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How many known vascular plant species are there in the world? An integration of multiple global plant databases

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ABSTRACT

Aims: Despite that vascular plants constitute an important component of overall global biodiversity and have been studied well over two centuries, the questions of "How many species of vascular plants are there in the world and how many of them have been discovered and described?" remain open. Here, we address the second of the two questions.

Method: We synthesized four global plant databases.

Results & Conclusions: Our study shows that for the entire global flora of vascular plants (including natural hybrids), 376,366 species have been discovered and validly described. When natural hybrids are excluded, the global flora includes 369,054 species of vascular plant species, of which pteridophytes (ferns and lycophytes), gymnosperms and angiosperms have 13,810, 1,172 and 354,072 species, respectively. The number of vascular plant species derived from our study is larger than any of the other four databases by at least 17,700 species.

Key words: angiosperm; fern, flowering plant; gymnosperm, lycophyte; pteridophyte; species diversity

1 Introduction

Vascular plants, i.e. pteridophytes, gymnosperms and angiosperms, form a large taxonomic sample of biodiversity. They are important not only in themselves but also in directly determining the diversity of many other taxonomic groups (Pimm & Joppa, 2015). Vascular plants constitute the basis of most terrestrial ecosystems (Borsch et al, 2020). Despite that vascular plants constitute an important component of overall global biodiversity and have been studied well over two centuries, the questions of how many species of vascular plants there are in the world and how many of them have been discovered and described remain open. Several studies have reported estimates of these numbers based on statistical models or selected taxonomic groups (e.g. families), but the estimated number of the world's vascular plant species varies greatly among studies, ranging from fewer than 250,000 to more than 400,000, and most of the estimated numbers fall in the range from 300,000 to 400,000 species (e.g. 308,312 species in Christenhusz & Byng (2016), 390,923 species in Pimm & Joppa (2015).

Accurately determining how many species of vascular plants in the world that have been discovered and described requires a synomized checklist that includes all published names of vascular plants and the relationships between synonyms and their accepted names. The Plant List (TPL; version 1.0, 2010; version 1.1, 2013; http://www.theplantlist.org) was the first synomized checklist of the world's plants, including both vascular plants and bryophytes. However, 22.8% of the plant names in the version 1.1 of TPL were not resolved. In addition, many names were incorrectly resolved. For example, according to TROPICOS (https://www.tropicos.org/home), *Cyclosorus procurrens* (Mett.) Copel. and *Thelypteris procurrens* (Mett.) C. F. Reed are homotypic synonyms for a single species, but TPL treated them as two accepted names (i.e. two different species). This would ultimately overestimate species diversity. TPL has been static since 2013.

Largely based on TPL, five other global plant databases have been developed in parallel in the past decade: World Flora Online (WFO; www.worldfloraonline.org), Plants of the World Online (POWO; www.plantsoftheworldonline.org), World Checklist of Vascular Plants (WCVP; wcvp.science.kew.org), The Leipzig Catalogue of Vascular Plants (LCVP; Freiberg et al, 2020), and World Plants (WP; https://www.worldplants.de).

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Although each of these plant databases can result in a more accurate number for global species diversity of vascular plants, compared to TPL, each of them includes a number of accepted species names that are absent from the other three databases. For example, according to WP (accessed on Feb. 21, 2021), the genus *Hysterobaeckea*, which was established and published in 2015, includes 11 accepted species; the genus was missing from LCVP; three species of the genus were treated as accepted species in the genera *Babingtonia* (*B. behrii* (Schltdl.) A. R. Bean) or *Baeckea* (*B. ochropetala* F. Muell.; *B. tuberculata* Trudgen) in LCVP and the other eight species were missing from LCVP (i.e. *Hysterobaeckea cornuta* Rye; *H. glandulosa* Rye; *H. graniticola* Rye; *H. longipes* Rye; *H. occlusa* Rye; *H. petraea* Rye; *H. pterocera* Rye; *H. setifera* Rye). In addition, for a particular database, some species names were treated as accepted names more than once due to misspellings in species names (e.g., *Helichrysum auronitens* Sch. Bip. versus *Helichrysum aureonitens* Sch. Bip.; *Senecio cinarifolius* H. Lév. versus *Senecio cinerifolius* H. Lév.; *Stevia strotheriana* B. L. Turner versus *Stevia strotherana* B. L. Turner; *Taraxacum idlomorphoides* Rail. versus *Taraxacum idiomorphoides* Rail.), which would have necessarily led to overestimate of species diversity in LCVP. Synthesizing the information available in the above-mentioned global plant databases can lead to a more accurate estimate for the number of vascular plant species known to science, compared to considering any one of the databases alone.

