Received: 4 May 2023 | Revised: 3 July 2023 | Accepted: 5 July 2023

DOI: 10.1002/ppp3.10425

RESEARCH ARTICLE

Plants People Planet PPP Open Access

Small and in-country herbaria are vital for accurate plant threat assessments: A case study from Peru

Jay Delves[1,2] | Joaquina Albán-Castillo[3] | Asunción Cano[3] | Carmen Fernández Aviles[4] | Edeline Gagnon[1,5] | Paúl Gonzáles[3] | Sandra Knapp[6] | Blanca León[3,7] | Jose Luis Marcelo-Peña[8] | Carlos Reynel[9] | Rocío del Pilar Rojas Gonzáles[10] | Eric F. Rodríguez Rodríguez[11] | Tiina Särkinen[1] | Rodolfo Vásquez Martínez[12] | Peter W. Moonlight[1,13]

[1]Royal Botanic Garden Edinburgh, Edinburgh, UK

[2]Hawkesbury Institute for the Environment, Western Sydney University, Sydney, New South Wales, Australia

[3]Herbario San Marcos, Museo de Historia Natural, Universidad Nacional Mayor de San Marcos, Lima, Peru

[4]Instituto Científico Michael Owen Dillon (IMOD), Arequipa, Peru

[5]Dept. Integrative Biology, College of Biological Science, University of Guelph, Guelph, Ontario, Canada

[6]Natural History Museum, London, UK

[7]Department of Geography and the Environment, University of Texas at Austin, Austin, Texas, USA

[8]Universidad Nacional de Jaén, Cajamarca, Peru

[9]Herbario, Departamento Académico de Biología, Universidad Nacional Agraria La Molina, Lima, Peru

[10]Herbario Selva Central (HOXA), Jardín Botánico de Missouri, Oxapampa, Pasco, Peru

[11]Herbarium Truxillense (HUT), Universidad Nacional de Trujillo, Trujillo, Peru

[12]Jardín Botánico de Missouri, Oxapampa, Pasco, Peru

[13]Botany, School of Natural Sciences, Trinity College Dublin, Dublin 2, Ireland

Correspondence
Peter W. Moonlight, Botany, School of Natural Sciences, Trinity College Dublin, Dublin 2, Ireland.
Email: moonligp@tcd.ie

Societal Impact Statement

Herbaria can be considered plant libraries, each holding collections of dried specimens documenting plant diversity in space and time. For many plant species, these are our only evidence of their existence and the only means of assessing their conservation status. Specimens in all herbaria, especially those in small and often under-resourced herbaria in megadiverse countries, are key to achieving accurate estimates of the conservation status of the world's plant species. They are also part of a country's shared heritage and critical contributions to knowledge of the world's diversity.

Summary

- Internationally agreed targets to assess the conservation status of all plant species rely largely on digitised distribution data from specimens held in herbaria.
- Using taxonomically curated databases of herbarium specimen data for the megadiverse genera *Begonia* (Begoniaceae) and *Solanum* (Solanaceae) occurring in Peru, we test the value added from including data from local herbaria and herbaria of different sizes on estimations of threat status using International Union for Conservation of Nature (IUCN) Red List criteria.
- We find that the Global Biodiversity Information Facility (GBIF) has litter data from Peruvian herbaria and adding these data influences the estimated threat status of these species, reducing the numbers of Critically Endangered and Vulnerable species in both genera. Similarly, adding data from small- and medium-sized herbaria, whether in-country or not, also improves the accuracy of threat assessments.
- A renewed focus on resourcing and recognising the contribution of small and in-country herbaria is required if we are to meet internationally agreed targets for plant conservation. We discuss our case study in the broader context of democratising and increasing participation in global botanical science.

Funding information
United States National Science Foundation Planetary Biodiversity Inventory Program; National Geographic Society; James and Eve Bennett Trust

KEYWORDS
Begonia, data inequality, herbaria, IUCN threat assessments, Peru, *Solanum*

1 | INTRODUCTION

Peru is recognised as one of the Earth's mega-diverse countries (https://worldpopulationreview.com/country-rankings/megadiverse-countries). With habitats ranging from coastal deserts to Andean areas above treeline to Amazonian rainforest, both plant diversity and endemism in Peru are extremely high (Gentry, 1988; León et al., 2006; Marcelo-Peña et al., 2016). Of the 107 recognised species of wild potato relatives, for example, 42 are endemic to Peru (Spooner et al., 2019).

Target 2 of the Global Strategy for Plant Conservation 2011–2020 (GSPC) is "an assessment of the conservation status of all known plant species, as far as possible, to guide conservation action" (https://www.cbd.int/gspc/). Conservation assessments can guide priorities for action and allocation of resources to those taxa under the greatest threat. The most widely applied methodology for conservation assessments is the International Union for Conservation of Nature (IUCN) Red List (IUCN, 2022a). IUCN assessments have been completed for approximately 62,600 species of plants (only a quarter of plant diversity), of which nearly 40% are considered threatened with extinction (IUCN, 2022a). These assessments directly inform conservation prioritisation and are increasingly used at national and regional, as well as international, levels (Gärdenfors et al., 2008; Le Breton et al., 2019). A Red List of endemic Peruvian plants (León et al., 2006) registered 61% as threatened with extinction.

IUCN assessments can be assessed based upon criteria including population sizes, trends, and fluctuations (Mace & Lande, 1991), which are difficult to use in most plants due to gaps in knowledge (Cazalis et al., 2022; ter Steege et al., 2011). Estimates of the conservation status of plants primarily rely upon geographic range size (Criterion B) usually estimated from herbarium data (Brummitt et al., 2015; Collen et al., 2016). The correlation between range size and extinction risk is well established (Le Breton et al., 2019; Purvis et al., 2000), but assessments based upon range size are sensitive to the quality and quantity of available occurrence data (Betts et al., 2020; Nic Lughada et al., 2018; Rivers et al., 2011; Speed et al., 2018,).

Our knowledge of the distribution of plant species, particularly tropical plant species, is limited and susceptible to bias (Daru et al., 2018; ter Steege et al., 2011; Tobler et al., 2007). Nine out of 10 tropical plant species are known from fewer than 20 records (Feeley & Silman, 2011) built up in an uneven manner through space and time and at all scales, creating "data voids" (Feeley & Silman, 2011). The consequences of data voids include but are not limited to unrealistic estimates of plant distributions in space and time (Lobo et al., 2007), undescribed species (Pimm & Joppa, 2015), erroneous estimates of species climatic niche (Hortal et al., 2015), unrecorded extinctions (Vorontsova et al., 2020), and species being treated as "data deficient" or "not evaluated" under IUCN criteria (Collen et al., 2008).

There are an estimated 3552 active herbaria in the world, the oldest of which are more than 500 years old (Thiers, 2001). The build-up of their collections has been the result of a nonrandom national, institutional, and individual priorities (Johnson et al., 2023; Tobler et al., 2007), including colonial legacies (Park et al., 2023). There are an estimated approximately 400 million herbarium specimens in the world, but approximately 90% of these are held within the largest 1% of herbaria, primarily located in the Global North (Heberling et al., 2019). Around 90% of the specimens in large herbaria are from countries outside the nation where they grow (Lavoie, 2013).

In contrast, 85% of herbaria hold fewer than 100,000 specimens and are considered small (Marisco et al., 2020). Small herbaria are often poorly funded, operate with a minimal staff, and are predominantly used for education within a limited geographical area (Harris & Marisco, 2017). Consequently, they often have a regional focus and hold geographically and temporally unique collections, as well as Indigenous and local knowledge (Marisco et al., 2020; Monfils et al., 2020). Despite their size, small herbaria contribute to our knowledge of plant diversity, providing, for example, accurate estimates of species richness in poorly known areas (e.g., Brazil; Colombo et al., 2016) and improvements to the accuracy of species distribution models (Glon et al., 2017), and extinction rates (North America; Knapp et al., 2020).

Digitisation and open online access greatly improve the availability of specimens for use in research (Johnson et al., 2023). The past decade has seen a dramatic increase in the use of digital herbarium data, including in fields such as global change (Heberling et al., 2019, 2021). Aggregation of data in repositories such as the Global Biodiversity Information Facility (GBIF) facilitate this use, but aggregated data are biased towards institutions with the funding and facilities required for large-scale digitisation and data sharing. In fact, greater wealth of a country as measured by GDP can even explain a higher density of occurrence records (Amano & Sutherland, 2013); wealthier nations, however, are not making faster progress towards completing IUCN threat assessments for plants (Gallagher et al., 2023), despite having more resource available. Data resources are far from exclusive to the Global North, and GBIF includes significant data from Brazilian, Colombian, and Mexican institutions (GBIF Secretariat, 2023), but most specimens shared through GBIF today are from institutions in Europe and the United States (Betts et al., 2020; Heberling et al., 2021; Park et al., 2023).

