys.htm; Thompson 2000). Approximately 150 000 species of fly have been described and over 250 000 names exist. The database has three main components: a nomenclator, which is 75% complete; a file for references, which is *ca.* 20% complete; and a species database and portal, which is at the planning stage.

The Universal Chalcidoidea Database (www.nhm.ac.uk/entomology/chalcidoids/; Noyes 2003) includes an enormous amount of information on this superfamily of parasitoid wasps. Incorporated is a bibliographic database listing over 40 000 references, which can be searched using 120 predefined keywords. This system enables users to locate references dealing with specified subjects. A similar search can also be conducted in the taxonomic part of the database.

Another Hymenoptera Web site with a nomenclatural backbone is Antbase (http://research.amnh.org/entomology/social_insects/) with records for each species being linked to associated information, notably on life history and distribution. Antbase is linked to an online bibliography database and has many pdf files available on ant literature. The site is already a rich source of information, and is under active development.

An example of a basic online list of names is that for spiders (http://research.amnh.org/entomology/spiders/catalog81-87/index.html; Platnick 2003). The site provides a taxonomic catalogue to the world genera and species of spiders, with a comprehensive list of references dating back to 1757. A similar alphabetical list of the current valid scientific names of birds of the world is available at www.zoonomen.net/ (Peterson 2002) and is based on the publication by Sibley & Monroe (1990).

Digital images of the index cards comprising a unique nomenclatural archive of the insect order Lepidoptera have been prepared (Beccaloni *et al.* 2003). The Lepidoptera comprise *ca*. 10% of the names of all described animals. Card images to the genera and species group names of the Pyraloidea and related superfamilies are available online at http://www.nhm.ac.uk/entomology/lepindex/ and an indexing mechanism to the remainder is being completed so that they can also be posted.

Nomenclatural and biological data are combined on the botanical Web site ILDIS—the International Legume Database & Information Service (http://www.ildis.org/database/), which documents and catalogues the legume species of the world. Its nomenclatural database, LegumeWeb, contains records for over 19 000 taxa. UT components of ILDIS are apparent in the use of a consistent, worldwide classification, and a system of management by which the database is updated by a network of expert taxonomic coordinators. The data given for each taxon include the name, broad distribution and a direct link to the name in the TROPICOS nomenclatural database of the Missouri Botanical Garden (http://mobot.mobot.org/W3T/Search/vast.html), itself a substantive source of information about plant names.

(b) *Descriptive Web sites*

Certain Web sites have been constructed as vehicles for descriptive information. Some of these are exact online reprints of printed publications, typically in the form of PDF files. The online version of volume 3 of *The moths of Borneo* (Holloway 1987) at www.arbec.com.my/moths/index.htm shows how taxonomic revisionary work can be transferred to the Internet once the legalistic demands of paper publication have been satisfied. A botanical equivalent may be found at http://plantnet.rbgsyd.gov.au/iopi/iopispp1.htm, where the International Organization for Plant Information (IOPI) is posting taxonomic data on the Internet by publishing, through the Species plantarum Project, Web versions of *Flora of the world* (www.deh.gov.au/biodiversity/abrs/publications/special/plantarum.html). This site also has provisional elements of a global plant checklist.

These sites illustrate the general point that once the criteria of what constitutes valid taxonomic publication are met, typically by the presence and availability of multiple copies of a paper version, there is nothing to stop taxonomic works (as with others) being made accessible on the Web. The journal *Zootaxa* (www.mapress.com/zootaxa/index.html) provides rapid, refereed publication with paper versions effectively produced for the purpose of validation: the emphasis is on online access.

Examples of sites composed of individual Web pages (not based on a relational database structure), and published on the Internet, rather than taking the form of an electronic reprint of a printed publication, are those to sea urchins (class Echinoidea) and to bumble-bees (the Hymenoptera genus *Bombus*).

The 'Echinoid Directory' (www.nhm.ac.uk/palaeontology/echinoids/; A. B. Smith) is being populated with information over the long term. The basis of the site is an alphabetical listing of genera, with a link from each name to a Web page with detailed information on the genus with which the names are associated. Currently, 350 pages are populated with information representing coverage of *ca*. 30% of the genera. Full treatment of a genus includes: citation of the original reference and, if appropriate, synonymy; a series of photographs of specimens; details of the type species; a list of diagnostic features; distribution; the higher classification; and a section entitled 'Remarks', which highlights special features and important monographic works on the genus.