The objective of this study is to synthesize the botanical information available in four major global plant databases (i.e. WFO, POWO, LCVP and WP) to determine how many species of vascular plants known to science there are in the world. We do not consider TPL because it is a predecessor of WFO. We do not consider WCVP because both WCVP and POWO were generated by Royal Botanic Gardens, Kew, and plant names of WCVP were included in POWO. We do not consider other global databases for particular groups of vascular plants and regional plant databases in this study because the information in them has already been included in the four major global plant databases considered in the present study (e.g., see Online-only Table 1 of Freiberg et al, 2020).

2 Methods

For LCVP, we used the checklist published in Freiberg et al. (2020). For WFO, POWO and WP, we retrived data from their websites as shown above (last time accessed in Feburary 2021). We took multiple steps to link plant names between each pair of the databases. First, we matched names using the combinations of Latin names and their authorities. Second, for those names that were not matched in the first step, we matched names based on Latin names and visually checked authorities for the matched Latin names. Third, we used fuzzy matching algorithms implemented in various software packages (e.g. Taxonstand, Cayuela et al, 2012; WorlfFlora, Kindt, 2020; lcvplants, Freiberg et al, 2020) or online name matching applications (e.g. Taxonomic Name Resolution Service, http://tnrs.iplantcollaborative.org) to match names (with or without name authorities) and visually checked the matched names first by their generic names and then by specific and infraspecific epithets. Fourth, we used various combinations of a given number of letters from a generic name and a given number of letters from a specific epithet (e.g. the first 10 letters of the generic name plus the first 6 letters of the specific epithet of a Latin name) and visually checked the matched names first by their generic names and then by specific epithets. In each of the above-outlined steps, we conducted several matching processes by slightly modifying Latin names and authorities. For example, for those names that were not matched in the initial matching processes using the original Latin names and authorities, we removed the hybrid sign '×' and hyphen and replaced 'ae', 'ai', 'ei', 'yi' and 'ii' with 'i' in Latin names; we removed dot and space and replacing 'fil.' with 'f.' in authorities; we changed all letters in the original Latin names and authorities to letters in their respective lower cases. Visual checking for matched names was applied in each matching process. These multi-step processes would have maximized matching for names among different databases.

We used the LCVP database as the nomenclature backbone of our study. For a given accepted species, if there are duplicate accepted species names due to misspellings (or orthographic variants) in one or more names, we only retained the one with correct spelling. For those names that were treated as accepted species names in one or more of the other three databases (i.e. POWO, WFO and WP), if none of them and their synonyms in the three databases were included in LCVP as either accepted names or synonyms, we considered them as accepted species names in addition to those in LCVP. We assigned each species to an order using the classification system developed by Pteridophyte Phylogeny Group (Schuettpelz et al, 2016) for pteridophytes, the classification system available at Angiosperm Phylogeny Website (http://www.mobot.org/MOBOT/research/APweb/) for gymnosperms, and APG IV (Angiosperm Phylogeny

Group, 2016) for angiosperms.

3 Results

For the entire global flora of vascular plants (including natural hybrids), 376,366 species have been discovered and described (Table 1). These include 14,307 species of pteridophytes and 362,059 species of seed plants. When gymnosperms and angiosperms are considered separately, the world flora includes 1,217 species for gymnosperms and 360,842 species for angiosperms. When natural hybrids are excluded, the global flora includes 369,054 species of vascular plant species. When different major taxonomic groups are considered separately, pteridophytes, gymnosperms and angiosperms have 13,810, 1,172, and 354,072 species, respectively.

