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# Moss diversity: New look at old numbers

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## Abstract

Moss names published since 1801 and subsequently adjusted by monographic, floristic and molecular work provide a benchmark to review and estimate moss diversity. Information about these names is stored in the TROPICOS data base an on-line, interactive community resource. Nomenclatural data along with associated Web based floristic, monographic and bibliographic projects, provide one view of moss diversity based on the history of moss nomenclature and associated natural history information linked to the names.

**Key words:** Bryophyta, diversity, mosses, species numbers

## Introduction

Moss diversity is defined by numbers. How many mosses occur in a country, ecological biome, study site or tree – literally or figuratively. The relatively recent addition of phylogenetic and molecular techniques have altered the circumscription of some entities being counted but not the fundamental need to view diversity based on the numbers of names, species, concepts, or other defined units. The TROPICOS botanical information system (www.tropicos.org) at the Missouri Botanical Garden has been the primary source for this paper because it contains information on names, their current usage, distribution, and history. This system provides a unique resource, open to the public, for exploring biodiversity information although primarily reflecting the research efforts of a single institution. A brief overview of some of the system's functionality will be explored to show how the system is used and how it currently functions as part of the history of moss nomenclatural indexes. The numbers used, conclusions drawn and projections offered refer to mosses only and must be combined with similar numbers from hepatics and hornworts to determine the biodiversity of bryophytes, see paper by Von Konrat et al. in this issue. Of the 45,958 validly published moss species names no more than 13,000 are in current use and recent monographs and floras suggest that that number may still be inflated.

## Discussion

Moss diversity can be defined in several ways depending on individual approaches to specific questions. Perceived diversity is altered by differences in interpretation of data, changes in concepts, and the quality or quantity of information available. Furthermore interpretative morphological concepts that have defined moss diversity are now being reinterpreted by molecular analysis as indeed are established naming convention. So what can be said of moss diversity, relating to the number of taxa in current use or recognized, from the perspective of taxonomy, floristics, and molecular studies?

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**FIGURE 1.** TROPICOS Family Word Cloud. The moss family cloud lists family names in alphabetical order with the family name size determined by the number of included taxa.

## Taxonomy

Published names of mosses provide an available and quickly circumscribed data set to approach a question of moss diversity. The names given to mosses have been defined entities since the selection of Hedwig's (1801) *Species Muscorum* as the starting point for moss nomenclature. The International Code of Botanical Nomenclature (McNeill, 2006) continues to define how names are established and effectively published. Thus a name provides a defined object for counting, analyzing, circumscribing or labeling under current morphological concepts.

Since Hedwig's compilation of *Species Muscorum*, names have periodically been gathered into lists of known taxa. Starting with Bridel's (1826) *Bryologia Universa*, these lists have steadily grown in size and scope and include publications by Müller (1849-1851), *Synopsis Muscorum Frondosorum*, Jaeger & Sauerbeck (1870–1880), *Genera et species Muscorum*, Paris (1894–1898, 1900) *Index Bryologicus*, and although in a different format, Brotherus' (1924-1925) *Mosses* in *Die Natürlichen Pflanzenfamilien*. In 1954, through the encouragement of the Bryology Section of the 8th International Botanical Congress in Paris, van der Wijk, Margadant and Florschütz (1959–1969) began the compilation of *Index Muscorum*, a 15 year project to bring the names of mosses into a modern context. The initial work, collected on 3x5 cards, was first based on the previous work of Paris for per-1900 names and Brotherus for names published between 1901 and 1925. However both works were found to be inadequate for compilation of the new *Index* and much of the original literature between 1801 and 1963 was checked to verify publication of names. The *Index* became a five volume compendium of moss names published before 1963 and attempted to list all names, whether nomenclaturally acceptable, invalid, illegitimate, orthographic variant, or synonym and to document where the names were published, nomenclaturally correct alternative names (the 1801 starting data required many name changes) and an indication of an accepted name's global distribution. The *Index* was a notable accomplishment and formed the baseline for much of the taxonomy of the latter twentieth century.

