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A model for determining ex situ conservation priorities in big genera is provided by analysis of the subgenera of *Rhododendron* (Ericaceae)

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Abstract The large size and complex taxonomy of big genera complicates decision making for conservation. We propose that *Rhododendron*, comprising some 1215 taxa, divided into nine subgenera and many sections, can be used as a model for other big genera. Although Red List assessments placed 715 taxa in a threat category, or listed them as Data Deficient, and moreover Target 8 of the Global Strategy for Plant Conservation requires 75 % of Red List taxa to be held in ex situ collections by 2020, to date there have been few studies of *Rhododendron* ex situ collections or conservation priorities. Utilising the subgenus structure of *Rhododendron* as a framework for examining conservation priorities, we analysed the Red List and determined that subgenera Vireya and Hymenanthes have the most acute conservation issues. Examination of taxa in cultivation shows that 844 of 1215 taxa (70 %) are in cultivation, with subgenera varying from 45 to 100 %. Of the 715 Red List taxa, 400 (56 %) are in cultivation, with subgenera varying from 28 to 72 %. Subgenera Vireya and Azaleastrum have the poorest representation in cultivation and should have precedence for ex situ conservation. As no subgenus reaches the requirement for Target 8, further planning is needed for ex situ conservation of *Rhododendron.* After combining the two analyses, we propose the priorities for ex situ conservation should be ordered (i) Vireya, (ii) Azaleastrum and (iii) Hymenanthes. Finally,

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we propose five conservation actions for *Rhododendron*, and summarise our approach as a model for conservation of other big genera.

Keywords Ex situ collections · Red List · Target 8 · Botanic gardens · Vireya · Hymenanthes · Azaleastrum

Introduction

One-third of plant species are threatened with extinction (Oldfield 2010), with threats ranging from conversion to agriculture, large infrastructure construction, overharvesting, deforestation, habitat loss, and climate change (Lasco et al. 2010; Oldfield 2010; Sharrock et al. 2014; Hong and Blackmore 2015). To respond to such threats, robust and structured methods for setting priorities and carrying out conservation are needed (Oldfield 2010). In this study we consider the ex situ conservation of living plants, which is structured around two key principles: acquiring and cultivating Red List taxa in ex situ collections, and applying various procedures to determine which taxa should take priority (Heywood and Iriondo 2003; Maunder and Byers 2005; Oldfield 2009, 2010; Blackmore et al. 2011; Pritchard et al. 2011). These principles underpin two of the Targets of the Global Strategy for Plant Conservation (IUCN 2011): Target 2, whereby Red List assessments of plant genera generate initial priorities for conservation, and Target 8, which states that 75 % of Red List taxa should be cultivated in ex situ collections by 2020 (Wyse-Jackson and Kennedy 2009; IUCN 2011; Sharrock 2012; Williams et al. 2012). Each principle (Target) has a series of associated practices; e.g., an effective ex situ collection should be correctly identified and labelled, of known wild origin, adequately sampled and of appropriate genetic representation, properly verified and well documented (Leadlay et al. 2006; Blackmore et al. 2011; Rae 2011). Priority setting frequently uses Red Lists to create an initial hierarchy, with additional factors such as geographic hotspots, endemism, and taxonomic distinctiveness also being used to identify priority taxa (Farnsworth et al. 2006; Kozlowski et al. 2012; Castaneda-Alvarez et al. 2015; Cavendar et al. 2015). Such additional factors may be needed in large or complex genera, or those with a broad geographic range.

Rhododendron (Ericaceae) comprising about 1215 taxa (Chamberlain et al. 1996; Gibbs et al. 2011; Argent 2015) is centred in Asia, with taxa also native to North America, Europe, Southeast Asia and Australia. *Rhododendron* is an excellent case study for conservation planning because of its status as a 'big genus' (Frodin 2004). There are more than 50 big genera (Frodin 2004), comprising a mix of woody and non-woody genera and with many of tropical origin, e.g. *Begonia* (Twyford et al. 2015), and *Peperomia* (Samain et al. 2009). In big genera the large size (more than 500 species) is combined with complex taxonomy and division into many subgroups. Active speciation contributes to the complexity, with a high degree of morphological variation often observed, and a high incidence of natural hybrids, polyploids, uncertain species boundaries and taxonomic queries (Frodin 2004; Ennos et al. 2005, 2012; Samain et al. 2009; Twyford et al. 2015). These features are present in *Rhododendron* (Crutwell 1988; Chamberlain 2003; Cullen 2005; Jones et al. 2007; Milne et al. 2010; Argent 2015), which has a complex taxonomic structure of nine subgenera of varying sizes (1–400 taxa), which are further divided into 74 sections of varying sizes (1–98 taxa) (Chamberlain et al. 1996; Argent 2015).

Study of big genera contributes to the understanding of evolution and diversification of flora (Frodin 2004; Samain et al. 2009; Twyford et al. 2015); however, conservation decision making can be challenging in big genera. Firstly, taxonomic uncertainty makes species definition and taxon sampling difficult (Goodall-Copestake et al. 2005; Ennos et al. 2005, 2012; Blackmore et al. 2011), which is problematic when Red List taxa are not easily distinguished from related common taxa. In such cases, conservation planning should be broader than the single-species approach and consider groups of related taxa (Ennos et al. 2005; Blackmore et al. 2011; Ennos et al. 2012). Secondly, the sheer size of the genus is also an issue, for example, a mechanism is needed to allocate priorities among the 241 *Rhododendron* taxa that were assessed as Vulnerable (Gibbs et al. 2011; Argent 2015).

Where smaller taxonomic groupings are available in a big genus, these provide a degree of focus and a useful framework for determining conservation priorities, particularly if Red List taxa are concentrated in some groups but not in others. This is also a useful way to consider conservation of groups of related species, and incorporate taxonomic complexity (at least at the smaller group level) into the conservation assessment. Thirdly, any group of taxa that has particular features, such as a specific geographic distribution, or a certain pattern of endemism, can be examined separately.

A further degree of complexity in a big genus can be a broad ecological range; *Rhododendron* is also an exemplar in this respect. Taxa are found in ecological zones ranging from lowland to high altitude forest, scrub and grasslands at various altitudes, bogs and swamps, as well as montane and alpine zones (Cox and Cox 1997; Gibbs et al. 2011; Argent 2015). In keeping with the wide range of habitats, life forms include groundcovers, shrubs, trees, and epiphytes (epiphytic habit is particularly common in subgenus Vireya). Many horticultural plants have been developed from wild *Rhododendron* taxa (Cox and Cox 1997) and there are thousands of horticultural cultivars (Leslie 2004). *Rhododendron* are subject to a range of threats to survival, including deforestation, habitat loss, firewood harvesting, and other agriculture and production uses (Paul et al. 2005; Lasco et al. 2010; Sekar and Srivastava 2010; Gibbs et al. 2011).

Once a Red List assessment of any genus is completed, ex situ collections of Red List taxa are required; however, in general such collections[1] frequently do not exist or are of poor quality. Although common taxa are likely to be held in ex situ collections (Kozlowski et al. 2012; Cires et al. 2013), Red List taxa are often entirely absent, or held in very few collections (Maunder et al. 2000, 2001a, b; Powledge 2011; Pritchard et al. 2011; Rae 2011; Cires et al. 2013). Presence in any fewer than three collections is a risk threshold (Lowe 1988, 1989), whereby the species may not be present at all, because: the plant died, or the identity was wrong, or a plan to acquire the taxon did not come to fruition. Where Red List taxa are held in collections, the number of accessions is often limited and genetic representation is either low or unknown (Rae 2011; Cavendar et al. 2015; Christe et al. 2014). Taxonomic or geographic groups are often poorly represented (Maunder et al. 2001a; Kozlowski et al. 2012; Cavendar et al. 2015). Hence current collections of many genera often have limited utility for conservation, and deliberate development is needed for such collections to become effective. Recording and assessment of what is already in collections is therefore a priority task (Cires et al. 2013).

