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RESEARCH ARTICLE

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Analysis of geographic and taxonomic groups informs conservation of *Rhododendron* subgenus *Vireya* (*Ericaceae*)

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Key words

botanic gardens
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Abstract Although *Rhododendron* subg. *Vireya*, comprising 400 taxa, is one of the largest plant genera in Southeast Asia, with taxa found throughout the region, it has a significant conservation problem, with conservation status assessments in 2011 and 2015 placing 201 taxa in an IUCN Red List threat category. Plant conservation is driven by the Global Strategy for Plant Conservation, with Target 8 requiring 75 % of threatened plant taxa to be conserved in *ex situ* collections, by 2020. To date there has been limited analysis of conservation priorities for subg. *Vireya*, or any consideration of how its geographic characteristics, complex taxonomy, and existing *ex situ* collections might influence priorities. We analyse the IUCN Red List status of geographic origins and taxonomic sections within *Rhododendron* subg. *Vireya*, then determine the representation of those groups in cultivation in New Zealand and selected international collections. Using a set of 'Red List' and 'not in cultivation' factors, our analysis shows that geographic origins New Guinea, Sumatra and Sulawesi, and taxonomic sections *Schistanthe*: malesia, *Schistanthe*: euvireya, and *Hadranthe* (*Phaeovireya*) should have priority for both *in situ* and *ex situ* conservation. Of the 400 taxa, 245 (61 %) are in cultivation, and of the 201 Red List taxa, 80 (40 %) are in cultivation. Wild-source material is held for 218 taxa, including 66 Red List taxa. These analyses provide baseline data for development of a conservation strategy for *Rhododendron* subg. *Vireya*, and we propose six actions that should be included in that strategy.

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INTRODUCTION

Rhododendron L. subg. *Vireya* (C.B.Clarke) H.F.Copel, commonly known as vireya rhododendron, is centred in Southeast Asia, a recognised biodiversity hotspot, and is one of the largest plant groups in the Malesian flora (Van Welzen et al. 2005, Webb & Ree 2012). The subgenus comprises about 400 taxa (Argent 2015) and, except for 20 taxa (17 from mainland Asia, one from Taiwan, and two from Australia), all taxa are found within the Southeast Asian floristic region (Van Welzen et al. 2005, Argent 2015). Subgenus *Vireya* has limited geographical overlap with the other eight subgenera of *Rhododendron* (which are mostly centred on mainland Asia), and there are strong reproductive barriers between *Vireya* and the other subgenera (Williams et al. 1990, Rouse et al. 1993), indicating that *Vireya* can be considered independently from the other subgenera for conservation. Two Red List assessments have been conducted for *Rhododendron*. Gibbs et al. (2011) examined the entire genus, including 338 taxa from subg. *Vireya*, while Argent (2015) revised the taxonomy of subg. *Vireya* and as part of that process updated the assessments of 37 taxa and added another 62 assessments for taxa that were either not considered in 2011 or were newly described. A subsequent analysis found that 201 of 400 vireya taxa were either placed in a threat category or listed as Data Deficient and that, of all subgenera, subg. *Vireya* had the highest priority for *ex situ* conservation (MacKay & Gardiner unpubl.).

Subgenus *Vireya* is a useful case study for conservation because it encompasses a wide range of life forms, (groundcovers, shrubs, trees, epiphytes), which are found in a range of vegetation types (forest, scrub, swamps, grasslands), and in habitats ranging from lowland to montane or alpine zones (Gibbs et al. 2011, Argent 2015). Many horticultural plants have been derived from vireya taxa, and there are hundreds of horticultural cultivars and hybrids (Leslie 2004). Vireyas are subject to a range of threats, mostly associated with deforestation and habitat loss due to agriculture and other production uses (Lasco et al. 2010, Gibbs et al. 2011, Argent 2015), while climate change is a particular threat for alpine species or narrow endemics (Oldfield 2010).

However, conservation planning in *Rhododendron* is complicated because it is a 'big genus' (Frodin 2004) with complex taxonomy. The sheer size requires a mechanism to determine priorities among many taxa, e.g. the 201 vireya taxa that were Red Listed[4], or the 60 taxa assessed as Vulnerable. While the Red List categories create an initial hierarchy, other factors such as geographic hotspots, endemism and taxonomic distinctiveness have also been used to shape priorities (Farnsworth et al. 2006, Kozlowski et al. 2012, Castañeda-Álvarez et al. 2015, Cavender et al. 2015). Identifying taxonomic distinctiveness can be problematic in 'big genera' because of their complex taxonomic structures with many subgroups, large numbers of taxonomic queries, frequent hybridisation and active speciation (Crutwell 1988, Frodin 2004, Ennos et al. 2005, Milne et al. 2010, Argent 2015); a comprehensive taxonomy is required to underpin any conservation assessment that considers taxonomic groups.