In 1992, the first volume of *Index of Mosses* was published by Crosby, et al. identifying moss names published after the cutoff date of *Index Muscorum*, 1 January 1963. One important advance of Crosby's *Index of Mosses* project was the collection of all new names in an electronic data base. In addition, all name records from *Index Muscorum* were captured into the data base to provide the foundation necessary to validate new names, verify basionyms for new combinations, and provide internal links to blocking, replaced, and correct names for nomenclatural completeness. This moss names data base is available on the Web through TROPICOS (www.tropicos.org) along with similar data for over a million names of liverworts, ferns, gymnosperms and angiosperms. The system also contains information about name use and acceptance, associated specimens, and relevant literature.

*Index of Mosses* collects and compiles information about newly published moss names, their place of publication, type information, protologue distribution, and nomenclatural status. The information is gathered directly from recently published literature, especially through the *Recent Literature on Bryophytes* project (vide Buck, Allen & Pursell, 2009) published in *The Bryologist*. This original protologue information is frequently supplemented as names are used on specimen labels or are treated in revisions, floras or checklists that add distribution, images, descriptions and keys, or report new synonymy, chromosome counts and common names.

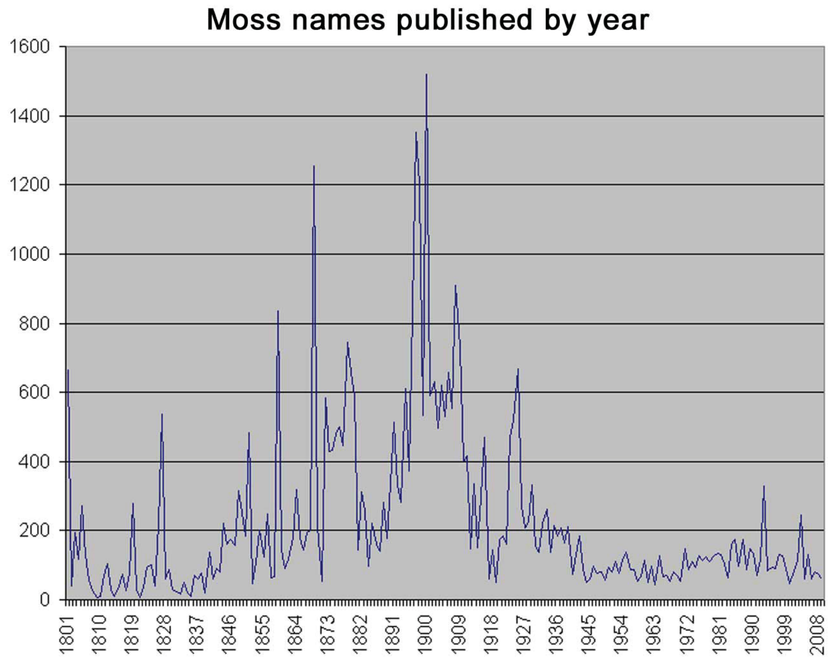


**FIGURE 2.** Chart of all validly published moss names, 1801-2009. The large center spike in the 1890's are primarily names described by Carl Müller (3426 in the 1890's, 4368 over all) with additional names from Bescherelle, Brotherus, Kindberg, Paris, and Renauld & Cardot, each contributing over 500 new names during this period.

TROPICOS is not the final arbitrator of the names but rather a repository for information about the names. The system attempts to capture as many uses, opinions and concepts for each name as possible from the literature and present these observations to users. *A Checklist of Mosses* (Crosby et al., 2000), on the other hand, is a new project that is developing a current view of moss names usage, an informed synonymy, and an overview of global distribution for each taxon. The first version of this checklist is available for download at http://www.mobot.org/MOBOT/tropicos/most/checklist.shtml. *A Checklist of Mosses* presents a list of recognized mosses not unlike those of the nineteenth century, but based on a modern, interactive, Web-based data base of bryological information.

