

WORKSHOP REPORT

The Future of Botanical Monography: Report from an international workshop, 12–16 March 2012, Smolenice, Slovak Republic

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Abstract Monographs are fundamental for progress in systematic botany. They are the vehicles for circumscribing and naming taxa, determining distributions and ecology, assessing relationships for formal classification, and interpreting long-term and short-term dimensions of the evolutionary process. Despite their importance, fewer monographs are now being prepared by the newer generation of systematic botanists, who are understandably involved principally with DNA data and analysis, especially for answering phylogenetic, biogeographic, and population genetic questions. As monographs provide hypotheses regarding species boundaries and plant relationships, new insights in many plant groups are urgently needed. Increasing pressures on biodiversity, especially in tropical and developing regions of the world, emphasize this point. The results from a workshop (with 21 participants) reaffirm the central role that monographs play in systematic botany. But, rather than advocating abbreviated models for monographic products, we recommend a full presentation of relevant information. Electronic publication offers numerous means of illustration of taxa, habitats, characters, and statistical and phylogenetic analyses, which previously would have been prohibitively costly. Open Access and semantically enhanced linked electronic publications provide instant access to content from anywhere in the world, and at the same time link this content to all underlying data and digital resources used in the work. Resources in support of monography, especially databases and widely and easily accessible digital literature and specimens, are now more powerful than ever before, but interfacing and interoperability of databases are much needed. Priorities for new resources to be developed include an index of type collections and an online global chromosome database. Funding for sabbaticals for monographers to work uninterrupted on major projects is strongly encouraged. We recommend that doctoral students be assigned smaller genera, or natural portions of larger ones (subgenera, sections, etc.), to gain the

necessary expertise for producing a monograph, including training in a broad array of data collection (e.g., morphology, anatomy, palynology, cytogenetics, DNA techniques, ecology, biogeography), data analysis (e.g., statistics, phylogenetics, models), and nomenclature. Training programs, supported by institutes, associations, and agencies, provide means for passing on procedures and perspectives of challenging botanical monography to the next generation of young systematists.

Keywords classification; internet; monograph; nomenclature; phylogeny; revision; synopsis

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■ INTRODUCTION

Monographs provide the cornerstones for systematic botany. These significant publications contain the basic statements of relationships among organisms, often focused at the specific level. To articulate this goal requires documenting vegetative and reproductive structures, modes of reproduction, distributions, ecology, biogeography, and evolution, along with clarification of correct names and affinities with related taxa (i.e., proposing a predictive classification). Armed with this information, valuable studies on evolutionary biology, floristics, and conservation can be completed. For understanding the dynamics of the evolutionary process, information is required on which species are closely related to each other. In fact, without basic information on sister-group relationships, it is virtually impossible to understand mechanisms of organic evolution. It is also fundamental for conservation issues to have precise ideas of morphological and geographical boundaries of species. Monographs also furnish data for reaching sound decisions about conservation by circumscribing rare and cryptic species often hidden among more common ones (Balakrishnan, 2005; Bebbler & al., 2010).

Monographers often have the best knowledge to perceive and circumscribe all the species in the group they study, which allows them to expertly identify living and preserved specimens of that group. This can be very important in many fields where accuracy of species identifications is needed. Measures of species richness, for example, are critical in ecological studies and assessments of conservation strategies—in these cases, the accuracy of these measurements is only as reliable as the species identifications upon which they are based (Gotelli, 2004; Godfray & al., 2007). In the emerging field of DNA-based determination of specimens (i.e., DNA barcoding; e.g., Hebert & Gregory, 2005), critical identification of reference specimens by a monographic expert is crucial. Furthermore, modern monographs are not simply a rehash of old taxonomies—an analysis of monographs in the *Flora Neotropica* series showed that over one-quarter of the species treated were described as new by the author of the monograph (Thomas, 1999, 2005).

The creation in recent years of JSTOR Plant Science and the Biodiversity Heritage Library (BHL), plus other online bibliographic repositories, have enhanced and improved monographic research through easier access to previously published information. This is particularly important in systematics

because we never escape the literature of the past—we continue to add to it each year. JSTOR has become the principal digital repository for botanical journals that contain plant taxonomic information, while the BHL is becoming the main site for digitized versions of books and journals that are no longer covered by copyright. Efficient and thorough access to published articles and books offers more powerful literature tools for the completion of contemporary monographs.

Monographers also analyze type specimens to make decisions on taxonomic concepts and proper nomenclature. It is in the hands of the monographer that the historical and biological data from type specimens can be evaluated and reinterpreted for the broader systematics community. As a large investment in digitization of type specimens of plants has already been made through the Global Plants Initiative (with JSTOR Plant Science and the Andrew W. Mellon Foundation; cf. Smith & al., 2011, on the African Plants Initiative); it makes sense to emphasize ways in which monographic studies can use type specimens more effectively and how results of these studies can be disseminated more widely by using the Internet.

That electronic publication of monographs is now possible also opens up new dimensions for inclusion of (and linking to) photographs of natural habitats, photographs of plants in their natural setting, illustrations of plants, type (and other) specimens, data analyses, comparisons, and interpretations. As digital space is virtually without limit, extensive illustrative materials can be presented to document features of species and their relationships to each other. It will also be possible to develop more powerful search or data-mining tools, to allow improved machine readability of monographs and thus lead to their more efficient use. Open Access is also an opportunity for dissemination of content instantaneously to anyone with Internet connections. These many developments can only result in more informative and rapid communication for users of monographs, both amateur and professional.

Furthermore, tools now exist to harvest the rich content of monographs. Various programs from GoldenGate (now a part of Oracle) allow semi-automatic mark-up of treatments and their elements for either exporting to databases or creating semantically enhanced documents. CharaParser (Cui, 2012) allows discovering and extracting morphological characters and states in monographic treatments that, if exported into data matrices, can create new identification keys or can “seed”

character databases, such as shown by Cui (2012) for the *Flora of North America* and *Flora of China*.

It is possible to recognize three types of monographic publications (Stuessy, 1975, 1993): (1) The *synopsis* (e.g., Robinson, 1901), whereby information is provided on species as far as practicable with available resources. This means that perhaps not all species will be described, all type specimens may not have been consulted, little ancillary information might be given, and no phylogenetic analysis is furnished. (2) The *revision* (e.g., Stuessy, 1978). This covers in comparative fashion all the necessary perspectives on species limits, distributions, nomenclature, and affinities, but it is limited in detail of information, particularly involving other types of data (i.e., beyond morphology and distribution). This type of approach has been advocated recently as the “foundation monograph” (Wood & Scotland, 2012). (3) The *monograph proper*. In addition to the basic information, this kind of work goes much further and includes lengthy data analyses, phylogenetic interpretations, discussions on modes of speciation, ecological and conservation aspects, etc. (e.g., Peralta & al., 2008). A monograph is also distinct from a Flora in that it is not geographically limited in scope and it includes substantial amounts of original research.

Over recent decades, particularly in view of the biodiversity crisis worldwide, attention from the systematic community has been to some extent re-directed toward the importance of monographic research (Prance, 1985; Hedberg, 1988). This interest continued into the 1990s, now with a strong call for more innovative and creative approaches to monography (Stuessy, 1993; Hopkins & al., 1998). A recent book has been published that stresses the importance of botanical monography (Stuessy & Lack, 2011a). Although this volume does an excellent job of emphasizing the importance of monography within broad contexts of our discipline, it does not provide a community-wide statement of specific perspectives and implementations. This was the task of the recent workshop, the outcomes from which are reported here.

■ OBJECTIVES AND ORGANIZATION OF THE WORKSHOP

The focus of the workshop was to assess the future of botanical monography and to offer recommendations for improvement. Several indicators have revealed that the training of plant systematists in botanical monography is dropping precipitously, especially in the developed world (Stuessy & Lack, 2011b). It is also realized that fewer young systematists are choosing monographs as vehicles of research within their Ph.D. programs. We are now in the DNA generation, and young investigators want to train using the newest molecular techniques and software for analysis. This is where most of the current jobs are, and young workers have understandably responded accordingly to train for maximization of employment success. The challenge is to encourage them to have expertise and fluency with DNA data and analyses, but at the same time to be able to utilize effectively a wide range of data and make the nomenclatural decisions necessary for monographic work.

If the new generation of workers focuses only on limited sets of data, the kinds of hypotheses they can tender will be limited, and how will our field advance into the future?

With generous support from the Andrew W. Mellon Foundation, and under the auspices of the International Association for Plant Taxonomy (IAPT), a workshop was held 12–16 March 2012 in Smolenice Castle, close to Bratislava, Slovakia, to address challenges facing modern botanical monography. Attending were 21 participants from many different backgrounds, countries, and expertise, including monographers, molecular workers, editors, and publishers. The objective was to obtain a representative group of international experts to offer advice on different aspects of the monographic challenge.