[1] In this study we use the terms "plant collections", "ex situ collections" and "collections" to refer to botanic gardens or other sites that contain an assemblage of living plants. The terms do not refer to the activity of 'plant collecting' where samples (herbarium, seed, or propagation material) are gathered from the field.

Rhododendron in particular has been the subject of two Red List assessments and a single survey of collections. The first Red List assessment considered the whole genus (as it was at the time) and examined 1155 taxa (Gibbs et al. 2011). Subsequently, Argent (2015) revised the taxonomy of subgenus Vireya and, in doing so, revised 37 assessments and added 60 new assessments (for recently described taxa, or taxa not considered in 2011). Following the 2011 assessment, Botanic Gardens Conservation International (BGCI) conducted a survey of taxa in botanic gardens and reported that 67 % of 'all taxa' and 53 % of Red List taxa were present in those gardens, and that the two most significant collections world-wide were at Royal Botanic Garden Edinburgh and Royal Botanic Garden Kew (BGCI 2012). They focused on the 48 most endangered taxa that were in cultivation at that time (using the Red List categories to determine priority) and reported an average of 5.8 records per taxon on the BGCI database for those taxa. However, the BGCI (2012) study did not examine any differences in Red List status among taxonomic groups or consider other factors that might influence conservation priorities.

In this study, the subgenus structure, which divides the genus into smaller groups of related species, was used as a framework for examination of the Red List status of *Rhododendron*, the extent to which subgenera are in cultivation, and the likely priorities for ex situ conservation. Our objectives were to (i) analyse the Red List assessments for the subgenera of *Rhododendron,* (ii) identify subgenera that should have priority for conservation, (iii) examine the extent to which taxa are in cultivation in selected international collections, (iv) identify subgenera that are poorly represented in cultivation, and (v) propose priorities for conservation action. Finally, we discuss the use of this strategy as a model for conservation planning in big genera.

Methods

A data-set of taxa in the subgenera of *Rhododendron*, their Red List status, and their presence in cultivation was constructed from several sources. These included a base list of taxa created from Argent (2015), Chamberlain et al. (1996) and Gibbs et al. (2011), using the subgenera definitions of Argent (2015) for subgenus Vireya, and Chamberlain et al. (1996) for the other eight subgenera (Azaleastrum, Candidastrum, Hymenanthes, Mumeazalea, Pentanthera, Rhododendron, Therorhodion, Tsutsusi). Data describing taxa in cultivation were then added—beginning with the number of records for each taxon on the online database at BGCI (BGCI 2015). Secondly, the online databases at Royal Botanic Gardens Edinburgh and Kew were searched in 2015 for the presence of each taxon (RBGE 2013; RBGK 2015). Finally, data on taxa in 21 collections in New Zealand were added (from surveys conducted 2010–2015). As there are known wild-source collectors in New Zealand (Adams 1996; Binney 2003; Argent 2015), these collections may contain taxa that could be relevant to an ex situ conservation programme. Taxa were defined as 'in cultivation' if there was a record at any of the locations investigated.

Red List data were obtained from Gibbs et al. (2011) and Argent (2015), with the assessment for each taxon included in the data-set. There are six threat categories (used when a conservation issue can be quantified according to the criteria of the International Union for Conservation of Nature (IUCN)), which are, with decreasing degree of risk: Extinct, Extinct in the Wild, Critically Endangered, Endangered, Vulnerable, Near Threatened. The other categories are Data Deficient; (used when there is likely to be a conservation issue but it cannot presently be quantified), and Least Concern, for taxa which are considered common and without any conservation issue.

Data were combined into a database using Filemaker Pro software. Each record included scientific name, authority, synonyms, subgenus (Chamberlain et al. 1996; Fang et al. 2005; Argent 2015), Red List assessment, presence in cultivation (at any of the sites investigated), and number of accessions on the BGCI database. Only valid taxa were included; scientific names for Vireya taxa were checked using Argent (2015), and other subgenera using Chamberlain et al. (1996), Gibbs et al. (2011), and Fang et al. (2005).

The first examination of the data was an analysis of the Red List whereby subgenera were ranked according to each of four Red List factors (number of taxa Red Listed, percentage of taxa Red Listed, number of Data Deficient taxa, percentage of Red List taxa rated Data Deficient) and a score assigned to each rank. (Ranking for both number and percentage facilitates comparison among subgenera of different sizes. Data Deficiency is used as an indicator of urgency for conservation, because high rates of Data Deficiency indicate a lack of knowledge and a need for further research.) Ranking scores were summed for each subgenus, for the four Red List factors, and subgenera with the highest scores were assigned highest priority for conservation action.

The second examination of the data considered taxa in cultivation, showing the extent to which 'all taxa' and Red List taxa for each subgenus are in cultivation—subgenera with greater numbers and percentages of taxa in cultivation are 'safer' than those with lower figures. However, urgency for ex situ conservation is also expressed by the numbers and percentages of taxa 'not in cultivation'. In the third data analysis subgenera were ranked according to five 'not in cultivation' factors (number of Red List taxa not in cultivation, percentage of Red List taxa not in cultivation, number of Data Deficient taxa not in cultivation, percentage of Data Deficient taxa not in cultivation, lowest average number of records per taxon at BGCI) and a score assigned to each rank. Scores for each subgenus were summed for the five factors, and those with the highest sum of scores were assigned highest priority. An overall priority was determined by summing the 'Red List score' and the 'not in cultivation score' to generate a Total Score, and ranking subgenera by that score, thereby prioritising subgenera that ranked highly in the Red List assessment yet had low frequency in cultivation.

Results and discussion

Red List analysis for *Rhododendron*

When the Red List assessments of Gibbs et al. (2011) and Argent (2015) were combined, they revealed a total of 1215 *Rhododendron* taxa, of which 715 (59 %) were Red Listed (Table 1). The percentage of taxa Red Listed is higher than recent assessments for tree species (42 %) (Newton and Oldfield 2008), *Acer* (44 %) (Gibbs and Chen 2009), or *Quercus* (53 %) (Oldfield and Eastwood 2007), indicating a marked conservation issue for *Rhododendron*. Within *Rhododendron*, the greatest numbers of taxa occur in the Vulnerable (260 taxa) and Data Deficient (315 taxa) categories. Furthermore, the percentage of Data Deficient[2] ratings (44 %) is higher than for recent assessments of *Acer* (35 %), *Quercus* (30 %) or *Magnoliaceae* (8 %) (MacKay et al. 2010), indicating a knowledge issue for *Rhododendron* that is likely to inhibit conservation planning (Newton and

[2] Number of Data Deficient/(Threat categories + Data Deficient) × 100.

