Rhododendron diversity conservation in global botanic gardens: a case study of *Maddenia* species

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Abstract Effective ex situ conservation of plants in botanic gardens requires sufficient wild accessions to represent wild diversity. In *Rhododendron* L. (Ericaceae), c. 64% of the taxa are threatened or require field investigation. As a case study of the analysis of ex situ conservation gaps we used ecogeographical representation as a proxy for genetic representation in ex situ collections of the 65 taxa of *Rhododendron* subsection *Maddenia*. We compiled the first list profiling both wild distributions and ex situ wild collections of all taxa in subsection *Maddenia*. Our results reveal that 55 *Maddenia* taxa are in cultivation. Of the 18 threatened taxa all are in cultivation but nine require further collection to capture adequate wild diversity. There are 12 Data Deficient taxa: these await further field investigation of wild populations and nine of them require wild collections to conserve genetic diversity. The UK, the USA, Australia, New Zealand and China are the top five countries holding ex situ collections of subsection *Maddenia*; in these countries nearly 66% of the ex situ sites hold > 86% of the global living collections of subsection *Maddenia*. We recommend that wild collections of endemic species of subsection *Maddenia* should be established in all 10 countries of origin and that data should be shared internationally for meta-collections. In addition to proposing priorities, our case study highlights the challenges facing data and collection management to help achieve effective ex situ conservation for *Rhododendron* species.

Keywords Ecogeographical representation, ex situ conservation, genetic representation, living collection, *Maddenia*, prioritization, *Rhododendron*, wild accession

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Introduction

Plant biodiversity conservation was prioritized for urgent action at the United Nations Biodiversity Conference CoP 15, with a particular focus on the development of the post-2020 global strategy for plant conservation (CBD, 2021). As a component of integrated plant conservation, ex situ conservation not only conserves plant diversity but also supports habitat restoration (Havens et al., 2006; Westwood et al., 2021). The genetic variation in ex situ collections at the species, population, individual, and allelic levels could be drawn from to facilitate the adaptation of species to potential environmental changes in habitat, as well as safeguarding against introduced diseases and pests (Sharrock, 2020).

Botanic gardens (including arboreta) are key repositories of living collections for plant ex situ conservation (Havens et al., 2006; O'Donnell & Sharrock, 2017; Sharrock, 2020; Hudson et al., 2021; Westwood et al., 2021). Target 8 of the Global Strategy for Plant Conservation (CBD, 2010) directs that at least 75% of threatened species be conserved in ex situ collections (preferably in their countries of origin), with over 20% available for restoration programmes. Examining the ex situ conservation status of species against Target 8 and identifying gaps enables botanic gardens to support ex situ conservation more effectively (Godefroid et al., 2011; Linsky et al., 2022). According to analyses of data from the largest plant conservation network in the world, Botanic Gardens Conservation International (BGCI), plant collections in global botanic gardens face problems, such as species being held disproportionately in temperate locations, outside their country of origin and in one institution only (Mounce et al., 2017; Sharrock, 2020). To overcome these problems, ex situ collections require scientific management to maximize conservation effectiveness.

A fundamental underpinning for effective ex situ conservation is a sufficient number of wild-source accessions that represent the wild diversity of species (IUCN SSC, 2014; Mounce et al., 2017; Maxted et al., 2020; Wei & Jiang, 2021; Westwood et al., 2021). The limited space and facilities of botanic gardens have to be allocated to prioritized species (Heywood, 2017; Sharrock, 2020). Factors such as species richness, taxonomic distinctiveness, vulnerabilities and threats in the wild as well as ongoing ex situ conservation activities have been considered to determine priorities for several plant genera (Kozlowski et al., 2012; Toppila, 2012; Hoban et al., 2018; MacKay et al., 2018; Linsky et al., 2022). To estimate the genetic representation (captured genetic variation) in ex situ collections, the concept of the ecogeographical representativeness of wild accessions has been proposed as a surrogate when the genetic diversity of the species is unknown (Rae, 2011; Griffith et al., 2015, 2020;

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Volis, 2017; Chen & Sun, 2018; Hudson et al., 2021; Wei & Jiang, 2021).

Using the number and provenance of wild accessions to estimate the captured genetic diversity can inform future collection management (Beckman, 2019; Linsky et al., 2022). Current practice includes the concept of metacollections to manage pooled collections in multiple botanic gardens, obtained from spatially separated populations with coordinated sampling internationally or regionally (Griffith et al., 2020; Westwood et al., 2021). Views differ on the number of wild accessions required to conserve sufficient genetic diversity of a species, but multiple wild samples should be collected from diverse populations, with each ex situ collection duplicated at multiple sites (Griffith et al., 2015; Ren et al., 2019; Zumwalde et al., 2022).