Here, we use taxonomically verified herbarium data from Peru to investigate whether the distribution of specimens across the world's herbaria and the digital availability of those data bias our knowledge

of species' distributions, with consequences for the accuracy of IUCN Conservation Assessments. Our aim is to assess the contribution local herbaria bring to not only our knowledge of plant diversity, but also their potential contribution to national conservation planning and resource use. We use our dataset to test the assumptions that (1) Peruvian herbaria are under-represented in globally aggregated data and that (2) data held in small herbaria and those in local (in-country) herbaria improve the accuracy of IUCN Red List Assessments.

2 | MATERIALS AND METHODS

2.1 | Study system and herbarium data

Begonia (Begoniaceae) and *Solanum* (Solanaceae) are both genera with more than 1000 species (Frodin, 2004) and are unique in having active, freely available databases of taxonomic, nomenclatural, and specimen data (Hughes et al., 2015; www.solanaceaesource.org). While these resources are global in scope, the data are particularly strong for Peru because of recent focused taxonomic studies (Moonlight et al., 2023; Särkinen et al., 2015), where authors visited and databased collections of most major herbaria in Peru, Europe, and the United States. While many herbarium databases contain significant numbers of identification errors (Goodwin et al., 2015), all data used in this study have been entered and evaluated by taxonomic experts.

We downloaded all specimen records in these specialist databases from Peru and georeferenced those lacking coordinates following standard practices (Chapman & Wieczorek, 2020). Occurrence records indicated as originating from plants in cultivation were excluded; species cultivated globally but native to Peru (e.g., *Solanum curtilobum*, *Solanum lycopersicum*, *Solanum quitoense*, and *Solanum tuberosum*) were retained. Synonymy was updated with respect to recent taxonomic treatments (Moonlight et al., 2023; Särkinen et al., 2015), we excluded introduced naturalised species that are not widely naturalised and resolved all subspecific taxa to species level. For our analyses, we combined all data for *Begonia* and *Solanum* because our aim is not to highlight genus-specific differences but rather to be instructive as to the effects of long-term efforts to prioritise the inclusion of data for all groups held in all types of herbaria.

The combined dataset included 358 species (76 *Begonia*; 282 *Solanum*) and a total of 23,892 specimen records, including duplicates (3425 *Begonia*; 20,467 *Solanum*). The complete curated dataset is available on the Natural History Museum Data Portal (https://doi.org/10.5519/m4u7c4gu). Individual species had from one (14 species) to 2331 (*Solanum candolleanum* Berthault) records; the largest number of records for a *Begonia* species was 388 (*Begonia bracteosa* A.DC.). The mean number of records per species was 67 (10 and 73 for *Begonia* and *Solanum*, respectively).

To compare the proportion of specimens in our dataset from Peruvian herbaria with the proportion of specimens from Peruvian herbaria mediated by GBIF, we also downloaded all occurrence records based upon specimen records of Peruvian *Begonia* and *Solanum* (*Begonia*, https://doi.org/10.15468/dl.yb7kdh; *Solanum*, https://doi.org/10.15468/dl.7etx2b; downloaded 6th July 2021). Raw specimen data in both datasets were assigned to Peruvian or international herbaria based upon Index Herbariorum (Thiers, 2001).

We used Index Herbariorum to rank herbaria in order of size (the estimated total number of accessioned herbarium specimens) and to score them by whether they are within Peru or not (designated as Peruvian and international herbaria, respectively). Herbaria with more than 1,000,000 specimens were classed as large, those with more than 500,000 as medium and those with fewer than 500,000 as small. Our dataset included specimens from the International Potato Centre in Lima, Peru (CIP), which is not included in Index Herbariorum, estimated to include 22,000 specimens.

2.2 | Conservation assessments

We estimated IUCN threat status based on geographic range size in the form of Extent of Occurrence (EOO, criterion B1) or Area of Occupancy (AOO, criterion B2), widely used criteria due to the availability of suitable data (Brummitt et al., 2015; Collen et al., 2016). We calculated EOO using the R package "ConR" (Dauby et al., 2017) and assigned species to categories following criterion B1 of the IUCN guidelines (IUCN, 2022b). Where AOO was greater than EOO, we used the AOO rather than the EOO, following IUCN guidelines. Species were only classified as DD if no specimen records were included in a dataset. This is consistent with the IUCN guidelines, which advise against an assessment of DD where possible (IUCN, 2022b) but bias towards overestimating threat, which is perhaps not such a bad thing (Parsons, 2016). For species whose range extends beyond Peru, we calculated threat based upon the Peruvian distribution only; thus, our estimated threat assessments are national rather than global.

To understand the effect of including specimen data held within Peruvian herbaria, we compared estimated threat assessments including and excluding these data. To determine the effect of herbarium size upon IUCN threat assessments, we estimated threat for all 358 species in the dataset based upon only the data held in the largest herbarium (Kew, approximately 8,125,000 sheets). We then added in data held in the next largest herbarium (New York Botanical Garden, approximately 7,921,000 sheets) and recalculated all threat assessments. We repeated this process for all herbaria in our dataset in order of size until all herbaria were included.

We did not compare our results with official IUCN Red List assessments. No such assessments yet exist for Peruvian *Begonia*, while all such assessments of Peruvian *Solanum* have been carried out using data from Solanaceae Source so do not represent an independent point of comparison. Further, we did not compare our results with those of León et al. (2006) for endemic Peruvian species because the taxonomic concepts in this work predate recent updates in the taxonomy of Peruvian *Begonia* and *Solanum* (Moonlight et al., 2023; Särkinen et al., 2015) so are not directly comparable.

3 | RESULTS

3.1 | The effect of Peruvian herbaria on threat status

Comparison of the curated data set of *Begonia* and *Solanum* specimens from Peru with data downloaded from GBIF shows that specimens from Peruvian herbaria comprise 56.1% of the data points used in our analyses, while only 1.4% of specimens in the aggregated GBIF dataset were from Peruvian herbaria (Figure 1).

Inclusion of Peruvian herbaria changed our estimated threat assessments (Table 1, Figure 2; results for individual species are available in Table S1). A total of 160 species (47%) were considered threatened in Peru when all data were included, 70% of *Begonia* and 40% of *Solanum* species. We assigned 46 (13%) of species to lower estimated threat categories when data from Peruvian herbaria were included and the number of species estimated as threatened or data deficient as reduced from 186 to 160 (−14.5%). The mean increase in EOO was 26% ranging from 0% (94 species) to >1000% (38 species).

Of those species whose estimated threat status changed when data in Peruvian herbaria were included, 33 (72%) were reduced by a single category (e.g., from CR to EN; Figure 2). However, the estimated threat status of seven species was reduced in two categories (two from CR to VU; five species From EN to LC) and that of six species was reduced by a remarkable three categories (CR to LC). The status of a further three 9 species was changed from DD (two to EN, seven to CR).

There was significant turnover of species within categories as Peruvian herbaria are added, even if the number of species within any given category remains similar. For example, the number of species estimated as vulnerable only decreased by seven (from 42 to 35) as data from Peruvian herbaria were added, but only 26 species (61%) that were considered vulnerable based upon data from international herbaria remained vulnerable when Peruvian data were considered (see individual assessments in Table S1).

3.2 | The effect of herbarium size on threat status

Estimated threat assessments are changed when data from medium and small herbaria are considered (Table 2, Figure 3, full results available in Table S2) instead of only data from large herbaria. When these data are included, we assign 37 (−10.5%) and 61 (−17%) species to lower estimated IUCN threat categories, respectively (see Table 2). An increase in the number of species considered Endangered (46 to 46 [±0%] and 54 [+13%]) was primarily driven by species reclassified either from DD or CR.

The number of species assigned to each threat category changes gradually as data from progressively smaller herbaria are added (Figure 4a, full results available in Table S2). There is however only a weak positive correlation between the size of an herbarium removed and the number of specimens removed from the analysis (correlation coefficient = 0.48), which demonstrates that specimens of Peruvian *Begonia* and *Solanum* are not randomly distributed. The largest numbers of collections added to the analysis are in large international herbaria or Peruvian herbaria (Figure 4b). The herbaria with the largest numbers of Peruvian *Begonia* and *Solanum* sheets are Universidad Nacional Mayor de San Marcos (USM, 5609); Missouri Botanical Garden (MO, 3998); Universidad Nacional de San Antonio

TABLE 1 The number and percentage of Peruvian *Begonia* and *Solanum* species estimated to fall under each International Union for Conservation of Nature (IUCN) threat status when herbarium data held in (i) only international herbaria; (ii) all herbaria are included. IUCN categories are as follows: Data Deficient (DD), Least Concern (LC), Vulnerable (VU), Endangered (EN), Critically Endangered.

