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RESEARCH ARTICLE

Plants People Planet PPP Open Access

Global access to nomenclatural botanical resources: Evaluating open access availability

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Societal Impact Statement

Primary occurrence data ('what, where, when') enable study of species distribution and diversity, facilitating reactions to societal challenges from food security to climate change mitigation. Scientific names integrate information and are made concrete through reference to a type specimen. Research and conservation planning requires timely open access to this data. Around 2000 vascular plant species are described each year, and many are narrowly endemic and face conservation threats. Twenty-four percent of those published between 2012 and 2021 is available openly, and only 12% of taxa is represented by digitised type material served from within their native range. We make several recommendations to increase open access to this vital information to support prompt conservation action and future research.

Summary

- We review access to literature and type specimens, key resources for taxonomic research. Takeup of open access (OA) publishing in plant naming is analysed using the International Plant Names Index (IPNI) data (2012–2021), and online availability of specimens analysed using the Global Biodiversity Information Facility (GBIF). Integration of the World Checklist of Vascular Plants (WCVP) taxonomy and distributional data is used to examine regional variation.
- We found that 23% of vascular plant names are published OA, and 41% are digitally undiscoverable: contained in bibliographic works without a Digital Object Identifier (DOI) or with an unresolvable DOI. The most common OA publishing model used is 'gold'.
- We also found that 30% of taxa are represented by a digitised type specimen mobilised from within the continent of their natural range and only 12% from the (more precise) country.
- We recommend clear article processing charge (APC) waivers for authors from low and middle income countries to better enable 'gold' OA and promotion of deposition repositories to better enable 'green' OA. Nomenclators should clearly indicate the OA status of literature and mobilise type citation data as material citations to aggregators like GBIF. Names registration systems should promote the

capture of code-recommended elements such as catalogue numbers for type specimens. Digital mobilisation of specimen metadata and images from collections based in low- and middle-income countries must be accelerated to help increase in country taxonomic capacity to document and conserve plant diversity.

KEYWORDS

botanical nomenclature, GBIF, herbarium, open access, specimen, taxonomic distribution, types, vascular plants

1 | INTRODUCTION

Names of plant species are a foundation for further research on the ecology and evolution of plant diversity. Open access to biodiversity information facilitates the downstream use of data for applied purposes such as macroecology (Cai et al., 2023; Sabatini et al., 2022), conservation, plant breeding and phylogenetics. Naming of new taxa is an essential service, enabling us to interact with existing bodies of knowledge—as Linnaeus warned: 'nomina si nescis, perit et cognitio rurem' (if you do not know the names, your knowledge gets lost) (Linnaeus, 1751). Accurate naming is also essential to develop our understanding of newly described organisms. We cannot protect what we have not named; legislative protection of species cannot proceed without a formal species description.

Despite the importance of naming and the many uses of a comprehensive taxonomic system, progress towards documenting and understanding plant diversity is challenged by the so-called 'taxonomic impediment'. This term was first introduced in 1976 and is a shorthand for the skills (and resources) gap in taxonomy (Taylor, 1976, 1983). Access to these necessary skills and resources is uneven and when viewed globally actually mismatches the areas of greatest need; the most species-rich areas are often the most resource-poor (Meyer et al., 2016).

The naming of algae, fungi and plants is governed by the International Code of Nomenclature for algae, fungi and plants (hereafter the Code) (Turland et al., 2018), which is revised every 6 years at an International Botanical Congress following proposals put forward by the botanical community (Knapp et al., 2004; Lindon et al., 2020). The Code has specific rules for publication of specific nomenclatural acts; unless these rules are followed (see Chapters IV and V of Turland et al., 2018), names are not considered code compliant and are not correctly available for use. Nomenclatural acts referring to names of taxa include names of new taxa and renaming of taxa (such as transfers to different genera or the establishment of a replacement name). Because nomenclatural acts must be published, they should be widely available for use by both taxonomic and downstream communities.

Names of taxa are associated with type materials; these are objects (often specimens) to which a name is attached and which serve as a reference for future taxonomists. The type method is a relatively recent innovation; prior to 1958 the citation of a type as necessary for the publication of a nomenclatural act as defined above was not required (Art. 40, Turland et al., 2018). The adoption of the type method in plant taxonomy means that there is an intimate connection between the names of plants and their type specimens in collections. The distribution of these preserved specimens has been influenced by colonial history, with comprehensive plant collections having been developed in the Global North, and just under 70% of the almost 400 million herbarium specimens being housed in Europe and North America whilst the areas richest in species diversity are often located in the tropics (Paton et al., 2020; Thiers, 2022). Indeed, the enormous wealth of existing collections means that many as yet unnamed taxa are already lodged in preserved collections, awaiting examination and description (Bebber et al., 2010).