Four working groups were organized and charged with discussing the issues and drafting reports on how botanical monography can be modernized and further implemented. The groups and participants were: (1) *Resources in Support of Monographic Studies* (L.J. Dorr, Melissa Tulig, Nicholas Turland [chair], Xian-Chun Zhang); (2) *Scientific Content of Monographs* (Mac Alford, Ana Crespo, Zuzana Ferencová, Dmitry Geltman, Norbert Kilian, Peter Linder [chair]); (3) *Training of Monographers and Production of More Monographs* (Mariam Agababian, Jorge Crisci, David Frodin [chair], Lucia Lohmann, Christoph Oberprieler); (4) *Publication of Monographic Works* (Donat Agosti, Lyubomir Penev, Gideon Smith [chair], Wayt Thomas). Karol Marhold and Tod Stuessy served as coordinators and facilitators of the meeting, and edited the final report.

■ PART ONE. RESOURCES IN SUPPORT OF MONOGRAPHIC STUDIES

Resources that are currently serving us well. — More resources are available to monographers now than ever before; particularly with the advent of the World Wide Web, access to resources is available to more people in more countries, especially those with the highest biodiversity (Smith & Figueiredo, 2010). These resources facilitate monographic work, sometimes greatly so, and the scientific community, including funding organizations, needs to support existing resources and not take them for granted.

Arguably the most important resource of all are the *specimens*, including type specimens, in herbaria and other collections. Quality specimens in adequate numbers representing the geographic distribution and morphological variation of a species provide the foundation for a good monograph. Herbaria also constitute resources for the discovery of new taxa (Bebber & al., 2010; Fontaine, 2012). However, in some cases, collections are the most threatened resource of all, e.g., some university herbaria have been “mothballed” or de-accessioned, while some collections have not been properly conserved and curated, resulting in deterioration of the specimens and a decrease in the value of the associated information. Continued conservation and curation of specimens is therefore vital for accurate and reliable monography.

A similar situation exists with botanical and other scientific *libraries*. Although a large body of scientific literature is

now available online in the form of scanned pages from books and journals (e.g., the Biodiversity Heritage Library, see below), the majority of the published literature is not yet in digital format and may be accessed only by looking at the actual printed matter, or by requesting a copy from a library. The continued support of libraries and trained librarians is therefore essential to maintaining access to this information. It should also be mentioned that there is nowadays also a rich body of useful data available to monographers in *online databases*.

Funding organizations can also be regarded as important resources for monography. The U.S. National Science Foundation (NSF), for example, has taken steps to encourage monographic work through two initiatives: the PEET program (Partnerships for Enhancing Expertise in Taxonomy; effectiveness reviewed in Rodman & Cody, 2003, Agnarsson & Kuntner, 2007) and the new ARTS program (Advancing Revisionary Taxonomy and Systematics). The EU has supported monographic work indirectly through EDIT (the European Distributed Institute of Taxonomy, Sixth Framework Programme project), SYNTHESYS (Synthesis of Systematic Resources, Seventh Framework Programme project) and ERASMUS (for short research stays for graduate students at major collections). A detailed account of funding possibilities is beyond the scope of this paper, as there are so many funding organizations around the world and great variation from country to country and year to year in the methods of their operation. One impediment has been the need to justify monography in a context of hypothesis-driven research, which is often required by funding agencies. Our community needs to learn better how to frame our monographic projects to be more competitive in such fiscally challenging arenas.

A considerable range of resources is now available to monographers. Several are listed below; further details appear in Appendix 1.

Taxonomy, floristics, collections, phylogeny, gene sequences

- Global Biodiversity Information Facility (GBIF): <http://www.gbif.org>
- Kew World Checklist of Selected Plant Families: <http://apps.kew.org/wcsp/home.do>
- The Plant List: <http://www.theplantlist.org>
- Species 2000/Catalogue of Life: <http://www.sp2000.org>
- Germplasm Resources Information Network (GRIN) Taxonomy for Plants: <http://www.ars-grin.gov/cgi-bin/npgs/html/queries.pl?language=en>
- Angiosperm Phylogeny Website: <http://www.mobot.org/MOBOT/Research/APweb/welcome.html>
- GenBank: <http://www.ncbi.nlm.nih.gov/genbank>
- Index Herbariorum: <http://sweetgum.nybg.org/ih>
- Specimen databases (online) of individual herbaria

Nomenclature

- *International Code of Nomenclature for algae, fungi, and plants* (ICN, *Melbourne Code*; McNeill & al., 2012): <http://www.iapt-taxon.org/nomen/main.php>

- International Plant Names Index (IPNI): <http://www.ipni.org>
- Tropicos: <http://www.tropicos.org>
- Index Nominum Genericorum (ING): <http://botany.si.edu/ing>
- Indices Nominum Supragenericorum Plantarum Vascularium: <http://www.plantsystematics.org/reveal/pbio/fam/allspgnames.html>
- Index Hepaticarum: <http://www.ville-ge.ch/musinfo/bd/cjb/hepatic/index.php>
- Index Nominum Algarum: <http://ucjeps.berkeley.edu/INA.html>
- Index Fungorum: <http://www.indexfungorum.org>
- MycoBank: <http://www.mycobank.org>
- Fungal Names, <http://fungalinfo.im.ac.cn/fungalname/fungalname.html>
- *Fossilium Catalogus II: Plantae* (Pars 1–110, 1913–2010; only in print)
- Results of Algal, Fungal, and Plant Nomenclature Proposals, a database of proposals to conserve and/or reject names under the *Code*: <http://www.ars-grin.gov/~sbmljw/cgi-bin/taxprop.pl>
- Books on names and their types (e.g., *Order out of Chaos* [Jarvis, 2007]: <http://www.nhm.ac.uk/research-curation/research/projects/linnaean-typification/databasehome.html>)

Bibliography

- Biodiversity Heritage Library (BHL): <http://www.biodiversitylibrary.org>
- JSTOR, a digital archive of scholarly journals (not limited to botany): <http://www.jstor.org> (subscription required)
- WorldCat: <http://www.worldcat.org/>
- Gallica (through Bibliothèque Nationale de France): <http://gallica.bnf.fr>
- Biblioteca Digital del Real Jardín Botánico de Madrid: <http://bibdigital.rjb.csic.es/spa/index.php>
- Library catalogues (online) of major botanical and natural history institutions
- *Botanico-Periodicum-Huntianum*, ed. 2 (BPH-2; Bridson & al., 2004): http://fmhibd.library.cmu.edu/fmi/iwp/cgi?-db=BPH_Online&-loadframes
- Guide to the plant species descriptions published in seed lists from Botanic Gardens for the period 1800–1900: <http://www.nationaalherbarium.nl/seedlists/home.htm>
- *Taxonomic Literature*, ed. 2 (TL-2; Stafleu & Cowan, 1976–1988; Stafleu & Mennega, 1992–2000; Dorr & Nicolson, 2008–2009): <http://www.sil.si.edu/digitalcollections/tl-2/index.cfm>
- Kew Bibliographic Databases: <http://kbd.kew.org/kbd/searchpage.do> (registration may be needed for full accessibility; parts are no longer being added to)
- Thomson Reuters Scientific (BIOSIS, SCI, Web of Knowledge): http://thomsonreuters.com/products_services/science/science_products/a-z/

- *Botany Subject Index* (U.S. Department of Agriculture Library, 1958; only in print)
- Auxilium ad Botanicorum Graphicem: <http://www.ville-ge.ch/musinfo/bd/cjb/auxilium/index.php>

Languages

- *Botanical Latin* (4th edition in English: Stearn, 1992; edition in Spanish: Stearn, 2006)
- Latin words by William Whitaker: <http://archives.nd.edu/words.html>
- Google Language Tools: http://www.google.com/language_tools

Geography (and georeferencing)

- Google Earth and Google Maps: <http://www.google.com/earth/index.html> and <http://maps.google.com/maps>
- MapCarta: <http://mapcarta.com>
- Online world gazetteers (e.g., Geonames, <http://www.geonames.org/>; Fuzzy Gazetteer, <http://isodp.hof.uni-versity.de/fuzzyg/query/>)
- Regional gazetteers and botanical atlases (some actively or passively online)
- WorldClim (global climate layers): <http://www.worldclim.org>
- *Guide to Best Practices for Georeferencing* (Chapman & Wieczorek, 2006—through GBIF, <http://www.gbif.org>)
- Digitised topographic maps. Good collections include the National Library of Australia and Perry-Castañeda Map Library (University of Texas, Austin)

Ways in which existing resources could be made even more useful and powerful. — There was a strong feeling among the Workshop participants that online data need to have open access, although it was understood that financial realities do not always allow this. A rich array of links and enhancements can be made with open access data but not when access is restricted. JSTOR, including JSTOR Plant Science, for example, could be improved with more open access, rather than the subscription service that is currently used. There seems to be a lack of awareness of JSTOR Plant Science and/or a reluctance to use it, perhaps because a subscription is required. In addition, it is unrealistic to assume that North American and European botanical institutions can subsidize subscriptions for institutions in developing countries as almost all botanical institutions face financial constraints. One possibility is to encourage authors to include costs for open access publication in grant proposals, as it facilitates dissemination of knowledge.