Threat status	International herbaria only	All herbaria (Peruvian and international)
CR	86 (24.0%)	71 (−17.5%)
EN	48 (13.4%)	54 (+13%)
VU	42 (11.7%)	35 (−16.5%)
LC	173 (48.3%)	198 (+14.5%)
DD	9 (2.5%)	0

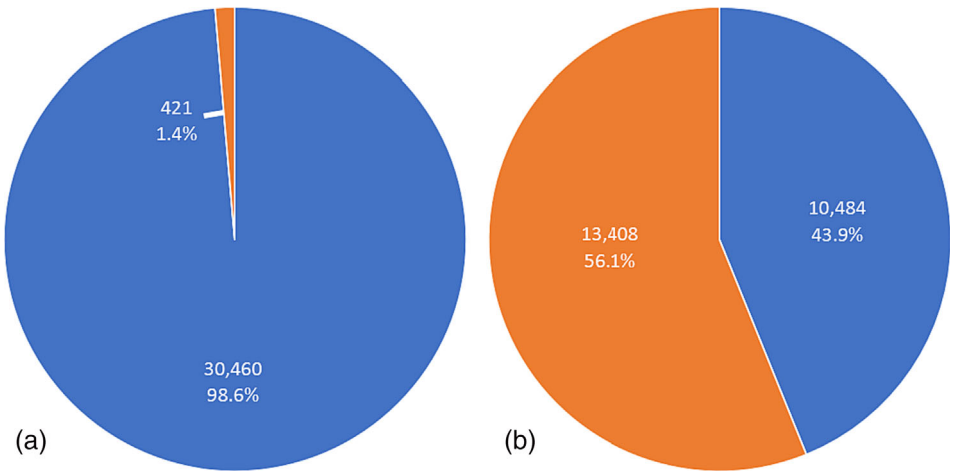

FIGURE 1 The proportion of specimens of Peruvian *Begonia* and *Solanum* held in Peruvian institutions (blue) versus international institutions (orange) in (a) the Global Biodiversity Information Facility (GBIF); (b) the Begonia Resource Centre and Solanaceae Source (see text for doi references for all datasets).

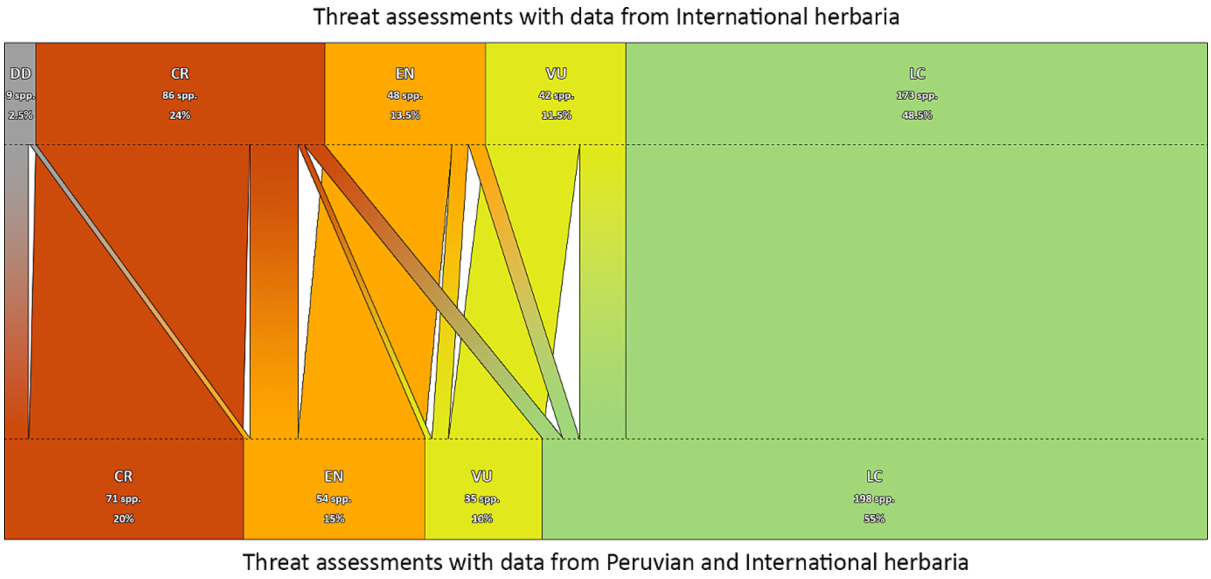

FIGURE 2 The effect of including data from Peruvian herbaria upon estimated International Union for Conservation of Nature (IUCN) threat assessments. The percentage of species assessed as DD (Data Deficient, grey), LC (Least Concern, green), VU (Vulnerable, yellow), EN (Endangered, orange), and CR (Critically Endangered, red) based upon data from: Top, international herbaria, and bottom, Peruvian and international herbaria.

TABLE 2 The number and percentage of Peruvian *Begonia* and *Solanum* species estimated to fall under each International Union for Conservation of Nature (IUCN) Red List threat status when herbarium data held in (i) only large herbaria; (ii) only large and medium herbaria; and (iii) all herbaria are considered. IUCN categories are as follows: Data Deficient (DD), Least Concern (LC), Vulnerable (VU), Endangered (EN), Critically Endangered (CR).

Threat status	Large herbaria only	Large and medium herbaria	All herbaria
CR	91 (25.5%)	84 (−7.7%)	71 (−15.5%)
EN	46 (12.8%)	46 (0%)	54 (−17.4%)
VU	40 (11.2%)	38 (−5.0%)	35 (−17.9%)
LC	171 (47.8%)	189 (+10.5%)	198 (+4.7%)
DD	10 (2.8%)	2 (−80%)	0

Abad del Cusco (CUZ, 2649); the UK Natural History Museum (BM, 1866); and the US National Herbarium at the Smithsonian Institution (US, 1633). There are corresponding increases in the estimated range size of threatened species (Figure 4c), most of which are reflected in small changes in the estimated IUCN assessments of species (Figure 4a).

4 | DISCUSSION

IUCN threat assessments are increasingly used at many levels to drive conservation policy and legislation (Le Breton et al., 2019) and are widely adopted to measure progress on multilateral agreements, such as biodiversity targets (Betts et al., 2020). Accurate estimation of species' range sizes requires enough high-quality data (Ribeiro et al., 2022), such that all parts of a species' range are represented (Gaston & Fuller, 2009). For plants, and particularly tropical plants, these assessments are largely based on data from herbarium specimens. Despite institutional efforts to make herbarium data digitally accessible, there are inherent biases in globally accessible specimen data that hinder a complete view of biodiversity (Feeley & Silman, 2011). Our study shows that including "immobilised" herbarium data in small and Peruvian herbaria is critical to achieving accurate threat assessments for the megadiverse plant genera *Begonia* and *Solanum*.

4.1 | In-country herbaria are essential for accurate threat assessments

Without data held by in-country herbaria, both the number of species of Peruvian *Begonia* and *Solanum* considered as potentially threatened are overestimated. The greatest contribution to our knowledge of threatened species' range sizes was provided by the Peruvian national herbarium (USM) but several large, international herbaria also have significant holdings of Peruvian *Begonia* and

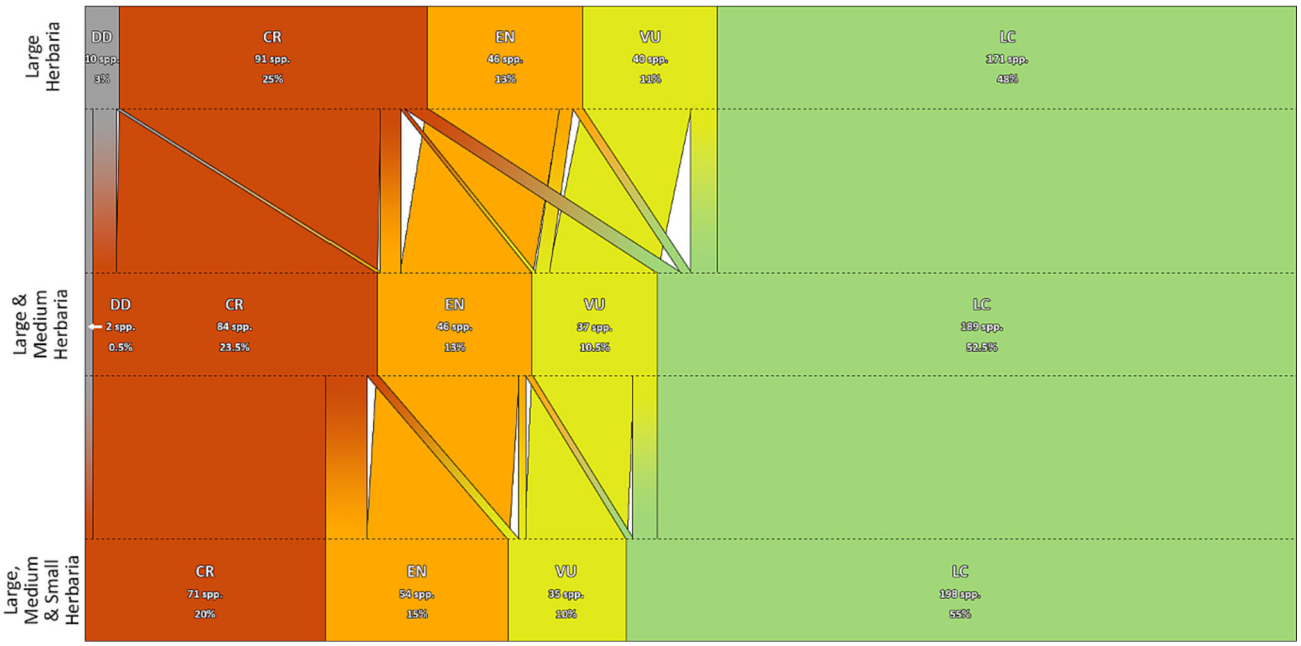

FIGURE 3 The effect of including data from different small and large herbaria upon estimated International Union for Conservation of Nature (IUCN) threat assessments. The percentage of species assessed as DD (Data Deficient, grey), LC (Least Concern, green), VU (Vulnerable, yellow), EN (Endangered, orange), and CR (Critically Endangered, red) based upon data from: top, large herbaria only (>1,000,000 sheets); middle, large and medium herbaria (>500,000 sheets); and bottom, large, medium, and small herbaria (all herbaria).