The taxonomic structure of *Rhododendron* has been studied many times (Cullen 2005: 11–25), and the current taxonomy

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[4] Another 514 taxa in other subgenera were also Red Listed, and will be discussed in other papers.

divides the genus into nine subgenera. In this research we focus on subg. *Vireya* of approximately 400 taxa, in 11 sections and subsections[5] of 1–119 taxa (Argent 2015); eight subgenera (950 taxa in 61 sections and subsections of 1–97 taxa (Chamberlain et al. 1996)) are not included in this research. DNA sequence analysis supports Argent's (2015) *Pseudovireya*, *Discovireya*, and *Malayovireya* sections, as well as a broad *Schistanthe* (*Euvireya*) grouping (Brown et al. 2006a, b, Craven et al. 2008, Goetsch et al. 2011, Fayaz 2012), although support for other sections is less certain. Craven et al. (2011) proposed an alternative structure; however, Argent's sections remain more-or-less intact (although they are at different taxonomic ranks). The molecular work is informative, but the range of taxa used is not yet comprehensive enough to revise the entire taxonomic structure of the subgenus, and Argent's structure remains the most complete framework for a conservation assessment.

Plant conservation practice is directed by the Global Strategy for Plant Conservation (GSPC) and its 16 Targets (Wyse-Jackson & Kennedy 2009, IUCN 2011, Sharrock 2012, Williams et al. 2012). GSPC Target 2 calls for an assessment of the conservation status of all known plants (as far as possible), to guide conservation action, and thus providing an overview of the 'conservation problem' and indicating initial priorities (Heywood & Iriondo 2003, Newton & Oldfield 2008, Kozlowski et al. 2012, Cavender et al. 2015), while *ex situ* conservation action is further focused by Target 8, which has the goal of having 75 % of threatened plant taxa in *ex situ* collections by 2020 (IUCN 2011). Such collections are usually found in botanic gardens, whose role in *ex situ* conservation is well known (Heywood & Iriondo 2003, Maunder & Byers 2005, Oldfield 2009, 2010, Blackmore et al. 2011, Pritchard et al. 2011), and has been recognised for many years (Given 1987). To be effective for *ex situ* conservation, the collections should meet certain criteria: they should be genetically representative, of known provenance and wild origin, adequately sampled, well documented, verified, and properly labelled (Blackmore et al. 2011, Rae 2011). Unfortunately, many collections do not meet these criteria and therefore have limited use for conservation.

Many collections are 'ad hoc horticultural collections' with few accessions of many taxa, instead of 'structured conservation collections' with appropriate representation (Rae 2011, Cavender et al. 2015). Collections should contain wild-source material; however, this is often limited and documentation is poor (Maunder et al. 2000, 2001a, Kozlowski et al. 2012, Christe et al. 2014). Correct identity is a fundamental principle of *ex situ* conservation (Leadlay et al. 2006), yet accessions are not always correctly identified (Goodall-Copestake et al. 2005, Paton 2009, Christe et al. 2014). Representation of taxonomic and geographic groups in collections is uneven (Maunder et al. 2001b, Kozlowski et al. 2012, Cavender et al. 2015), and the majority of collections are not in the country of origin (Maunder et al. 2001a, b, Kozlowski et al. 2012). Genetic diversity of most *ex situ* populations is unknown and is likely to be low (Maunder et al. 2001a, Cavender et al. 2015).

When Red List taxa are in cultivation, the range of taxa present is often limited, whereas most common taxa are in cultivation (Maunder et al. 2001a, b, Oldfield 2010, Kozlowski et al. 2012, Cires et al. 2013, Beech et al. 2015). Furthermore, Red List taxa are often held in three-or-fewer collections, e.g. 46 %, 63 %, and 85 % of rare species were in three-or-fewer collections (Maunder et al. 2001a, b, Rae 2011). In other cases, 29–50 % of Red List taxa were present in only one collection (Maunder et al. 2001a, Powledge 2011, Pritchard et al. 2011, Cires et al. 2013). Presence in three-or-fewer collections is effectively 'below the margin of error' and there may be no accessions at all (Lowe 1988, 1989) because: the plant died in the first collection, the identity was wrong in the second collection, and the third collection was going to obtain it but never did. Therefore any taxon recorded in 'three-or-fewer' collections is not secure in cultivation.