Taxonomic treatments are also given for members of *Bombus*, with 239 species and many more names (www.nhm.ac.uk/entomology/bombus/; P. A. Williams). The stated purpose of this site is to provide a framework and encourage further research on the group. An attractive feature of the site is the presence of distribution maps for the species using the Worldmap software (www.nhm.ac.uk/science/projects/worldmap/index.html; P. A. Williams).

A particularly rich Web site is FishBase (www.fishbase.org/home.htm; Froese & Pauly 2002), a global information system (not purely taxonomic) with a wealth of data on fishes for various readers, including fish researchers and fisheries managers. It has elements specially designed for use by the general public. The scope and magnitude of FishBase requires that it be underpinned by a relational database. The Web site has been constructed and is maintained by an impressive consortium of institutions (a feature strongly encouraged by UT), and has gained the support of several funding bodies. Numerous illustrations provide both drawings and photographs, and there is much descriptive information, many anatomical measurements, and details of distribution (including point data and maps) and diet for individual species. Links to other Web sites provide access to specimen data for a given species. FishBase is not a Web revision, but rather a site that posts information derived essentially from secondary sources in an attractive and well-integrated form. However, our knowledge of the biology of fishes is such that its content is more comprehensive than could be achieved for many groups—particularly most invertebrates. FishBase has several of the elements one would wish to see in a Web revision, but it is not a primary taxonomic site.

(c) *Web sites of taxonomic institutions*

Almost all museums and herbariums have institutional Web sites. Increasingly, these are also being used to host taxonomic databases besides providing a public interface. In the larger institutions they are often highly developed integrated sites and also host or mirror those of other organizations with which they collaborate or which share their goals. An example may be found at www.nhm.ac.uk/hosted_sites/index.html on the Web site of the Natural History Museum, London. Institutions can, therefore, have a unifying effect by providing access to their own data and by supporting associated initiatives.

At the Web site of the Royal Botanic Gardens, Kew, ePIC, the electronic Plant Information Centre (Royal Botanic Gardens, Kew 2002), has a portal allowing users to search Kew's major specimen, bibliographic and taxonomic databases. One of these databases, the International Plant Names Index (IPNI), at www.ipni.org, with a list of *ca*. 1.4 million plant names, is a collaborative effort between Kew, the Harvard Herbarium and the Australian National Herbarium, Canberra. This example also shows, reassuringly, that, like some of those mentioned above, authoritative taxonomic sites can be, and are being, developed by members of the international community. Kew also hosts a world checklist of Fagales (Royal Botanic Gardens, Kew 2000). A general or more specific search can be made to a particular taxon, which will provide access to typical checklist information such as name, author, date of description and reference. Additionally, a linked table provides basic distribution data to species. There is a wealth of taxonomic data available by clicking on the various entries at www.rbgkew.org.uk/data/az.html.

(d) *Infrastructures*

The nomenclatural Web sites for bacteria and viruses, already mentioned above, are comprehensive and have become part of the infrastructure for their user communities. The growth in other taxonomic material being posted on the Internet, and the pressure on the taxonomic community to demonstrate its wider function more conspicuously, have led to attempts to consolidate information or, alternatively, to improve navigation across distributed systems of databases and various Web sites by means of portals and common access systems.

To provide information about diversity, history and characteristics of all organisms is the aim of the Tree of Life http://tolweb.org/tree/phylogeny.html, a collaborative Web project, produced by biologists from around the world but edited centrally. Whereas much information is already present, it is a massive and very long-term initiative. The site, although informative, is not intended as a primary source of original taxonomy. It takes the form of a series of Web pages, each page containing information on a group of organisms (e.g. Coleoptera, Cephalopoda, fungi, frogs). Underpinning the project is an evolutionary tree, which links all the individual pages. Users can cruise the site by means of the trees, which are present on each individual page. Links are made from each major group to subgroups and to some species.