Solanum (e.g., BM, E, and NY). The richness of these international collections in terms of Peruvian data is likely a result of their historical or contemporary agendas, including the country- and taxon-specific interests of their staff and curators (Daru et al., 2018). Regardless, it is striking that all Peruvian herbaria in our analyses, regardless of their size, provide unique distribution data for our study taxa. Our dataset lacks data from 15 further small Peruvian herbaria (Thiers, 2001), which almost certainly hold *Begonia* and *Solanum* specimens that would exacerbate our findings. These results are especially troubling because we also show that only 1% of data for Peruvian *Begonia* and *Solanum* specimen records on GBIF are from Peruvian herbaria. Further, the infrastructure and funding stability of many Peruvian herbaria is poor as evidenced by the tragic loss of HAO herbarium by fire in 2010, and the loss of many unique specimens of northern Peruvian taxa that were never held outside that herbarium (Thiers, 2001).

Peruvian herbaria are younger than most large, international herbaria (Cano et al., in press; Reynel et al., 2020; Thiers, 2001; Treviño et al., 2012). Consequently, they likely contain younger specimens, which usually contain more locality data and more accurate coordinates, which are key for accurate conservation assessments (Willis et al., 2003). While historical specimens are often key for taxonomy and studies of temporal change, younger specimens may be more representative of species current ranges (Pergl et al., 2012) or characteristics (Kozlov et al., 2021). Rare species are often represented by recent collections that are in local herbaria, reflecting intensified collecting effort by local taxonomists (e.g., Gonzáles et al., 2022). In comparison with international herbaria, Peruvian institutions hold greater densities of specimens from smaller areas, reflecting the research agendas of local botanists who collect at a more often in their study regions and may visit more remote or inaccessible sites.

4.2 | Small herbaria are essential for accurate threat assessments

Specimen data held in large herbaria alone or even large and medium herbaria combined are insufficient for accurate estimation of IUCN Red List status of all taxa considered in this study. This applies equally to species irrespective of range size but is particularly evident for threatened species. Indeed, 10 species in our analyses are completely unrepresented in large herbaria and two are only found in small herbaria. Our results support previous assertions that herbarium size is a poor indicator of relative significance or value (Monfils et al., 2020). We show that data held in small herbaria make an extremely valuable contribution to threatened species' ranges, reinforcing the value of these herbaria globally (Colombo et al., 2016; Harris & Marisco, 2017; Marisco et al., 2020). Delves (2021) used the same dataset as this study to test whether small herbaria contain a significantly higher proportion of globally unique specimen records. This was not the case, so we suspect our results are largely due to the quantity of specimens held in small and Peruvian herbaria.

Small herbaria are often overlooked by botanists travelling to tropical countries because the time and cost of visiting is only rewarded by a small number of specimens. Large, international herbaria have been used for convenience due to their large

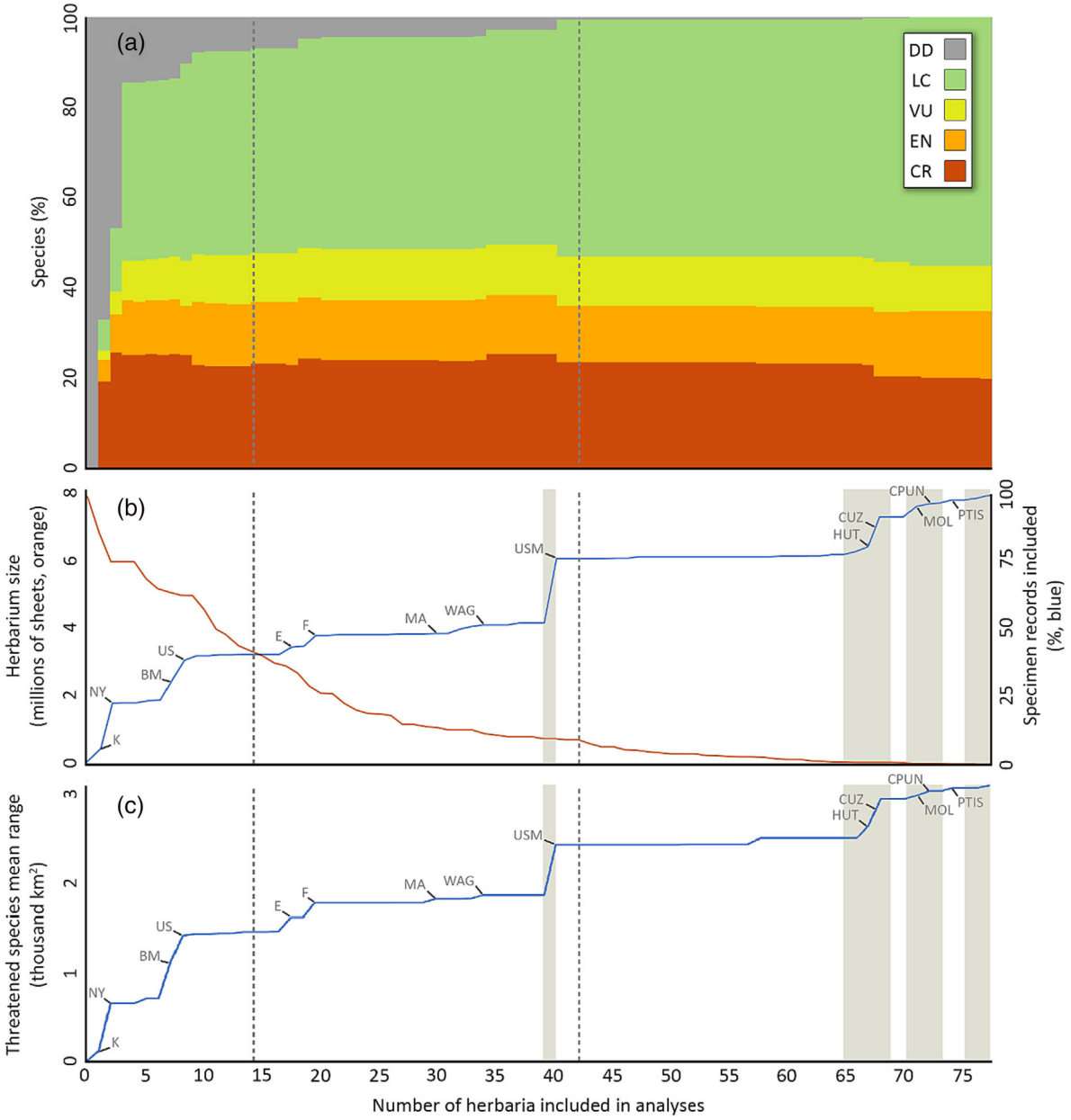

FIGURE 4 The effect of including data from herbaria in size order upon estimated International Union for Conservation of Nature (IUCN) threat assessments. (a) Percentage of species assessed as DD (Data Deficient, grey), LC (Least Concern, green), VU (Vulnerable, yellow), EN (Endangered, orange), and CR (Critically Endangered, red); (b) the size (number of accessions) of herbaria added (orange) and number of specimen records included (blue); (c) the mean range of species considered threatened when all data are considered. Dashed, vertical lines indicate the limits of large (>1,000,000 sheets) and medium (>500,000 sheets) herbaria. Grey shading indicates Peruvian herbaria. Selected herbaria are indicated in C. Herbarium abbreviations in panels B and C follow Thiers (2001).

geographically rich collections, but this has come at the cost of the lack of support for smaller herbaria and the under-representation of the data they hold. Furthermore, it also affects the careers of local botanists whose work does not reach the international stage.

In this study, we focus on IUCN Red List status estimates as a proxy for all analyses that rely upon specimen distribution data. This is in part because there are automated pipelines for estimating IUCN Red List status from distribution data (e.g., Dauby et al., 2017) but also because the measures of range size favoured by the IUCN is intentionally insensitive to data quantity (IUCN, 2022b). We would expect even more pronounced effects if we carried out analyses more sensitive to data quantity (e.g., species distribution models; Gaul et al., 2020).