So what does the nomenclator, TROPICOS, tell us about moss names and diversity? The data base has 226 family names for mosses containing 1,315 validly published genera. There are 45,958 validly published species names but only 13,053 are in current use or without recent synonymy. Some of these names have not been treated since their original publication and must be considered insufficiently known. As indicated by Paton et al. (2008) the TROPICOS moss data base will provide the moss names component for *The Plant List*, Target 1 of the Global Strategy for Plant Conservation; although the 13,370 number cited there for bryophytes was actually the number for mosses only. The mosses will be included with vascular plants as part of a working list of all known plant species which is envisioned to be the starting point for a world flora. Crosby et al. (2000) cites 12,754 recognized species in *A Checklist of Mosses*, and Shaw (2008) uses this estimate. Goffinet et. al (2008) however cite an approximate number of 13,000 species for all bryophytes.

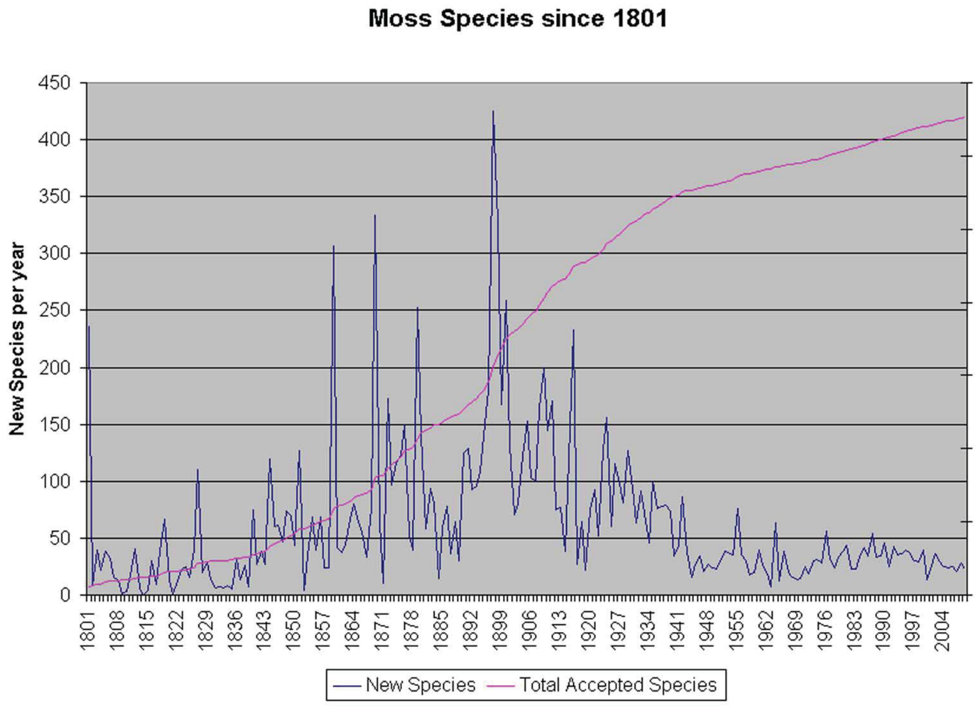


**FIGURE 3.** Valid moss names published in the years between 1801 and 2009 and the accumulated total names in current use – 13,053.

Most recent monographs and floras continue to report significant numbers of new synonyms for accepted names as species concepts are refined and global observation and voucher data is incorporated. While an average of 4 synonyms per accepted name is common, the most blatant example of re-naming is *Amblystegium rotae* De Notaris (1867: 291) that had 18 new combinations published by 1922. The last combination *Warnstorfia rotae* (De Not.) Wheldon (1922: 107) was made in 1922 where it remained until 1995 when the species was put into the synonymy of *Warnstorfia exannulata* var. *nigricans* (Bridel 1827: 629) Ochyra (1995: 919).