Table 1 Number of *Rhododendron* taxa in Red List categories in each subgenus (Chamberlain et al. 1996; Argent 2015), as assessed by Argent (2015) and Gibbs et al. (2011)

Threat category	Number of taxa from each subgenus in each Red List category									Total
	Ther	Cand	Mume	Azal	Tsut	Pent	Hyme	Rhod	Vire	
Extinct									2	2
Extinct in the Wild					1					1
Critically Endangered					4		6	14	12	36
Endangered				1	6		17	3	12	39
Vulnerable				6	20	5	120	49	60	260
Near Threatened					7		27	26	2	62
Total in threat categories				**7**	**38**	**5**	**170**	**92**	**88**	**400**
Data Deficient				18	42	9	70	63	113	315
Total Red Listed	**0**	**0**	**0**	**25**	**80**	**14**	**240**	**155**	**201**	**715**
Least Concern	2	1	1	13	44	20	118	102	199	500
Total assessed	**2**	**1**	**1**	**38**	**124**	**34**	**358**	**257**	**400**	**1215**

Gibbs et al. (2011) assessed 1155 taxa. Argent (2015) updated the assessments of 37 taxa, and made new assessments for another 60 taxa that were not considered by Gibbs et al. (2011)

Cand Candidastrum, *Mume* Mumeazalea, *Ther* Therorhodion, *Azal* Azaleastrum, *Pent* Pentanthera, *Tsut* Tsutsusi, *Hyme* Hymenanthes, *Rhod* Rhododendron, *Vire* Vireya

Oldfield 2008; Blackmore et al. 2011; Cires et al. 2013). Clearly, additional research into Data Deficient taxa must be an important component of any conservation action for *Rhododendron*.

When the Rhododendron Red List is analysed by subgenus (Table 1), the greatest numbers of Red List taxa are found in Hymenanthes, where 240 of 358 taxa were Red Listed and 70 of the 240 were deemed Data Deficient. Subgenus Hymenanthes has almost twice the number of threatened taxa as the next largest subgenera (Vireya and Rhododendron[3]), largely because of the high number of Vulnerable taxa; however, subgenus Vireya has the greatest number of Data Deficient taxa (indicating an acute knowledge and research problem for that subgenus). Subgenera Rhododendron and Vireya have the greatest numbers of Critically Endangered taxa, and two Vireya taxa are Extinct. Three of the smallest subgenera have no Red List taxa.

Table 2 shows the ranking of subgenera for each of four Red List factors: number of taxa Red Listed, percentage of taxa Red Listed, number of Red List taxa rated Data Deficient, and percentage of Red List taxa rated Data Deficient. Considering the factors individually, Hymenanthes and Vireya have the greatest number of taxa Red Listed, while Hymenanthes and Azaleastrum have the highest percentages of taxa Red Listed (five of the nine subgenera have 50 % or more of taxa Red Listed). Pentanthera is the only subgenus (apart from the three subgenera that have no Red List taxa) to have less than 50 % of taxa Red Listed. The greatest numbers of Data Deficient taxa are in Vireya and Hymenanthes, while the highest percentages of Red List taxa rated Data Deficient are in Azaleastrum and Pentanthera. Each subgenus, in each ranking, is assigned a 'ranking score' (in the left-hand

[3] To avoid confusion between *Rhododendron* the genus, and Rhododendron the subgenus, italic text is used for the genus, and plain text is used for the subgenus (and the other subgenera).

Table 2 *Rhododendron* subgenera (Chamberlain et al. 1996; Gibbs et al. 2011; Argent 2015): ranked according to four Red List factors

Ranking score	No. of taxa Red Listed		Percentage of taxa Red Listed		No. of Red List taxa rated Data Deficient		Percentage of Red List taxa rated Data Deficient	
	Subgenus	No.	Subgenus	%	Subgenus	No.	Subgenus	%
6	Hymenanthes	240	Hymenanthes	67	Vireya	113	Azaleastrum	72
5	Vireya	201	Azaleastrum	66	Hymenanthes	70	Pentanthera	64
4	Rhododendron	155	Tsutsusi	65	Rhododendron	63	Vireya	56
3	Tsutsusi	80	Rhododendron	60	Tsutsusi	42	Tsutsusi	53
2	Azaleastrum	25	Vireya	50	Azaleastrum	18	Rhododendron	41
1	Pentanthera	14	Pentanthera	41	Pentanthera	09	Hymenanthes	29
0	Therorhodion	0	Therorhodion	0	Therorhodion	0	Therorhodion	0
	Mumeazalea		Mumeazalea		Mumeazalea		Mumeazalea	
	Candidastrum		Candidastrum		Candidastrum		Candidastrum	

column of the table), e.g., the ranking scores for Hymenanthes are 6 + 6 + 5 + 1, while those for Pentanthera are 1 + 1 + 1 + 5.

Summing the ranking scores for each subgenus, for each the four Red List factors in Table 2, and prioritising subgenera for conservation according to the total, indicates that Hymenanthes (18 points) and Vireya (17 points) should take priority for conservation. These are the two largest subgenera; Hymenanthes scores highly in the ranking because of the high number and percentage of Red List taxa, while Vireya scores highly because of a high number of Red List taxa combined with a high number of Data Deficient taxa. Next in the ranking are Azaleastrum (15 points), Rhododendron (13), and Tsutsusi (10). By the Red List analysis, Pentanthera has the lowest overall score, at 8 points, and hence has the lowest priority for conservation.

Rhododendron subgenera 'in cultivation'

Of the 1215 *Rhododendron* taxa examined in the Red List assessments, 844 (70 %) are 'in cultivation' as defined in this study, with the greatest numbers in subgenus Hymenanthes (288), followed by Vireya (245) and Rhododendron (195) (Fig. 1). Of the 844 taxa in cultivation, 290 (34 %) are insecure in cultivation as they have three-or-fewer records at BGCI, while 143 (17 %) have only one record at BGCI. The overall percentage in cultivation is a small increase from the 67 % reported in 2012 (BGCI 2012). Three subgenera (Vireya 61 %, Tsutsusi 53 %, Azaleastrum 45 %) are below the overall averages for the present study and the 2012 study (BGCI 2012). Of the other six subgenera, the three smallest subgenera (Candidastrum, Mumeazalea, Therorhodion) have 100 % of taxa in cultivation, while the remaining three all have more than 75 % of 'all taxa' in cultivation (Pentanthera 85 %, Hymenanthes 80 %, and Rhododendron 76 %). Considering the broader (than the single taxon) approach to conservation that is recommended for large and complex genera (Ennos et al. 2005, 2012), those subgenera with more than 75 % of 'all taxa' in cultivation are well placed for ex situ conservation. In contrast, subgenera Vireya, Tsutsusi and Azaleastrum are poorly placed.

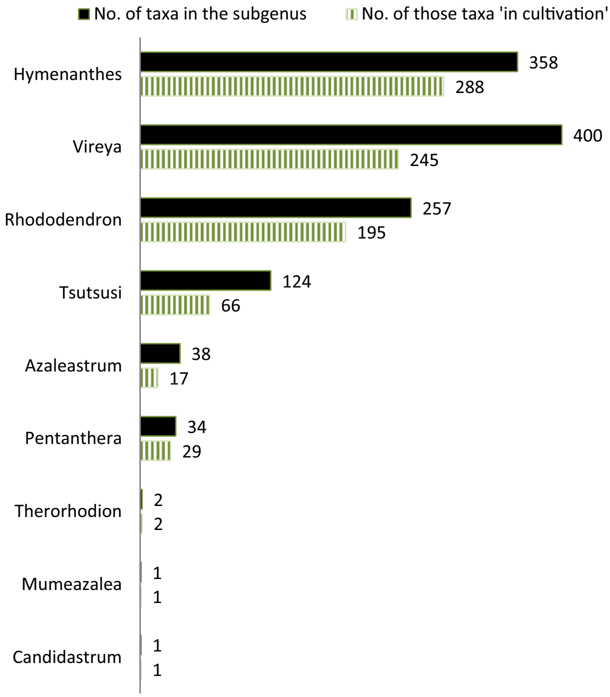

Fig. 1 *Rhododendron* subgenera (Chamberlain et al. 1996; Gibbs et al. 2011; Argent 2015): number of taxa in each subgenus 'in cultivation' in 2015