Rhododendron is a big genus (i.e. one with 500 or more species; Frodin, 2004) of ≥ 1,000 species across a wide geographical range, with the greatest diversity extending from the southern Himalayas to south-west China (Gibbs et al., 2011; MacKay et al., 2018; Shrestha et al., 2018). Assessing the number and geographical range of *Rhododendron* populations in the wild is challenging because of their inaccessible habitats in montane or remote regions (Gibbs et al., 2011). Under the scope of BGCI, the Global Conservation Consortium for Rhododendron was established in 2018 to coordinate conservation action worldwide. Despite the large number of *Rhododendron* taxa conserved in botanic gardens (78% of threatened taxa in cultivation; MacKay & Hootman, 2018; MacKay et al., 2018) and ongoing ex situ conservation projects (Ma et al., 2014; McMeekin, 2022), the genetic representation of ex situ collections of *Rhododendron* species is seldom studied.

Here we present subsection (ss.) *Maddenia* as a case study for the conservation of genetic diversity in global ex situ collections. Subsection *Maddenia* (subgenus *Rhododendron*, section *Rhododendron*) exhibits conservation issues that occur across the genus, including poorly known wild distribution (Gibbs et al., 2011), complex taxonomy (Cubey, 2003; Donald, 2012; McMeekin, 2022; Hu et al., 2023), taxonomic debates over the conservation status of species (Gibbs et al., 2011; Li et al., 2018) and recently published species requiring field investigation (Chang et al., 2021; Rushforth et al., 2022). We analysed ecogeographical representation as a proxy for genetic representation in current wild collections of ss. *Maddenia* to identify ex situ conservation gaps for future action. Data from ex situ collections (at taxon and accession levels) together with taxon distribution are used to (1) update a checklist of taxa in the subsection including IUCN Red List assessment and wild distribution, (2) characterize the ex situ conservation status of taxa including presence or absence in cultivation and location and size of ex situ collections, (3) examine the ecogeographical representation of wild-source accessions, and (4) identify gaps and derive conservation strategies.

Methods

Firstly, we compiled an updated checklist of all ss. *Maddenia* taxa. Secondly, we compiled two datasets for ss. *Maddenia*: (1) taxa in the wild, annotated by IUCN Red List category (IUCN, 2022), country/region of distribution and altitude of habitat; and (2) taxa in ex situ conservation, annotated by cultivation status (whether a taxon is in cultivation), location of global ex situ sites and number of living collections (taxon-level data; Supplementary Table 1), wild collection provenance and number of wild accessions per taxon (accession-level data; Supplementary Table 2). Thirdly, we formulated these data into a profile for each taxon in ss. *Maddenia* and used these to produce a map with known distribution and ex situ sites of living collections plotted together with origins of wild accessions (Supplementary Material 1). Ex situ conservation gap analysis was based on the compiled datasets.

In this study, we defined taxa as in cultivation if there was a living collection recorded in any one of the data sources used. We defined a living collection as the record of a taxon with living plants cultivated in a botanic garden, and any one collection could include multiple accessions.

Checklist of subsection *Maddenia*

In the checklist, we based all taxa of ss. *Maddenia* (species, subspecies and botanical varieties) with their synonyms on Chamberlain et al. (1996), with updates from post-1996 studies (Argent et al., 2008; Gibbs et al., 2011; Donald, 2012; Mao & Bhaumik, 2015; Mao et al., 2017; MacKay et al., 2018; Rushforth & Nguyen, 2019; Chang et al., 2021; Rushforth et al., 2022). We initially obtained threatened categories of taxa from the IUCN Red List of Rhododendrons (Gibbs et al., 2011) and from assessments for recently published species (Mao & Bhaumik, 2015; Chang et al., 2021). Additional sources were the published IUCN Red List assessments (IUCN, 2022) and national assessments of endemic species in China (MEP–CAS, 2013; Qin et al., 2017). We also indexed the BGCI ThreatSearch database for existing conservation assessments (BGCI, 2022b).

We mapped distributions and countries of origin for each taxon using polygons based on geographical information from the literature and online databases (Cullen, 1980; Davidian, 1982; Feng, 1988, 1992; Feng & Yang, 1999; Fang et al., 2005, 2011; Gibbs et al., 2011; Mao & Bhaumik, 2015; Mao et al., 2017; RBGE, 2018a,b; Chang et al., 2021; GBIF, 2021; Rushforth et al., 2022). We georeferenced distribution data and generated maps using *QGIS 3.20.3* (QGIS Development Team, 2021). We stacked polygons for each taxon to produce a species richness map. See Supplementary Material 1 for details of data processing and taxon information.