The Biodiversity Heritage Library (BHL) and similar resources should continue to scan books and journals, especially rare ones. BHL could be enhanced if it contained more metadata, e.g., authors and publication date, which may be different for various parts of a book or journal volume. This might be

achieved by encouraging BHL to fully utilize the data in TL-2. Keyword searching on content, as in Google Books (<http://books.google.com>), would also be useful. Currently it is possible to search for scientific names through uBio's TaxonFinder, a taxonomic name recognition algorithm, although this is based on uncorrected text automatically generated from optical character recognition (OCR) programs and is of variable quality for each scanned book. There are, however, limits to the utility of data in older publications, e.g., descriptions and geographic distributions are not necessarily accurate for species circumscriptions, identifications, and the meaning of terminology may well have changed over the years.

Better sharing of specimen data and specimen annotations would benefit everyone, and efforts to digitize herbarium specimens and make images freely available online should be supported. A good model for co-operative capture of shared data is that of libraries (e.g., WorldCat, provided by the Online Computer Library Center [OCLC] see above). We are as yet nowhere near digitizing significant percentages of major herbaria, although PE (Beijing) has digitized ca. 70% of its ca. 2.5 million specimens so far, with ca. 600,000 images already freely available online in the Chinese Virtual Herbarium (<http://www.cvh.org.cn>) and all types (ca. 17,000 specimens) to be made available soon; large portions of other Chinese herbaria, e.g., KUN are available for study via this gateway as well. Paris (P) is also currently scanning holdings from their general herbarium at a rapid rate. Another activity, the Filtered-Push project, allows sharing of annotations and transcriptions of herbarium labels (Dou & al., 2011), hence mobilizing contributors from various locations and avoiding duplication of work.

GBIF could be improved if it included an indication of which specimens have been cited in a monograph, i.e., which specimens have been checked by whom. Papers to be added automatically to GBIF in the future will contain such data.

Some resources, e.g., ING and INSUPRA, often depend on one or a few people, who eventually retire, after which the databases become out-of-date or new data are of lesser quality. Perhaps IAPT could help identify such “dying” databases and save them by providing a home or funding for their maintenance and expansion. Also, inasmuch as ING covers all plant (and algal and fungal) groups treated by the *Code*, it cannot be folded easily into any of the existing projects that cover narrower nomenclatural subsets of organisms.

The index of plant fossils, *Fossilium Catalogus II: Plantae*, could be digitized and made available online as an index similar to IPNI.

Language issues: collaboration between people from different countries and translation tools may help reduce the tendency of some authors to ignore relevant literature in languages not their own. Online translators such as Google Language Tools are often crude, but can still enable a text to be understood, and they are improving all the time. Google now includes Latin among the languages that can be translated. If the quality of the translation improves, this could be useful in maintaining access to botanical literature written at a time when Latin was the international language of science (whereas it is now understood by rather few).

Better linking or integration of databases should be pursued, e.g., between IPNI and Tropicos, between Index Herbariorum and TL-2. Some databases, e.g., ING and Indices Nominum Supragenericorum Plantarum Vascularium, could even be incorporated into others, e.g., IPNI. Actions legislated by the *Code*, e.g., conserved or rejected names or names in suppressed works, could be embedded in major nomenclatural databases (such as is already being done by Tropicos). Linking of molecular datasets to names and other information, e.g., voucher specimens for sequences deposited in GenBank, would be desirable. This applies also to datasets for subjects other than DNA, e.g., pollen, chromosomes, and images. Indeed, a seamless search capability of authenticated image data across institutions, so as not to have to search each institution separately, would be highly desirable.

The “top three” new resources. — The Workshop participants examined several suggestions for new resources, with the three following the most favoured:

(1) An *index of type designations*, specifically designations of lectotypes, neotypes, and epitypes. This is currently a major gap in the resources available to monographers. This could be a project initiated by, and operated under the auspices of, IAPT. Voluntary registration of typification could be achieved in collaboration with major institutions and publishers. Relevant literature (Floras, revisions, monographs) could be scanned for typification. Content could also be provided by others, moderated by the project manager. One person, already with a basic knowledge of nomenclature and then suitably trained, could function as a project manager and achieve much even after only one year working full time. The data model and method of operation could draw from the Linnaean Plant Name Typification Project (<http://www.nhm.ac.uk/research-curation/research/projects/linnaean-typification/index.html>) and repositories such as MycoBank that already register nomenclatural data. Linking or integration with existing nomenclatural databases from the very start of the project would be desirable. The project should not seek specialists to carry out new typification (which would be extremely labour intensive), but should seek existing typification published in the literature, which in the absence of any index are currently difficult, sometimes extremely so, to find.

(2) An *integrated global chromosome database*. Currently available electronic resources on chromosome number reports are in several separate datasets. Complete (or nearly complete) data are available only for individual countries, e.g., Italy (<http://www.biologia.unipi.it/chrobase/>), Poland (<http://chromosomes.binoz.uj.edu.pl/chromosomes/>), or Slovakia (<http://www.chromosomes.sav.sk/>), or for some families, e.g., Asteraceae (http://www.lib.kobe-u.ac.jp/infolib/meta_pub/G0000003asteraceae_e), or genera, e.g., *Cardamine* (<http://www.cardamine.sav.sk/>; Kučera & al., 2005), or *Hieracium* (<http://www.botanischestaatssammlung.de/projects/chrzlit.html>). The only global dataset, Index of Plant Chromosome Numbers (IPCN, currently part of the Tropicos database, <http://www.tropicos.org/Project/IPCN>), does not cover older (pre-1979) chromosome data, which are in printed matter only. IPCN also currently does not list localities of the origin of the analysed material, which seriously limits the use of data deposited in this database. For the future, it would be desirable

to embed raw data, images, etc. (although copyright issues may apply) so that chromosome numbers could be verified from the database, provide locality data, and include a mechanism for users to provide feedback and correct errors. Chromosome numbers should not only be included but also ploidy level, as this is very important evolutionarily (albeit ascertaining ploidy level can sometimes be difficult). It is particularly frustrating to attempt to draw conclusions from molecular data if the ploidy levels of the organisms being analysed are unknown. IAPT is currently taking over responsibility for the IPCN, and the extent of information recorded for each chromosome number report newly included in the database will be enhanced. Nevertheless, a large online database that would contain all published chromosome number reports is urgently needed.

(3) One of the most elusive resources, not listed above, is *time*. Many specialists are engaged in administration, applying for grants, curatorial work, teaching, and reviewing grant proposals and manuscripts, all of which leave little time for monographic work. When all data needed for a monograph have finally been gathered together, writing could be made possible by providing a commitment-free *sabbatical*. Such would need to be funded—and any *overall* program would require a large and sustainable source of money. Perhaps it could be achieved with a “corporate responsibility” scheme, whereby a global network of botanical institutions could contribute annually to support a fund for monographers to finish specific projects. This would have the additional benefit of helping to unify the systematic botany community.

Additional new resources that would significantly help monographic work. — We need to convince heads of institutions of the value of producing monographs (with a means of measuring progress) versus simply measuring numbers of papers published and impact factors of the journals in which they appear.

Direct funding for monographic projects is laudable, but the large amounts of money needed would be beyond the budget of associations such as IAPT. It might be more appropriate to seek funding from large funding bodies such as NSF or the EU. Funding for longer-duration projects is needed; indeed “short-termism” and monography are incompatible. Perhaps the call by the Convention on Biological Diversity (CBD) for “an online flora of all known plants”, the Global Strategy for Plant Conservation (GSPC) Target 1 for 2020, could be used to stimulate funding for monography both before and beyond 2020. Notably and understandably, however, Target 1 of the GSPC does not require revisionary taxonomy to achieve an online world Flora by 2020; compilation primarily from existing resources for the time being must be sufficient. The EU-funded Pro-iBiosphere project, which has the goal of developing a whitepaper on the feasibility of building a biodiversity knowledge management system through production of Floras and Faunas, might be broadened to include also the preparation of monographs.

It would be useful to have automated devices for ascertaining the itineraries and localities for major historical (especially 19th-century) collectors (e.g., Humboldt and Bonpland, Wallich, Spruce, Baron, Clarke, Rock; cf. Bebbler & al., 2012). This could involve digitizing field books and mapping locations where the collectors and their collaborators were active. This

would create a valuable resource for locating type specimens. Similarly, collector guides with details of itineraries tied to Flora projects are useful, and many of their data have been captured and incorporated into JSTOR through the work of the Botanical Collectors Project at the Natural History Museum (London) and other avenues. Examples include Steenis-Kruseman (1950) for *Flora Malesiana*, Dorr (1997) for *Flore de Madagascar et des Comores*, and Polhill & Polhill (in prep.) for *Flora of Tropical East Africa*.

Nowadays very few protologues exist that cannot be found, either as electronic images in portals such as BHL or as printed matter in a library. In the latter case, online library catalogues enable us to find which libraries hold the relevant publication. Literature in languages that do not use the Roman alphabet, e.g., Chinese and Russian, are more problematic. Initiatives such as BHL-China (<http://www.bhl-china.org>) are filling the gaps in what can be readily located. The copious Russian botanical literature could be placed online together with a comprehensive transcribed index, and the text translated as needed using translation tools. (The authors of TL-2 acknowledged that they did not treat adequately literature published in Cyrillic.) A lot of literature sources covering the area of the former Soviet Union are already available online created by Alexey B. Shipunov: Fundamental'naya elektron'naya biblioteka "Flora i fauna" (Basic electronic library "Flora and fauna", <http://herba.msu.ru/shipunov/school/sch-ru.htm>). In general, searching in the Roman alphabet for titles transcribed from other alphabets or ideographs can be problematic, as systems of transcription differ. The search functions of digital libraries and library catalogues could therefore be enhanced so that publications could be searched for in, e.g., English as well as their original language using non-Roman text or ideographs.