Patterns of colonialism mean that the specimens associated with the naming of new taxa—the types—are often not held in the country or even continent of origin (Das & Lowe, 2018; Park et al., 2021). The pattern of type deposition, however, has not been assessed on a global scale. Various global initiatives (e.g., the Mellon Foundation's Global Plants Initiative) have sought to redress this imbalance through digital access. The adoption of the Convention on Biological Diversity (CBD), the associated Nagoya Protocol and related national legislation (The Nagoya Protocol on Access and Benefit-sharing) mandates sharing of the benefits arising from access to biodiversity. As a result, countries encourage and can legislate deposition of specimens collected within national boundaries in national herbaria (Paknia et al., 2015). The degree to which these international instruments, now ratified by most countries, have changed in post-colonial practice is not well documented.

Increasingly, digitisation is providing free open access to these specimens (Soltis, 2017) and broadening their scientific use (James et al., 2018; Lendemer et al., 2019). However, it is necessary to build human and infrastructural capacity to properly document plant diversity in order to prioritise conservation action (Cheek et al., 2020; Fazey et al., 2005). Recent work by the Global Biodiversity Information Facility's Biodiversity Information for Development initiative (see GBIF BID impact summary) has shown that by targeting underrepresented regions in digitisation efforts, numbers of threatened taxa available in globally accessed datasets can be significantly increased.

Although it could be argued that the taxonomic impediment is in part due to the shortage of taxonomists (Engel et al., 2021), open access to information is also critical as it facilitates the training of researchers, the circumscription and recircumscription of taxa and provides the basis for further downstream analyses. Approximately 2000 vascular plant species are described as new to science each year

(Nicolson et al., 2017), and most of them are likely to have narrow distributions and to be threatened with extinction (Nic Lughadha et al., 2020) or have uses as yet undiscovered by plant scientists and others. In addition to new taxa, taxonomists work to understand and document relationships of plants, leading to name changes and recircumscriptions of taxa, in turn leading to new names.

Electronic publication of nomenclatural acts was, until 1 January 2012, not permitted under the code. Before that date, all nomenclatural acts for algae, fungi and plants had to be published in print on paper. The adoption of electronic publication by the community (at the Melbourne International Botanical Congress, see Nicolson et al., 2017) led to an increase in this method of publication, but did not substantially change patterns of taxonomic activity. During discussions over electronic publication leading up to and at the Melbourne Congress, there was conflation of electronic publication with open access publication (Flann et al., 2014; Knapp et al., 2011). This conflation led some to suggest that this change in the rules would be a watershed for access to information about the names of organisms, but this was not the case (Nicolson et al., 2017)—publication by electronic means and open access are very different things.

Copyright is another term often confounded with access in discussions of publications of all types. Copyright is the right to determine how creative works are used, distributed and displayed, and unless transferred, this right is owned by the creator of the work. Others are not permitted to take these rights without the owner's consent. The open access movement provides a means by which copyright holders can simply state that they want their creative work to be open to all, which they do by providing an open licence. Good examples of this are the licences of the Creative Commons organisation.

The open access movement champions free and open access to all information. A foundational event of the open access movement was the Budapest Open Access Initiative (BOAI) (Chan et al., 2002). It was recognised in the initiative that scholarly publications were an important and public good that, with the advent of the internet, could be shared completely freely to all those who wanted to read it, whether out of need or curiosity. By removing barriers to scientific literature, it was hoped that open access would '… accelerate research, enrich education, share the learning of the rich with the poor and the poor with the rich, make this literature as useful as it can be, and lay the foundation for uniting humanity in a common intellectual conversation and quest for knowledge' (Chan et al., 2002). The Initiative recommended two complementary strategies to achieve these goals, firstly self-archiving in open repositories (so-called green open access) and publication in completely open access journals (so-called gold open access), usually associated with an article processing charge to the author. Subsequently other shades of open access publication have emerged that are detailed in Table 1.