Table 3 *Rhododendron* subgenera (Chamberlain et al. 1996; Gibbs et al. 2011; Argent 2015): average number of Botanic Gardens Conservation International (BGCI) records per taxon for all taxa, and for only those taxa 'in cultivation'

Subgenus	All taxa: average no. of BGCI records per taxon	Taxa in cultivation: average no. of BGCI records per taxon
Pentanthera	48.0	56.3
Therorhodion	26.5	26.5
Mumeazalea	20	20
Hymenanthes	13.7	17.0
Rhododendron	10.8	14.3
Candidastrum	10	10
Tsutsusi	5.6	10.5
Azaleastrum	3.0	6.6
Vireya	2.1	3.6

The same three subgenera are also poorly represented in cultivation, as denoted by the average number of records per taxon on the BGCI database (Table 3), although other subgenera are relatively secure in cultivation. When calculated across all taxa (which is indicative of the extent to which the whole subgenus is in cultivation), six subgenera have an average of 10 or more records per taxon, and Tsutsusi has 5.6 records per taxon. Azaleastrum (3.0 records per taxon) and Vireya (2.1 records per taxon) fall into the three-or-fewer range, indicating poor representation in cultivation. When the calculation is restricted to only those taxa in cultivation (which describes the relative security of those taxa that are in cultivation), all subgenera except Vireya have more than six records per taxon, while Vireya, at 3.6 records per taxon, is only just above the three-or-fewer risk threshold (Lowe 1988). That is, for eight of nine subgenera, the taxa in cultivation are reasonably secure—but this is not the case for subgenus Vireya. Whichever calculation method is used, Vireya, Azaleastrum and Tsutsusi have the poorest representation in cultivation, and Vireya is in the worst position.

When Red List taxa are considered (Fig. 2), 400 of the 715 Red Listed taxa (60 %) are in cultivation, with the greatest numbers from Hymenanthes (174) and Rhododendron (101). As with ‘all taxa’, the overall percentage in cultivation is an increase over the 53 % reported in 2012 (BGCI 2012), and is considerably better than the 30 % for all Red List plants (Oldfield 2010). Individual subgenera vary: Hymenanthes (73 % of Red List taxa in cultivation) approaches the Target 8 criterion, whereas three subgenera (Vireya 40 %, Tsutsusi 36 %, Azaleastrum 28 %) are well below that target, and below the overall averages for this study and the BGCI study (BGCI 2012). (Percentages of Red List taxa in cultivation are 65 % for Rhododendron and 64 % for Pentanthera.) While the overall percentage of taxa in cultivation has increased over time, the same three subgenera (Vireya, Tsutsusi, Azaleastrum) have the lowest scores for both ‘all taxa’ and Red List taxa, and no subgenus meets the 75 % requirement for Target 8. When Red List taxa are considered overall, 91 (23 %) have only one record at BGCI and 174 in total (44 %) have three-or-fewer records, underscoring the somewhat limited representation in cultivation. A concerted effort will be needed to achieve Target 8, especially for Vireya, Tsutsusi and Azaleastrum.

When subgenera are examined for average number of records per Red List taxon on the BGCI database (Table 4), three subgenera (Pentanthera, Hymenanthes, Rhododendron) have an average of more than three records per Red List taxon and are relatively secure in cultivation. Red List taxa from Tsutsusi, Vireya and Azaleastrum have scant representation in cultivation, with averages of only 1.6, 0.9 and 0.8 respectively. When the calculation is restricted to only those taxa in cultivation, Tsutsusi improves to 4.5 records per taxon, Azaleastrum has 3.0 records per taxon, but Vireya remains below the three-or-fewer value

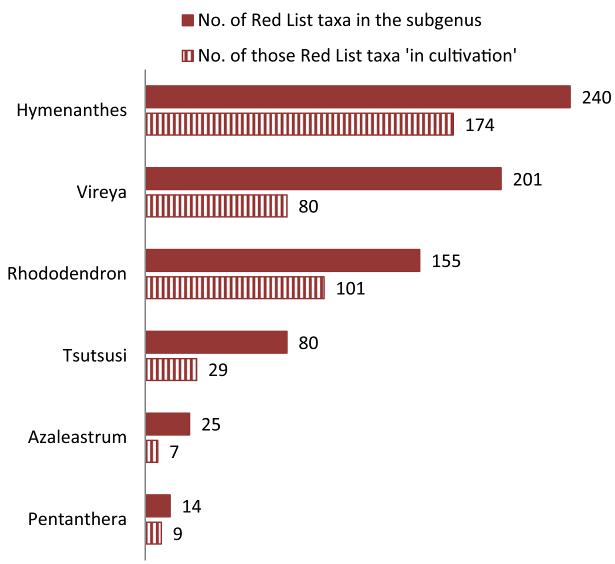

Fig. 2 *Rhododendron* subgenera* (Chamberlain et al. 1996; Gibbs et al. 2011; Argent 2015): number of Red List taxa in each subgenus ‘in cultivation’ in 2015 (* three subgenera, total four taxa, have no Red List taxa so are not included in this figure)

Table 4 *Rhododendron* subgenera (Chamberlain et al. 1996; Gibbs et al. 2011; Argent 2015): average number of Botanic Gardens Conservation International (BGCI) records per taxon for all Red List taxa, and for only those Red List taxa 'in cultivation'

Subgenus	All Red List taxa: average no. of BGCI records per Red List taxon	Red List taxa in cultivation: average no. of BGCI records per Red List taxon
Pentanthera	11.2	17.4
Hymenanthes	8.2	11.3
Rhododendron	5.4	8.3
Tsutsusi	1.6	4.5
Vireya	0.9	2.2
Azaleastrum	0.8	3

at 2.2 records per taxon. Representation of the other subgenera ranges from 8.3 to 17.4 records per taxon. In 2012 BGCI reported an average of 5.8 records per taxon for the 48 most endangered taxa, which is in the mid-range of the figures reported here, but as they did not report any range over subgenera, no direct comparison can be made. However, the same calculation for the same 48 taxa can be made, and this now shows an average of 9.5 records per taxon with a range of 0–11, although five taxa are no longer in cultivation. While the increasing average is a positive trend, the loss of five taxa from cultivation is unfortunate.

Urgency for ex situ conservation action is also indicated by an absence from cultivation; Table 5 shows the ranking of subgenera for five 'not in cultivation' factors. Subgenus Vireya has the greatest number of Red List taxa 'not in cultivation', followed by Hymenanthes, while the highest percentages of Red List taxa 'not in cultivation' are found in Azaleastrum and Tsutsusi. Number and percentage of Data Deficient taxa 'not in cultivation' place Vireya, Hymenanthes and Azaleastrum at the top of the individual rankings. Subgenera Azaleastrum and Vireya have the poorest average number of records per Red List taxon at BGCI, and are therefore ranked highest for that factor.

When ranking scores for the five 'not in cultivation' factors in Table 5 are summed for each subgenus, and subgenera ranked according to that total, Vireya (6 + 4 + 6 + 5 + 5 = 26 points) should take the highest priority for ex situ conservation, followed by Azaleastrum (22 points), Tsutsusi (19 points) Hymenanthes (16 points) and Rhododendron (15 points). Pentanthera, with 7 points, is relatively secure in cultivation, and the three small subgenera which have all taxa in cultivation all score zero. (As this indicator measures '*not* in cultivation', a low score is indicative of security in cultivation.)