Presence of subsection *Maddenia* in ex situ living collections

We collected data describing the presence of ss. *Maddenia* taxa in cultivation from three key sources. Firstly, we used the BGCI PlantSearch database (BGCI, 2021b) as the primary indicator of presence in cultivation. However, the public website PlantSearch only presents occurrence of taxa and not the location or number of ex situ collections. Therefore, we used an unpublished set of BGCI data (BGCI, 2020) that includes all *Rhododendron* records from GardenSearch and PlantSearch databases as the second source. We compiled taxon-level collections data for ss. *Maddenia* in global botanic gardens from these two sources (Supplementary Table 1). We used the unpublished BGCI data (BGCI, 2020) and BGCI GardenSearch database (BGCI, 2022a) to identify ex situ collections held in countries worldwide. The third source was accession-level data from seven gardens in New Zealand, a hotspot of ex situ conservation of ss. *Maddenia*, and the seven largest collections of ss. *Maddenia* outside New Zealand. Data from the third source included unpublished data from MacKay et al. (2018) and additional data or individual garden updates from 2020. We have compiled accession-level data from the third source in Supplementary Table 2.

Provenance and number of wild accessions

To evaluate the ecogeographical representation of ss. *Maddenia* conserved ex situ, we collated provenance and number of accessions of wild collections in the 14 botanic gardens from the third data source. We analysed the data for each taxon. Determinants for our evaluation of conservation were number of wild collections (identified by the unique Collector ID for each wild collection), number of wild accessions per collection (identified by accessions under the same Collector ID), cultivation source material, Collector ID and provenance (habitat location or coordinates and altitude) of wild accessions (Supplementary Table 2).

We mapped wild accessions of each taxon with documented coordinates in *QGIS*. When a wild accession was described from a certain location but without coordinates, we assigned the location around the centre of the geographical area, with the habitat and altitude of the taxon cross-referenced. When an accession was noted as from the wild but without provenance information, we considered it as a wild accession but did not plot it on the map.

Results

Checklist of subsection *Maddenia*

The checklist reveals 65 taxa in *Rhododendron* ss. *Maddenia*, and we compiled a profile for each taxon (Supplementary Material 3). Information on conservation status and wild distribution are included in each profile. The checklist includes 18 threatened taxa (three Critically Endangered, two Endangered, 13 Vulnerable), four Near Threatened, 12 Data Deficient, 20 Least Concern and 11 Not Evaluated. Subsection *Maddenia* spans 10 countries across southern Asia (China, Myanmar, India, Viet Nam, Bhutan, Thailand, Nepal, Laos, Bangladesh and Indonesia; Fig. 1a; Table 1). China has the greatest number of native taxa (45), followed by Myanmar (20) and India (19). The mountainous areas in the China–north-east India and China–Myanmar borders are the geographical hotspots for this subsection.

Ex situ living collections per taxon by IUCN Red List category

We summarized numbers of ex situ sites and countries per taxon and classified them by Red List category (Supplementary Fig. 1a). All threatened (Critically Endangered, Endangered, Vulnerable) and Near Threatened taxa are conserved in at least three botanic gardens. However, the 12 Data Deficient taxa have poorer representation: three (*Rhododendron amandum*, *Rhododendron yaogangxianense*, *Rhododendron yizhangense*) are not in cultivation and four (*Rhododendron kuomeianum*, *Rhododendron linearilobum*, *Rhododendron rhombifolium*, *Rhododendron valentinioides* (ined.)) are cultivated in only one or two botanic gardens. Least Concern taxa are well represented, with only four of the 20 taxa not in cultivation or held in fewer than three botanic gardens.

Ex situ living collections in native and other countries

We identified 592 collection records of the 55 taxa in cultivation at 73 ex situ sites in 17 countries (Fig. 2; Supplementary Fig. 1; Supplementary Table 1). Ten taxa are not in cultivation (Table 2). Ex situ collections of ss. *Maddenia* are widely cultivated in Europe, North America, Southeast Asia and Oceania. There were no records in Africa or South America (Fig. 2a). The UK, the USA, Australia, New Zealand and China are the top five countries holding ex situ collections of ss. *Maddenia* (Fig. 2b), where nearly 66% of the ex situ sites hold $> 86\%$ of the living collections. Although a smaller number of ex situ collections are conserved in Canada, Belgium and France, the remaining nine countries hold only c. 6% of the ex situ collections of this subsection, either at one ex situ site or with one collection record.

Amongst the countries of origin, only China had ex situ collections of ss. *Maddenia* reported to BGCI, with 32 collections representing 22 taxa at five sites (Supplementary Table 1). There was no ex situ collection of ss. *Maddenia* recorded in the other nine native countries. Using the BGCI GardenSearch database, several botanic gardens were