Rhododendron subg. *Vireya* was partially examined in a survey of collections in 2012 (BGCI 2012). This international survey of botanic gardens internationally identified that the largest collections (of the whole genus) world-wide were at Royal Botanic Garden, Edinburgh and Royal Botanic Gardens, Kew. It was also reported that 67 % of 'all taxa' and 53 % of Red List taxa (for the whole genus) were in cultivation, with an average of 5.8 records per taxon for the 48 Endangered and Critically Endangered taxa; however, that study did not consider subg. *Vireya* separately or examine any geographic or taxonomic groups. Furthermore, the 2012 study did not canvas the breadth of New Zealand collections, accessing only incomplete data from one vireya collection (L. Coxshead pers comm. 2015). New Zealand has a wide diversity of exotic taxa (including Red List taxa) in cultivation (MacKay 1995, 2005, Brockerhoff et al. 2004, Dawson 2010, Arnet et al. 2015); however, there has not previously been any examination specific to *Rhododendron* and, as there are several New Zealand wild-source collectors of *Rhododendron* (Argent 2015), there are likely to be other collections that may be applicable for *ex situ* conservation.

In this study we investigate the Red List status and presence in cultivation of groups of taxa (by geographic origins and taxonomic sections) in *Rhododendron* subg. *Vireya* and determine their priority for conservation. The objectives of this work were to:

i. analyse the Red List for *Rhododendron* subg. *Vireya* and identify geographic origins and taxonomic sections that should have priority for conservation;
ii. examine the extent to which geographic and taxonomic groups are represented in cultivation, or are not in cultivation;
iii. combine the Red List analysis and the cultivation analysis to identify those groups of taxa that should have priority for *ex situ* conservation; and
iv. propose conservation action and priorities.

METHODS

A dataset on *Rhododendron* subg. *Vireya* was constructed by creating a base list of taxa (including species, subspecies, and varieties) from Argent (2015), and then adding other data elements. The Red List assessment for each taxon was sourced from Gibbs et al. (2011) and Argent (2015). In those assessments the World Conservation Union (IUCN) assessment criteria (outlined in Gibbs et al. 2011) were used to assign taxa, that have a quantifiable conservation problem, to one of the threat categories (with decreasing degrees of risk): Extinct, Extinct in the Wild, Critically Endangered, Endangered, Vulnerable, and Near Threatened. Those taxa which assessors believe may have a conservation problem, but for which there are insufficient data to quantify the problem, are rated as Data Deficient. High rates of Data Deficiency indicate a paucity of knowledge on the group in question, and therefore a high priority for further research and field work (Newton & Oldfield 2008, Blackmore et al. 2011, Cires et al. 2013). Those taxa for which there is no evidence of an extinction risk that meets the thresholds in the IUCN Red List system are rated Least Concern.

Data describing taxa in cultivation were obtained from several sources. Firstly, the number of records for each vireya taxon

[5] Sections are: *Pseudovireya*, *Discovireya*, *Malayovireya*, *Albovireya*, *Siphonovireya*, *Hadranthe* (previously known as *Phaeovireya*), and *Schistanthe* (previously known as *Euvireya*) which is divided into 5 subsections.

on the online Plant Search database at BGCI was added to the dataset (https://www.bgci.org/plant_search.php. Searched 9–10 Oct. 2015). Secondly, international data were obtained from the online collection databases at Royal Botanic Garden, Edinburgh (Catalogue of the Living collections. http://elmer.rbge.org.uk/bgbase/livcol/bgbaselivcol.php. Searched 9–10 Oct. 2015), Royal Botanic Gardens, Kew (Electronic Plant Information Centre: Living Collections. http://epic.kew.org/searchepic/searchpage.do. Searched 29 Oct. 2015), and National Botanic Garden Dublin (Alphabetical index to the dicotyledon collections. http://www.botanicgardens.ie/nbg/dicoidex.htm. Downloaded 11 Oct. 2015). The last named was included because, although it ranks only 12th for *Rhododendron* collections world-wide (BGCI 2012), it contains some taxa from the Edinburgh vireya collection (G.Argent pers comm. 2013). Finally, data on New Zealand collections were obtained from prior studies (MacKay 2005, 2013b) and other unpublished data (Smith 2009, unpubl. inventory of the *Rhododendron* collection at Pukeiti), and from a survey of New Zealand collections (conducted in 2011–2013) for which data were obtained for six private collections and two institutions. Taxa were defined as 'in cultivation' if there was a record from any one data source.