Ex situ conservation priority according to total score

When 'Red List' and 'not in cultivation' scores are summed (Table 6), Vireya has the highest Total Score (43 points), with Azaleastrum next (37 points), followed by Hymenanthes (34 points). Hence, these subgenera should have highest priority for ex situ conservation and a strategy is required to improve the status of these subgenera in cultivation. Subgenera Rhododendron and Tsutsusi are similarly placed, with 29 and 28 points respectively, while Pentanthera (15 points) has the lowest urgency for ex situ conservation.

Table 5 *Rhododendron* subgenera (Chamberlain et al. 1996; Gibbs et al. 2011; Argent 2015): ranked according to five 'not in cultivation' factors

Ranking score	No. of Red List taxa 'not in cultivation'		Percentage of Red List taxa 'not in cultivation'		No. of Data Deficient taxa 'not in cultivation'		Percentage of Data Deficient taxa 'not in cultivation'		Average no. of records per Red List taxon at BGCI*	
	Subgenus	No.	Subgenus	%	Subgenus	No.	Subgenus	%	Subgenus	No.
6	Vireya	121	Azaleastrum	72	Vireya	87	Azaleastrum	83	Azaleastrum	0.8
5	Hymenanthes	66	Tsutsusi	64	Hymenanthes	43	Vireya	77	Vireya	0.9
4	Rhododendron	54	Vireya	60	Rhododendron	38	Tsutsusi	74	Tsutsusi	1.6
3	Tsutsusi	51	Pentanthera	36	Tsutsusi	33	Hymenanthes	61	Rhododendron	5.4
2	Azaleastrum	18	Rhododendron	35	Azaleastrum	15	Rhododendron	60	Hymenanthes	8.2
1	Pentanthera	5	Hymenanthes	28	Pentanthera	4	Pentanthera	44	Pentanthera	11.2
0	Therorhodion	0	Therorhodion	0	Therorhodion	0	Therorhodion	0		
	Mumeazalea		Mumeazalea		Mumeazalea		Mumeazalea			
	Candidastrum		Candidastrum		Candidastrum		Candidastrum			

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Table 6 *Rhododendron* subgenera (Chamberlain et al. 1996; Gibbs et al. 2011; Argent 2015): ranked according to Total Score (Red List score + 'not in cultivation' score)

Subgenus	Total score (maximum score = 54)	Red List score = sum of ranking scores for Red List factors (Table 2). (maximum score = 24)	"Not in cultivation" score = sum of ranking scores for 'not in cultivation' factors (Table 5). (maximum score = 30)
Vireya	43	17	26
Azaleastrum	37	15	22
Hymenanthes	34	18	16
Tsutsusi	29	10	19
Rhododendron	28	13	15
Pentanthera	15	8	7

Priority subgenera: Vireya, Azaleastrum, and Hymenanthes

Subgenus Vireya is centred in Malesia and contains 11 taxonomic sections of different sizes; Red List taxa are spread among those sections, although the largest sections have the greatest number of Red List taxa (Online Resource 1). Subgenus Azaleastrum is centred on mainland Asia and Japan, and has only two sections; Chionastrum has the greatest number of Red List taxa (Online Resource 1). Hymenanthes has 25 taxonomic sections, and has a disjunct distribution, with taxa in Asia, Europe and North America—again the greatest numbers of Red List taxa are in the largest sections (Online Resource 2). Of note is the relatively high number of Data Deficient taxa in Pontica: taliensia and Pontica: irrorata; two groups of mainland Asian origin. High numbers of Data Deficient taxa are also seen in Schistanthe: euvireya and Schistanthe: malesia (Malesian origin) in subgenus Vireya, and Chionastrum (Chinese origin) in subgenus Azaleastrum.

Data Deficient taxa in these subgenera are also poorly represented in cultivation (Figs. 3, 4, 5), with low average numbers of BGCI records per taxon (Online Resource 3); Vireya has 0.5 records per Data Deficient taxon, Azaleastrum 0.9, and Hymenanthes 2.5 records. Hymenanthes is in a somewhat better position overall as it has a smaller proportion of Data Deficient taxa, and most of its Vulnerable taxa are in cultivation (Fig. 5). Hymenanthes also has relatively high average numbers of BGCI records per taxon, greater than three in all instances, except where Data Deficient taxa are calculated across all Data Deficient taxa (as opposed to only those in cultivation). In contrast, Vireya is poorly placed: no Red List category has more than three BGCI records per taxon. Azaleastrum is similarly poorly placed; only 'Data Deficient taxa in cultivation' has an average greater than three. Least Concern taxa are well represented in Hymenanthes, but poorly so in Vireya, where BGCI averages are only slightly over three records per taxon.

With respect to ex situ conservation, Red List taxa in Hymenanthes are relatively well placed, while those in Vireya and Azaleastrum are in a poor position. The problem of Data Deficiency is highlighted by these data; Data Deficient taxa in these subgenera are concentrated in certain taxonomic sections, which are poorly represented in cultivation.

Fig. 3 *Rhododendron* subgenus Vireya (Argent 2015): number of taxa in each Red List category 'in cultivation' in 2015

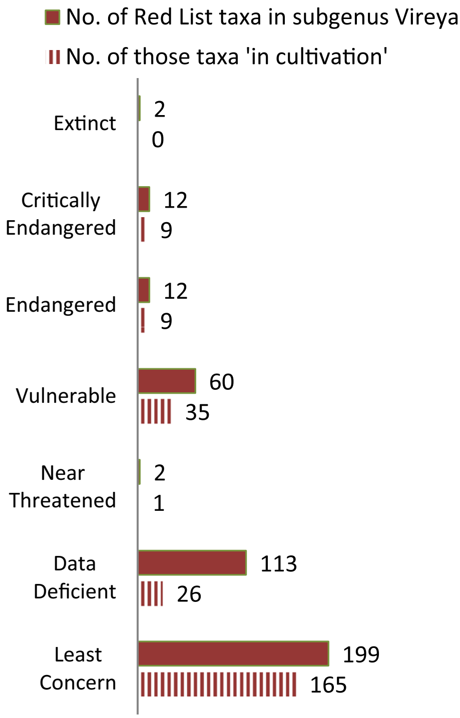


Fig. 4 *Rhododendron* subgenus Azaleastrum (Chamberlain et al. 1996): number of taxa in each Red List category 'in cultivation' in 2015

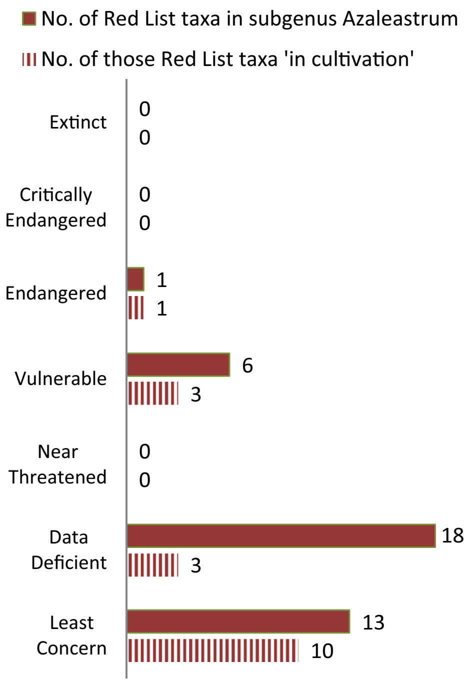
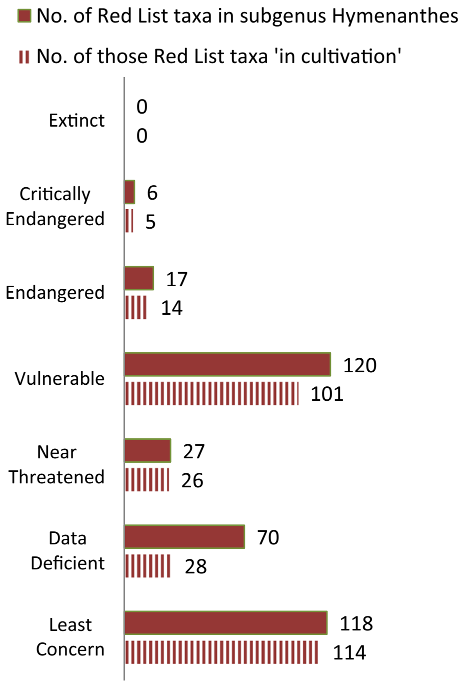