We reported a list of all vascular plant orders with the numbers of described and accepted species in Table 1. The five largest orders are Asparagales (42,236 and 40,736 species with and without hybrids, respectively), Asterales (41,868 and 41,459), Lamiales (29,365 and 28,447), Fabales (26,412 and 26,301), and Poales (25,379 and 24,667).

4 Discussion

Our study aims at addressing the long-standing question: How many species of vascular plants in the world have been discovered? Answering this question is difficult because many plant names are synonyms (i.e. different names given to the same plant) and the relations of many synonyms to their accepted names are difficult to resolve. Many vascular plants have more than one scientific name (averaging 2.7 names per vascular plant; https://stateoftheworldsplants.org/2016/report/sotwp_2016.pdf). This happens when the same plant species has been given different names, mostly by different people at different times. Nevertheless, the number of unresolved plant names in the backbone database that we used in this study (i.e. LCVP) is relatively small, compared some other global plant databases (e.g. 5% in LCVP versus 21% in TPL; Freiberg et al, 2020). By synthesizing the botanical information in the four databases of the world's plants, we provide the most accurate estimate for the number of the world's vascular plant species known to science (i.e. 376,366 and 369,054 species with and without hybrids, respectively), compared to previous estimates based on statistical models (e.g. Nic Lughadha et al, 2016; Paton et al, 2008; Pimm & Joppa, 2015) or a single synonymized checklist (e.g. Freiberg et al, 2020). For example, for vascular plants, LCVP includes 351,180 accepted species (Freiberg et al, 2020), WP includes 351,263 accepted species (https://www.worldplants.de/world-plants-complete-list/total-species-count; accessed Feb. 21, 2021), and POWO includes 348,705 accepted species (www.plantsoftheworldonline.org; accessed Feb. 21, 2021). WFO includes 350,510 accepted species for both vascular plants and bryophytes (www.worldfloraonline.org; accessed Feb. 21, 2021). Thus, the number of vascular plant species derived from our study is larger than any one of the other four databases by at least 17,700 species.

The vast majority of the species that are additional to LCVP were taken from POWO and WP. In their Online-only Table 1, Freiberg et al (2020) stated that LCVP used data in POWO. Although they didn't directly list WP as a source database for LCVP, they did list WP along with Catalogue of Life as one of the data sources that they used. An interesting question is: Why did LCVP miss so many plant names that are available in POWO and WP? One possible reason may be that LCVP used substantially outdated versions of POWO and WP databases. As Freiberg et al (2020) stated, the POWO data used in LCVP was obtained directly from Kew in November 2018, which included only ~793,000 plant names (~335,000 accepted species names, ~458,000 names of vascular plants marked as synonyms). The version of the POWO database that we used, which included ~1.1 millions of plant names, had ~300,000 more names than the version of the POWO database that Freiberg et al (2020) used to build LCVP. The version of the WP database that Freiberg et al (2020) used to build LCVP was generated by Hassler (2019) for Catalogue of Life. This was a substantially outdated version of the WP database, compared with the version of the WP database that we used in the present study.

About 63,000 of the plant names in LCVP are unresolved. Of these names, 60,710 are plant names at the species rank. However, ~14,500 of these names were resolved in POWO and WP as either accepted names or synonyms. Thus, the proportion of unresolved names was reduced from 5% in LCVP to 3.7% in our study. Although some of the still unresolved names in LCVP may become accepted names in future, the result of our study supports the notion of Freiberg et al (2020) that most of these unresolved names are likely synonyms.