Taking into account the high number of synonyms being published and the large number of published names that remain insufficiently known, the currently accepted number of moss species appears too high. The relatively small number of newly discovered taxa, better circumscription of species concepts, and an historic average of up to 4 synonyms per accepted name, suggest that a conservative number of mosses may be no larger than 9,000 species.

## Floristic diversity

Recent floristic moss projects have contributed to the questions around floristic diversity by reporting new regional records, new species and new synonymy, and overall provide a much better circumscription of existing taxa. Some of these projects are regional treatments nearing completion include the *Flora of North America bryophyte* volumes (FNA Editorial Committee, 2007) - http://www.efloras.org/volume_page.aspx?volume_id=1027&flora_id=1 treating around 1,600 mosses, *Moss Flora of China* (Gao et al. 1999, 2003; Hu et al. 2008; Li et al. 2001, 2007; Wu et al. 2002, 2005) - http://www.tropicos.org/Project/MFC treating around 2,500 species, and *Moss Flora of Central America* (Allen, 1994, 2002) - http://www.mobot.org/MOBOT/Moss/centralamerica/welcome.shtml covering almost 970 species.

In addition to these publications, Web floras have begun to appear building on available information and new collecting. The advantages of Web-based flora include wider access to the information, quick and easy updates and additions, a wide variety of images, links to other sites, and direct access to bryological literature. A Web flora can also be made available on personal devices – phones, pads – in the field or lab. Two examples of Web floras are Churchill's Andean Bryophytes (http://www.tropicos.org/Project/ANBRY ) and the Bolivian Moss Project (http://www.tropicos.org/Project/BMP ), both provide interactive keys, illustrations, lists of specimens, maps and descriptive information in addition to external links to related resources. These two examples are run as projects in TROPICOS which contributes information on nomenclatural aspects of the names, worldwide specimen coverage, protologue and related literature, and cross references to other system projects. The Web projects module in TROPICOS provides input and update options for each project and allows data gathering and treatment updates away from the projects home base using the Internet, i.e. from the field or collaborating herbaria.

Other recent country level floristic research also contribute floristic diversity information about mosses, for example the work done on Brazilian mosses, the floristic work in China, Vietnam, Australia and Russia in addition to numerous checklists and revisions. A review of the new moss names published over the last twenty years (see Figure 4) reflects where this work has been concentrated and highlights other areas, like Africa, India, Central Asia, and Southeast Asia, where information is minimal at best.