Species 2000 is an example of a system of databases, specifically GSDs, distributed across many institutions (www.sp2000.org/). The aim of the initiative is to encourage the construction of GSDs covering the world's organisms and link them to the Species 2000 system allowing access to information through a Common Access System. This federated approach depends on those who create and contribute GSDs to update their databases. Several basic fields are required to meet the GSD standard defined by Species 2000. A similar North American and Mexican initiative (the Integrated Taxonomic Information System, ITIS; www.itis.usda.gov/), is a partner of Species 2000 and has both regional and global databases. Both Species 2000 and ITIS are essentially lists of species with fundamental nomenclatural information associated.

A list of names, however, provides just one classification. Attractive as a single and supposedly authoritative or preferred classification is to many users, multiple classifications and multiple taxonomic concepts, past and present, actually exist in the literature and in databases. In the Prometheus Taxonomic Model (Pullan *et al*. 2000; and see www.prometheusdb.org), it was emphasized that different concepts of any taxon are most objectively compared on the specimens on which their circumscriptions are based. (For other models addressing the issue of multiple classifications see Berendsohn 1995; Ytow *et al.* 2001; Geoffroy & Berendsohn 2003.) Although the Prometheus project is not a Web site with taxonomic data, it demonstrates that specimen information underpinning taxonomic revisions can be incorporated into a taxonomic model to provide objective comparison of multiple classifications. The model was designed for botanists, specifically incorporating regulations in the Botanical Code, but the problem being addressed applies to all taxa. Prometheus is a taxonomic tool, but is considered here because, were it to be adopted widely, it would have a structuring effect on improving objectivity in comparing classifications and retaining legacy information. This does not prevent preferred classifications being proposed. Multiple taxonomies and their implications for UTs are addressed in § 6.

Considerable enthusiasm exists among the curatorial community for computerizing data at the unit (i.e. specimen and observation) level in museums and herbariums (see, for example, Berendsohn (2000 and http://www.bgbm.fu-berlin.de/biocise/), Scoble (2003 and www.nhm.ac.uk/science/enhsin/) and BioCASE (a Biological Collections Access Service for Europe) (www.biocase.org)). Databasing specimen information in collections has been motivated largely for purposes of collections management and to provide wider knowledge of, and access to, material. Although revisionary taxonomists will value information about such potential sources, the quality of the data is likely to be highly variable. The identities of most specimens databased from collections have not been established by thorough taxonomic analysis. It is specimens on which taxa are actually circumscribed (not just types) that are of the greatest value in comparing taxon definitions objectively.

A concern of simply keyboarding data on specimens in a collection, and then posting the details on the Internet without critical taxonomic judgement, is that the Web is as effective a means of disseminating misinformation as it is of providing access to high-quality data. Although further progress is needed, conceptual and practical links between unit-, collection- and species-level databasing are being explored, not least by Prometheus and related projects. Whereas UT was framed in terms of taxonomy at the revisionary level, integrating specimen-level information will enrich and inform the endeavour. With increasing storage capacity on servers, there is ample opportunity for the incorporation of specimen and observational data (unit data; see Berendsohn 2000, 2003) on taxonomic Web sites.

It has been suggested that species might best be defined by using molecular sequences. If they could, and if sequences were to be collected across all organisms routinely, the infrastructure so created might have a unitary effect, at least for identification. So-called 'barcoding' (see Blaxter 2004) of species, using mitochondrial gene sequences to give objectivity to species definitions and identification, was proposed by Hebert *et al.* (2003), who considered that a database of such barcodes should be established for all organisms, thus facilitating biodiversity assessment and taxon identification. In a similar mode, Tautz *et al.* (2003) proposed 'a DNA taxonomy system to provide a new scaffold for the accumulated taxonomic knowledge and as a convenient tool for species identification and description'. Apart from doubts about just how objective such sequences are, serious reservations have been expressed about the defining role of such data in taxonomy (Lipscomb *et al.* 2003; Seberg *et al.* 2003; Scotland *et al.* 2003). The practicalities of building what would essentially be a new taxonomic infrastructure of such breadth are surely immense. Although such data might have a role in facilitating identification, there is a fear that giving them a central position in taxonomic systems would impoverish the much wider information base that is so much needed in describing biodiversity.