The number of accepted species of the world's vascular plants known to science that was reported in this study was based on four major global plant databases (i.e. LCVP, POWO, WFO and WP). We believe these databases have collectively included all published plant names up to at least 2019. Christenhusz

Table 1 Number of species that have been validly described for each of the orders of vascular plants in the world

Order	Number of species		Order	Number of species	
	Incl. hybrid	Excl. hybrid		Incl. hybrid	Excl. hybrid
Pteridophyte			Crossosomatales	77	77
Cyatheales	793	782	Cucurbitales	3232	3215
Equisetales	45	35	Dilleniales	567	567
Gleicheniales	177	173	Dioscoreales	909	907
Hymenophyllales	637	634	Dipsacales	1471	1432
Isoetales	208	203	Ericales	14638	14445
Lycopodiales	522	513	Escalloniales	154	147
Marattiales	151	151	Fabales	26412	26301
Ophioglossales	132	128	Fagales	1670	1435
Osmundales	26	24	Garryales	27	27
Polypodiales	10560	10123	Gentianales	23687	23600
Psilotales	19	19	Geraniales	953	934
Salviniales	82	81	Gunnerales	67	66
Schizaeales	224	213	Huerteales	30	30
Selaginellales	731	731	Icacinales	187	187
Gymnosperm			Lamiales	29365	28447
Cupressales	458	441	Laurales	3955	3954
Cycadales	376	375	Liliales	1897	1876
Ginkgoales	1	1	Magnoliales	3565	3542
Gnetales	120	117	Malpighiales	20197	19749
Pinales	262	238	Malvales	7770	7605
Angiosperm			Metteniusales	66	66
Acorales	2	2	Myrtales	15400	15203
Alismatales	4832	4729	Nymphaeales	109	101
Amborellales	1	1	Oxalidales	2164	2160
Apiales	6400	6377	Pandanales	1699	1698
Aquifoliales	770	766	Paracryphiales	42	42
Arecales	2814	2784	Petrosaviales	4	4
Asparagales	42236	40736	Picramniales	57	57
Asterales	41868	41459	Piperales	4512	4512
Austrobaileyales	91	91	Poales	25379	24667
Berberidopsidales	4	4	Proteales	2085	2080
Boraginales	3711	3674	Ranunculales	6328	6207
Brassicales	5502	5393	Rosales	11985	11428
Bruniales	90	90	Santalales	2636	2632
Buxales	135	135	Sapindales	7071	7036
Canellales	129	129	Saxifragales	3359	3134
Caryophyllales	15362	15020	Solanales	5493	5469
Celastrales	1437	1437	Trochodendrales	2	2
Ceratophyllales	7	7	Vahliales	5	5
Chloranthales	75	75	Vitales	1105	1101
Commelinales	959	956	Zingiberales	2999	2986
Cornales	744	731	Zygophyllales	343	343

& Byng (2016) and Cheek et al (2020) showed that the numbers of new vascular plant species published per year (excluding new combinations) was, on average, ~2000 in the last two decades, including recent years (Cheek et al, 2020). We predict that about 2000 new vascular plant species will be discovered annually in the next few years or decade.

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References

Borsch T, Berendsohn W, Dalcin E, Delmas M, Demissew S, Elliott A, Fritsch P, Fuchs A, Geltman D, Güner A, Haevermans T, Knapp S, Roux MM, Loizeau PA, Miller C, Miller J, Miller JT, Palese R, Paton A, Parnell J, Pendry C, Qin HN, Sosa V, Sosef M, Raab-Straube E, Ranwashe F, Raz L, Salimov R, Smets E, Thiers B, Thomas W, Tulig M, Ulate W, Ung V, Watson M, Jackson PW, Zamora N (2020) World Flora Online: Placing taxonomists at the heart of a definitive and comprehensive global resource on the world's plants. Taxon, 69, 1311–1341.

Angiosperm Phylogeny Group (2016) An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV. Botanical Journal of the Linnean Society, 181, 1–20.

Cayuela L, Granzow-de la Cerda Í, Albuquerque FS, Golicher DJ (2012) Taxonstand: An R package for species names standardisation in vegetation databases. Methods in Ecology and Evolution, 3, 1078–1083.