Here, we explore patterns in publication of the names of vascular plants using publication data from the International Plant Names Index (IPNI), along with data from global specimen data aggregators coupled with taxonomy and distribution from the World Checklist of Vascular Plants (WCVP, Govaerts, 2021). We examine the degree and global distribution of open access publication of these important data to answer three research questions: (1) how has open access publishing been adopted in the publication of names, (2) does open access availability vary with the distribution of the taxon and (3) does the location of the data provider responsible for mobilisation of digitised type specimen metadata correlate with the natural range of the taxon. We make recommendations we feel will help better support work to document and conserve plant diversity for downstream use and suggest next steps for research and improvement of the data sets that we used.

2 | MATERIALS AND METHODS

We downloaded name data from the International Plant Names Index (IPNI, www.ipni.org) using the pykew Application Programming Interface (API). We used a date range of 2012–2021 for the main name publication analysis, as the data entry guidelines were revised in 2012 to include the recording of a digital object identifier (DOI) for the bibliographic work if one were available. We attempted to backfill any missing DOIs using a dataset from the Catalogue of Life (Page, 2022). We passed each DOI to the unpaywall service using the *unpaywall* library (Haupka & Morrison, 2020). Unpaywall is an open database of scholarly articles organised by DOI. It offers a flag to indicate if the content is available open access, a link to the content (if available) and

TABLE 1 Types of open access (OA) described, with indication of who bears the costs and examples of publications or archives used in botanical nomenclature.

Type	Description	Who pays	Example
Closed	Not available to read without paying for access	Reader	*Systematic Botany*
OA - Green	Self-archiving in open repositories	Mixed	Zenodo (repository)
OA - Gold	Completely open access journals	Author	*PhytoKeys*
OA - Bronze	Freely available to read, but does not have an open access licence	Publisher	*Phytoneuron*
OA - Hybrid	An article processing charge to publish openly in an otherwise closed journal	Author or publisher	*Taxon*
OA - Diamond	Openly licensed, but neither the author nor the reader pays charges	Publisher	*European Journal of Taxonomy*

a further categorisation to indicate what kind of open access model is used. A flowchart of the assignment process for open access takeup and open access status is given in Figure 1. We recorded and analysed results at two levels of granularity—the takeup of open access and what kind of open access is used (green, gold, etc.).

We attached the World Checklist of Vascular Plants (WCVP, wcvp.science.kew.org/) dataset (comprising taxonomy and distribution) to the IPNI data extract to enable the analysis of open access takeup by the distribution of the taxon, which is recorded using the Biodiversity Information Standards Taxonomic Databases Working Group (TDWG) World Geographic Scheme for Recording Plant Distributions (WGSRPD) levels 1 (continent), 2 (region) and 3 (botanical country) (Brummitt et al., 2001). We also visualised open access takeup by publication for those titles including 80% of the names published between 2019 and 2021.

To look at the open access availability of type specimen metadata, we used the Global Biodiversity Information Facility (GBIF, www.gbif.org) to download a DarwinCore dataset of all vascular plant occurrences based on preserved specimens with a type status (Gbif.Org, 2022). We did not use any date restriction (neither date of collection nor date of digitisation) for this download. We used the GBIF registry to determine the spatial coordinates of the data provider for each record. We integrated the GBIF backbone taxonomy (Registry-Migration.Gbif.Org, 2021) (used to organise the occurrence records) with WCVP to allow us to determine if the type specimen occurrence was mobilised to GBIF from within its native range. To make this assessment, we executed a spatial join between the point location of the data provider and the WGSRPD polygons comprising the native range of the taxon.

3 | RESULTS

Our dataset extracted from IPNI comprised 64,332 nomenclatural act records published in 987 different publications between 2012 and 2021. Of these, 37,665 had DOIs recorded in IPNI, and 1957 were backfilled with DOIs recorded in the Catalogue of Life. We found that each year, the IPNI dataset includes acts published in an average of 289 different publications ($n = 10$). Eighty-eight percent of names is published in serials. The spike in numbers of nomenclatural acts pub-