Data were combined into a database, with each record including scientific name, authority, synonyms, taxonomic section (Argent 2015), Red List assessment, geographic origin, presence in collections (New Zealand or internationally), number of accessions on the BGCI database, and presence of wild-source accessions in any of the collections studied. Plant names were checked using Argent (2015), and only valid taxa were included in the dataset.

Once the dataset was constructed, it was examined in several ways. Firstly, the Red List was analysed, with geographic origins and taxonomic sections (of vireya taxa) ranked according to each of four Red List factors (number of taxa Red Listed, percentage of taxa Red Listed, number of Red List taxa rated Data Deficient, percentage of Red List taxa rated Data Deficient). A score was assigned to each rank. Each geographic origin or taxonomic section had four ranking scores (one for each Red List factor) and those scores were summed to generate a Red List score, e.g. the score for New Guinea is 11+4+11+9=35, and for *Schistanthe*: malesia is 9+9+9+6=33. Origins and sections with the highest scores were assigned highest priority. Geographic origins in Southeast Asia were assigned to islands, not countries; for example New Guinea and Borneo were the assigned origins, not the countries within those islands. Secondly, data on taxa in cultivation were collated to show the extent to which geographic and taxonomic groups are in cultivation. Thirdly, a set of 'not in cultivation' factors were examined, as the absence from cultivation also generates a high priority for *ex situ* conservation. Using the same process as the Red List analysis (described above), geographic origins and taxonomic sections were ranked for four 'not in cultivation' factors, a score assigned to each rank, and a 'not in cultivation' score was generated for by summing the ranking scores. For example, the score for New Guinea is 10+9+10+8=37, and for *Hadranthe* is 9+9+8+7=33. The final aspect of data processing was generation of a Total Score (Red List score + 'not in cultivation' score), thereby identifying those groups of taxa that ranked highly in the Red List assessment but which also had low frequency in cultivation. These groups will have highest priority for *ex situ* conservation.

RESULTS AND DISCUSSION

Red List status for subg. Vireya

When combined, the Red List assessments of Gibbs et al. (2011) and Argent (2015) examined 400 vireya taxa, of which 201 (50 %) were Red Listed (Table 1). The percentage Red Listed is similar to or slightly higher than recent assessments for *Quercus* (53 %), *Acer* (44 %), and *Betulaceae* (43 %) (Oldfield & Eastwood 2007, Gibbs & Chen 2009, Shaw et al. 2014). *Magnoliaceae* (Rivers et al. 2016) had a higher percentage of taxa Red Listed (85 %), from a group of 304 taxa. The greatest number of vireya Red List taxa occur in the Vulnerable (60 taxa) and Data Deficient (113 taxa) categories; indeed, the percentage of Data Deficient[6] ratings for vireya (56 %) is high compared with those for *Acer* (25 %), *Quercus* (30 %), or *Magnoliaceae* (38 %) (Oldfield & Eastwood 2007, Gibbs & Chen

Table 1 *Rhododendron* subg. *Vireya* (Argent 2015): number of taxa in Red List categories*.

Threat category	No. of taxa
Extinct	2
Extinct in the Wild	0
Critically Endangered	12
Endangered	12
Vulnerable	60
Near Threatened	2
Total in threat categories	*88*
Data Deficient	113
Total Red Listed	*201*
Least Concern	199
Total Assessed	*400*

* Gibbs et al. (2011) assessed 338 taxa. Argent (2015) assessed another 62 and updated 37 others.