An "index of monographers", i.e., who is working on which groups, and of monographs and revisions, would be useful so as to inventory current taxonomic research and reveal under-researched groups, which could then be listed so as to provide incentives for people to monograph particular groups. Some of these data exist in the online membership list of the American Society of Plant Taxonomists, or the Index Herbariorum online, but many entries are out-of-date, and it is not obvious how recently records were updated (data are provided voluntarily by the specialists themselves, not proactively sought by the indices). In populating such an index, however, there is a danger of "posturing", which can reduce quality of the data or discourage much needed work.

Bibliographies for monographs, and for legacy, or "historical" literature on biodiversity as a whole, are one of the most difficult tasks to solve on the way to the world of semantically linked data. The difficulties are connected in part by the lack of commonly accepted standard for bibliographic referencing. There are several styles used for that (depending mostly by the established tradition of the different publishers, journals and societies). Several extensive bibliographies based on taxa or subjects exist and are even digitized (e.g., the systematic botany bibliography TL-2, now made available online by the Smithsonian Institution). Nonetheless, digitization, although improving accessibility, does not necessarily mean easy download

and handling of reconciled and unambiguous references. For example, the world's richest source of digitized literature, the Biodiversity Heritage Library (BHL), does not maintain an extensive thesaurus of article-level metadata, and therefore does not allow searching for article titles or authors in journals. Projects like Citebank, BioStor and, recently, BoL (see below) are addressing this issue. At the same time, most of the recently published biodiversity literature is properly retrieved and indexed by large international bibliographical platforms, such as BIOSIS/SCI, CrossRef, PubMed and Mendeley.

One more attempt to solve the problem with indexing and disambiguation of the biodiversity literature, including the historical, called Bibliography of Life (BoL), is being developed by the EU-funded project ViBRANT (www.vbrant.eu; see also King & al., 2011) as a stand-alone application, developed to help scientists to quickly search for, store, find and download bibliographic references. BoL consists of two modules, RefBank (reference store) and ReFinder (reference finder). BoL is assisting authors in finding references in external trusted databases, known as content-rich sources for biodiversity references. Databases to be queried and used for searching are CrossRef, PubMed, Mendeley, CiteBank, BioStor, Scratchpads Biblio Module, Pensoft's reference database, and others. A quite interesting feature of BoL will be a module that automatically extracts reference lists from biodiversity papers published in open access and stores these in the RefBank. Such a workflow has been elaborated and is routinely implemented between RefBank and Pensoft's online journals.

Field work is, of course, irreplaceable to monographic studies, but it is becoming rather problematic for some monographers to conduct in countries not their own, with difficulty of obtaining permits, exporting duplicate sets of specimens, and subsequent access to the collected specimens. Unfortunately, at least some of these problems were precipitated in the past by less than desirable conduct by visiting scientists (Smith & Figueiredo, 2011). Online, collaborative monographs, with contributors conducting field work in their own countries, may help circumvent such barriers. An "index of collecting permits" would also be useful. Contact information for obtaining permits for different countries could be provided and kept up to date, e.g., whether a country's permit systems are centralized or decentralized, and what are the requirements for applying for a permit. This could be facilitated by the establishment of national focal points under the Convention on Biological Diversity (1992), which are envisioned as contact-points for researchers planning fieldwork in a foreign country.

■ PART TWO. SCIENTIFIC CONTENT OF MONOGRAPHS

Biological monographs are systematic and biological treatments of all the species of a given group and, therefore, are often substantial. In general, a monograph proper should contain the following information concerning included taxa (e.g., in *Flora Neotropica Monographs* or *Systematic Botany Monographs*; Thomas & Thiers, 2011):

- Accepted name and synonymy
- Well-defined circumscription and description
- Diagnostic characters distinguishing that taxon from relatives
- Means (e.g., keys, images, and illustrations) with which to identify taxa
- Specimen data of collections examined and identified by the author
- Hypotheses of relationships of the studied group to related groups, and among species within the studied group
- Information on overall distribution and ecology
- Known uses, common names, and conservation status (including Red List status recommendation)

Unlike a synopsis or revision, a monograph thoroughly addresses all aspects of the taxon's history and biology *and* integrates research on the specific units into a narrative that not only emphasizes the taxon's units but also their typification, evolution and historical relationships, characteristic features, distributions, and ecological and physiological parameters.

Monographs are commonly divided into two major parts: the general information and the specific information. The specific information is usually about species, although other taxa, such as genera (e.g., *Genera Palmarum*, Dransfield & al., 2008; *Genera Graminum*, Clayton & Renvoize, 1986), may also be the minimal monographic units.

General information. — The general part of a monograph usually includes a number of headings, such as the following:

- Introduction
- Taxonomic history
- Morphology and anatomy
- Reproductive biology
- Ecology and habitat
- Biogeography
- Conservation status
- Systematic position and phylogenetic relationships

The introduction indicates general aspects of the group, its systematic position, and why the group is considered natural. This is followed by a detailed taxonomic history, which is essential for understanding the current application of names and circumscriptions of taxa and makes the reader aware of problems that will be clarified later in the monograph. The history usually addresses a timeline of collectors and collections, how concepts of taxa have changed, and what taxonomic problems need solution.

Following the introduction and taxonomic history, the ideal monograph includes a thorough section on materials and methods. The monograph should address which herbarium specimens were studied, when and where field work was undertaken, where vouchers, photos, and/or seeds are deposited, where plants exist in cultivation, justification for the selection of characters and coding for analyses of species delimitation and inference of relationships, where measurements were taken (herbarium specimens vs. live plants), and how measurements were obtained (including sample size and whether taken randomly, from smallest and largest, or other). The methods section should also include explicit techniques for obtaining

structural or DNA data, sources of terminology, computer software (e.g., used for statistics, phylogenetic inference, maps), and any sources of secondary data. Associated with methods are the taxon concepts. The monograph should explicitly state the concept used for the units and how that concept is applied (e.g., Balakrishnan, 2005). For example, a researcher should establish how the experimental evidence supports the recognition and circumscription of taxa presented, e.g., reproductive data or inference of isolation for the Biological Species Concept (Mayr, 1942) or diagnostic character states or combinations for the Phylogenetic Species Concept (Nixon & Wheeler, 1990; Davis & Nixon, 1992).

Descriptions of the taxa and sources of data for species delimitation and phylogenetic inference are often based on character analysis. A character analysis section describes the morphology and anatomy of the organisms, often and desirably augmented with illustrations. This section is usually extensive and describes everything from habit and phyllotaxy to pollen and embryo morphology. It permits the author to discuss variation within characters and explain the significance of distinctive features. In woody plants, it is common to include a review of wood anatomy, in addition to anatomical studies of other parts, such as leaves, indumentum, or floral parts. Taxonomic and functional significance of the characters is elaborated, and experimental evidence for the utility of certain data may be presented, such as from common garden experiments (e.g., Clausen & al., 1940). A monographer is at a distinct advantage in describing the characters, because variation is observed in the context of related taxa. These data from morphology, anatomy, karyology, and DNA can often be easily structured in tables and are particularly amenable to presentation in digital databases (and described using the SDD format), which can easily be downloaded and used for other studies, or in e-publications linked to the external database. If the data are stored as electronic files available on the Internet, links should be as robust, widely-used, and as permanent as possible (e.g., GBIF, Morphobank, Morphbank, GenBank/EMBL/DBJ, TreeBase). This emphasizes one advantage of electronic publication of monographs, as these links are easy to implement. Refer to modes of publication below (Part Four).

Analyses of the data are presented in sections on phylogeny and character evolution, biogeography, and speciation. Although historically monographs have been descriptive, with minimal discussion of the evolutionary history of the group being treated, more recent monographs have included sections on phylogeny (e.g., Farjon & Styles, 1997; Delprete, 1999; Alford, 2008). This synthesis is to be strongly encouraged. The relationships of the taxa are inferred and interpreted, sometimes followed by an infra-group classification that reflects these relationships. Occasionally, the analyses may indicate the presence of cryptic species. The phylogeny is used to examine character evolution and may be used in conjunction with statistical tools to introduce, support, or refute hypotheses about diversity, ecological or functional properties, or other patterns. Augmented with geographical and fossil data, the phylogeny may also be used to infer broader scale biogeographical patterns, timing of historical events, and patterns of diversification.

With a thorough dataset from phylogeny, karyology, and reproductive experiments, a section on speciation can elaborate on inferred isolation mechanisms, spatial speciation modes (allopatric/sympatric), and polyploid speciation. Finally, the general section ends with the conservation status of the group, highlighting rare species, important habitats, and potential areas for conservation. With the establishment of the Convention on Biological Diversity (1992), the link between conservation of species diversity and systematics has become clearer. The monographer is usually the one to notice, identify, describe, and map rare species, and can provide the most accurate assessment of each species' conservation status (e.g., Maas & al., 1992).