A total of 45% of the species in our analysis (70% and 40% of Peruvian *Begonia* and *Solanum* species, respectively) are considered threatened when all data in our analyses are considered. We believe these results are representative of large, tropical genera because we include a genus with an unusual percentage of narrow endemics (49%

of *Begonia*; Moonlight et al., in prep.) and a second with many widespread, global weeds (*Solanum*; Särkinen et al., 2015). Fewer species are considered potentially threatened than when in-country (51.5%) or small and medium herbaria (52%) are included but we do not argue that there may be fewer threatened species than currently believed. Our threat estimates are based entirely upon range size and ignore habitat loss, as well as reductions and fluctuations in species' ranges or population sizes. Rather, we argue that improving the accuracy of range size-based threat assessments is critical to effectively prioritise and track the conservation and recovery of tropical species. Our results support the idea that data in small and in-country herbaria are essential to that process, as well as the contention (Walker et al., 2020) that studies aiming to estimate conservation status at a global scale should be treated with caution and recent proposals for automated evaluations (e.g., Bellot et al., 2022; Cazalis et al., 2022) must consider all collections equally.

4.3 | Mobilisation of data from small and in-country herbaria

Herbarium specimens are valuable assets that have contributed to the development of botanical science and knowledge (Baber, 2016; Eichhorn et al., 2020; Vorontsova et al., 2020). While digitisation of herbarium specimens has been underway since the turn of the century, it has been concentrated in large herbaria in the Global North (e.g., the Museum d'histoire Naturelle in Paris with more than 5.4 million specimens; Le Bras et al., 2017). For small herbaria, particularly in tropical countries, there are significant barriers to digitisation due to lack of capacity, staffing, and reliable computing resources (Drew et al., 2017; Harris & Marisco, 2017; Vorontsova et al., 2020) and reliance on national funding structures (Beck et al., 2014). Some procedures aimed at streamlining digitisation have been tailored for small and medium herbaria or those that have limited workforce or budgets (Takano et al., 2019), while student participation (Harris & Marisco, 2017) and citizen science programmes (Ellwood et al., 2015) have been successful in some contexts. The current rate of digitisation, however, is slower than required for assessing threats to biodiversity (Bachman et al., 2019; Ball-Damerow et al., 2019).

The most rapid and greatest advances in generating online biodiversity data from countries with high biodiversity have been through national or cross-national funding dedicated to mobilising existing biodiversity collections and knowledge (Meyer et al., 2015). In both Mexico and Brazil, concentrated efforts aimed at specimen mobilisation have resulted in digitisation of millions of specimen records from collections both in and outside the countries (Canteiro et al., 2019; Nelson & Ellis, 2018; Sarukhán & Jiménez, 2016). In Brazil, this has led to a significant reduction in the number of data deficient plant species (Sousa-Baena et al., 2014).

The Atlas of Living Australia (ALA, Belbin et al., 2021) and GBIF created a replicable framework and tools to incentivise creation of national biodiversity data portals through national GBIF nodes (https://living-atlases.gbif.org/participants/). These country level and internationally collaborative e-infrastructures show the impact of targeted funding, although even such large-scale projects are often threatened by the lack of longer-term funding (Canhos et al., 2015). Funding targeted at tropical herbaria currently not involved in digitisation is crucial to promote the democratisation of biodiversity data (Drew et al., 2017) and reduce the inequalities between countries that have benefited from biodiversity collections and those who have not.

Joining together to form national or transnational herbarium consortia has the potential to bring visibility to small collections and increase funding prospects for their digitisation and development. The Small Collections Network established in North America assists small herbaria with day-to-day management challenges but also provides a louder, collective voice to these herbaria (Monfils & Nelson, 2014). The developing national nodes of the DiSSCo partnership in Europe are similarly empowering collections of all sizes to significantly ramp up cooperation in digitisation efforts (e.g., Smith et al., 2022). These kinds of consortia will be even more critical in tropical countries, and the Biodiversity Information for Development (BID, https://www.gbif.org/programme/82243/bid-biodiversity-information-for-development) programme of GBIF organised through the national nodes is a significant step in helping to mobilise the important data held in herbaria and other natural history collections in biodiversity-rich regions. Local herbaria are part of a country's shared heritage and a critical contribution to knowledge of the world's diversity.

5 | CONCLUSIONS AND RECOMMENDATIONS

Our analyses for *Begonia* and *Solanum* from Peru demonstrate that local herbaria hold collections that are vital for assessing the threat status of local flora. Overlooking data from local, in-country herbaria in tropical countries results in threat assessments that overestimate extinction risk, potentially resulting in scarce conservation resources being diverted from where they are most needed. We suggest the following recommendations to help increase the impact of local herbaria, especially those in the species-rich tropics, for global biodiversity analyses that will enable sound policy at national and regional levels for plant conservation based on threat estimates:

1. All efforts to assess the conservation status of tropical species should consider data held in small and in-country herbaria.
2. The flora of species-rich countries like Peru is still under-collected (e.g., Gonzáles et al., 2018); plant collections made for research must be deposited in herbaria in-country.
3. Scientists from the Global North should spend time working with collections in herbaria in the countries in which they collect and avoid doing "parachute science," while host institutions should define and communicate norms for collaborative, inclusive science.
4. Botanists within and outside their study countries should invest resources in identifying, curating, and utilising the data held in small and local herbaria, as well as in training and collaborating with taxonomic specialists from these institutions.

5. All stakeholders should advocate for allocation of resources to local and tropical herbaria, both for mobilisation of data and for long-term sustainability. All such efforts require a long-term, shared and country-wide commitment of local leadership, as seen for Brazil and Mexico, as well as international commitment to assist with funding for local institutions.

AUTHOR CONTRIBUTIONS

Jay Delves, Sandra Knapp, Tiina Särkinen, Edeline Gagnon, and Peter W. Moonlight designed the study. Jay Delves and Peter W. Moonlight collected and analysed data. Jay Delves, Joaquina Albán-Castillo, Asunción Cano, Carmen Fernández Aviles, Edeline Gagnon, Paúl Gonzáles, Sandra Knapp, Blanca León, Jose Luis Marcelo-Peña, Carlos Reynel, Rocío del Pilar Rojas Gonzáles, Eric F. Rodríguez Rodríguez, Tiina Särkinen, Rodolfo Vásquez Martínez, and Peter W. Moonlight contributed to the manuscript.

ACKNOWLEDGEMENTS

We thank all of the herbaria in Peru and internationally for allowing to access and database their collections and to share these data openly; B. Thiers provided a "behind the scenes" download of Index Herbariorum; M. Tebbitt (CalU) contributed data for *Begonia*; M. Pullen and M. Hughes (RBGE) developed and established the Begonia Resource Centre; the Solanaceae Source database was developed with funding from the United States National Science Foundation Planetary Biodiversity Inventory Program (NSF-PBI) project "PBI Solanum: a worldwide monograph" (DEB-0316614) to SK and enhanced by Peruvian specimen data received from L. Bohs (University of Utah) S. Stern (Colorado Mesa University), E. Tepe (Miami University), L. Giacomin (Universidade Federal da Paraiba), and especially the late D.M. Spooner (USDA); field work for *Solanum* in Peru was in part funded by a grant from the National Geographic Society to TS and done under collecting permits from the Servicio Nacional Forestal y de Fauna Silvestre (SERFOR) del Ministerio de Desarollo Agrrario y Riego (MIDAGRI permisos de recolección No. 084-2012-AGDGFFS-DGEFFS - 0148-2013-AG-DGFFS-DGEFFS [CARTA N° D077-2014-MIDAGRI-SERFOR-DGGSPFFS, CARTA N° D096-2017-MIDAGRI-SERFOR-DGGSPFFS, CARTA N° D000013-2022-MIDAGRI-SERFOR-DGGSPFFS-DGSPF, CARTA N° D001203-2021-MIDAGRI-SERFOR-DGGSPFFS]); field work in Begonia was in funded by the James and Eve Bennett Trust and collecting done under MINAGRI permit 077-2014-SERFOR-DGGSPFFS.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Occurrence data for *Begonia* and *Solanum* from the Begonia Resource Centre and Solanaceae Source are available in a static data set on the Natural History Museum Data Portal (https://doi.org/10.5519/m4u7c4gu). Data downloaded from the Global Biodiversity Information facility can be found at the following links (*Begonia*, https://doi.org/10.15468/dl.yb7kdh; *Solanum*, https://doi.org/10.15468/dl.7etx2b).