5. THE INTERNATIONAL CODES OF NOMENCLATURE AND UNITARY TAXONOMY

Although nomenclatural acts cannot validly be published on the Internet at present, publication using a method other than paper after 1999 is allowed in zoology if the work is permanent, if copies are multiple and made available freely or by purchase, and if they are deposited in at least five major publicly accessible libraries (ICZN 1999, article 8.6). CD-ROMs, therefore, are an acceptable medium for publication. Remarks made in the latest edition of the Zoological Code reveal a view that the community is moving closer to publication of taxonomy on the Internet. By contrast, the Botanical Code expressly excludes electronic publication where nomenclature is involved, although subsequent online versions of publications with taxonomic novelty are common. So for an increasing amount of taxonomic literature, publication on paper meets legalistic requirements while users gain access to that information on the Web. A mood is apparent within at least a part of the taxonomic community that we are in a transition from one form of publishing (on paper) to another (on the Web).

Approved lists of names are examples of UTs with new nomenclatural starting dates. The starting date in the codes are Linnaeus 1753 for many plant taxa (there are later dates for others), and Clerck 1757 and Linnaeus 1758 for animals. The principle of priority is followed back to these dates for names, but there are provisions in the codes for accepting names other than the earliest if nomenclatural stability is threatened. Given the flexibility inherent in this proposal, and the effective referral of species names to name-bearing (type) specimens, neither the zoological nor botanical communities have found it necessary to adopt new (later) start dates for their respective nomenclatures. Where problems have been encountered, resolution has been possible on a case-by-case basis (see Knapp *et al.* 2004). Regulatory bodies publish the outcomes, and the resulting lists have elements of a unitary system in adopting names that may not always be the oldest. However, they fall short of the UT proposal.

Even some taxonomists may be surprised to learn that explicit provision actually exists in the latest edition of the Zoological Code (ICZN 1999, article 79) for international bodies to propose, in consultation with the Commission, 'that the Commission adopt for a major taxonomic field (or related fields) a 'Part' of the List of Available Names in Zoology. If, after a long process of consultation with the relevant taxonomic community, such a list is adopted, then a name occurring in the list will be 'deemed [to] be an available name and to have the spelling, date, and authorship recorded in the *List* (despite any later evidence to the contrary)'. Furthermore, and significantly, 'No unlisted name within the scope … of an adopted Part of the *List of Available Names in Zoology* has any status in zoological nomenclature *despite any previous availability*' (my emphasis). This provision goes a considerable way towards meeting the UT proposal on fixing names. It differs from UT in not being Web-based, in the rather longer period required for the community to make its assessment and suggest changes to the Part, and in requiring formal acceptance of the Part by the Commission. (For further comment see Ride in ICZN (1999), pp. xxv, xxviii, and Minelli & Kraus in ICZN (1999), p. xvii).

The Botanical Code (Greuter *et al.* 2000) does not offer the botanical community the same possibility. Rather, lists of conserved names for families, genera and species are published in appendices, such names being 'legitimate even though initially they may have been illegitimate'. Such *nomina conservanda* are intended to confer stability of nomenclature.

In contrast to the Zoological Code and the Botanical Code, an entirely new start date (1 January 1980) for the names of bacteria (prokaryotes) was adopted by the Bacteriological Code. The enormous numbers of names unrecognizable to taxa required a radical solution (Sneath 1986), and this was provided by priority of bacterial names being based upon the Approved Lists of Bacterial Names (Skerman *et al.* 1980). Names that were not included in these lists lost standing in bacterial nomenclature. Bacterial nomenclature was, in effect, made unitary. Before they can be considered validly published, taxa described since 1980 must be described in the *International Journal of Systematic Bacteriology*, a more formal and restrictive requirement than would be expected in UT.

6. DISCUSSION

Few taxonomists are likely to object to their revisions being made more accessible by having them posted on the Internet, provided that authorship is credited adequately, and peer-review criteria are established to give any publication academic credibility. Although these qualifications have not been resolved fully, solutions are likely to be found.

There remains no full UT Web revision on the Internet, although, as shown above, Web sites with substantial UT components exist. At present, what can broadly be described as taxonomic information on the Internet is growing idiosyncratically, as is the case for much other Web content. Although much of the value of the Web lies in such unplanned growth, the essence of UT is to render classifications available at a single site.