Fig. 5 *Rhododendron* subgenus Hymenanthes (Chamberlain et al. 1996): number of taxa in each Red List category ‘in cultivation’ in 2015



Rhododendron collections

Of the 844 *Rhododendron* taxa recorded in cultivation in this study, the largest number is held at Edinburgh (613 taxa, 2561 accessions), followed by a New Zealand collection[4] (483 taxa, 764 accessions) and Kew (320 taxa, 1840 accessions). Of the 400 Red List *Rhododendron* taxa in cultivation, the greatest number is held at Edinburgh (245 taxa, 681 accessions), followed by the New Zealand collection (178 taxa, 232 accessions) and Kew (128 taxa, 506 accessions). Of these three sites, Kew has the greatest number of accessions per taxon, followed by Edinburgh and the New Zealand site.

It should be noted that the numbers of taxa found in this study for Edinburgh and Kew are fewer than those reported by BGCI (2012) who listed 734 for Edinburgh and 404 for Kew. Given that the same databases were used in this study as the 2012 study, some possible explanations for the different figures are: death of taxa between 2012 and 2015; a data management issue whereby not all taxa are displayed on the databases in 2015; the 2012 study having different access permissions and viewing a different data-set. Also, we recorded another 95 taxa at Edinburgh and 60 at Kew, which would reduce the discrepancy between our data and BGCI (2012), but these taxa were not considered by Gibbs et al. (2011) and so were not included in this analysis. BGCI (2012) is not clear on whether unevaluated taxa were included in their data.

[4] Under our data sharing agreement with New Zealand collection owners, individual sites are not named in publications.

Limitations of this study

This study has established priorities for ex situ conservation of *Rhododendron* subgenera by identifying subgenera that rank highly for risk according to Red List factors, and which are poorly represented in cultivation. There has not been any examination of taxonomic levels below subgenus, or any geographic groupings; for example, conservation priority may be adjusted for subgenera with high rates of endemism, or groups of taxa that originate in particular geographic hotspots. The potential influence of such factors on conservation priorities has not been considered in this study and these factors should be examined in future research.

A second possible limitation is the scope of the data used to define taxa as 'in cultivation'. Taxa were so defined if they were listed on the Plant Search database at BGCI (which covers 1,363,723 entries of 496,775 taxa from 1147 botanic gardens world-wide (bgci.org, accessed 2.5.2016)), or listed in the two largest ex situ collections as assessed by BGCI (2012), or listed in New Zealand. BGCI (2012) surveyed 304 botanic gardens worldwide; however, some private sites in United Kingdom and North America were not included, and Asia (the geographic centre for *Rhododendron*) was represented by only eleven sites (eight in China, and three in Southeast Asia), although five of the Chinese sites are major botanic gardens for that region (Hong and Blackmore 2015). Further research should determine which other ex situ collections are likely to be significant and investigate those collections.

The subgenera definitions of *Rhododendron* are the third possible limitation, as our use of the subgenera as a framework to subdivide a big genus assumes that the definitions are robust. We used the morphologically based definitions of Chamberlain et al. (1996) and Argent (2015), (although Argent did consider molecular research), primarily because they are comprehensive. Molecular research on the taxonomic structure of *Rhododendron* largely supports the morphological taxonomy, except for some sections of Vireya (Zhou et al. 2009; De Keyser et al. 2010; Milne et al. 2010; Kutsev and Karakulov 2011). Molecular data also supports most sections and some subgenera (some are monophyletic), although there are different views on the organisation of the sections into subgenera (Goetsch et al. 2005; Zhou et al. 2009; Kron and Powell 2009; Milne et al. 2010; Craven et al. 2011; Tsai et al. 2012; Yan et al. 2015). However, despite the number of molecular studies, the range of taxa used is not yet comprehensive enough to entirely confirm or revise the morphologically-based taxonomy, and thus Chamberlain et al. (1996) and Argent (2015) remain the most complete taxonomies. Research into the taxonomic structure of *Rhododendron* is on-going; if a new definition of the subgenera is eventually accepted, our analysis should be repeated using the new definitions.

The Red List process is the fourth potentially limiting aspect. Analysis of a Red List assumes the underlying Red List process is robust, and while the process requires quantification of threats, degree of protection, habitat, and extent of population, it can be difficult to assemble the knowledge in one place at one time for an assessment (Oldfield 2010; Cires et al. 2013). Some weaknesses of the 2011 assessment for *Rhododendron* were observed (MacKay 2013; Ma et al. 2014), and several iterations of the assessment may be needed.

The final possible limitation of this study concerns the New Zealand data. These data were built-up over a period of time, so it is possible that some accessions are no longer extant; conversely, there may be further accessions in collections that are yet to be identified. Of the 21 collections recorded, the authors have verified some accessions in two collections; otherwise taxa in the collections have not been verified by the authors.

Conclusions

Rhododendron conservation planning

Analysis of the Red list for subgenera of *Rhododendron* demonstrates that Hymenanthes, Vireya and Azaleastrum have the most acute conservation issues. However, because the latter two subgenera are poorly represented in cultivation, the priority order for ex situ conservation should be (i) Vireya, (ii) Azaleastrum and (iii) Hymenanthes. Of the next two subgenera, which are similarly placed for Total Score, Rhododendron has a higher Red List priority than Tsutsusi; however, it is better represented in cultivation than Tsutsusi, and thus Tsutsusi takes priority for ex situ conservation (whereas subgenus Rhododendron would take priority for in situ conservation). Subgenus Pentanthera is the 'safest' of the subgenera, with the lowest rate of conservation issues and the best representation in cultivation.

This study found 844 *Rhododendron* taxa, including 400 Red List taxa, to be in cultivation. While the percentage of taxa in cultivation has increased since 2012 (BGCI 2012), our study shows marked variation in the extent to which subgenera are in cultivation, and that two subgenera (Vireya and Azaleastrum) are very poorly placed. No subgenus meets the Target 8 requirement of 75 % of Red List taxa in cultivation. Further to this study, we propose priorities for conservation action and further research:

1. Develop a plan to improve the representation in cultivation of subgenera Vireya and Azaleastrum. Steps a–d of point 2 may be used to identify priority taxonomic sections or geographic origins.
2. Undertake further investigation of subgenera Vireya, Azaleastrum, and Hymenanthes, in this priority order, and with respect to:

    a. Red List and 'in cultivation' characteristics of the taxonomic sections within each subgenus, to identify priority sections in each subgenus,
    b. Presence of wild-source material in cultivation, thereby assessing the utility for ex situ conservation of plant material currently in cultivation,
    c. Red List and 'in cultivation' characteristics of geographical groups within each subgenus, to identify groups that should have priority for conservation,
    d. Identification of collections that hold the largest range of taxa from each subgenus, and consideration of the number and location of those collections, with a view to developing at least three globally distinct collection locations for each subgenus,
    e. Integration of the above information to develop an ex situ conservation plan for each subgenus.