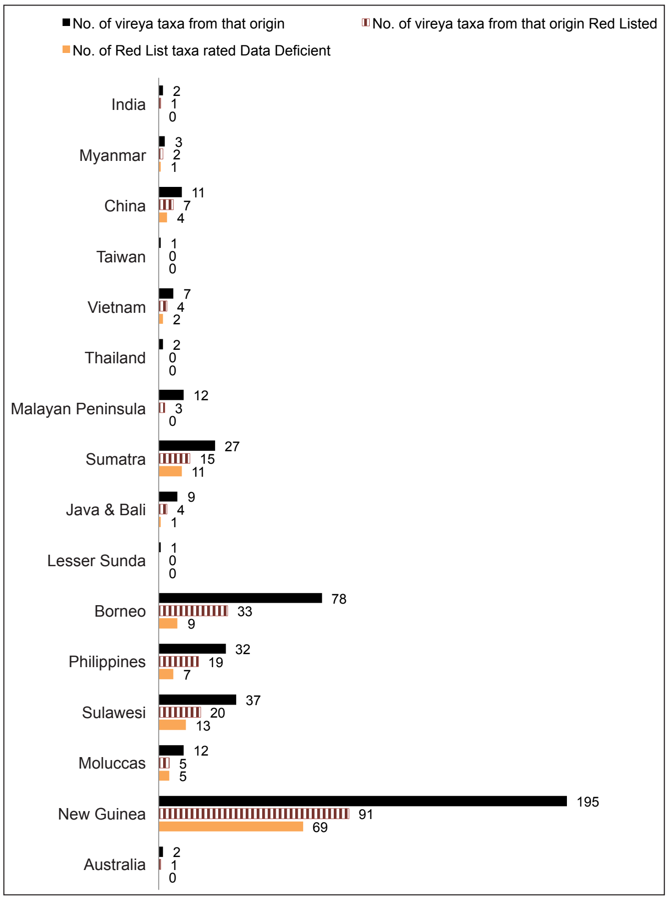

Fig. 1 Red List analysis for geographic origins of *Rhododendron* subg. *Vireya* (Argent 2015): number of taxa, number of Red List taxa, and number of Red List taxa rated Data Deficient, from each origin. (Total no. of taxa = 400; however, top bars will not sum to 400 as some taxa have more than one origin.)

[6] Number of Data Deficient taxa / (No. of taxa in Threat categories + Number of Data Deficient taxa) × 100.

Table 2 Geographic origins of *Rhododendron* subg. *Vireya* (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	
	Origin	No.	Origin	%	Origin	No.	Origin	%
11	New Guinea	91	Myanmar	67	New Guinea	69	Moluccas	100
10	Borneo	33	China	64	Sulawesi	13	Sumatra	73
9	Sulawesi	20	Philippines	59	Sumatra	11	New Guinea	69
8	Philippines	19	Vietnam	57	Borneo	09	Sulawesi	65
7	Sumatra	15	Sumatra	56	Philippines	07	China	57
6	China	07	Sulawesi	54	Moluccas	05	Myanmar Vietnam	50 50
5	Moluccas	05	Australia India	50 50	China	04	Philippines	37
4	Java & Bali Vietnam	04 04	New Guinea	47	Vietnam	02	Borneo	27
3	Malayan Peninsula	03	Java & Bali	44	Myanmar Java & Bali	01 01	Java & Bali	25
2	Myanmar	02	Borneo Moluccas	42 42				
1	Australia India	01 01	Malayan Peninsula	25				
0: nil taxa for the factor	Lesser Sunda Thailand Taiwan		Lesser Sunda Thailand Taiwan		Australia India Lesser Sunda Malayan Peninsula Thailand Taiwan		Australia India Lesser Sunda Malayan Peninsula Thailand Taiwan	

2009, Rivers et al. 2016), although *Betulaceae* was more poorly placed with 80 % of Red List taxa rated Data Deficient (Shaw et al. 2014). High percentages of Data Deficiency indicate a knowledge and research issue which may hinder development of conservation plans (Newton & Oldfield 2008, Blackmore et al. 2011, Cires et al. 2013).

Red List analysis for geographic origins of subg. Vireya

Among the geographic origins of vireya taxa, New Guinea (91 taxa) and Borneo (33) have the greatest number of Red List taxa, while New Guinea (69) and Sulawesi (13) have the greatest number of Data Deficient taxa (Fig. 1, which displays an eastwards progression of geographic origins from top to bottom). Myanmar and China have the highest percentage of taxa Red Listed (Table 2), although there are only 12 taxa from those origins. The highest percentages of Red List taxa rated Data Deficient originate from the Moluccas and New Guinea (Table 2). The Red List score shows that New Guinea, Sumatra, and Sulawesi are priority geographic origins for conservation, followed by the Philippines, China and the Moluccas (Table 3). New Guinea dominates because of the number of taxa

Table 3 Geographic origins of *Rhododendron* subg. *Vireya* (Argent 2015) ranked according to Red List score.