(a) *Arguments supporting unitary taxonomy*

(i) *Better access to information*

Having a rich, unitary and authoritative source of information for any group of organisms would be invaluable both to the broader user community and to those many systematists distant from major collections and specialist library facilities. That at least some part of the taxonomic community is capable of agreeing and implementing a radical mechanism for a unitary system of nomenclature (Web- or paper-based) has already been shown for bacteria.

For many species-rich taxa there is rarely more than one specialist (or team) in a position to compose a worldwide catalogue, let alone a full revision. On those relatively rare occasions when contemporary taxonomists are publishing on the same group, the community will have to live with any discordance: in some cases, differences might stimulate further critical research. The problem of several different contemporary and primary classifications being generated is unlikely to prove serious for many groups, although there will be exceptions for high-profile taxa (Vane-Wright 2003). (The situation over multiple taxonomic concepts, both from the legacy literature, and from works generating functional lists from multiple sources, is a very different matter.)

Besides improved accessibility, a further advantage of having Web-based revisions is that they could be updated easily. Editors usually discourage publication of printed papers dealing with one or a few species of a higher taxon. A consequence of such delayed publication is that users are frequently denied access to revisions until the author(s) has resolved issues over all the species. Web publication of somewhat incomplete revisions would be a distinct advantage. Moreover, having an authoritative classification online would enable those contributing further, subsequent information to have a better chance of getting the taxonomy 'right' and enable users to be much better able to track changes and additions. It is of concern in this information age that Zoological Record still fails to record an estimated 10% of new animal names because there is no requirement that names must be registered to be validly published (Thorne 2003). Fears that a clique might dominate Web sites would seem to be far less of a disadvantage than the empowerment that authoritative taxonomic Web sites would provide.

(ii) *Free access*

At present, access to online publications from learned journals typically requires a subscription. Although taxonomists are usually interested in a limited number of taxa, coverage still falls generally across a wide range of journals requiring the unattractive prospect of multiple subscriptions. For those outside the taxonomic community who need access to information about a wide range of taxa, the difficulty is even greater.

This problem is particularly acute for taxonomy; papers in most other areas of biology tend to be restricted to fewer journals and the importance of legacy data is much less significant. Shifting taxonomy to the Internet and making the information free at the point of access would be a marked improvement over the current situation. Free access should not be confused with truly open source access. Ashburner (2002) drew a distinction between taxonomic databases, where access to data is typically made available through a Web interface, and those of the molecular community where major databases are available for unconditional downloading onto personal computers. He considered the same level of access to be essential for improving taxonomy.

(iii) *Redesigning the taxonomic revision*

Computerization of taxonomic information has the potential not just to post PDF files of printed monographs on the Web but to change the very form and usage of the revision. For example, interactive keys to taxa might be incorporated and the number of illustrations could be increased dramatically. Effectively designed, an electronic revision can enable users to move around more easily and cope with a wealth of information less accessible in book form. These advantages are capable of being provided by CD-ROMs or optical disks as well as by the Internet, but, as with paper products, these media lack the accessibility of the Web, have less space available, and probably will carry a charge. The Internet also enables the addition of dynamic links to related Web sites dealing with other aspects of the biology of the target taxon.

A novel approach to handling computerized information is the Web-based taxonomic editor software that was developed originally for the Euro+Med project (http://www.euromed.org.uk/). Euro+Med is an online database and information system for the vascular plants of Europe and the Mediterranean region with a critically evaluated consensus taxonomic core of the species concerned. This unites Web-based editing with a concept-orientated database model (the Berlin Model, see below; Güntsch *et al.* 2003). Although originally the editor was specific to the Euro+Med project, it is being expanded (MoReTax project, see below) to cover concept relationships more widely.

(iv) *Dual medium*

By no means does Web publication mean that paper versions cannot also be produced; I doubt that we shall ever wish to lose that model of good ergonomic design—the book. Printed field guides are a trusted medium, although handheld computers are likely to be used increasingly for field keys.

The tendency for many journals to make articles available both on paper and on the Internet has highlighted a distinction: print can still be used for legalistic purposes, while the primary means of accessibility shifts to the Web. Even with the extensive use of the Web in bacterial taxonomy, paper publication remains a requirement for valid publication of taxa. Since taxonomic papers differ from other scientific publications in having both 'legal' and scientific functions (Minelli 2003), a means of retaining the perceived security of paper, while providing the wider accessibility of the Internet, might be achieved by central deposition of paper versions and simultaneous Web publication.