3. Undertake further investigation of New Zealand collections, considering the range of accessions, the presence of wild-source material, and further comparison between those collections and international holdings (to identify sites or accessions relevant to an international ex situ strategy).
4. As our Red List assessment is also indicative of the need for in situ conservation, the same three subgenera should be investigated in the priority order (i) Hymenanthes, (ii) Vireya, (iii) Azaleastrum. Investigations may include the geographic spread of Red

List taxa and the extent to which in situ initiatives are in place in relevant countries, and examination of the three subgenera for any additional factors that may influence in situ priorities.

5. In due course, the previous recommendations are likely to require international cooperation and a policy framework, and the plans for each subgenus should be integrated into a global ex situ conservation plan for *Rhododendron*. Given possible limitations on exchange of plant material between countries, some countries may be constrained to working with taxa already present, while other countries may be able to accumulate additional accessions and taxa.

A model for conservation planning for big genera

Our use of the subgenus structure of a big genus as a framework, against which Red List and 'not in cultivation' characteristics were analysed, is a method that could be applied to other big genera. Critical steps would be:

1. Assemble three elements of underpinning data;
   - A comprehensive taxonomy,
   - A recent Red List assessment,
   - Knowledge of ex situ collections,
2. Use a selected criterion to divide the genus into smaller groupings of taxa. We used a taxonomic criterion and divided according to subgenera; although other major taxonomic groupings could also be used. Other criteria may also be informative, e.g. geographic or ethnobotanical groupings.
3. Assess each subgenus for Red List factors (our method uses four), rank subgenera for those factors, and generate a Red List score,
4. Acquire data on taxa in cultivation, using BGCI as the primary source, and adding data from relevant botanic gardens and ex situ collections,
5. Assess each subgenus for 'not in cultivation' factors (our method uses five), rank subgenera for those factors, and generate a 'not in cultivation' score,
6. Combine the Red List score and 'not in cultivation' score to generate a Total Score and rank subgenera by that score,
7. Propose conservation actions and priorities.

Our two-step analysis can inform all types of conservation: the Red List analysis applies to both in situ and ex situ conservation, while the 'not in cultivation' analysis and Total Score focuses ex situ conservation on those groups that have a conservation problem but which are poorly represented in cultivation. Our application of this method to the subgenera of *Rhododendron* has demonstrated that it can identify subgenera that should have priority for ex situ conservation action.

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Compliance with ethical standards

Conflict of interest We do not identify any particular conflicts of interest; however, we have various roles in the Rhododendron community. We are both members of the New Zealand Rhododendron Association.

Susan Gardiner is a member of the Board of the Rhododendron Species Botanic Garden (Federal Way, USA) and of the Council of the New Zealand Rhododendron Association. Marion MacKay is a member of the Trust Board of the Pukeiti Rhododendron Trust (New Zealand).

References

Adams K (1996) Notes from a plant hunter's diary. Journal of the America Rhododendron Society, 50(1). Downloaded from VirginiaTech Digital Archive 29 Jan 2016

Argent G (2015) *Rhododendron* of the subgenus *Vireya*. 2nd edition. Royal Botanic Garden, Edinburgh. In: association with The Royal Horticultural Society

BGCI (2012) Global survey of ex situ *Rhododendron* collections. Botanic Gardens Conservation International, London. Downloaded from bgci.org on 2 Dec 2015

BGCI (2015) Botanic Gardens Conservation International: Plant Search. Online at: https://www.bgci.org/plant_search.php. Searched 9–10 Oct 2015

Binney D (2003) Rhododendron collecting in Sulawesi. In: Argent G, MacFarlane M (eds) Rhododendrons in horticulture and science. Royal Botanic Garden Edinburgh, Edinburgh

Blackmore S, Gibby M, Rae D (2011) Strengthening the scientific contribution of botanic gardens to the second phase of the global strategy for plant conservation. Bot J Linn Soc 166:267–281

Castaneda-Alvarez NP, de Hann S, Juarez H, Khoury CK, Achicanoy HA, Sosa CC, Bernau V, Salas CC, Heider B, Simon R, Maxted N, Spooner DM (2015) Ex situ conservation priorities for the wild relatives of potato (*Solanum* L., section Petota). PLoS One 10(4):e0122599. doi:10.1371/journal.pone.0122599

Cavendar N, Westwood M, Bectholdt C, Donnelly G, Oldfield S, Gardner M, Rae D, McNamara W (2015) Strengthening the conservation value of ex situ tree collections. Oryx. doi:10.1017/S0030605314000866

Chamberlain DF (2003) Rhododendrons in the wild: a taxonomist's view. In: Argent G, McFarlane M (eds) *Rhododendrons* in horticulture and science. Royal Botanic Garden Edinburgh, Edinburgh, pp 42–52

Chamberlain D, Hyam R, Argent G, Fairweather G, Walter KS (1996) The genus *Rhododendron*: its classification and synonymy. Royal Botanic Garden Edinburgh, Edinburgh

Christe C, Kozlowski G, Fry D, Fazan L, Betrisey S, Pirintsos S, Gratzfeld J, Naciri Y (2014) Do living collections capture the genetic variation of wild populations? A molecular analysis of two relict tree species, *Zelkova abelica* and *Zelkova carpinifolia*. Biodivers Conserv 23:2945–2959

Cires E, De Smet Y, Cuesta C, Goetghebeur P, Sharrock S, Gibbs D, Oldfield S, Kramer A, Samain M (2013) Gap analysis to support ex situ conservation of genetic diversity in *Magnolia*, a flagship group. Biodivers Conserv 22:567–590

Cox PA, Cox KNE (1997) The encyclopedia of *Rhododendron* species. Glendoick Publishing, Scotland

Craven LA, Danet F, Veldkamp JF, Goetsch LA, Hall BD (2011) Vireya Rhododendrons: their monophyly and classification (Ericaceae, *Rhododendron* section *Schistanthe*). Blumea 56:153–158

Crutwell NEG (1988) Natural hybridization among rhododendrons in Papua New Guinea. The Rhododendron (Australia), vol 27 no 3

Cullen M (2005) Hardy rhododendron species: a guide to identification. Royal Botanic Garden Edinburgh, Edinburgh

De Keyser E, Scariot V, Kobayashi N, Handa T, De Riek J (2010) Azalea phylogeny reconstructed by means of molecular techniques. Methods Mol Biol. doi:10.1007/978-1-60327-114-1_30

Ennos RA, French GC, Hollingsworth PM (2005) Conserving taxonomic complexity. Trends Ecol Evol 20(4):164–168

Ennos RA, Whitlock R, Fay MF, Jones B, Neaves LE, Payne R, Taylor I, De Vere N, Hollingsworth PM (2012) Process-based species action plans: an approach to conserve contemporary evolutionary processes that sustain diversity in taxonomically diverse groups. Bot J Linn Soc 168:194–203

Fang MY, Fang RC, He MY, Hu LZ, Yang HB, Chamberlain DF (2005) Rhododendron flora of China, vol 14. Science Press, Beijing, pp 260–455

Farnsworth EJ, Klionsky S, Brumback WE, Havens K (2006) A simple set of decision matrices for prioritising collection of rare plant species for ex situ conservation. Biol Conserv 28:1–12

Frodin DG (2004) History and concepts of big plant genera. Taxon 53(3):753–776

Gibbs D, Chen Y (2009) The Red List of Maples. Botanic Gardens Conservation International, Richmond

Gibbs D, Chamberlain D, Argent G (2011) The Red List of *Rhododendrons*. Botanic Gardens Conservation International, Richmond