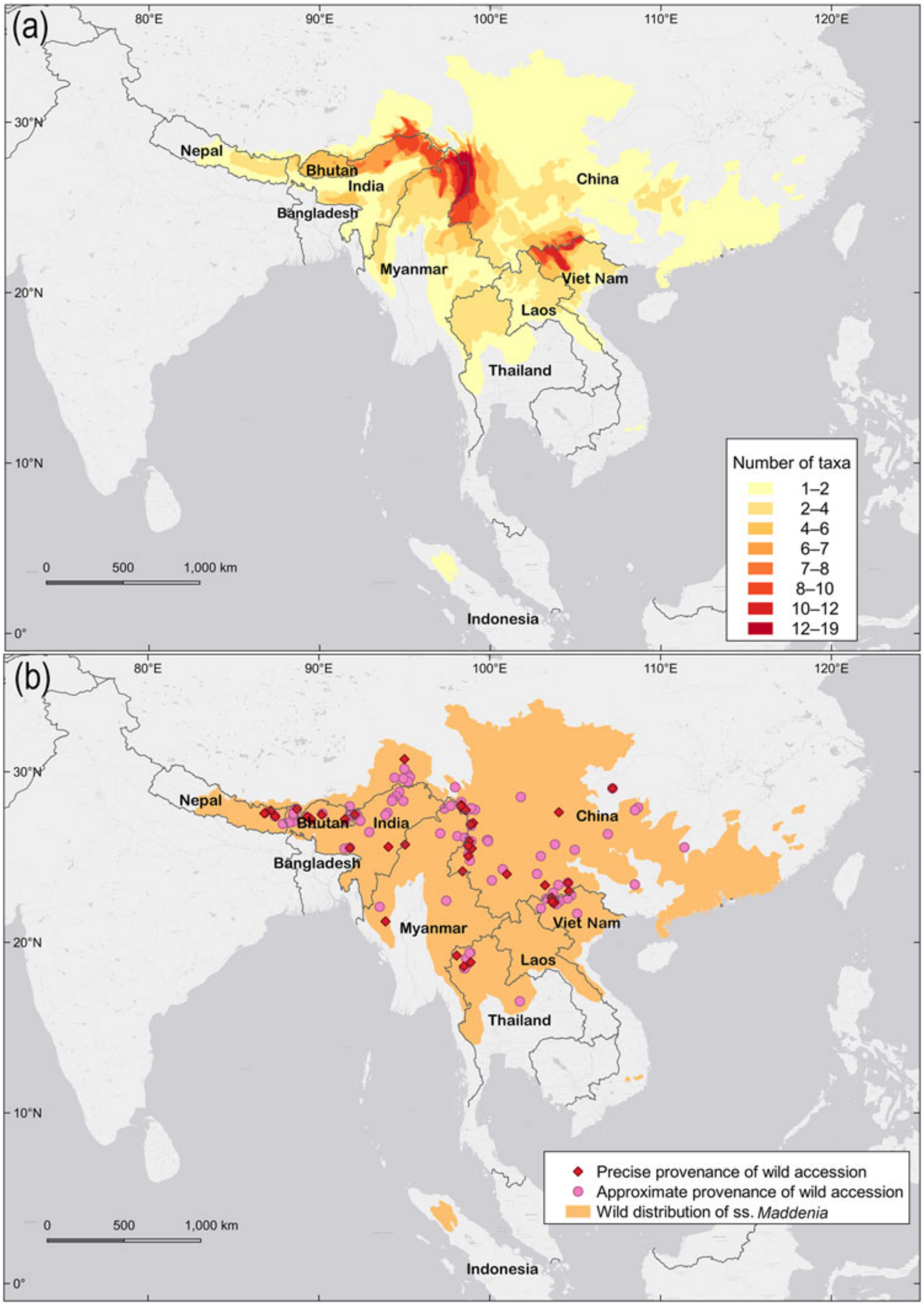

Fig. 1 Mapped wild distribution and geographical provenance of ex situ collections of *Rhododendron* subsection *Maddenia*. (a) Taxon distribution and richness in native countries (the 10 country names shown on the map). (b) Geographical origins of ex situ wild collections of *Rhododendron* subsection *Maddenia*, mapped according to provenance data (the wild distribution of species is indicated as a uniform plain background to highlight the provenance of the wild collections).

indexed in these native countries but they did not have data of ss. *Maddenia* reported to BGCI (Table 1). Bhutan, Laos and Indonesia each reported one garden holding *Rhododendron* collections but ss. *Maddenia* was not recorded.

We recorded numbers of ss. *Maddenia* taxa conserved per site to determine the leading botanic gardens in terms of ex situ conservation (Supplementary Table 1). Amongst all 73 ex situ sites there were 12 holding living collections of > 10 ss. *Maddenia* taxa, and these held nearly 66% of the global collections (Table 3). Three botanic gardens (Royal Botanic Garden Edinburgh, Rhododendron Species Botanical Garden and University of British Columbia Botanical Garden) held more than half of the taxa (48, 37 and 33, respectively).

Number of wild accessions by taxon

Our dataset identified 598 wild accessions from 277 documented wild sources of ss. *Maddenia* in the surveyed 14 botanic gardens (Supplementary Fig. 1b; Supplementary Table 2). Overall, the number of wild accessions per taxon

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TABLE 1 Number of botanic gardens in the countries of origin of *Rhododendron* subsection *Maddenia*. Countries are listed in descending order by number of taxa. Numbers of gardens with ss. *Maddenia* or *Rhododendron* collections are from PlantSearch (BGCI, 2021b), and numbers of BGCI or non-member botanic gardens are from BGCI GardenSearch (BGCI, 2022a).