Specific information.— The heart of the monograph is the treatment of species. If a family is being treated, the treatment starts with a family nomenclature, a detailed morphological description, and a key to the genera. Each generic treatment follows the same pattern, with a key to species. Each species treatment should include:

- Nomenclature and typification for each included name
- A detailed morphological description
- Notes on geographical distribution (usually with a map)
- Notes on habitats and phenology
- Notes on conservation status, local names, uses, phylogenetic relationships, and diagnostic characters, depending upon the group
- Illustrations (line drawings or photographs)
- A list of specimens examined

The specific part of the monograph first clarifies the nomenclature of the unit of study, often the genus, and provides a thorough description. Identification tools are presented for determining the specific units, often the species, or groups of specific units. If there are groups, a formal infrageneric classification may be presented and provided with diagnoses or synopses, or species may be arranged by informal groups. Identification is typically done by means of dichotomous keys, although synoptic keys, multi-access (interactive) keys (Dallwitz, 1980; Dallwitz & al., 2000), barcoding (Hebert & al., 2003; Kress & al., 2005), Leaf-Snap (Cope & al., 2012), and other futuristic rapid identification methods are now augmenting this section. If barcoding, Leaf-Snap, or other methods are used, the monographer should indicate the degree of sampling and effectiveness of the tools and which vouchers were verified.

The special part continues with treatments of the specific units. Each unit is named; the typification, including that of synonyms, is thorough and precise, and nomenclatural decisions and judgments are briefly noted and clearly justified. Ideally, photographs or links to type specimens and protologues, as well as LSIDs (Life Science Identifiers, unique identification numbers; Clark & al., 2004) will be provided. Where common names are used, they should be reported, including language and country (or region), and their source indicated (e.g., specimen label, collector's notes, etc.). If common names do not exist their creation may be justified.

Each minimal monographic unit is then thoroughly described. Sometimes descriptive information that applies to the whole group is not repeated for each of the units, but that

unfortunately makes information easier to take out-of-context. If descriptive data are also provided in digital format (e.g., DELTA), the data can be more concise in the text but can be accessed digitally in exhaustive form for comparisons across larger groups or for easily generating multi-access keys. Sampling for the descriptions should be explicit in the Methods section, or explicit notes on small sample sizes should be given for those based on a subset of specimens examined (e.g., anatomy, floral dissections, seeds, secondary metabolites, reagent reactions). After each specific unit, notes should justify delimitation of the taxon and describe variation in the taxon (or subunits). Diagnostic features are useful here, as well as information highlighting differences between the taxon and similar taxa. Illustrations are especially useful, especially for taxonomically important characters, although analytical line drawings can be costly. Inclusion of, and links to, photographs (e.g., Morphbank) or citations of illustrations are also useful.

Following the nomenclature, description, and notes about the specific units, a monograph usually includes a section on exsiccatae and specimen data, as monographs are fundamentally based on specimens, which are subject to future scientific inquiry as vouchers. The original specimen (label) data should be preserved, but locality information should also be modernized, giving current names of locality, latitude/longitude (where possible), elevation, and other data. A commonly used approach is to use square brackets to indicate which data are interpretations of the original label data. Databases of this information should be made available in standard format (e.g., Darwin Core, TDWG standards) to facilitate exchange with existing and contemplated herbarium databases. A section on distributional data usually summarizes the details of the specimen data and explains differences from previously published maps or reports range extensions. Data may be plotted on standard political maps or on maps with relevant environmental parameters (e.g., soils, precipitation, elevation) as background. The latter is likely to stimulate additional ecological research or to draw attention to areas for further exploration. Habitats (autecology) are described, based on critical evaluation of habitat notes on specimens, vegetation observations, and primary field work. Interactions with pollinators, herbivores, fruit/seed dispersers, and other organismal interactions are noted for the specific units. These data are commonly integrated into the general sections on biogeography and speciation.

Phenological data should be reported and should be linked to presumed triggers, sometimes at a regional level. Although rarely given, timing of fruiting and release of seeds, age at first flowering, and shifts in growth form with flowering are also important ecological data. Chromosome counts or other cytological data (e.g., karyotype analysis, DNA content from flow cytometry) should be given, if possible. Given the small sampling in most cases, the availability of vouchers, correctness of determination, and evaluation of contradictory reports are critical.

The economic importance, cultivation notes, and conservation notes conclude each treatment of a specific unit. Economic importance includes poisons and useful secondary compounds, use of secondary metabolites, weeds and invasives, as well as

the obvious uses for food, fiber, or wood. Cultivation notes include information about germination (e.g., scarification, smoke treatment, recalcitrance), culturing and preservation (in the case of fungi), growth rates under different environmental parameters, and history of cultivation.

Conservation notes are strongly encouraged, as monographs represent one of the few broad-scale, supra-national critical studies (Kirschner & Kaplan, 2002). Author(s) should suggest a red list status, and if the unit is threatened, information about *ex situ* conservation, *in situ* conservation, seedbanks, and genetic resource collections should be provided if available.

The monograph ends with a list of excluded names, either transferred to other groups or misapplied (if not allowed under the specific unit treatments by the editors), an index to names, and literature cited.

With the increased development of online literature and supplements, the future of monographs is promising. Text can highlight the synthetic aspects of systematic studies, primary literature and specimen images for nomenclature can be readily accessed and compared, and large datasets (photo albums, characters, data matrices, localities, examined specimens) can be efficiently downloaded, analyzed, modified, and used in other studies.

■ PART THREE. TRAINING OF MONOGRAPHERS AND PRODUCTION OF MORE MONOGRAPHS

During the past two decades, we have seen great improvements in a variety of tools and methodologies associated with molecular phylogenetics, phylogeography, and population genetics, as well as various uses of phylogenies for studies of morphological evolution, diversification, biogeography, and comparative biology. While these advances indeed contribute significantly towards a better understanding of the origin and

evolution of biological diversity, they are also driving students towards hypothesis-driven and experimental research at the expense of more descriptive (but still hypothesis-supported) areas of systematics, including the preparation of taxonomic revisions and monographs. In addition, increasing use of “scientometrics” by administrators (including journal impact factors and the “Hirsch index”) has led to greater pressure for frequent publication of results in high-impact journals, making it difficult for aspiring and established monographers to see themselves as competitive in the early- and later-career jobs market. As a result, research projects strictly focused on monographs have become less attractive in any career stage.

Perceptions of a “skills gap”, therefore, have now arisen, with calls for action to redress this situation. We believe that one response would be through the orientation of education and training of students in such a way that, along with normal preparation, a broader view of the sciences is imparted and, hence, a place for monography may more clearly be perceived. Brief instruction and subsequent employment of parataxonomists, especially in countries with megadiverse floras, as well as elsewhere, may provide a partial solution (e.g., Basset & al., 2000; Fontaine & al., 2012) to the skills deficit, but training of a new generation of professionals with monographic skills is obviously still very much needed.

Enhancing attractiveness of monographic research. —

A change in the way that we prepare monographs is clearly recommended, and there are many ways in which this can be accomplished (Fig. 1). In particular, we need to produce treatments of a broader scope, particularly so that detailed information on the phylogenetic, ecological, evolutionary, and biogeographical history of organisms can also be included. Products should also be capable of translation into different formats for use or dissemination. To bring that about, we need to change how we train monographers, so that students are also engaged at unravelling the evolutionary history of their focal taxa in such a way that the monograph itself becomes the foundation of

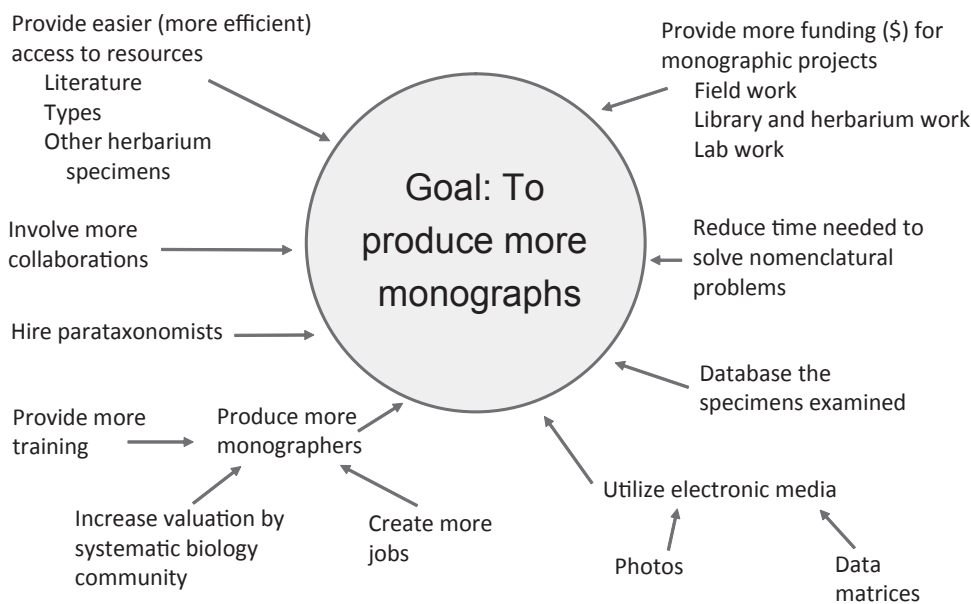


Fig. 1. Different ways to enhance production of monographs in systematic botany. While all are important, the workshop views the training of more monographers as particularly vital for the long perspective.

its study but not the exclusive product. Such training will lead to individuals who are better prepared and in a better position to pursue a wider range of career opportunities.