Goetsch L, Eckert AJ, Hall B (2005) The molecular systematics of *Rhododendron* (Ericaceae): a phylogeny based on RPB2 gene sequences. Syst Bot 30(3):616–626
Goodall-Copestake WP, Hollingsworth ML, Hollingsworth PM, Jenkins GI, Collin E (2005) Molecular markers and ex situ conservation of the European elms (*Ulmus* ssp.). Biol Conserv 122(2005):537–546
Heywood VE, Iriondo JM (2003) Plant conservation: old problems, new perspectives. Biol Conserv 113(2003):321–335
Hong D, Blackmore S (eds) (2015) Plants of China. A companion to the Flora of China, 2nd edn. Cambridge University Press, UK
IUCN (2011) The Global Strategy for Plant Conservation 2011–2020. IUCN Plant Conservation Committee Fact Sheet February 2011
Jones JR, Ranney TG, Lynch NP, Krebs SL (2007) Ploidy levels and relative genome sizes of diverse species, hybrids, and cultivars of Rhododendron. J Am Rhododendr Soc Fall 2007:220–227
Kozlowski G, Gibbs D, Huan F, Frey D, Gratzfield J (2012) Conservation of threatened relict trees through living ex situ collections: lessons from the global survey of the genus Zelkova (Ulmaceae). Biodivers Conserv 21:671–685
Kron KA, Powell EA (2009) Molecular systematics of *Rhododendron* subgenus Tsutsusi (Rhodoreae, Ericodeae, Ericaceae). Edinb J Bot 66(1):81–95
Kutsev MG, Karakulov AV (2011) Reconstruction of phylogeny of the genus *Rhododendron* L. from Russia based on the molecular genetic data. For Ideas 17(1):62–65
Lasco RD, Uebelhör K, Jnr Follisco F (2010) Facing the challenge of biodiversity conservation and climate change in Southeast Asia. Clim Dev 2(3):291–294
Leadlay E, Willison J, Wyse-Jackson P (2006) Taxonomy: the framework for botanic gardens in conservation. In: Leadlay E, Jury S (eds) Taxonomy and plant conservation. Cambridge University Press, Cambridge, pp 274–293
Leslie AC (2004) The International Rhododendron register and checklist, 2nd edn. Royal Horticultural Society, Woking
Lowe RAW (1988) The national council for the conservation of plants and gardens (NCCPG). R N. Z. Inst Hortic Annu J 15:29–31
Lowe T (1989) The way ahead. The Garden 114:364–368
Ma Y, Nielsen J, Chamberlain DF, Li X, Sun W (2014) The conservation of Rhododendrons is of greater urgency than has been previously acknowledged in China. Biodivers Conserv 23:3149–3154
MacKay MB (2013) Report on the Rhododendron Species Conservation Conference: April 21–22, Edinburgh. The Rhododendron (New Zealand) 1, pp 6–9
MacKay MB, Fayaz A, Gardiner SE, Wiedow C, Smith G, Oldfield S (2010) Meeting Target Eight: *Rhododendron* subgenus *Vireya* in New Zealand as an example of ex situ conservation. In: Proceedings of the Fourth Global Botanic Gardens Congress: Botanic Gardens Conservation International, London, pp 1–14
Maunder M, Byers O (2005) The IUCN technical guidelines on the management of ex situ populations for conservation: reflecting major changes in the application of ex situ conservation. Oryx 39(1):95–98
Maunder M, Culham A, Alden B, Zizka G, Orliac C, Lobin W, Bordeu A, Ramirez JM, Glissmann-Gough S (2000) Conservation of the Toromiro tree: case study in the management of a plant extinct in the wild. Conserv Biol 14(5):1341–1350
Maunder M, Lyte B, Dransfield J, Baker W (2001a) The conservation value of botanic garden palm collections. Biol Conserv 98:259–271
Maunder M, Higgins S, Culham A (2001b) The effectiveness of botanic garden collections in supporting plant conservation: a European case study. Biodivers Conserv 10:383–401
Milne RI, Davies C, Prickett R, Inns L, Chamberlain DF (2010) Phylogeny of *Rhododendron* subgenus *Hymenanthes* based on chloroplast DNA markers: between-lineage hybridisation during radiation? Plant Syst Evol 285:233–244
Newton A, Oldfield S (2008) Red listing the world's tree species: a review of recent progress. Endang Species Res 6:137–147
Oldfield S (2009) Botanic gardens and the conservation of tree species. Trends Plant Sci 14(11):581–583
Oldfield S (2010) Plant conservation: facing tough choices. Bioscience 60(10):778–779
Oldfield S, Eastwood A (2007) The red-list of Oaks. Flora and Fauna International, Cambridge
Paul A, Khan ML, Arunchalam A, Arunchalam K (2005) Biodiversity and conservation of rhododendons in Arunchal Pradesh in the Indo-Burma biodiversity hotspot. Curr Sci 89(4):623–634
Powledge F (2011) The evolving role of botanical gardens. Bioscience 61(10):743–749
Pritchard DJ, Fa JE, Oldfield S, Harrop SR (2011) Bring the captive closer to the wild: redefining the role of ex situ conservation. Oryx 46(1):18–23

Rae D (2011) Fit for purpose: the importance of quality standards in the cultivation and use of live plant collections for conservation. Biodivers Conserv 20:241–258

RBGE (2013) Royal Botanic Gardens Edinburgh: Catalogue of the Living collections. http://elmer.rbge.org.uk/bgbase/livcol/bgbaselivcol.php. Searched 9–10 Oct 2015

RBGK (2015) Royal Botanic Garden Kew: Electronic Plant Information Centre. http://epic.kew.org/searchepic/searchpage.do. Searched 29 Oct 2015

Samain M, Vanderschaeve L, Chaerle P, Goetghebeur P, Neinhuis C, Wanke S (2009) Is morphology telling the truth about the evolution of the species rich genus Peperomia (Piperaceae)? Plant Syst Evol 278:1–21

Sekar KC, Srivastava SK (2010) *Rhododendrons* in Indian Himalayan region: diversity and conservation. Am J Plant Sci 1:131–137

Sharrock S (2012) Global strategy for plant conservation a guide to the GSPC: all the targets, objectives and facts. Botanic Gardens Conservation International, Richmond

Sharrock S, Oldfield S, Wilson O (2014) Plant Conservation Report 2014: a review of progress in implementation of the Global Strategy for Plant Conservation 2011–2020. Technical Series No. 81. Secretariat of the Convention on Biological Diversity, Montréal, Canada, and Botanic Gardens Conservation International, Richmond

Tsai C, Chen C, Chou C (2012) DNA barcodes reveal high levels of morphological plasticity among *Rhododendron* species (Ericaceae) in Taiwan. Biochem Syst Ecol 40:169–177

Twyford AD, Kidner CA, Ennos RA (2015) Maintenance of species boundaries in a Neotropical radiation of *Begonia*. Mol Ecol 24(19):4982–4993. doi:10.1111/mec.13355

Williams S, Jones JPG, Clubbe C, Sharrock S, Gibbons JM (2012) Why are some biodiversity policies implemented and others ignored? lessons from the uptake of the global strategy for plant conservation by botanic gardens. Biodivers Conserv 21:175–187

Wyse-Jackson P, Kennedy K (2009) The global strategy for plant conservation: a challenge and opportunity for the international community. Trends Plant Sci 14(11):578–580

Yan L, Liu J, Moller M, Zhang L, Zhang X, Li D, Gao L (2015) DNA barcoding of *Rhododendron* (Ericaceae), the largest Chinese plant genus in biodiversity hotspots of the Himalayan-Hengduan Mountains. Mol Ecol Res 15:932–944. doi:10.1111/1755-0998.12353

Zhou L, Wan Y, Zhang L (2009) Genetic diversity and relationship of 43 *Rhododendron* species based on RAPD analysis. Bot Res J 2(1):1–6