Origin	Red List score = sum of ranking scores for four Red List factors (Table 2). Maximum score = 44
New Guinea	35
Sumatra	33
Sulawesi	33
Philippines	29
China	28
Moluccas	24
Borneo	24
Vietnam	22
Myanmar	22
Java & Bali	13
Australia	6
India	6
Malayan Peninsula	4
Lesser Sunda	0
Thailand	0
Taiwan	0

and the number of taxa rated Data Deficient, while Sumatra and Sulawesi rank highly because of Data Deficiency. Borneo, which has the second highest number of Red List taxa, is sixth in the Red List score ranking, because of the relatively low percentages of taxa Red Listed and taxa rated Data Deficient.

Red List analysis for taxonomic sections of subg. Vireya

The greatest numbers of Red List taxa are in taxonomic sections *Schistanthe*: euvireya (59 taxa) and *Schistanthe*: malesia (34 taxa); those two sections also had the greatest numbers

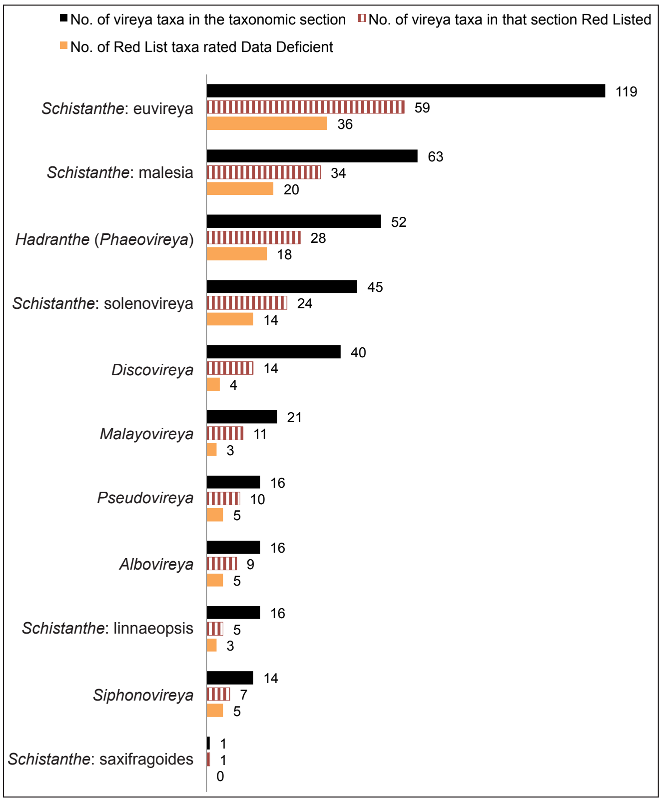

Fig. 2 Red List analysis for taxonomic sections of *Rhododendron* subg. *Vireya* (Argent 2015): number of taxa, number of Red List taxa, and number of Red List taxa rated Data Deficient, in each section.

Table 4 Taxonomic sections of *Rhododendron* subg. *Vireya* (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	
	Section	No.	Section	%	Section	No.	Section	%
10	*Schistanthe*: euvireya	59	*Pseudovireya*	63	*Schistanthe*: euvireya	36	*Siphonovireya*	71
9	*Schistanthe*: malesia	34	*Schistanthe*: malesia	57	*Schistanthe*: malesia	20	*Hadranthe* (*Phaeovireya*)	64
8	*Hadranthe* (*Phaeovireya*)	28	*Albovireya*	56	*Hadranthe* (*Phaeovireya*)	18	*Schistanthe*: euvireya	61
7	*Schistanthe*: solenovireya	24	*Hadranthe* (*Phaeovireya*)	54	*Schistanthe*: solenovireya	14	*Schistanthe*: linnaeopsis	60
6	*Discovireya*	14	*Malayovireya*	53	*Albovireya*	05	*Schistanthe*: malesia	59
			Schistanthe: solenovireya	53	*Pseudovireya*	05		
					Siphonovireya	05		
5	*Malayovireya*	11	*Siphonovireya*	50	*Discovireya*	04	*Schistanthe*: solenovireya	58
			Schistanthe: euvireya	50				
4	*Pseudovireya*	10	*Discovireya*	35	*Schistanthe*: linnaeopsis	03	*Albovireya*	55
					Malayovireya	03		
3	*Albovireya*	09	*Schistanthe*: linnaeopsis	31			*Pseudovireya*	50
2	*Siphonovireya*	07					*Discovireya*	29
1	*Schistanthe*: linnaeopsis	05					*Malayovireya*	27
0: nil taxa for the factor	*Schistanthe*: saxifragoides		*Schistanthe*: saxifragoides		*Schistanthe*: saxifragoides		*Schistanthe*: saxifragoides	

Table 5 Taxonomic sections of *Rhododendron* subg. *Vireya* (Argent 2015) ranked according to Red List score.