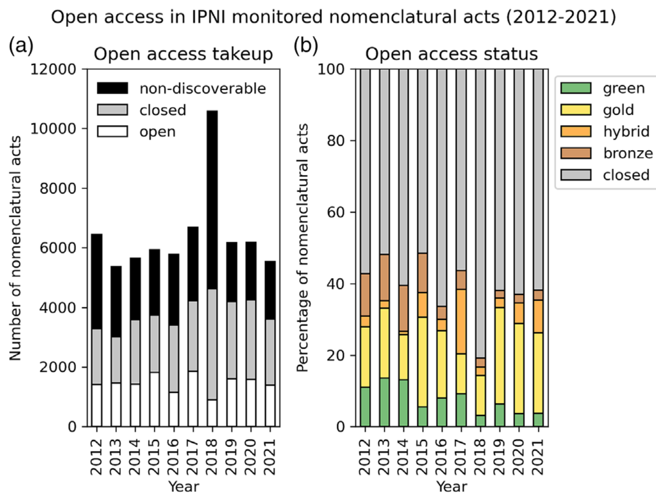

FIGURE 2 Open access (a) takeup and (b) status for nomenclatural acts recorded in the International Plant Names Index per year of study (2012–2021).

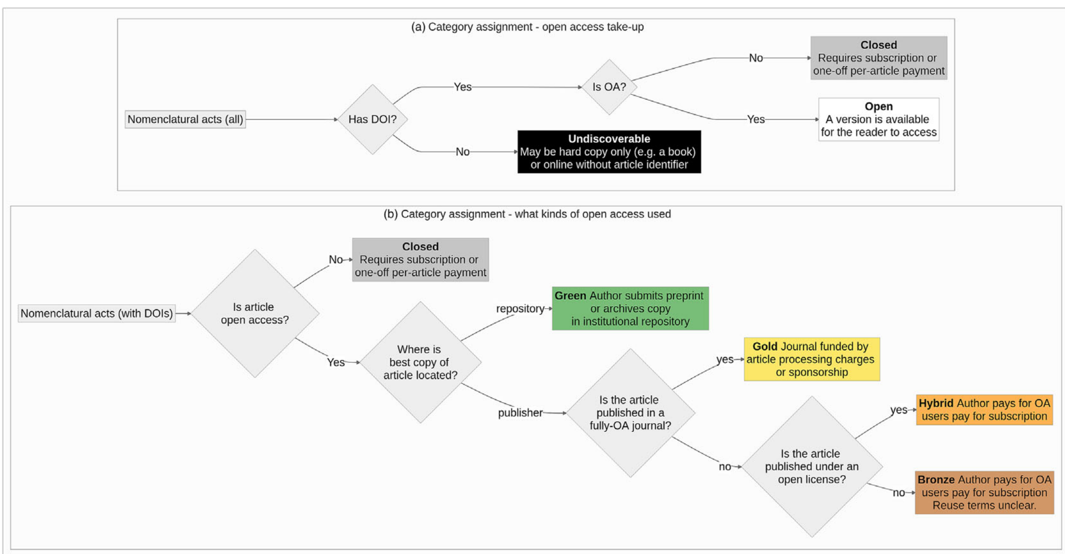

FIGURE 1 Flowchart depicting category assignment for (a) takeup of open access and (b) open access status.

lished for 2018 was caused by the large volume of combinations (3708) published in GLOVAP (Christenhusz et al., 2018). On average each year, less than one quarter (24%) of nomenclatural acts is published open access. We did not observe a trend towards open access throughout the time period analysed (Figure 2a). When looking at the kinds of open access used (Figure 2b), we find that *gold* dominates. Here, we do find a small difference through time, with *green* (self-archiving) showing a slightly greater representation in the earlier years in the study. The distribution of nomenclatural acts in different publication titles follows a 'long tail' (leptokurtic) pattern. We have visualised the number of nomenclatural acts per publication titles and their open/closed statuses using a more restricted time scale (2019–2021), to better reflect current working practices (Figure 3). For legibility, we cut the 'long tail' at 80% of the dataset. When analysing the IPNI data, we find that many journals active in the publication of nomenclatural acts are undiscoverable—the containing bibliographic work is not labelled with a DOI (Figure 3)—or the acts are labelled with a DOI, which is now unresolvable (1626 in total, in 47 different publications).