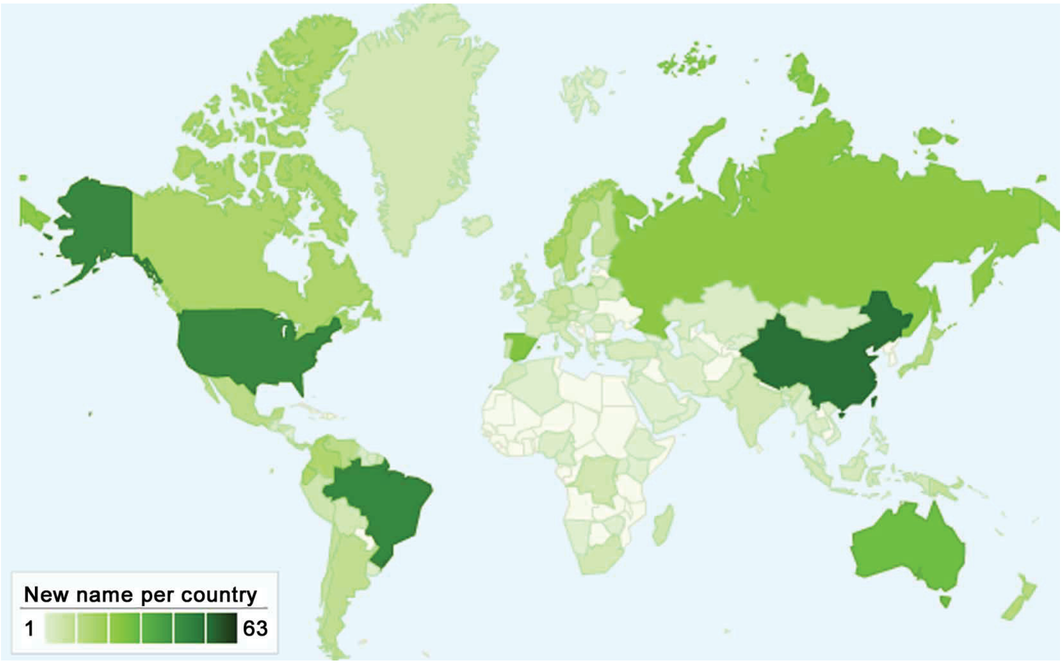


**FIGURE 4.** New moss names published over the last twenty year grouped by country of origin. Darker colors indicate countries with more names published between 1989 and 2009.

Collection bias and the order in which legacy specimen data are being captured will distort the information when querying existing bryophyte data bases. The Missouri Botanical Garden holds over 500,000 bryophyte specimen and just over 232,000 have been captured in to the data base. A world view of the distribution of these specimens shows the current status of the encoded collection for this one herbarium. The collection distribution map, see Figure 5, shows recently entered label data for a worldwide collecting program and legacy specimen data reflecting project interests in the Americas and China. Several community efforts to promote the capture of specimen data in natural history collections could provide a significant new resource for climate change research by exposing the diversity held in herbaria and pinpoint areas in need of further study, but financial and community support for these projects must be found.

Several ecological factors influence floristic diversity in mosses but perhaps none more so than long distance dispersal. Long distance dispersal plays a role in moss distribution but has not resulted in a uniform flora even within similar ecological regimes. There remain many clear examples of endemics, both continental and local, that support the hypothesis that restraints, ecological and physical, are in place, e.g. documented observation of invasion of southern hemisphere taxa in to Europe.

Obvious similarities between significant parts of the floras of South America and Africa or between China and the eastern United States seem to document the prolonged effect of spore dispersal within at least the different hemispheres and the rare establishment of colonies when ecological conditions and competition permit. The fact that we don't have a uniform moss flora clearly demonstrates that constraints exist and are maintaining defined floras within broad ecological regions. Moss diversity is highest in the tropics, where there is high topographical relief providing the maximum number of habitats, ecological conditions and open niches or in humid, cool seasonal temperate forests. This is demonstrated for mid-elevation tropical forests by the large number of species represented in the small Central American landmass (fide Allen, 1994, 2002) and for cool, humid temperate forests by the higher diversity in the Pacific northwest of North America. Both of these areas are not high in endemics but exceptional in overall number of species. Deserts and dry habitats also provide an excellent opportunity for discovery of unique new families and genera primarily because they have not been as carefully explored as other areas. The harsh environments restrict the mosses to much more remote and isolated niches, but the numbers of interesting and new taxa being found in xeric conditions make long, tedious searches worth the effort (vide Hedderson & Zander, 2007, 2008, 2008a).