Country	Number of ss. *Maddenia* taxa	Number of gardens with ss. *Maddenia* collections	Number of gardens with *Rhododendron* collections	Number of BGCI member gardens	Number of botanic gardens
China	45	5	16	40	173
Myanmar	20	0	0	1	5
India	19	0	0	10	138
Viet Nam	13	0	0	1	10
Bhutan	7	0	1	1	1
Thailand	4	0	0	7	18
Nepal	3	0	0	0	2
Laos	3	0	1	1	1
Bangladesh	2	0	0	0	5
Indonesia	1	0	1	3	5

showed a similar pattern to the number of ex situ sites/countries (Supplementary Fig. 1). However, taxa are generally not well conserved with wild accessions. Amongst the 18 threatened taxa, *Rhododendron coxianum* (1 wild accession), *Rhododendron fleuryi* (2), *Rhododendron kiangsiense* (1) and *Rhododendron taronense* (2) had fewer than three wild accessions, with none for *Rhododendron roseatum* and *Rhododendron sinonuttallii*. Although all four Near Threatened taxa had > 10 wild accessions, the 12 Data Deficient taxa had few wild accessions in cultivation. Only four Data Deficient taxa were represented by more than three wild accessions. Notably, *R. linearilobum* and *R. rhombifolium* had no documented wild accessions, although they were in cultivation (Table 2; Supplementary Fig. 1). For the 20 Least Concern taxa, although little conservation concern is indicated, *Rhododendron crenulatum*, *Rhododendron mianningense*, *Rhododendron parryae* and *Rhododendron pseudomaddenii* had fewer than three wild accessions and two (*Rhododendron vanderbiltianum* and *Rhododendron yungchangense*) are not in cultivation. The two subspecies of the *Rhododendron maddenii* complex, *R. maddenii* subsp. *maddenii* and *R. maddenii* subsp. *crassum*, were represented by the greatest number of wild accessions.

Ecogeographical representation of ex situ collections

Using available provenance data (either coordinates or locations), we mapped 179 of the 277 wild collections to show the geographical origins of ss. *Maddenia* in ex situ conservation (Fig. 1b; Supplementary Table 2). Most of the wild accessions were from south-west China, north-east India, Bhutan, eastern Nepal, northern Myanmar, northern Viet Nam and north-west Thailand. Amongst the taxa threatened or at risk (Critically Endangered, Endangered, Vulnerable, Near Threatened, Data Deficient), 10 (2 Critically Endangered, 2 Endangered, 3 Vulnerable, 3 Data Deficient) had documented wild accessions but from fewer than three wild sources (Supplementary Fig. 2). Because of a lack of provenance data we did not map a proportion of wild collections (98/277, 35%; Supplementary Fig. 2; Supplementary Material 3). Although identified as from the wild, these collections were recorded with no geographical information. This resulted in six taxa not being mapped (*R. coxianum*, *R. kiangsiense*, *R. taronense*, *Rhododendron levinei*, *R. parryae*, *R. pseudomaddenii*) among the 49 taxa having recorded wild accessions in cultivation (Table 2).

Discussion

Ex situ conservation of *Rhododendron* subsection *Maddenia*

Our analysis of living collections will inform ex situ conservation management of this subsection of 65 taxa towards the Global Strategy for Plant Conservation Target 8 (CBD, 2010). The 85% of ss. *Maddenia* taxa in cultivation is an improved position compared to the 73% for the whole genus in 2018 (MacKay et al., 2018), with all threatened taxa now cultivated in at least three sites (Supplementary Fig. 1a). This meets the Target's criterion of 'taxon cultivated in at least three ex situ sites and have at least three wild accessions' to adequately capture genetic diversity in ex situ conservation. However, amongst the 34 taxa threatened or at risk, only two (*Rhododendron excellens*, *Rhododendron nuttallii*) are conserved with over 15 wild collections (number of wild sources in Supplementary Table 2; Supplementary Material 3), and half (17/34) do not meet the criterion (Supplementary Figs 1b & 2). In particular, six threatened taxa (*R. coxianum*, *R. fleuryi*, *R. kiangsiense*, *R. roseatum*, *R. sinonuttallii*, *R. taronense*; Supplementary Fig. 1b) have no or fewer than three wild accessions at any site. In addition, Data Deficient taxa account for 28% (18/65 taxa) of the whole