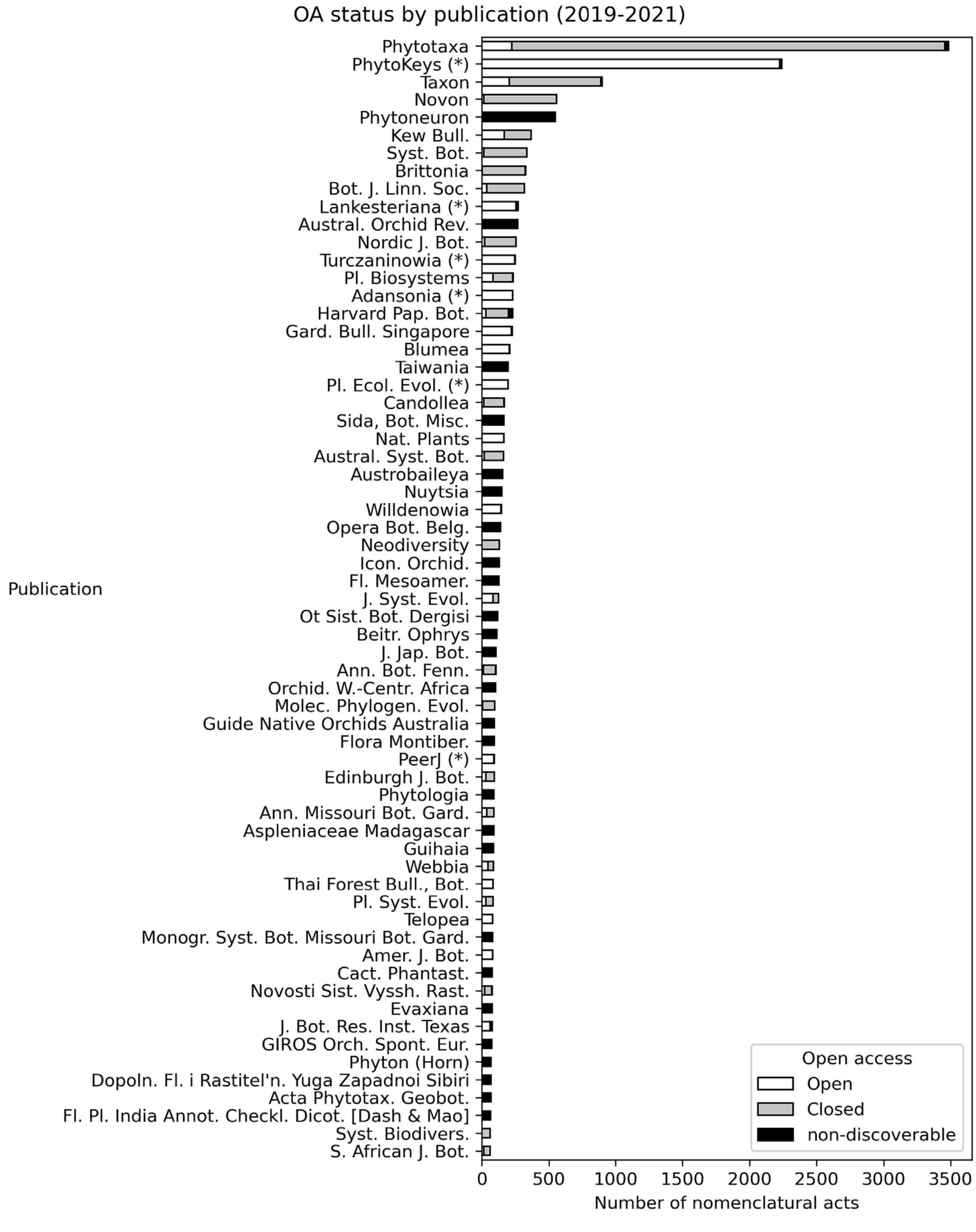

FIGURE 3 Bibliographic works containing vascular plant nomenclatural events published between 2019 and 2021 and their use of open access (OA), coverage of top 80% of the International Plant Names Index (IPNI) dataset (journal abbreviations follow IPNI, asterisk indicates that the title is included in the Directory of Open Access Journals).