ORCID

Jay Delves https://orcid.org/0000-0001-6203-7827
Joaquina Albán-Castillo https://orcid.org/0000-0003-4104-2912
Asunción Cano https://orcid.org/0000-0002-5759-4650
Edeline Gagnon https://orcid.org/0000-0003-3212-9688
Paúl Gonzáles https://orcid.org/0000-0002-6799-376X
Sandra Knapp https://orcid.org/0000-0001-7698-3945
Blanca León https://orcid.org/0000-0001-6307-8639
Jose Luis Marcelo-Peña https://orcid.org/0000-0002-0095-4643
Carlos Reynel https://orcid.org/0000-0002-6173-9023
Rocío del Pilar Rojas Gonzáles https://orcid.org/0000-0003-2114-548X
Eric F. Rodríguez Rodríguez https://orcid.org/0000-0003-0671-1535
Tiina Särkinen https://orcid.org/0000-0002-6956-3093
Rodolfo Vásquez Martínez https://orcid.org/0000-0002-2282-5009
Peter W. Moonlight https://orcid.org/0000-0003-4342-2089

REFERENCES

Amano, T., & Sutherland, W. J. (2013). Four barriers to the global understanding of biodiversity conservation: Wealth, language, geographical location and security. *Proceedings of the Royal Society B: Biological Sciences*, *280*, 20122649. https://doi.org/10.1098/rspb.2012.2649

Baber, Z. (2016). The plants of empire: Botanic gardens, colonial power and botanical knowledge. *Journal of Contemporary Asia*, *46*, 659–679. https://doi.org/10.1080/00472336.2016.1185796

Bachman, S. P., Field, R., Reader, T., Raimondo, D., Donaldson, J., Schatz, G. E., & Nic Lughadha, E. (2019). Progress, challenges and opportunities for Red Listing. *Biological Conservation*, *234*, 45–55. https://doi.org/10.1016/j.biocon.2019.03.002

Ball-Damerow, J. E., Brenskelle, L., Barve, N., Soltis, P. S., Sierwald, P., Bieler, R., LaFrance, R., Ariño, A. H., & Guralnick, R. P. (2019). Research applications of primary biodiversity databases in the digital age. *PLoS ONE*, *14*, e0215794. https://doi.org/10.1371/journal.pone.0215794

Beck, J., Böller, M., Erhardt, A., & Schwanghart, W. (2014). Spatial bias in the GBIF database and its effect on modeling species' geographic distributions. *Ecological Informatics*, *19*, 10–15. https://doi.org/10.1016/j.ecoinf.2013.11.002

Belbin, L., Wallis, E., Hobern, D., & Zerger, A. (2021). The atlas of living Australia: History, current state and future directions. *Biodiversity Data Journal*, *9*, e65023. https://doi.org/10.3897/BDJ.9.e65023

Bellot, S., Lu, Y., Antonelli, A., Baker, W. J., Dransfield, J., Forest, F., Kissling, W. D., Leitch, I. J., Nic Lughadha, E., Ondo, I., Pironon, S., Walker, B. E., Cámara-Leret, R., & Bachman, S. P. (2022). The likely extinction of hundreds of palm species threatens their contributions to people and ecosystems. *Nature Ecology & Evolution*, *6*, 1710–1722. https://doi.org/10.1038/s41559-022-01858-0

Betts, J., Young, R. P., Hilton-Taylor, C., Hoffmann, M., Rodriguez, J. P., Stuart, S. N., & Milner-Gulland, E. J. (2020). A framework for evaluating the impact of the IUCN Red List of threatened species. *Conservation Biology*, *34*, 632–643. https://doi.org/10.1111/cobi.13454

Brummitt, N. A., Bachman, S. P., Griffiths-Lee, J., Lutz, M., Moat, J. F., Farjon, A., Donaldson, J. S., Hilton-Taylor, C., Meagher, T. R., Albuquerque, S., Aletrari, E., Andrews, A. K., Atchinson, G., Baloch, E., Barlozzini, B., Brunazzi, A., Carretero, J., Celesti, M., Chadburn, H., … Nic Lughada, E. N. (2015). Green plants in the red: A baseline global assessment for the IUCN Sampled Red List Index for plants. *PLoS ONE*, *10*, e0135152. https://doi.org/10.1371/journal.pone.0135152

Canhos, D. A., Sousa-Baena, M. S., de Souza, S., Maia, L. C., Stehmann, J. R., Canhos, V. P., de Giovanni, R., Bonacelli, M. B., Los, W., & Peterson, A. T. (2015). The importance of biodiversity

e-infrastructures for megadiverse countries. *PLoS Biology*, *13*, e1002204. https://doi.org/10.1371/journal.pbio.1002204

Canteiro, C., Barcelos, L., Filardi, F., Forzza, R., Green, L., Lanna, J., Leitman, P., Milliken, W., Pires Morim, M., Patmore, K., Phillips, S., Walker, B., Weech, M. H., & Nic Lughada, E. (2019). Enhancement of conservation knowledge through increased access to botanical information. *Conservation Biology*, *33*, 523–533. https://doi.org/10.1111/cobi.13291

Cazalis, V., Di Marco, M., Butchart, S. H. M., Akcakaya, H. R., González-Suárez, M., Meyer, C., Clausnitzer, V., Böhm, M., Zizka, A., Cardoso, P., Schipper, A. M., Bachman, S. P., Young, B. E., Hoffmann, M., Benítez-López, A., Lucas, P. M., Pettorelli, N., Patoine, G., Pacifici, M., … Santini, L. (2022). Bridging the research-implementation gap in IUCN RED List assessments. *Trends in Ecology & Evolution*, *37*, 359–370. https://doi.org/10.1016/j.tree.2021.12.002

Chapman, A. D., & Wieczorek, J. R. (2020). *Georeferencing best practices*. GBIF Secretariat. https://doi.org/10.15468/doc-gg7h-s853

Collen, B., Dulvy, N. K., Gaston, K. J., Gärdenfors, U., Keith, D. A., Punt, A. E., Regan, H. M., Bohm, M., Hedges, S., Seddon, M., Butchart, S. H., Hilton-Taylor, C., Hoffmann, M., Bachman, S. P., & Akcakaya, H. R. (2016). Clarifying misconceptions of extinction risk assessment with the IUCN Red List. *Biology Letters*, *12*, 20150843. https://doi.org/10.1098/rsbl.2015.0843

Collen, B., Ram, M., Zamin, T., & McRae, L. (2008). The tropical biodiversity data gap: Addressing disparity in global monitoring. *Tropical Conservation Science*, *1*, 75–88. https://doi.org/10.1177/194008290800100202

Colombo, B., Kaehler, M., & Calvente, A. (2016). An inventory of the Bignoniaceae from the Brazilian state of Rio Grande do Norte highlights the importance of small herbaria to biodiversity studies. *Phytotaxa*, *278*, 19–28. https://doi.org/10.11646/phytotaxa.278.1.2

Daru, B. H., Park, D. S., Primack, R. B., Willis, C. G., Barrington, D. S., Whitfeld, T. J. S., Seidler, T. G., Sweeney, P. W., Foster, D. R., Ellison, A. M., & Davis, C. C. (2018). Widespread sampling biases in herbaria revealed from large-scale digitization. *New Phytologist*, *217*, 939–955. https://doi.org/10.1111/nph.14855

Dauby, G., Stevart, T., Droissart, V., Cosiaux, A., Deblauwe, V., Simo-Droissart, M., Sosef, M. S. M., Lowry, P. P., Schatz, G. E., Gereau, R. E., & Couvreur, T. L. P. (2017). ConR: An R package to assist large-scale multispecies preliminary conservation assessments using distribution data. *Ecology and Evolution*, *7*, 11292–11303. https://doi.org/10.1002/ece3.3704

Delves, J. (2021). *Decolonise herbaria and specimen data: Quantifying the contribution of local herbaria to biodiversity patterns* (pp. 1–104). University of Edinburgh. MSc Thesis. https://hdl.handle.net/20.500.12594/19879

Drew, J. A., Moreau, C. S., & Stiasssny, M. L. J. (2017). Digitization of museum collections holds the potential to enhance researcher diversity. *Nature Ecology and Evolution*, *1*, 1789–1790. https://doi.org/10.1038/s41559-017-0401-6

Eichhorn, M. P., Baker, K., & Griffiths, M. (2020). Steps towards decolonising biogeography. *Frontiers of Biogeography*, *12*(1), e44795. https://doi.org/10.21425/F5FBG44795

Ellwood, E. R., Dunckel, B. A., Flemons, P., Guralnick, R., Nelson, G., Newman, G., Newman, S., Paul, D., Riccardi, G., Rios, N., Seltmann, K. C., & Mast, A. R. (2015). Accelerating the digitization of biodiversity research specimens through online public participation. *Bioscience*, *65*, 383–396. https://doi.org/10.1093/biosci/biv005

Feeley, K. J., & Silman, M. R. (2011). The data void in modeling current and future distributions of tropical species. *Global Change Biology*, *17*, 626–630. https://doi.org/10.1111/j.1365-2486.2010.02239.x

Frodin, D. G. (2004). History and concepts of big plant genera. *Taxon*, *53*, 753–776. https://doi.org/10.2307/4135449