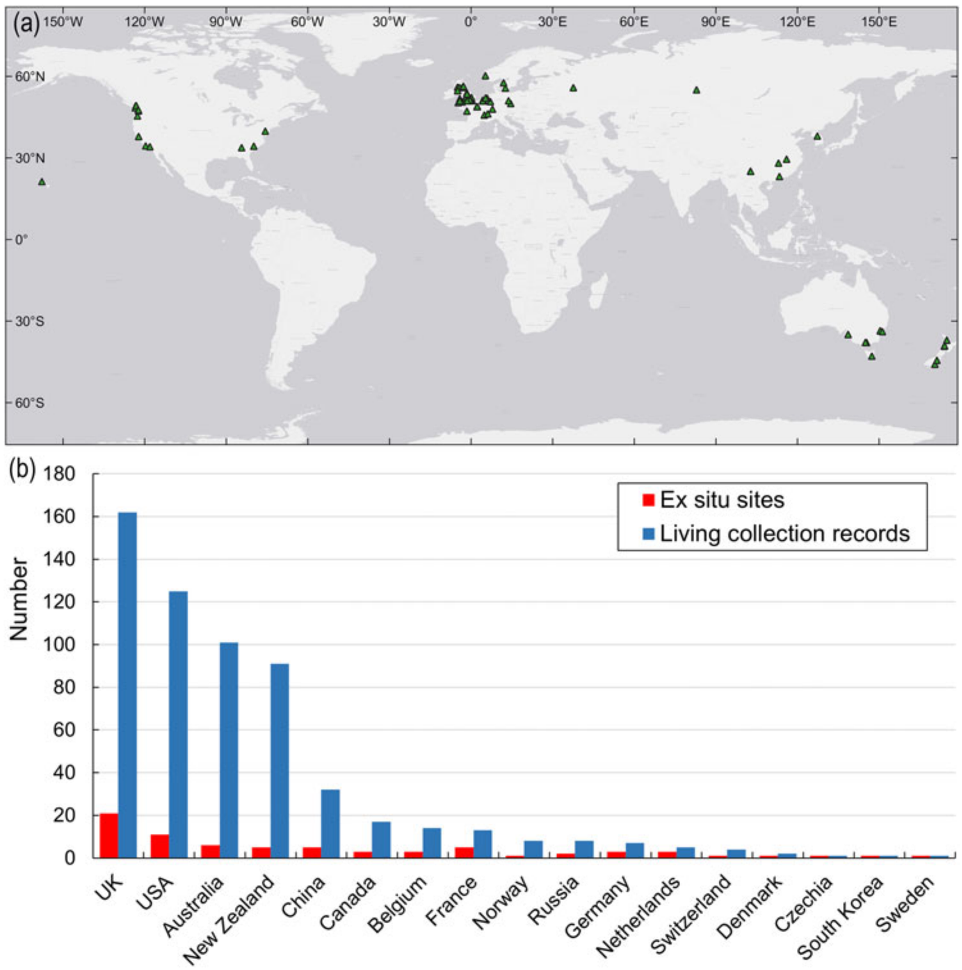

FIG. 2 *Rhododendron* subsection *Maddenia* in ex situ conservation. (a) The 73 global ex situ sites of living collections. (b) The number of ex situ sites and living collections in countries of ex situ conservation.

subsection, and seven of these Data Deficient taxa are represented by no or fewer than three wild accessions. For threatened and Data Deficient taxa, targeted fieldwork and data collection should be undertaken. In addition, some of the 10 taxa not in cultivation (three Data Deficient, two Least Concern and five Not Evaluated; Table 2) await further investigation to confirm their conservation status.

Mapping of the wild collections showed similar hotspots to the wild distribution of ss. *Maddenia* (Fig. 1), indicating a relatively adequate ecogeographical representation of ex situ living collections. However, the distribution may not have been well sampled for individual taxa. For example, although *Rhododendron leptocladon* is native to the China–Viet Nam border and categorized as Vulnerable globally, its wild populations are still under examination (Data Deficient in China), and current wild accessions have only been collected from northern Viet Nam (Supplementary Material 3). In addition, the ecogeographical representation of ex situ collections could reflect collector bias and limitations as a result of administrative boundaries. Under legislation such as the Nagoya Protocol (CBD, 2011), field expeditions, species introductions and plant material exchanges may become less frequent because of local restrictions, which highlights the need to determine the wild diversity in existing living collections.

Globally, ex situ collections of ss. *Maddenia* are widespread over countries in both the Northern and Southern Hemispheres but rare in their countries of origin (Fig. 2b; Table 1). Sharrock (2020) noted this trend for threatened species, and this is not unique to *Rhododendron* but also occurs in other plant groups such as *Magnolia* (Magnoliaceae; Linsky et al., 2022) and *Zelkova* (Ulmaceae; Kozlowski et al., 2012). Considering the small number of botanic gardens in countries of origin that report to BGCI (Table 1), ex situ collections in these countries may not be well covered by our study. However, although lacking published data on ex situ collections, countries of origin may be active regarding in situ conservation. In China, the country of origin of the greatest number of ss. *Maddenia* taxa, additional data on ex situ collections of *Rhododendron* (Ericaceae) have been published (Wang, 2022) from the Ex Situ Flora of China project (Huang et al., 2017). In India, plants of the *Rhododendron formosum* complex are under on-site observation in Meghalaya (Mao et al., 2017). Conservation policies in Nepal and Bhutan also indicate that *Rhododendron* species are more likely to be protected

TABLE 2 *Rhododendron* ss. *Maddenia* taxa that lack wild collections, categorized as not in cultivation, in cultivation but with no wild-source accessions, and in cultivation with wild-source accessions of unknown provenance (not mapped in Fig. 1b). These taxa require either further wild collection or investigation regarding the origins of the wild collections.