Engaging students effectively in such integrated and diverse research programmes requires that professors and lecturers do a better job of demonstrating the importance and value of organismal biology by changing some of their teaching practices. In particular, through regular field-based activities, herbarium identification sessions, and detailed morphological work, they might be able to demonstrate how a detailed knowledge of the organisms themselves can help formulate interesting biological questions. Indeed, only through a more detailed understanding of the morphology, ecology, and distribution of organisms will we be able to understand the key processes that may have led to the origin and diversification of life as a whole. Certainly, broader and more diverse research programs will lead to better-prepared students. Such an approach would also be useful in modified form in the secondary school curriculum (Crisci & Katinas, 2011), to get as early a start on developing interests as possible.

New training programs. — Well-founded undergraduate and graduate teaching programs are needed. At the former level, teaching plant systematics should, for example, emphasize the importance of a detailed understanding of biodiversity, evolutionary relationships, and past biogeographic history over all areas of organismal and non-organismal biology. Philosophically, the significance of integration and synthesis should be emphasized, and teaching should address the fascination of diversity. Such a combination should attract students who consider it more promising and more rewarding to obtain an overall picture of the diversity of life around us rather than doing research in a very particular and fragmented fashion as is found in many other areas of biological research.

At the graduate level, courses should involve more in-depth knowledge and the acquisition of a solid training in various areas including: (a) botanical terminology, morphology, nomenclature, and history; (b) herbarium curation and common herbarium practices; (c) field work, collecting, and preparing specimens; (d) general knowledge of geography, earth history, climatology, and geology; (e) theoretical background on speciation and evolutionary processes (including controversies); and (f) biodiversity informatics. By placing plant systematics into a broader context, taxonomic and organismal research can be put easily into an hypothesis-driven context that can be rigorously addressed with new methods of analysis and additional evidence as they emerge. Some of this information might be disseminated effectively through a “Virtual Institute of Monography” on the Internet.

As a result of an effective educational program, students should acquire a large range of skills along with a strong knowledge of organisms *per se*. In addition, a broad formation will likely lead to an increased number of publications in a variety of research areas, and hence increasing the chances of success by those students in the professional marketplace. The successful training of a large number of monographers in this next generation should hopefully lead to an exponential growth of people undertaking monographs in the years to

come. Otherwise, monographers may well become extinct, at least in the professional world—and yet another “skills gap” will indeed appear.

■ PART FOUR. PUBLICATION OF MONOGRAPHIC WORKS

Successful publication of monographic works provides yet another challenge to the monographer. Finding the time to dedicate to a comprehensive monographic project is one hurdle that must be surmounted, but even when a manuscript is finished, a suitable outlet for publication must be found. Large monographic treatments in hard copy format are costly to publish and, even when support is found, the outlet is often in a journal of low impact or as a book from a little-known publisher. Print-on-demand options might represent a partial solution to this problem, but even more attractive are various forms of electronic publication and dissemination. Three aspects are here considered: publication, dissemination, and the monographic infrastructure as a knowledge management system.

Publication. — Whatever their form, monographic studies often contain descriptive information on large numbers of species, substantial evolutionary analyses and discussions, keys, identification lists (and/or other appendices), and comprehensive indices. Consequently, the resulting manuscript and associated figures (including maps) are lengthy and exceed page limits allowed by most scientific journals. This problem can be approached through “alternative” conventional outlets or electronic publication.

Conventional outlets. — Monographs have customarily appeared either as complementary series within botanical journals, in institutional or independent series, or as independent books. Examples of the first type include *Strelitzia* (related to *Bothalia*), *Opera Botanica* (*Nordic Journal of Botany*), *Blumea Supplements* (*Blumea*), *Systematic Botany Monographs* (*Systematic Botany*), and *Botanical Magazine Monographs* (*Curtis's Botanical Magazine*). Examples of the second type are *Contributions from the U.S. National Herbarium*, *Fontqueria*, *Komarovia*, *Symbolae Botanicae Upsalienses* (now a series of *Acta Universitatis Upsaliensis*), *Flora Neotropica*, *Memoirs of the New York Botanical Garden*, *Monographs in Systematic Botany from the Missouri Botanical Garden*, and *Species Plantarum: Flora of the World*. These are all irregular in publication, and therefore at a disadvantage under evaluation with current scientometric practices. They also usually have low print runs that cater to a limited audience. Despite their apparent low impact, however, they have a long utility, gathering citations over many decades. The third principal outlet for monographs has been stand-alone, hard copy books. These often treat horticulturally important taxa and may have extensive illustrative material, making them costly to acquire. They, too, can have a long useful life. Such monographs may be supplemented by electronic media furnished either as an included CD or DVD or as additional online, Web-published content.

Two particular difficulties with conventionally published monographs involve inclusion or exclusion of primary data, and

publication of nomenclatural novelties. With respect to primary data, such as specimens examined, they are often not published in an accessible manner, if at all, due to space constraints of the journals. When they are included, such data are often “closed” in the hard copy or pdf versions, or even “hidden” electronically behind textual content. Such practices hamper onward use of such data for testing new hypotheses and generating new scientific results.

As for nomenclatural novelties, some uncertainty has existed over whether names established in theses and dissertations for M.S. and Ph.D. degrees were effectively published. Although *The International Code of Botanical Nomenclature* (now the *International Code of Nomenclature for algae, fungi, and plants*) specifically excludes them from consideration, some academic institutions require theses to be published in a specifically designed journal, which sometimes are accorded ISBN or ISSN numbers. Print runs are small, often numbering a dozen or more copies, and the costs are high (although the issues may be used by libraries as exchange for other journals). Novelties in these series are usually re-published in more conventional outlets, which can cause confusion.

Modern outlets. – Since the advent of the World Wide Web over 20 years ago, and especially with the launch of Web 2.0 practices during the past few years, substantial progress has been made using the Internet as an increasingly stable and reliable outlet for a range of scientific products, including monographs. Some journals now serve as outlets that cater to the rapid publication of monographs.

At first the Web was widely seen as only a useful and comparatively affordable mechanism for disseminating the results of research endeavours. However, increasingly the Web is now also used as an integral part of research infrastructure that not only provides rapid access to essential research materials used in systematics and beyond (Smith & Figueiredo, 2011; Beaulieu & al., 2012; Goff & al., 2012; Hamer & al., 2012; Parr & al., 2012) but also enables the construction of scientific (and other) research outputs on the Web in real time. This approach also allows the participation of geographically separated individuals and teams with benefit of rapid input; this is further considered below.

These developments have been accompanied by new or revised database management/information systems for delivery of outputs from systematic research suitable for monographic production. Good examples include: (1) the widely used Botanical Research and Herbarium Management System (BRAHMS; <http://herbaria.plants.ox.ac.uk/bol/>), now in Version 7 and providing tools to format data for monographs and to have these sent directly to a word processor; and (2) Scratchpads (<http://scratchpads.eu>), a biodiversity “social networking tool” currently a part of the joint EU Framework Programme 7 e-infrastructure/e-Monocot initiative, ViBRANT (Virtual Biodiversity Research and Access Network for Taxonomy; <http://vbrant.eu>).

A further set of tools, called TRIADA 2.0, was recently launched by Pensoft Publishers. TRIADA provides a collaborative online platform for writing biodiversity manuscripts, including monographs (Pensoft Writing Tool, PWT), an editorial

manager and peer-review platform (Pensoft Journal System, PJS), Pensoft Markup Tool (PMT), Pensoft Wiki Converter (PWC), and more. TRIADA 2.0 tools are implemented in the production process of the journal *PhytoKeys* (www.pensoft.net/journals/phytokeys).

Additional advantages of using a website to host monographic works include virtually unlimited colour work, detailed maps, and other features at a fraction of the cost of conventional printing, plus the inclusion of supporting data such as specimen records, morphological measurements, species geographic occurrences, etc. The latter have become increasingly valued as support for biodiversity conservation. To remain useful, obviously, the infrastructure of websites must be kept up-to-date.

It is important to stress that the Web is about *links* as well as *site content*. With the advent of near-instantaneous global e-connectivity, the possibility of linking an intact monograph to multiple Web resources has become increasingly attractive and feasible. For example, links can be created to monograph-related biodiversity information that is hosted by like-minded and partner organizations, such as the Global Biodiversity Information Facility (GBIF: <http://www.gbif.org/>), Encyclopedia of Life (EoL: <http://eol.org/>), Biodiversity Heritage Library (BHL: www.biodiversitylibrary.org), and others. Links can also be established to a range of different sorts of type specimens (e.g., those held in JSTOR Plant Science, <http://jstorplants.org/>, or other collections), or to protologues (e.g., those in BHL). In the monograph proper, links can be provided to bibliographic data and sources, or to atomized content, such as taxon treatments, herbarium specimens, locality and geographical distribution data, or even to any taxon name mentioned or referenced in the monograph. An example of the routine linking of taxon names to external resources through an automated process [also referred to as “on the fly”], is the Pensoft Taxon Profile (PTP; see such a profile created for the genus *Quercus*: http://ptp.pensoft.eu/external_details.php?query_label=Type+taxon+name+here&query=Quercus).