Cheek M, Nic Lughadha E, Kirk P, Lindon H, Carretero J, Looney B, Douglas B, Haelewaters D, Gaya E, Llewellyn T, Ainsworth AM, Gafforov Y, Hyde K, Crous P, Hughes M, Walker BE, Campostrini Forzza R, Wong KM, Niskanen T (2020) New scientific discoveries: Plants and fungi. Plants, People, Planet, 2, 371–388.

Christenhusz MJM, Byng JW (2016) The number of known plants species in the world and its annual increase. Phytotaxa, 261, 201.

Freiberg M, Winter M, Gentile A, Zizka A, Muellner-Riehl AN, Weigelt A, Wirth C (2020) LCVP, The Leipzig catalogue of vascular plants, a new taxonomic reference list for all known vascular plants. Scientific Data, 7, 416.

Hassler M (2019) World Plants: Synonymic Checklists of the Vascular Plants of the World (version Nov. 2018). In: Species 2000 & ITIS Catalogue of Life. 2019 Annual Checklist (eds Roskov Y, Ower G, Orrell T, Nicolson D, Bailly N, Kirk PM, Bourgoin T, DeWalt RE, Decock W, Nieukerken E van, Zarucchi J, Penev L). http://www.catalogueoflife.org/annual-checklist/2019/details/species/id/327754a53d1d6be643f32eedfc8a2958.

Gardens R Kew (2016) The state of the world's plants report 2016. Royal Botanic Gardens, Kew.

Kindt R (2020) WorldFlora: An R package for exact and fuzzy matching of plant names against the World Flora Online taxonomic backbone data. Applications in Plant Sciences, 8, e11388.

Nic Lughadha E, Govaerts R, Belyaeva I, Black N, Lindon H, Allkin R, Magill RE, Nicolson N (2016) Counting counts: Revised estimates of numbers of accepted species of flowering plants, seed plants, vascular plants and land plants with a review of other recent estimates. Phytotaxa, 272, 82.

Paton A, Brummitt N, Govaerts R, Harman K, Hinchcliffe S, Allkin R, Nic Lughadha E, Puentes F (2008) Towards Target 1 of the Global Strategy for Plant Conservation: A working list of all known plant species—Progress and prospects. Taxon, 57, 602–611.

Pimm SL, Joppa LN (2015) How Many Plant Species are There, Where are They, and at What Rate are They Going Extinct? Annals of the Missouri Botanical Garden, 100, 170–176.

Schuettpelz E, Schneider H, Smith AR, Hovenkamp P, Prado J, Rouhan G, Salino A, Sundue M, Almeida TE, Parris B, Sessa EB, Field AR, de Gasper AL, Rothfels CJ, Windham MD, Lehnert M, Dauphin B, Ebihara A, Lehtonen S, Schwartsburd PB, Metzgar J, Zhang LB, Kuo LY, Brownsey PJ, Kato M, Arana MD, Assis FC, Barker MS, Barrington DS, Chang HM, Chang YH, Chao YS, Chen CW, Chen DK, Chiou WL, Dittrich VAD, Duan YF, Dubuisson JY, Farrar DR, Fawcett S, Galan JMGY, Goes-Neto LAD, Grant JR, Grusz AL, Haufler C, Hauk W, He H, Hennequin S, Hirai RY, Huiet L, Kessler M, Korall P, Labiak PH, Larsson A, Leon B, Li CX, Li FW, Link-Perez M, Liu HM, Lu NT, Meza-Torres EI, Miao XY, Moran R, Mynssen CM, Nagalingum N, Ollgaard B, Paul AM, Pereira JBD, Perrie LR, Ponce M, Ranker TA, Schulz C, Shinohara W, Shmakov A, Sigel EM, de Souza FS, Sylvestre LD, Testo W, Triana-Moreno LA, Tsutsumi C, Tuomisto H, Valdespino IA, Vasco A, Viveros RS, Weakley A, Wei R, Weststrand S, Wolf PG, Yatskievych G, Xu XG, Yan YH, Zhang L, Zhang XC, Zhou XM, (2016) A community-derived classification for extant lycophytes and ferns. Journal of Systematics and Evolution, 54, 563–603.