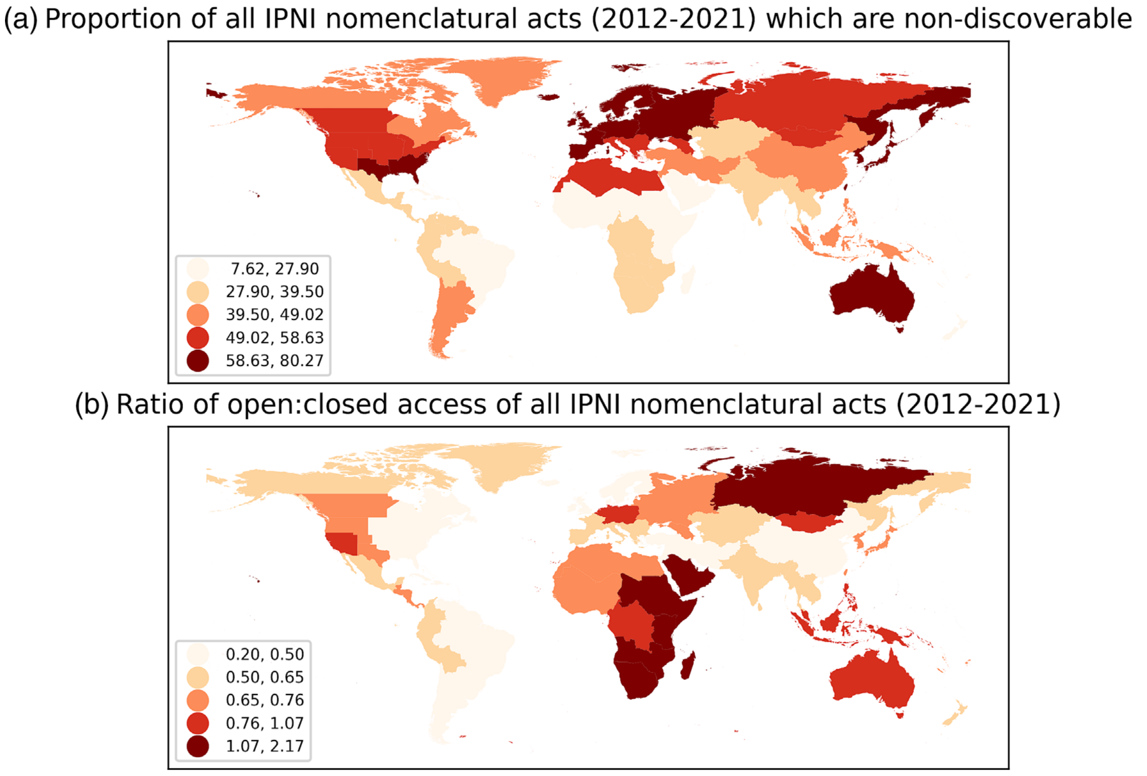

FIGURE 4 (a) Proportion of International Plant Names Index (IPNI) nomenclatural act records that are non-discoverable and (b) their ratio of open to closed access by World Geographic Scheme for Recording Plant Distributions (WGSRPD) level 2.

Africa, South America and South Asia, some of the botanically most diverse areas, have the greatest proportion of undiscoverable nomenclatural acts (Figure 4a), whereas Europe, North America and Australia have the lowest proportion. When considering only the discoverable literature using DOIs (Figure 4b), South America and South Asia have the lowest proportion of open publication of nomenclatural acts, though Africa has a higher proportion.

When considering the taxa with digitised type specimen metadata available online in GBIF, 69% of taxa in the WCVP taxonomy have type material available (256,618 of 372,103) in the dataset downloaded. Examination of the intersection of the location of the GBIF data provider with the native range of the taxon from the WCVP distribution dataset shows that 30% are represented by type material mobilised from within the continent of the native range of the taxon (the lowest level of geographical precision) and 12% are mobilised to GBIF from within a country of the native range of the taxon (the highest level of precision for the distribution dataset). This is an example of the most species-rich areas being often the most resource-poor (Meyer et al., 2016).

4 | DISCUSSION

A decade after electronic publication was adopted by the botanical community with the hope that it would make plant diversity information more openly and widely accessible, it is clear that despite initial uptake (Nicolson et al., 2017), it has still not made a real difference in the availability of this information in an open way. We show that 41% of the nomenclatural acts published between 2012 and 2021 are in literature that remains undiscoverable by electronic means (Figure 2b) and only 23% are published in open access literature. 'Undiscoverable' does not mean that this information is not available in electronic space, but the lack of identifiers means that searching for, retrieving and ultimately refinding such resources is time-consuming and can be costly. This may not seem a problem for individuals and institutions with access to computers and server time, but for those botanists working in institutions where internet access and computing facilities are limited or expensive, or who use mobile data for searches, this is a significant barrier.