The use of semantic enhancements, describing the content using domain-specific domain-defined tags, and the linking to external resources is corollary to the shift from traditional publishing via print, pdf, or html, to using extended markup language (XML). Such a marked text is barely readable by a human, but it is interpretable by a machine that contains a vocabulary, called a *schema* or *data definition table* (DTD), which defines the meaning of the enclosed content in a semantic and technical way. Such a document can be considered a complex free-standing database, and with the help of a transformation based on a style sheet (XSLT), can be formatted as a human-readable html or pdf file. This can also be used for the creation of hard copies. An additional virtue of an XML file, however, is that it can be imported into dedicated databases, such as the Plazi treatment repository. From here, certain parts of the XML document, taking specimens cited as one example, can be disseminated to users (e.g., EOL and GBIF). Use of such a file also facilitates automated discovery, enables linking to semantically related articles, provides access to data within the article in actionable form, or facilitates integration of data between articles (Shotton, 2009). A successful application of

the XML in practice is Pensoft's use of the TaxPub, a DTD extension of the Journal Archiving and Publishing Tag Suit of the U.S. National Library of Medicine (Penev & al., 2010a, b, c, 2012).

With respect to collaboration, while this has often been a feature of traditional hard copy monographs (Thomas & al., 2011), an important aspect of the new electronic technologies is that they greatly facilitate the writing of monographs simultaneously in a *collaborative manner*, i.e., by a team of specialists situated in different parts of the world. Existing tools that facilitate this, such as Google Docs, are very useful, but do not yet provide templates or services (e.g., markup, automated linking, automated XML queries, or exports to aggregators and/or indexers of data). These are tools that will be increasingly desired by monographers. In addition, it is nowadays possible to export materials for monographs from information systems (e.g., from Brahms, Scratchpads and Triada) in the form of manuscripts in XML format and to submit these to publishers for peer-review and editorial processing.

These last two steps, peer-review and definitive editing of monographs, are of vital importance for increasing the quality of science they contain. Finding reviewers for large revisionary works, however, can be extremely challenging. A solution to this problem may come from innovative use of publishing platforms that allow collaborative online evaluation of a manuscript, including public peer-review, as well as post-publication peer-review, and comments and annotations to the published texts (for which Scratchpads might provide solutions).

In summary, monographers need tools or software platforms that can provide:

- Collaborative writing of monographs
- Upfront markup of essential text elements prior to submission to publishers
- Standard XML schemas, such as TaxPub, that backup the markup process, as well as the subsequent dissemination of atomized content)
- Compliance with internationally recognized standards, such as the Darwin Core for describing occurrence data (Willemse & al., 2008)
- Online peer-review and editorial processes, including open/public peer-review workflows
- Automated linking of monograph content to web resources and provision of semantic enhancements to the published texts
- Automated dissemination of discrete units (including taxon descriptions, synonymies, localities, images, and more), along with associated metadata to provide citation mechanisms
- Up-to-date mechanisms for publishing, preservation and dissemination of primary data with associated metadata

Dissemination. — Once a monograph has been completed, the content and its underlying primary data become infinitely more useful if these are exposed not only through conventional e-dissemination, but also via tools that allow extracting and mining of the content. These tools can be offered to the monographer as an additional service (e.g., Pensoft species profile), or

the monographer should be encouraged to expose the primary data in a way that allows others to trawl them and build applications that will cover needs and specifications.

Electronic dissemination can include various versions of the same monographic content, such as pdf, html or XML. If disseminated in the correct way, considerable additional information on the group being monographed, such as its phylogeny, biogeography, ecology, cytology, dates of collecting of specimens, collectors and their collecting routes, to name a few, will also be obtainable with appropriate links to external resources and metadata (e.g., bibliographic information; King & al., 2011). However, two key issues exist which are integral to any effective, well-formed e-dissemination. They are *peer review* and *open access*, and are further considered below.

Electronic publishing and peer review. — Current advances in desktop and web-publishing technology have made it possible for anyone to publish, in an effective sense (as governed by the *Code*), monographs at lower cost and in larger numbers. This has the potential disadvantage, however, of deliberately or unintentionally limiting or excluding peer review, which is essential for ensuring veracity of scientific content. The actual peer-review(s) can be published as accessory material, or reviews can be posted with the monograph at the post-publication stage. A Wikipedia or citizen science-style refereeing process could be advantageous and draw on a wider pool of review expertise. Regardless of the pros and cons of publishing monographs in this way, it is likely that dissemination of such texts unencumbered by peer-based input will increasingly be seen as an enabling, lucrative and affordable possibility. In addition, such independently produced and hosted works may have the same, or at least similar, stability to that offered by large publishing houses, and will be cited and referenced by interested researchers.

Open Access. — The volume of open access dissemination of outputs from biodiversity research is increasing, hence ensuring the widest possible, barrier-free distribution of the whole content at no charge to the readers. Botanical, and other monographers in general, should engage and influence the current debate that is considering how, and at what cost, the outputs of scientists, who are often funded by their respective governments, should be disseminated (e.g., Leptin, 2012). This debate is gaining momentum and large numbers of scientists, being irked by copyright, access and cost considerations, have stated their intention to disengage with some publishing houses (see for example Taylor, 2011). The texts produced by monographers are often voluminous, and having to pay electronic or hard copy page charges from modest research budgets frustrates many systematists. The same applies to fees charged for open access. Fortunately, open access to scientific results obtained through public funding is becoming a non-negotiable part of the policies of governments and funding agencies, at least in some countries (e.g., Austria). In addition, open access does not require subscription fees.

All the technological capabilities of the modern Web for publishing botanical monographs can only be utilized to their fullest extent under conditions of open access. Open access facilitates reading and dissemination of a pdf version of published

texts, and it insures further use of such data, both by humans and machines. An additional advantage of open access is that information generated by monographers can reach a larger end-user community (Steenkamp & Smith, 2003), well beyond systems developed by, for example, JSTOR and AGORA (Access to Global Online Research in Agriculture by FAO) for the developing world.

The monographic infrastructure as a knowledge management system. — The full and real value of monographic work is not solely that of only having a single, thorough taxonomic treatise on a specific group. It is also the seamless stitching together of information in several monographs to provide building blocks of a knowledge management system. The power of such a system is enhanced through utilizing semantic markup functionalities that allow interaction with databased content derived from similar treatments (e.g., Plazi.org). Creating such datasets will allow powerful searches and data-mining possibilities through use of multiple information sets. Two significant issues, however, have to be addressed in relation to any effective implementation of such methodologies: additional infrastructure (and its costs), and archiving (including long-term survival).

New infrastructure and its costs. — Electronic publishing comes at some cost. For traditionally produced hard copies, storage costs have been minimal. The storing and maintaining of accessible electronic versions of documents, as well as reference databases (e.g., images, bibliographies, specimens), will require additional funding and long-term commitment by host institutions. This must include support for development of journal production work flows, data and data-exchange protocols, reference databases for bibliographic references, and ontologies (Walls & al., 2012) for morphological terminology. Also important are stable URLs, development of authoring tools to create semantically enhanced documents, creating interfaces to data by both humans and machines (such as APIs, Application Programming Interfaces), and training of personnel. Costs might be shared equitably among several institutions.

Archiving and longevity. — An existing possibility to secure the long-term archiving of monographic content is established through the U.S. National Library of Medicine Pub Med Central, which can accept publications in the TaxPub NLM DTD (National Library of Medicine, Document Type Definition) format (Catapano, 2010), with the additional advantage that the content is linked to the rapidly growing publications library in their repository, including currently in PubMed (the minimalist version containing only the abstract).

■ SUMMARY OF RECOMMENDATIONS

Unsurprisingly, workshop participants unanimously reaffirmed the central importance of monography in systematic botany. Perhaps more surprising, however, was that the group strongly preferred monographs with a full descriptive, evolutionary, and interpretive content, rather than some abbreviated format. Use of the internet and other forms of electronic publication were strongly encouraged. Workshop participants

stressed the importance of training Ph.D.s using the monograph as a central vehicle. In a realistic context, this means assigning doctoral students smaller monophyletic (or presumably monophyletic) groups (10–15 species), so that they can also work with modern aspects involving DNA, cytogenetics, phylogeny, biogeography, and the processes of evolution. A distinct advantage of publishing monographs electronically is that, despite the storage and maintenance costs, semantically enhanced and linked e-publications improve the possibility to test hypotheses for which all the original data are accessible. This is not possible, or at least very inefficient, through hard copies. Electronic publication allows a much wider dissemination of the knowledge inherent in a monograph, hence fostering future innovation.

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Appendix 1. Details of current resources for monographers.