(v) *Centralization*

Unlike other areas of science, once validly published, all taxonomic work making nomenclatural changes, whatever the quality, currently becomes part of the established taxonomic legacy and cannot be ignored. UT would help resolve this problem in two ways. The first Web revision of any group would be reviewed by all those interested in the taxon, rather than just selected referees, thus leading, potentially, to the best possible quality. Once published in its final form, the nomenclature adopted would mean that names excluded would be treated as unavailable. Although the legacy literature would, of course, remain available, future workers would not need to spend time searching it for older names, a process that has been described as the 'burden of history' (Thompson 1993) and denounced as 'bibliographical archaeology' (H. C. J. Godfray, personal communication). Gaining access to what is often rare literature is an extraordinarily difficult task for the large body of taxonomists working outside the few major taxonomic libraries. Thompson (1993) pointed out that systematists have currently to deal with the 'ancient history' of largely lost and forgotten names published 250 years ago. He suggested that the answer is to change the rules of nomenclature; gather together, as far as possible, all the existing names and, after a reasonable search, accept them as correct; and then require wide dissemination or registration of new names. Achieving consensus will be impossible in some cases, as was demonstrated vividly by Vane-Wright (2003) for a group of African butterflies, and users will have to live with discordant classifications. But this should not prevent the taxonomic community, probably through the forums of international societies, from agreeing a preferred classification while highlighting areas of debate.

(vi) *Internet taxonomy as a 'fait accompli'*

The existence of the Internet is increasing the expectation of users that information, of whatever kind, will be provided through this medium. This expectation will continue to grow. The new medium does not, as such, require a change in nomenclatural regulations but, with the increase in number of Web-based taxonomic databases, it is likely to hasten demands for nomenclatural consistency and registration, which are elements of UT.

(b) *Concerns about Unitary Taxonomy*

(i) *Paper remains valuable*

Although large Web sites are easier to navigate than large printed monographs, publications on paper continue to be valued not just for legalistic purposes but also for content. The Botanical Code is available online already, and the Zoological Code is expected to be made so soon. Yet many readers still find, and probably will continue to find, paper copies easier and often quicker to use. Furthermore, gaining access to sites on the Internet is often unreliable. Printed field guides are more accessible than those on handheld computers, although this situation may not remain the case for long.

(ii) *Is UT needed for all kinds of organisms?*

The new list of validly published prokaryote names formally adopted in 1980 (described as a new *Species plantarum* for bacteria by Sneath 1986, p. 39) was established precisely because bacterial taxonomy was in disarray. Problems of this magnitude did not, and do not, exist in zoological and botanical nomenclature, so no such radical solution has seriously been proposed. Names, including many from the time of Linnaeus, frequently have extant type specimens or adequate illustrations that act as types. Even without types, most early names, particularly of common species, have been associated with taxa. If there is a lack of clarity, actions by the respective communities or Commissions under their plenary powers have enabled resolution.

One consequence of the long history of zoological and botanical nomenclature is that modern rules have been able to enshrine long-standing practice, their complexity being the result of dealing with inconsistencies. Another is that protocols between the two have diverged over a long period. The magnitude of the resulting differences was considered to be so great that unification of the two codes seemed to Jeffrey (1986) a remote possibility, although he thought that some degree of harmonization of, for example, definitions and criteria for publication, might be achievable. This situation does not appear to have changed significantly, despite attempts to resolve the differences to encourage the emergence of a unified code of nomenclature (Greuter *et al.* 1996).

(iii) *Multiple taxonomies*

A fundamental concern over promoting UT is implicit in the word *unitary*. Although almost simultaneous publication of more than one classification for a group is not a frequent occurrence, there are multiple concepts behind almost every taxonomic name, so a modern 'consensus' is actually an imposition on the diversity inherent in the taxonomic history of any group. It is frequently overlooked that naming and classifying are fundamentally separate processes (Berendsohn 1995, 2003; Pullan *et al.* 2000; Ytow *et al.* 2001; see also the Universal Biological Indexer Organizer discussion at www.ubio.org/constituency/presentations/background/index.html). In the words of Pullan *et al.* (2000), using names as identifiers of taxon concepts 'unrealistically forces the adoption of a single consensus classification. Considering the increasing use of databases in botanical research and international policy-making ... we feel that these limitations are, in fact, driving decision-making concerning the standardization of taxonomic treatments and creating a false impression of the state of taxonomic knowledge. This compromises the scientific integrity of many data sets currently under construction, and is an area that requires serious and immediate consideration.' The authors propose a model for 'a system that supports all views of taxonomic classifications without forcing a judgement as to which are "correct"'.