Gallagher, R. V., Allen, S. P., Govaerts, R., Rivers, M. C., Allen, A. P., Keith, D. A., Merow, C., Maitner, B., Butt, N., Auld, T. D., Enquist, B. J., Eiserhardt, W. L., Wright, I. J., Mifsud, J. C. O., Espinosa-Ruiz, S., Possingham, H., & Adams, V. M. (2023). Global shortfalls in threat assessments for endemic flora by country. *Plants, People, Planet*. https://doi.org/10.1002/ppp3.10369

Gärdenfors, U., Hilton-Taylor, C., Mace, G. M., & Rodríguez, J. P. (2008). The application of IUCN Red List Criteria at regional levels. *Conservation Biology*, *15*, 1206–1212. https://doi.org/10.1111/j.1523-1739.2001.00112.x

Gaston, K. J., & Fuller, R. A. (2009). The sizes of species' geographic ranges. *Journal of Applied Ecology*, *46*, 1–9. https://doi.org/10.1111/j.1365-2664.2008.01596.x

Gaul, W., Sadykova, D., White, H. J., Leon-Sanchez, L., Caplat, P., Emmerson, M. C., & Yearsley, J. M. (2020). Data quantity is more important than its spatial bias for predictive species distribution modelling. *PeerJ*, *8*, e10411. https://doi.org/10.7717/peerj.10411

GBIF Secretariat. (2023). *GBIF overview slides, [May, 2023]*. GBIF Secretariat. Available online at: https://www.gbif.org/document/81771

Gentry, A. H. (1988). Tree species richness of upper Amazonian forest. *Proceedings of the National Academy of Sciences, USA*, *85*, 156–159. https://doi.org/10.1073/pnas.85.1.156

Glon, H. E., Heumann, B. W., Carter, J. R., Bartek, J. M., & Monfils, A. K. (2017). The contribution of small collections to species distribution modelling: A case study from Fuireneae (Cyperaceae). *Ecological Informatics*, *42*, 67–78. https://doi.org/10.1016/j.ecoinf.2017.09.009

Gonzáles, P., Capcha-Ramos, J., Niño-de-Guzmán, P., Goodwin, Z. A., Särkinen, T., Valencia, N., & Cano, A. (2022). Geographic distribution, conservation status and lectotypification of *Pedersenia weberbaueri* (Suess.) Holub (Amaranthaceae), an endemic and highly threatened shrub from the Marañón valley of Peru. *Revista Peruana de Biología*, *29*, e23214. https://doi.org/10.15381/rpb.v29i4.23214

Gonzáles, P., León, B., Cano, A., & Jørgensen, P. M. (2018). Flora vascular y conexiones fitogeográficas de las montañas Carabaya, Perú. *Revista Peruana de Biología*, *25*, 191–210. https://doi.org/10.15381/rpb.v25i3.15228

Goodwin, Z. A., Harris, D. J., Filer, D., Wood, J. R., & Scotland, R. W. (2015). Widespread mistaken identity in tropical plant collections. *Current Biology*, *25*, R1066–R1067. https://doi.org/10.1016/j.cub.2015.10.002

Harris, K. M., & Marisco, T. D. (2017). Digitizing specimens in a small herbarium: A viable workflow for collections working with limited resources. Applications. *Plant Science*, *5*, apps.1600125. https://doi.org/10.3732/apps.1600125

Heberling, J. M., Miller, J. T., Noesgaard, D., Weingart, S. B., & Schigel, D. (2021). Data integration enables global biodiversity synthesis. *Proceedings of the National Academy of Sciences USA*, *118*, e2018093118. https://doi.org/10.1073/pnas.2018093118

Heberling, J. M., Prather, L. A., & Tonsor, S. J. (2019). The changing uses of herbarium data in an era of global change: An overview using automated content analysis. *Bioscience*, *69*, 812–822. https://doi.org/10.1093/biosci/biz094

Hortal, J., de Bello, F., Diniz-Filho, J. A. F., Lewinsohn, T. M., Lobo, J. M., & Ladle, R. J. (2015). Seven shortfalls that beset large-scale knowledge of biodiversity. *Annual Review of Ecology, Evolution, and Systematics*, *46*, 523–549. https://doi.org/10.1146/annurev-ecolsys-112414-054400

Hughes, M., Moonlight, P.W., Jara-Muñoz, A., Tebbitt, M.C., Wilson, H.P., Zhong, K. & Pullan, M. (2015). Begonia Resource Centre. Continuously updated. Online database available from http://padme.rbge.org.uk/begonia/

IUCN. (2022a). IUCN Red List of Threatened Species. https://www.iucnredlist.org/ (accessed 12 April 2023).

IUCN. (2022b). Guidelines for using the IUCN red list categories and criteria. https://www.iucnredlist.org/resources/redlistguidelines (Accessed 12 April 2023).

Johnson, K. R., Owens, I. F. P., & Global Collection Group. (2023). A global approach for natural history museum collections. *Science*, *379*, 1192–1194. https://doi.org/10.1126/science.adf6434

Knapp, W. M., Frances, A., Noss, R., Naczi, R. F. C., Weakley, A., Gann, G. D., Baldwin, B. G., Miller, J., McIntyre, P., Mishler, B. D., Moore, G., Olmstead, R. G., Strong, A., Gluesenkamp, D., & Kennedy, K. (2020). Regional records improve data quality in determining plant extinction rates. *Nature Ecology and Evolution*, *4*, 512–514. https://doi.org/10.1038/s41559-020-1146-1

Kozlov, M. V., Sokolova, I. V., Zverev, V., & Zvereva, E. L. (2021). Changes in plant collection practices from the 16th to 21st centuries: Implications for the use of herbarium specimens in global change research. *Annals of Botany*, *127*, 865–873. https://doi.org/10.1093/aob/mcab016

Lavoie, C. (2013). Biological collections in an ever changing world: Herbaria as tools for biogeographical and environmental studies. *Perspectives in Plant Ecology, Evolution and Systematics*, *15*, 68–76. https://doi.org/10.1016/j.ppees.2012.10.002

Le Bras, G., Pignal, M., Jeanson, M. L., Muller, S., Aupic, C., Carre, B., Flament, G., Gaudeul, M., Gonçalves, C., Invernon, V. R., Jabbour, F., Lerat, E., Lowry, P. P., Offroy, B., Pimpare, E. P., Poncy, O., Rouhan, G., & Haevermans, T. (2017). The French Museum national d'histoire naturelle vascular plant herbarium collection dataset. *Scientific Data*, *4*, 170016. https://doi.org/10.1038/sdata.2017.16

Le Breton, T. D., Zimmer, H. C., Gallagher, R. V., Cox, M., Allen, S., & Auld, T. D. (2019). Using IUCN criteria to perform rapid assessments of at-risk taxa. *Biodiversity and Conservation*, *28*, 863–883. https://doi.org/10.1111/cobi.13112

León, B., Roque, J., Ulloa Ulloa, C., Pitman, N., Jørgensen, P. M., & Cano, A. (Eds.). (2006). *El Libro Rojo de las plantas endémicas del Perú* (Vol. 13, pp. S1–S980). Revista Peruana de Biológia. https://sisbib.unmsm.edu.pe/bvrevistas/biologia/v13n2/contenido.htm

Lobo, J. M., Baselga, A., Hortal, J., Jiménez-Valverte, A., & Gómez, J. F. (2007). How does the knowledge about the spatial distribution of Iberian dung beetle species accumulate over time? *Diversity and Distributions*, *13*, 772–780. https://doi.org/10.1111/j.1472-4642.2007.00383.x

Mace, G. M., & Lande, R. (1991). Assessing extinction threats: Toward a revaluation of IUCN threatened species categories. *Conservation Biology*, *5*, 148–157. https://doi.org/10.1111/j.1523-1739.1991.tb00119.x

Marcelo-Peña, J. L., Huamantupa, I., Särkinen, T., & Tomazello, M. (2016). Identifying conservation priority areas in the Maraon valley in Peru based on woody floristic composition and endemism. *Edinburgh Journal of Botany*, *73*, 95–123. https://doi.org/10.1017/S0960428615000281

Marisco, T. D., Krimmel, E. R., Carter, J. R., Gillespie, E. L., Lowe, P. D., McCauley, R., Morris, A. B., Nelson, G., Smith, M., Soteropoulos, D. L., & Monfils, A. K. (2020). Small herbaria contribute unique biogeographic records to county, locality, and temporal scales. *American Journal of Botany*, *107*, 1577–1587. https://doi.org/10.1002/ajb2.1563

Meyer, C., Kreft, H., Guralnick, R., & Jetz, W. (2015). Global priorities for an effective information basis of biodiversity distributions. *Nature Communications*, *6*, 8221. https://doi.org/10.1038/ncomms9221

Monfils, A. & Nelson, G. (2014). The small collections network: Recruiting, retaining, and sustaining small collections in biodiversity digitization. https://www.idigbio.org/wiki/images/3/33/Monfils_Recruiting_small_collections_Final.pdf