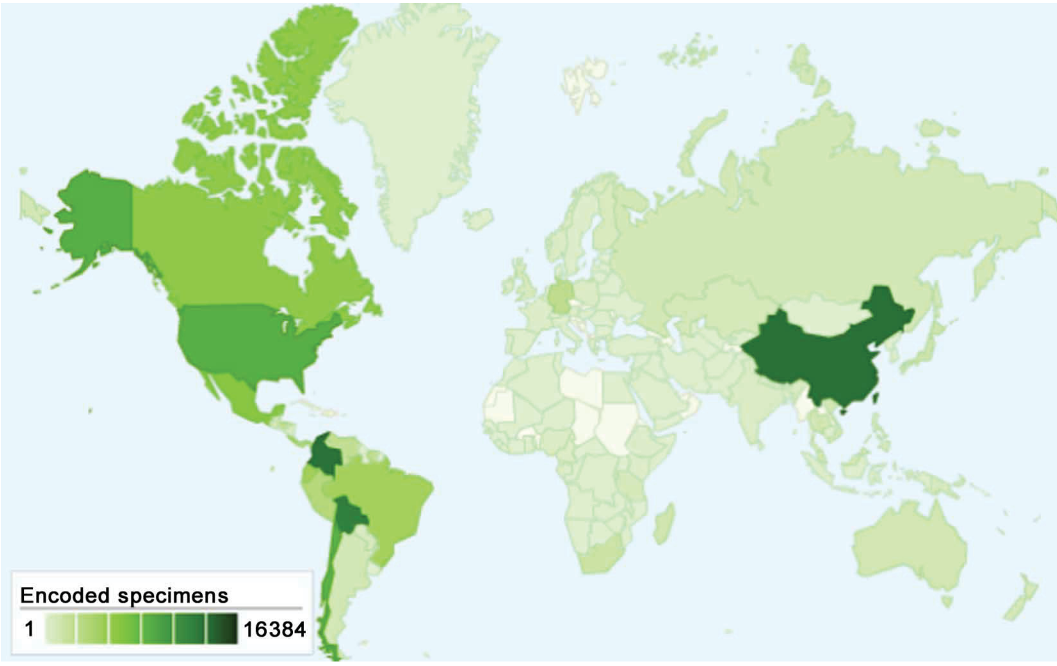


**FIGURE 5.** Current country distribution for encoded moss collections held in TROPICOS. Darker country colors indicates more captured specimens. Data for approximately half of the 500,000 specimens in the collection at MO have been captured and supplemented by data from several partners (including AAU, GB, HUA, LPB, USZ), but with an obvious new collection and project bias.

## Molecular studies

Molecular systematics focused on using DNA data to investigate population genetics, dispersal and biography is discussed in detail in another contribution (vide Vanderpoorten & Shaw, this issue). From a systematic standpoint the biodiversity information provided by molecular research on mosses has been concentrated almost entirely on the higher classification categories, focusing on the placement of an assortment of taxa within a broad phylogenetic framework. This molecular data has contributed significantly to the understanding of diversity in terms of the higher taxa or a resolution of older lineages, but not significantly at the species level. To be sure there has been research efforts focused on 'species' groupings or even populations (fide Shaw, 2008a, 2008b), but this potentially important work, that would define biodiversity using molecular techniques, is not widespread. Molecular phylogenies within revisionary work have been too few to shed much light on the extent or accuracy of current numbers for mosses. The perception, at least at this time, is that molecular studies have not altered the absolute number arrived at through conventional means.

The Consortium for the Barcode of Life (Schindel, 2010) has more promise in defining the numbers or objects counted. The use of a widely accepted unique identifier to group collections, plot samples, or vouchering observations, has the potential to produce a 'molecular species' count.

## Conclusions

Precise numbers can not be given for moss diversity, although modern revisions, floras, and molecular data have begun to refine the objects being counted and to deal with the inflated numbers created by the 'geographical species concept' of Müller and others in the mid to late nineteenth century. Moss names provide one view of diversity especially with associated data coming in from a variety of other research areas, but an absolute answer remains elusive even from a nomenclature standpoint. Questions of how to circumscribe or define this diversity, e.g. names, clades, concepts, clouds, etc., must be reconciled. Perhaps statements like "9,000 species of mosses", or "13,000 monophyletic bryophyte clades" are as precise as possible today, but systematics, encompassing morphological, ecological and molecular data, is sharpening the response to what constitutes moss diversity.

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