Specifically, this model is designed to compare and manipulate 'multiple classifications arising from the combination of historical data, newly described taxa, new revisions, and conflicting opinions in an unbiased matter'. So if a taxon is a concept, any name has meaning only in the context of that taxon. The most time-consuming part of the work of taxonomists is caused, I suspect, less by an obsession with nomenclature and finding the oldest names, than with the need to understand the taxonomic concept behind each name when reviewing alternative taxonomic treatments in the legacy literature. We may hope that the most recent revision of a group is an improvement on previous ones, but alternatives reflect disagreement on interpretation of data (Pullan *et al.* 2000). With molecular data being used increasingly in taxonomy, the number of alternative classifications is likely to increase.

The Prometheus system, in which different classifications of a group are capable of being compared and manipulated on the basis of the actual specimens and observations used in the construction of the various classifications, is emerging as a powerful tool. It is geared, however, rather more to the taxonomist than the wider user. An attempt to combine the benefits of including multiple concepts of a taxon into taxonomic database systems while providing a 'preferred taxon view' has been the subject of research by Berendsohn (1995, 2003), who, with his colleagues, has developed a concept-based taxonomic information model (the Berlin model). Both approaches differ from the more restricted system of providing GSDs, the latter typically imposing a universal system of names or, at best, one with a single alternative.

The problem of multiple classifications is by no means confined to the better-studied groups such as flowering plants, birds and butterflies. Indeed, the extent of the problem was summarized by Geoffroy & Berendsohn (2003) from a study of German mosses by Koperski *et al.* (2000), which is not a high-profile group. By allowing different taxonomic concepts to be included in dedicated taxonomic computer software, it became possible to evaluate the stability, or lack of it, of names and concepts for the mosses. Results revealed that for only 13% of the taxa were both the name and the taxonomic concept stable and thus usable for databasing.

The above has significant implications for the way we view UT. However, the fact that data models are being developed to account for multiple taxon concepts in databases means that taxonomic Web sites may still provide a single site of access for information on a taxon. Moreover, such access could enable comparison between non-congruent classifications (Prometheus), and also suggest a preferred classification without losing information in others (the Berlin model). A practical means of effective data retrieval from large networks can be enabled by a suitable thesaurus, such as that being developed in BioCASE (see Copp 2003).

Although many users might prefer a single, stable classification for any given group, the taxonomic universe is not structured to meet that preference. Prometheus and MoReTax are attempting to provide a practical resolution to the complex situation that pertains in taxonomy.

7. CONCLUSION AND OPINION: TOWARDS GREATER UNIFICATION

In their response to the original proposal, Knapp *et al.* (2002) had two main criticisms of UT. First, they suggested that taxonomists would be unwise to abandon a system of regulation that has worked reasonably well for so long. Second, they noted that there is already a great deal of taxonomic information available on the Web. I agree strongly that taxonomy should be perceived as an information science based on the Internet with, preferably, a single, authoritative Web site for any given taxon agreed by the relevant section of the taxonomic community. Progress with incorporating multiple taxonomic concepts and multiple classifications into single Web sites are encouraging and, if made functional, will meet the main objection to UT. There is little sign as yet that the broad taxonomic community is prepared to agree to adopting lists of names, but this should not prevent Web revisions from being implemented. Indeed, there does not seem to be any good reason for taxonomists to do other than endorse their construction enthusiastically. Resisting the idea of re-basing taxonomy on the Web seems as perverse as an early taxonomist insisting on the use of phrase names instead of Linnaean binomials.

Despite what taxonomists often suggest, financial support does exist for the discipline. Unfortunately (my opinion), although much of this support is being placed in areas of high-quality science, it is the kind of research that is less pressing than that dedicated to documenting the biodiversity of the planet (see Wheeler 2004). Many descriptive taxonomists seem to accept that their work is somehow less interesting or demanding than question-driven research. This is a misperception: understanding taxonomic structure, revising that structure taxonomically and integrating associated complex and diverse information is no less intellectually challenging.