Monfils, A. K., Krimmel, E. R., Bates, J. M., Bauer, J. E., Belitz, M. W., Cahill, B. C., Caywood, A. M., Cobb, N. S., Colby, J. B., Ellis, S. A., Krejsa, D. M., Levine, T. D., Marsico, T. D., Mayfield-Meyer, T. J., Miller-Camp, J. A., Nelson, R. M., Phillips, M. A., Revelez, M. A., Roberts, D. R., … Zaspel, J. M. (2020). Regional collections are an essential component of biodiversity research infrastructure. *Bioscience*, *70*, 1045–1047. https://doi.org/10.1093/biosci/biaa102

Moonlight, P. W., Jara-Muñoz, O. A., Purvis, D. A., Delves, J., Allen, J. P., & Reynel, C. (2023). The genus *Begonia* (Begoniaceae) in Peru. *European Journal of Taxonomy*, *881*, 1–334. https://doi.org/10.5852/ejt.2023.881.2175

Nelson, G., & Ellis, S. (2018). The history and impact of digitization and digital data mobilization on biodiversity research. *Philosophical Transactions of the Royal Society, B: Biological Sciences*, *374*, 20170391. https://doi.org/10.1098/rstb.2017.0391

Nic Lughada, E., Walker, B. E., Canteiro, C., Chadburn, H., Davis, A. P., Hargreaves, S., Lucas, E. J., Schuiteman, A., Williams, E., Bachman, S. P., Baines, D., Barker, A., Budden, A. P., Carretero, J., Clarkson, J. J., Roberts, A., & Rivers, M. C. (2018). The use and misuse of herbarium specimens in evaluating plant extinction risks. *Philosophical Transactions of the Royal Society, B: Biological Sciences*, *374*, 20170402. https://doi.org/10.1098/rstb.2017.0402

Park, D. S., Feng, X., Akiyama, S., Ardiyani, M., Avendaño, N., Barina, Z., Bärtschi, B., Belgrano, M., Betancur, J., Bijmoer, R., Bogaerts, A., Cano, A., Danihelka, J., Garg, A., Giblin, D. E., Gogoi, R., Guggisberg, A., Hyvärinen, M., James, S. A., … Davis, C. C. (2023). The colonial legacy of herbaria. *Nature Human Behaviour*, *7*, 1059–1068. https://doi.org/10.1038/s41562-023-01616-7

Parsons, E. C. M. (2016). Why IUCN should replace "data deficient" conservation status with a precautionary "assume threatened" status—A cetacean case study. *Frontiers in Marine Science*, *3*, 193. https://doi.org/10.3389/fmars.2016.00193

Pergl, J., Pysek, P., Perglova, I., Jarosik, V., & Proches, S. (2012). Low persistence of a monocarpic invasive plant in historical sites biases our perception of its actual distribution. *Journal of Biogeography*, *39*, 1293–1302. https://doi.org/10.1111/j.1365-2699.2011.02677.x

Pimm, S. L., & Joppa, L. N. (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. https://doi.org/10.3417/2012018

Purvis, A., Gittleman, J. L., Cowlishaw, G., & Mace, G. M. (2000). Predicting extinction risk in declining species. *Proceedings of the Royal Society B: Biological Sciences*, *267*, 1947–1952. https://doi.org/10.1098/rspb.2000.1234

Reynel, C., Terreros, S., & Palacios, S. (2020). *El herbario de la Facultad de Ciencias Forestales de la UNALM*. FCF UNALM.

Ribeiro, B. R., Guidoni-Martins, K., Tessarolo, G., Elías Velazco, S. J., Jardim, L., Bachman, S. P., & Loyola, R. (2022). Issues with species occurrence data and their impact on extinction risk assessments. *Biological Conservation*, *273*, 109674. https://doi.org/10.1016/j.biocon.2022.109674

Rivers, M. C., Taylor, L., Brummitt, N. A., Meagher, T. R., Roberts, D. L., & Nic Lughada, E. (2011). How many herbarium specimens are needed to detect threatened species? *Biological Conservation*, *144*, 2541–2547. https://doi.org/10.1016/j.biocon.2011.07.014

Särkinen, T., Baden, M., Gonzáles, P., Cueva, M., Giacomin, L. L., Spooner, D. M., Simon, R., Juárez, H., Nina, P., Molina, J., & Knapp, S. (2015). Listado anotado de *Solanum* L. (Solanaceae) en el Perú. *Revista Peruana de Biología*, *22*, 3–62. https://doi.org/10.15381/rpb.v22i1.11121

Sarukhán, J., & Jiménez, R. (2016). Generating intelligence for decision making and sustainable use of natural capital in Mexico. *Current Opinion in Environmental Sustainability*, *19*, 153–159. https://doi.org/10.1016/j.cosust.2016.02.002

Smith, V. S., Hardy, H., Wainwright, T., Livermore, L., Fraser, N., Horak, J., Aspinall, J., & Howe, M. (2022). *Harnessing the power of natural science collections: A blueprint for the UK*. Natural History Museum. https://doi.org/10.5281/zenodo.6472239

Sousa-Baena, M. S., Garcia, L. C., & Peterson, T. A. (2014). Knowledge behind conservation status decisions: Data basis for "data deficient" Brazilian plant species. *Biological Conservation*, *173*, 80–89. https://doi.org/10.1016/j.biocon.2013.06.034

Speed, J. D. M., Bendiksby, M., Finstad, A. G., Hassel, K., Kolstad, A. L., & Presto, T. (2018). Contrasting spatial, temporal and environmental

patterns in observation and specimen based species occurrence data. *PLoS ONE*, *13*, e0196417. https://doi.org/10.1371/journal.pone.0196417

Spooner, D. M., Jansky, S., Rodríguez, F., Simon, R., Ames, M., Fajardo, D., & Castillo, R. O. (2019). Taxonomy of wild potatoes in northern South American (Solanum section Petota). *Systematic Botany Monographs*, *108*, 1–305.

Takano, A., Horiuchi, Y., Fujimoto, Y., Aoki, K., Hiromune, M., & Takahashi, A. (2019). Simple but long-lasting: A specimen imaging method applicable for small- and medium-sized herbaria. *PhytoKeys*, *118*, 1–14. https://doi.org/10.3897/phytokeys.118.29434

ter Steege, H., Harripersaud, P. P., Bánki, O. S., & Schievin, F. (2011). A model of botanical collectors' behavior in the field: Never the same species twice. *American Journal of Botany*, *98*, 31–37. https://doi.org/10.3732/ajb.1000215

Thiers, B. M. (2001). *Index Herbariorum*. updated continuously. https://sweetgum.nybg.org/science/ih/

Tobler, M., Honorio, E., Janovec, J., & Reynel, C. (2007). Implications of collection patters of botanical specimens on their usefulness for conservation planning: An example of two neotropical plant families (Moraceae and Myristicaceae) in Peru. *Biodiversity and Conservation*, *16*, 659–677. https://doi.org/10.1007/s10531-005-3373-9

Treviño, I. F., Sotomayor, D. A., Cueva, M. A., Perez, R., Cáceres, L., Ramos, D., Ortiz, E. M., & Quipuscoa, V. (2012). Herbarium Arequipense (HUSA): Informatización y representividad de su colección. *Revista Peruana de Biología*, *19*(2), 219–222. http://www.scielo.org.pe/scielo.php?script=sci_arttext&pid=S1727-99332012000200016&lng=es&nrm=iso

Vorontsova, M. S., Lowry, P. P., Andriambololonera, S. R., Wilmé, L., Rasolohery, A., Govaerts, R., Ficinski, S. Z., & Humphreys, A. M. (2020). Inequality in plant diversity knowledge and unrecorded plant extinctions: An example from the grasses of Madagascar. *Plants, People, Planet*, *3*, 45–60. https://doi.org/10.1002/ppp3.10123

Walker, B. E., Leão, T. C. C., Bachman, S. P., Bolam, F. C., & Lughadha, E. N. (2020). Caution needed when predicting species threat status for conservation prioritization on a global scale. *Frontiers in Plant Science*, *11*, 520. https://doi.org/10.3389/fpls.2020.00520

Willis, F., Moat, J., & Paton, A. (2003). Defining a role for herbarium data in Red List assessments: A case study of *Plectranthus* from eastern and southern tropical Africa. *Biodiversity and Conservation*, *12*, 1537–1552. https://doi.org/10.1023/A:1023679329093

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Delves, J., Albán-Castillo, J., Cano, A., Fernández Aviles, C., Gagnon, E., Gonzáles, P., Knapp, S., León, B., Marcelo-Peña, J. L., Reynel, C., Rojas Gonzáles, R. P., Rodríguez Rodríguez, E. F., Särkinen, T., Vásquez Martínez, R., & Moonlight, P. W. (2023). Small and in-country herbaria are vital for accurate plant threat assessments: A case study from Peru. *Plants, People, Planet*, 1–12. https://doi.org/10.1002/ppp3.10425