Taxon (by status)	Country of origin	IUCN Red List category[1]	Number of wild sources	Number of living collections
Not in cultivation				
R. amandum	China	DD	0	0
R. yaogangxianense	China	DD	0	0
R. yizhangense	China	DD	0	0
R. vanderbiltianum	Indonesia	LC	0	0
R. yungchangense	China	LC	0	0
R. × *carvori*		NE	0	0
R. basfordii	Bhutan	NE	0	0
R. eheinense	China	NE	0	0
R. grothausii	China, Bhutan	NE	0	0
R. rubrantherum	Myanmar	NE	0	0
In cultivation, no wild-source accessions				
R. roseatum	China, Myanmar	VU	0	3
R. sinonuttallii	China	VU	0	3
R. linearilobum	China	CR	0	1
R. rhombifolium	China	CR	0	2
R. carneum	Myanmar	NE	0	8
R. iteophyllum	India	NE	0	3
In cultivation, wild-source accessions of unknown provenance				
R. coxianum	India	CR	1	3
R. kiangsiense	China	NT	1	4
R. taronense	China	VU	1	6
R. levinei	China	DD	4	9
R. parryae	India	LC	1	9
R. pseudomaddenii	India	LC	1	1

[1]DD, Data Deficient; LC, Least Concern; NE, Not Evaluated; VU, Vulnerable; CR, Critically Endangered.

on site (IUCN Nepal, 2010; DoFSC, 2019; Namgay & Sridith, 2021). Nevertheless, our results can be utilized by global databases or organizations such as the Global Tree Assessment (BGCI, 2021a), World Flora Online and Global Conservation Consortium for *Rhododendron*. Although it is the largest global plant conservation network, the databases of BGCI do not cover all ex situ collections (Table 1). Gardens not in the BGCI GardenSearch database are probably not reporting collection data to BGCI, including the private gardens in New Zealand that hold *Rhododendron* collections.

Knowledge gaps in assessing genetic representation of ex situ collections of *Rhododendron*

A globally updated taxon list is a necessary basis for studying biodiversity. Complex taxonomy is a problematic feature of big genera (Frodin, 2004) such as *Rhododendron*. For example, the unresolved taxonomy of ss. *Maddenia* species remains a significant challenge for their conservation assessment; nine of the 20 threatened or at risk taxa were described as being under taxonomic debate in Gibbs et al. (2011). In addition, new taxa may have been proposed based on morphological observations but have not yet been officially published, such as *R. valentinioides* (Supplementary Material 3). In our analysis we included wild accessions of infraspecific taxa and affinities, as we considered their variation part of the diversity within a species. However, the contribution of these accessions to the genetic representation of relevant species can only be examined realistically based on determined taxonomic status.

Conservation assessments also require further work. Field investigation is needed for Data Deficient taxa (e.g. *R. formosum* var. *inaequale*) in the previous Red List of Rhododendrons (Gibbs et al., 2011), or updates are needed for taxa that are to be re-evaluated. Global and regional (e.g. China, India) conservation status could affect decision-making at different administrative levels. Recent surveys of the wild populations of threatened *Rhododendron* species (Ma et al., 2014), updates of China's Red Lists (Qin & Zhao, 2017; Qin et al., 2017) together with upcoming assessments coordinated by BGCI would contribute to improving our understanding of the distribution of *Rhododendron* taxa and their conservation status.

Wild populations of ss. *Maddenia* in their countries of origin often lack investigations of both size and distribution. Our geo-mapping relied on information derived from published literature and databases, with varying levels of data

TABLE 3 Botanic gardens conserving living collections of > 10 ss. *Maddenia* taxa, in descending order of total number of conserved taxa, with the number of taxa in each IUCN Red List category in contrast to that in cultivation globally. Numbers in parentheses are number of taxa in cultivation/number of total taxa in the category.

			IUCN Red List status[1]						
Botanic garden	Country	Number of conserved taxa (55/65)	CR (3/3)	EN (2/2)	VU (13/13)	NT (4/4)	DD (9/12)	LC (18/20)	NE (6/11)
Rhododendron Species Botanical Garden	USA	48	3	2	12	4	6	18	3
Royal Botanic Garden Edinburgh[2]	UK	37	2	1	10	3	4	15	2
University of California Botanical Garden at Berkeley	USA	33	3	1	8	3	2	14	2
Dandenong Ranges Botanic Garden	Australia	31	3	1	5	3	4	14	1
Dunedin Botanic Garden	New Zealand	27	1	1	7	2	2	13	1
RhodoBG_02[3]	Australia	25	2	1	5	2	1	13	1
Pukeiti Garden	New Zealand	23	1	1	4	2	2	12	1
Royal Botanic Gardens Kew[4]	UK	19	1	0	4	1	1	12	0
Blue Mountains Botanic Garden	Australia	19	2	0	4	2	0	10	1
Germplasm Bank of Wild Species	China	14	1	1	0	2	1	8	1
St Andrews Botanic Garden	UK	14	0	0	4	1	1	8	0
University of British Columbia Botanical Garden	Canada	11	0	0	3	3	0	5	0