Members of the taxonomic community would be well advised to embrace the technical developments that could turn taxonomy into a coherent infrastructure. Fortunately, there is considerable support for the medium of the Internet, even if one continues to be frustrated by the large number of 'sites under construction'. Although we may wish for more money, funding for taxonomy by the American National Science Foundation's Partnerships to Enhance Expertise in Taxonomy (PEET) programme and from the European Commission for treating collections as an infrastructure are encouraging. Taxonomists may feel that funding for infrastructures might be focused on producing more and better content. I empathize, but a more constructive approach, surely, is to compromise by engaging with bodies that evidently are prepared to support collections-based work, so as to make the conceptual and practical links, say, between mechanistic specimen databasing and those computer models that integrate taxonomic concepts with specimen data. Funding bodies often value such connections when reviewing policy. There is an iterative process between funders and funded, and the taxonomic community might do well to be demonstrably more conscious of it.

Certainly, limited support for the creation of taxonomic content (revisionary work) is more worrying. Collection-rich institutions tend to assign much of their research allocation to question-driven work (understanding the processes that underlie biological patterns rather than analysing and describing their structure) and their infrastructural support to the management and curation of the collections. A consequence of such a policy is that content development of the kind typified by revisionary research is squeezed, falling between 'cutting-edge' research and curation. Here again, revisionary taxonomy could well be made more conspicuous by aggressively adopting the Internet as its primary medium so rendering data content better available and unified. Revisionary taxonomists, who argue that the Internet is merely the medium, should appreciate that this medium has a transforming power that differs from others, both in shaping the message and in the dissemination of its results.

I do not share the view that most Web-based classifications are likely to suffer from being run by a clique dominated by the larger institutions. Cynics might retort that this is because I work in one. Yet what I encountered in surveying taxonomic Web sites for this paper were, on the contrary, many more signs of cooperation and collaboration. Building effective taxonomic infrastructures requires all the data that we can get, provided that quality controls are in place. Such controls are already evident in the form of the taxonomic coordinators, located across the world, for the ILDIS (legume) database. Although doubtless there are exceptions, signs so far suggest that Web sites are authoritative rather than authoritarian. Should competing classifications be developed, rendering them Web- rather than paper-based is likely to speed the process of natural selection or lead to a better classification by comparing the strengths and weaknesses of what are likely to be overlapping systems. The threat of over-dominance seems small compared with the gains to be made in reducing what is seen within and beyond the taxonomic community as a currently chaotic situation (Thompson 1993; Godfray 2002*a*,*b*; Ashburner 2002).

The idea of treating the nomenclature of the current Web revision of a taxon as the accepted version is the equivalent of having a series of new start dates for particular groups, but without needing to gain the authorization of the relevant nomenclatural body. Despite the example of the bacterial taxonomists, it is unlikely that the botanical and zoological communities will follow the procedure of adopting existing names or registering new ones in the near future—although registration is more likely to be agreed than adoption. Much more important will be the need to ensure that *unitary* classifications do not lose the richness inherent in multiple taxonomies by failing to address the distinction between the processes of naming and classification. Fortunately, the fact that multiple concepts do seem capable of being incorporated into taxonomic models means that the richness in the taxonomic system can potentially be retained in single Web revisions. This suggests that Web revisions might better be viewed as having a unifying rather than a strictly unitary function.

Even if the Web offers taxonomists a very different medium with special advantages for providing wide access to data and novelty of form, the most demanding requirement of taxonomists lies in the labour-intensive creation of content. There is no short-cut to the processes of comparing, analysing and describing the diversity of organisms. Yet, even with this proviso, that of the existence of multiple taxonomic concepts, and the restrictions of the current international codes of nomenclature, there is no reason why a Web revision cannot or should not be constructed as a trial. It is tempting, sometimes, to become too academic. The answer, surely, is to try.

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GLOSSARY

BioCASE: Biological Collections Access Service for Europe
GSD: Global Species Database
ILDIS: International Legume Database & Information Service
ITIS: Integrated Taxonomic Information System
UT: unitary taxonomy