Taxonomic section	Red List score = sum of ranking scores for four Red List factors (Table 4). Maximum score = 40
Schistanthe: malesia	33
Schistanthe: euvireya	33
Hadranthe (*Phaeovireya*)	32
Schistanthe: solenovireya	25
Siphonovireya	23
Pseudovireya	23
Albovireya	21
Discovireya	17
Malayovireya	16
Schistanthe: linnaeopsis	15
Schistanthe: saxifragoides	0

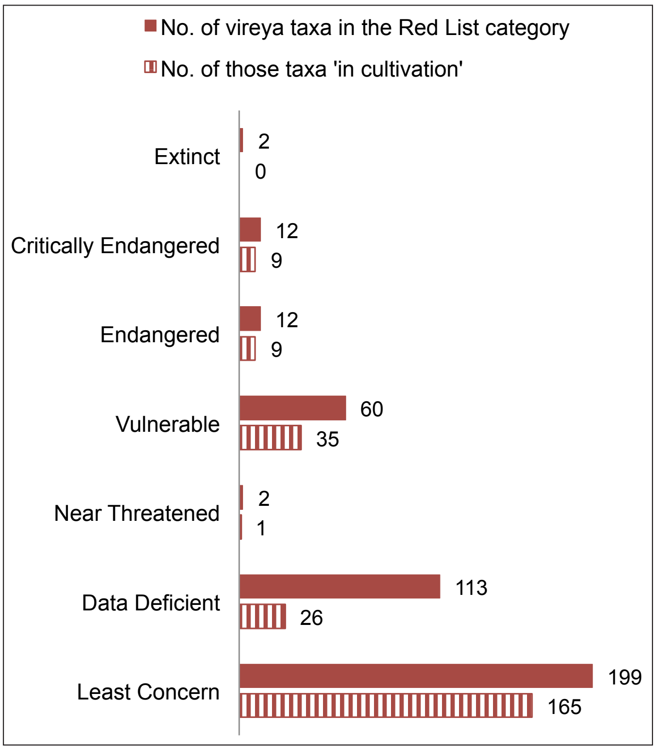

Fig. 3 Taxa in cultivation for Red List categories of *Rhododendron* subg. *Vireya* (Argent 2015): number of taxa from each category 'in cultivation' in 2015 (MacKay & Gardiner unpubl.).

of Data Deficient taxa (Fig. 2, Table 4). Ranking of taxonomic sections by percentage of taxa Red Listed (Table 4), reveals that *Pseudovireya* and *Schistanthe*: malesia have the highest percentages, while *Siphonovireya* and *Hadranthe* (*Phaeovireya*) have the highest percentages of taxa rated Data Deficient. The Red List score shows that *Schistanthe*: malesia, *Schistanthe*: euvireya (equal first rank), and *Hadranthe* (*Phaeovireya*) are priority taxonomic groups for conservation (Table 5).