We anticipate further proposals for the revision of the nomenclatural Code at the forthcoming nomenclatural section of the International Botanical Congress scheduled for 2024 in Madrid. These are likely to provoke discussion of access to botanical resources, such as proposing the inclusion of photographs of type specimens (Renner, 2021) or recommending type deposition in countries of origin (Mosyakin, 2021). Meanwhile, we outline below some specific recommendations for actions that could aid accessibility to resources, and for future research that could help further analyse the situation.

Our recommendations are targeted as follows, starting with the communities whose actions we as botanists can best influence:

Authors publishing new taxa in books should encourage deposition of taxonomic data in repositories, for example, descriptions in treatment bank (Agosti et al., 2022) or another suitable repository (Miralles et al., 2020). Authors producing large taxonomic revisions including type citation information should mobilise these as material citation datasets to GBIF. If available, authors should include specimen catalogue numbers or persistent URLs when citing specimens (Nelson et al., 2018), and nomenclators should capture these identifiers for types to assist discovery and reuse of the specimen data.

Institutions that maintain their own publication repositories should ensure that they are included in the sources searched by unpaywall (see unpaywall.org/sources) and encourage staff to self-archive (deposit a freely available copy of the work online) using an institutional or subject-based publication repository where possible. Several institutions with herbaria are associated with the publication of botanical journals; these include many nomenclatural acts and the botanical community would benefit from a move to an OA publishing model to facilitate access.

Nomenclators have a potential role in promoting the understanding of open access amongst both authors and users of nomenclature. We recommend that flags are displayed alongside nomenclatural act records to indicate the OA status of the containing work. The publication record should also indicate if the title is present in the Directory of Open Access Journals (DOAJ). Prototype systems for names registration (Govaerts et al., 2022) are being developed in preparation for the next International Botanical Congress (to be held in Madrid in July 2024); these should facilitate the inclusion of code-recommended data items associated with nomenclatural acts—for example, catalogue numbers for digitised specimens (if available).

Journals that currently publish online but which do not assign DOIs to their content (categorised as undiscoverable in this analysis) should assign DOIs at article level. There could be a role for collaborative projects like the Biodiversity Heritage Library (who are assigning DOIs to historic content through initiatives such as their RetroPIDS project) to also assign DOIs to more recent content which they display—for example, articles in the title 'Phytoneuron' that are archived in BHL. Eligible journals should register in the Directory of Open Access Journals (DOAJ).

Publishers could shorten the embargo period for articles with nomenclatural content, to allow broader dissemination through self-archiving. Publishers should also waive or lower publication costs for primary biodiversity data encouraging greater use of the data and facilitating downstream research including allowing new data to facilitate urgent conservation action.

Funders and the botanical community should facilitate wider mobilisation of specimen data to promote research, by increasing digitisation of herbaria particularly in South America, Africa and South Asia (Hedrick et al., 2020; Nelson & Ellis, 2019).

We propose future work on better understanding participant's ability to use open access, by examining information that can be derived from authors and places of publication such as affiliations, career stage seniority, collaboration makeup and roles (e.g., as collectors of specimen material from the field, identifiers of material in institutional collections and authors of published taxonomic work).

AUTHOR CONTRIBUTIONS

Conceptualization: Nicky Nicolson. *Methodology*: Nicky Nicolson. *Software*: Nicky Nicolson and Maarten Trekels. *Validation*: Nicky Nicolson. *Investigation*: Nicky Nicolson. *Data curation*: Nicky Nicolson. *Writing—original draft*: Alan J. Paton, Quentin J. Groom, and Sandra Knapp. *Writing—review and editing*: Nicky Nicolson, Alan J. Paton, and Sandra Knapp. *Visualization*: Nicky Nicolson and Maarten Trekels. *Supervision*: Alan J. Paton and Sandra Knapp. *Project administration*: Nicky Nicolson.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

All data access, analysis, result visualisation and document compilation outlined here was automated using a toolkit based on *Python* scripts using *pandas* and *GeoPandas* for data management and *Matplotlib* for charting. Execution and dependencies were managed by the build tool *make*, which generated an archivable output which was attached to each analytical repository. *Github actions* were used to download analysis results and to compile the article document using *Pandoc* and *laTeX*.

WCVP data are available from RBG Kew at http://sftp.kew.org/pub/data-repositories/WCVP/Special_Issue_28_Feb_2022/. All analytical code is openly licenced and available on Github at: https://github.com/OA-WCVP.

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