[1]CR, Critically Endangered; EN, Endangered; VU, Vulnerable; NT, Near Threatened; DD, Data Deficient; LC, Least Concern; NE, Not Evaluated.
[2]Including Royal Botanic Garden Edinburgh at Edinburgh, Logan and Benmore.
[3]Garden anonymised as permission for naming the garden was not acquired.
[4]Including Royal Botanic Gardens Kew at Richmond and Wakehurst.

available for different taxa, hence our capturing of distributions could differ amongst species. The distribution of ss. *Maddenia* is often not well described to specific localities but rather to broad administrative units, especially in areas where few taxa have been found (Fig. 1a; Supplementary Material 3).

Assessment of ecogeographical representation requires wild collections to be well documented. Adequate geographical data, especially with precise coordinates of the source specimens, and regular updates on the living status of accessions are essential to record in wild collections. However, ex situ collections usually suffer from poor documentation, and the extent of the documentation of details of wild collections differs amongst botanic gardens. This causes difficulties in tracing the origins of wild collections and limits the accuracy of evaluations of captured diversity.

Recommendations for urgent conservation action of subsection *Maddenia*

We suggest that relevant botanic gardens collaborate to conserve subsection *Maddenia* by: (1) investigating and/or establishing ex situ collections in their countries of origin; (2) sharing ex situ data with BGCI and the Global Conservation Consortium for *Rhododendron*; (3) establishing an accessions database with fields for individual gardens to facilitate genus-wide analyses; and (4) developing a meta-collection of ss. *Maddenia* across sites and nations to pool wild accessions for the conservation of genetic diversity.

Field investigation and wild sampling should be further developed, particularly in the border regions between countries of origin. Genetic information could be added to the database of wild accessions developed in this study to underpin research within the global conservation network.

Based on the criterion of three wild accessions per taxon we propose urgent action: (1) to establish ex situ collections for the three Data Deficient taxa that are not in cultivation (*R. amandum*, *R. yaogangxianense*, *R. yizhangense*) unless they are reassessed as Least Concern; (2) to obtain wild collections for the two Vulnerable (*R. roseatum*, *R. sinonuttallii*) and two Data Deficient taxa (*R. linearilobum*, *R. rhombifolium*) that currently have no wild accessions conserved; and (3) to extend the ecogeographical range of wild sampling for the 10 taxa that are threatened or at risk but with documented wild accessions from fewer than three wild sources, including two Critically Endangered taxa (*R. coxianum*, *R. fleuryi*), two Endangered taxa (*Rhododendron fletcherianum*, *R. kiangsiense*), three Vulnerable taxa (*Rhododendron dalhousiae* var. *rhabdotum*, *R. taronense*, *Rhododendron walongense*) and three Data Deficient taxa (*Rhododendron chunienii*, *Rhododendron ciliipes*, *R. kuomeianum*).

In this study we have identified the gaps in knowledge of *Rhododendron* ss. *Maddenia* in ex situ conservation, with a focus on the ecogeographical representation in ex situ collections for guiding further conservation efforts. We find that botanic gardens are important repositories for this group: 86% of the taxa, including all threatened taxa, are in cultivation, and 33 of the 65 taxa and 12 of the 18 threatened taxa have at least three different wild accessions present in at least three sites. Although Global Strategy for Plant Conservation Target 8 is met for the subsection overall, for 17 taxa the ecogeographical representation of wild accessions is insufficient and requires urgent action in terms of wild sampling and ex situ cultivation. We also find that ex situ collections are lacking in the countries of origin. Further collaboration and data sharing amongst botanic gardens are desirable to develop a metacollection managed under BGCI and the Global Conservation Consortium for *Rhododendron*, although our data could also be used by the Global Tree Assessment (BGCI, 2021a) and World Flora Online. Ex situ cultivation of threatened plant species is a valuable component of integrated plant conservation, but analysis of existing collections is necessary to support decision-making. Our study illustrates an approach for analysing wild collections, thereby facilitating better management of species conservation.

Author contributions Study design: all authors; data collection: LH, MM; data analysis, writing: LH; revision: MM, SEG, JAT.

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Conflicts of interest None.

Ethical standards This research abided by the *Oryx* guidelines on ethical standards. There was no collection of specimens associated with this work. BGCI GardenSearch and PlantSearch data were used and published under the BGCI Data Sharing Agreement (signed between MM and the BGCI representative Abby Meyer on 10 July 2020). The use of collections data and permissions for publishing the compiled dataset and presenting garden names (Table 3) were approved by the source botanic gardens.

Data availability All data can be found within the article and its supplementary material, or are otherwise available on request from the corresponding author.

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