Taxonomy, floristics, collections, phylogeny, DNA

- Global Biodiversity Information Facility (GBIF), established by governments in 2001 to encourage free and open access to biodiversity data: <http://www.gbif.org>
- Kew World Checklist of Selected Plant Families, providing the latest peer-reviewed and published opinions on the accepted scientific names and synonyms of selected plant families: <http://apps.kew.org/wcsp/home.do>
- The Plant List, based on IPNI and Tropicos and other datasets,

including over 1,000,000 names of vascular plants and bryophytes with preliminary data on acceptance and synonymy: <http://www.theplantlist.org>

- Species 2000/Catalogue of Life, a validated, synonymised checklist for a large range of algae, fungi and plants with contributions from ITIS, the Kew World Checklist of Selected Plant Families, IOPI Global Plant Checklist, and some family-specific validated databases (e.g. AnnonBase, ILDIS, Solanaceae Source): <http://www.sp2000.org> (an Annual Checklist in the form of a DVD is also issued with an

Appendix 1. Continued.

accompanying booklet in which all contributors are listed)

- Germplasm Resources Information Network (GRIN) Taxonomy for Plants, providing information on scientific and common names, classification, distribution, references, and economic impacts for all families and genera of vascular plants and over 46,000 species from throughout the world, especially economic plants and their relatives: <http://www.ars-grin.gov/cgi-bin/npgs/html/queries.pl?language=en>
- Angiosperm Phylogeny Website, a set of characterizations of all orders and families of extant seed plants (not only angiosperms): <http://www.mobot.org/MOBOT/Research/APweb/welcome.html>
- GenBank, the National Institutes of Health (NIH) genetic sequence database, an annotated collection of publicly available DNA sequences: <http://www.ncbi.nlm.nih.gov/genbank>
- Index Herbariorum, with details of the world's herbaria, their collections, and current staff: <http://sweetgum.nybg.org/ih>
- Specimen databases (online) of individual herbaria, often with associated images of whole specimens or labels thereof. Coverage varies considerably, but so far very few collections are entirely online. The GPI and its precursors have focused on types.

Nomenclature

- *International Code of Nomenclature for algae, fungi, and plants* (ICN, *Melbourne Code*; McNeill & al., 2012): <http://www.iapt-taxon.org/nomen/main.php>
- International Plant Names Index (IPNI), for names of vascular plants, incorporating Index Kewensis, the Gray Card Index, the Australian Plant Names Index, and Index Filicum; an index of authors of plant names (based on Brummitt & Powell, 1992); and an index of publications: <http://www.ipni.org>
- Tropicos, incorporating Index of Mosses, including names, with data on acceptance and synonymy, specimens, images, and publications; also incorporating the Index to Plant Chromosome Numbers (IPCN): <http://www.tropicos.org>
- Index Nominum Genericorum (ING), for generic names of plants, fungi, algae, and fossils: <http://botany.si.edu/ing>
- Indices Nominum Supragenericorum Plantarum Vascularium, for names of vascular plants above the rank of genus: <http://www.plantsystematics.org/reveal/pbio/fam/allspgnames.html>
- Index Hepaticarum, for names of hepatics (Marchantiophyta or liverworts): <http://www.ville-ge.ch/musinfo/bd/cjb/hepatic/index.php>
- Index Nominum Algarum, for names of algae: <http://ucjeps.berkeley.edu/INA.html>
- Index Fungorum, <http://www.indexfungorum.org>; MycoBank, <http://www.mycobank.org>; Fungal Names, <http://fungalinfo.im.ac.cn/fungalname/fungalname.html>, all for names of fungi and associated data, accepted as official repositories for registration of fungal names by the Nomenclature Committee for Fungi (Taxon 62: 173–174, 2013).
- *Fossilium Catalogus II: Plantae* (Pars 1–110, 1913–2010, printed matter only), for names of fossils
- Results of Algal, Fungal, and Plant Nomenclature Proposals, a database of proposals to conserve and/or reject names under the *Code*: <http://www.ars-grin.gov/~sbmljw/cgi-bin/taxprop.pl>
- Books on names and their types, e.g., *Order out of Chaos* (Jarvis, 2007), the definitive treatise on the ca. 9000 Linnaean plant names and their types, and the Linnaean Database (of the Linnaean Plant Name Typification Project): <http://www.nhm.ac.uk/research-curation/research/projects/linnaean-typification/databasehome.html>

Bibliography

- Biodiversity Heritage Library (BHL), containing ca. 40,000,000 pages of scanned literature mostly up until 1922: <http://www.biodiversitylibrary.org>
- JSTOR, a digital archive of scholarly journals. Although a not-for-profit service, a paid subscription is necessary to access the data. Access to certain journals is available at various botanical libraries: <http://www.jstor.org>
- WorldCat, a search facility for locating books and other materials in thousands of libraries worldwide: <http://www.worldcat.org/>
- Gallica, the digital library project of the Bibliothèque Nationale de France, especially rich in French-language publications: <http://gallica.bnf.fr>
- Biblioteca Digital del Real Jardín Botánico de Madrid, containing numerous publications that are not included in the BHL: <http://bibdigital.rjb.csic.es/spa/index.php>
- Library catalogues of major botanical and natural history institutions,

e.g., Harvard University Herbaria (Hollis Catalog); Missouri Botanical Garden; Muséum National d'Histoire Naturelle, Paris; Natural History Museum, London; New York Botanical Garden; Royal Botanic Gardens, Kew; Smithsonian Institution Libraries

- Guide to the plant species descriptions published in seeds lists from Botanic Gardens for the period 1800–1900: <http://www.nationaalherbarium.nl/seedlists/home.htm>
- *Botanico-Periodicum-Huntianum*, ed. 2 (BPH-2; Bridson & al., 2004), a comprehensive listing of almost all botanical journals with standard abbreviations for their titles: http://fmhibd.library.cmu.edu/fmi/iwp/cgi?-db=BPH_Online&-loadframes
- *Taxonomic Literature*, ed. 2 (TL-2; Stafleu & Cowan, 1976–1988; Stafleu & Menega, 1992–2000; Dorr & Nicolson, 2008–2009), including a massive amount of information on botanical works published between 1753 and 1940 (including some pre-Linnaean materials), giving standard abbreviations for titles, precise dates of publication, location of copies, authors' biographic details and location of their herbarium specimens including types: <http://www.sil.si.edu/digitalcollections/tl-2/index.cfm>
- Kew Bibliographic Database, incorporating the Kew Record of Taxonomic Literature, the Plant Micromorphological Bibliographic Database, and the Economic Botany Bibliographic Database, containing a bibliography of over 200,000 entries on the taxonomy of vascular plants published from 1971 up to the end of 2007 (when data-entry ceased): <http://kdb.kew.org/kdb/searchpage.do>
- Thomson Reuters Scientific (BIOSIS, SCI, Web of Knowledge): A major bibliographic indexing service, with full citations and abstracts; coverage (for Biological Abstracts) dates back to 1926. For subscribers Biological Abstracts can be accessed either directly (http://wokinfo.com/products_tools/specialized/ba/) or through Web of Knowledge (<http://wokinfo.com/about/whatitis/>). Overall information is at: http://thomsonreuters.com/products_services/science/science_products/a-z/
- *Botany Subject Index* (U.S. Department of Agriculture Library, 1958; only in print). A photo-offset fifteen-volume reproduction of the USDA National Agricultural Library botanical subject card catalogue (1906–1952). Very comprehensive for older literature (315,000 entries).
- Auxilium ad Botanicorum Graphicem, providing images of botanists' handwriting, useful for evaluating annotations on herbarium specimens: <http://www.ville-ge.ch/musinfo/bd/cjb/auxilium/index.php>

Languages

• *Botanical Latin*, now in its 4th edition (Stearn, 1992), with a recent Spanish translation, *Latín botánico* (Stearn, 2006), containing practically everything one could ever need to know about the use of the Latin language in plant systematics

• Latin words by William Whitaker, an accurate and comprehensive online Latin-English and English-Latin dictionary, which usefully includes all inflected forms of <http://archives.nd.edu/words.html>

• Google Language Tools, providing translations between more than 60 modern languages, as well as Latin; the quality of the translations varies: http://www.google.com/language_tools

Geography

• Google Earth and Google Maps, very useful for generating distribution maps and georeferencing older specimens without latitude and longitude data: <http://www.google.com/earth/index.html> and <http://maps.google.com/maps>

• MapCarta provides an overlay of localities on satellite imagery. A sidebar opens when one of the white locality dots is clicked, giving georeferences in DMS and DM, elevations, and connections to Google Maps, MapQuest, Geonames and others: <http://mapcarta.com>

• Online world gazetteers (e.g. Geonames, <http://www.geonames.org/>; Fuzzy Gazetteer, <http://isodp.hof-university.de/fuzzyg/query/>). These are interactive, providing latitudes and longitudes in DMS format.

• Regional gazetteers and botanical atlases (some actively or passively online)

• WorldClim, a set of global climate layers (climate grids) that can be used for mapping and spatial modelling in a geographic information system (GIS) or with other computer programs: <http://www.worldclim.org>

• *Guide to Best Practices for Georeferencing* (Chapman & Wieczorek, 2006; through GBIF: <http://www.gbif.org>)

• Digitised topographic maps. Good collections include the National Library of Australia and Perry-Castañeda Map Library (University of Texas, Austin).