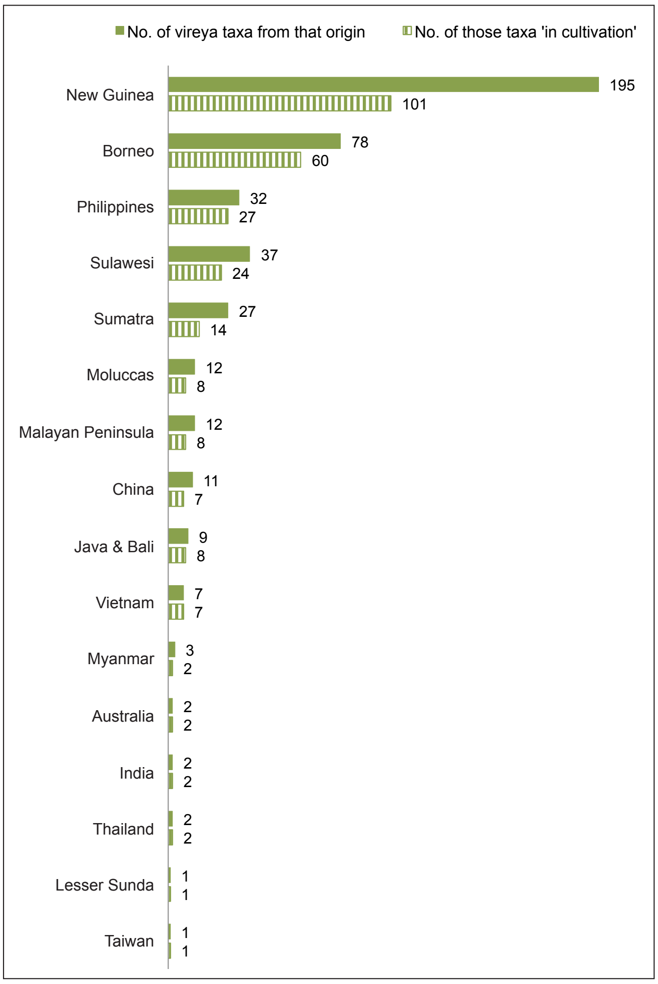

Fig. 4 Taxa in cultivation for geographic origins of *Rhododendron* subg. *Vireya* (Argent 2015): number of taxa from each geographic origin 'in cultivation' in 2015.

Table 6 Geographic origins of *Rhododendron* subg. *Vireya* (Argent 2015): ranked according to the average number of records per taxon at Botanic Gardens Conservation International (BGCI) for Red List taxa from each origin.

Origin	Average number of records per Red List taxon at BGCI	No. of Red List taxa from that origin
Moluccas	0	5
Sumatra	0.3	15
New Guinea	0.6	91
Sulawesi	0.7	20
Myanmar	1.0	2
Malayan Peninsula	1.0	3
Borneo	1.3	33
China	1.4	7
Java & Bali	1.8	4
Philippines	1.8	19
Vietnam	2.0	4
India	5.0	1
Australia	10	1

Table 7 Taxonomic sections of *Rhododendron* subg. *Vireya* (Argent 2015): ranked according to the average number of records per taxon at BGCI for Red List taxa in each section.

Taxonomic section	Average number of records per Red List taxon at BGCI	No. of Red List taxa in the section
Siphonovireya	0.1	7
Hadranthe (*Phaeovireya*)	0.3	28
Schistanthe: linnaeopsis	0.4	5
Discovireya	0.5	14
Schistanthe: malesia	0.8	34
Albovireya	0.9	9
Schistanthe: solenovireya	1.0	24
Malayovireya	1.2	11
Schistanthe: euvireya	1.2	59
Pseudovireya	1.7	10

Subg. Vireya 'in cultivation'

MacKay & Gardiner (unpubl.) found that of the 400 *Vireya* taxa examined by Argent (2015) and Gibbs et al. (2011), 245 (61 %) were 'in cultivation' (using the same definition as in this study), including 80 of the 201 Red List taxa (40 %) (Fig. 3). When Red List taxa were considered by category, they found that 61 % of taxa in threat categories were in cultivation, but only 23 % of Data Deficient taxa. *Vireya* taxa were also poorly placed by the BGCI database, with an average of only 2.1 records per taxon for 'all vireya taxa' and 0.9 for Red List taxa (MacKay & Gardiner unpubl.), well below the 'three-or-fewer' indicator of risk.

When taxa in cultivation are considered by geographic origin (Fig. 4), New Guinea is the origin of the greatest number of taxa in cultivation (101 taxa), followed by Borneo (60). Six origins have all their taxa in cultivation (15 taxa in total), and another five origins (Java & Bali, Philippines, Borneo, Moluccas, Malayan Peninsula) have more than 75 % of their taxa in cultivation. The geographic origin with the greatest number of Red List taxa in cultivation (Fig. 5) is New Guinea (24 taxa), followed by Borneo (20). Three origins (India, Australia, Vietnam, six taxa in total) have 100 % of their Red List taxa in cultivation, and the Philippines (79 %) and Java & Bali (75 %) have more than 75 % of Red List taxa in cultivation; however, these areas represent only 14 % of the Red List taxa, and the origins with the greatest number of Red List taxa do not reach the 75 % Target (e.g., only 26 % of Red List taxa from New Guinea are in cultivation). Furthermore, the average number of records on the BGCI database is poor: only India (one taxon) and Australia (one taxon) have more than three records per Red List taxon (Table 6). Of the other origins, the Moluccas (0 records per taxon), Sumatra (0.3), New Guinea (0.6), and Sulawesi (0.7) have an average of less than one BGCI record per Red List taxon.

With respect to taxonomic sections, the largest sections (*Schistanthe*: euvireya, *Schistanthe*: malesia) have the greatest number of taxa in cultivation (Fig. 6). Only *Schistanthe*: saxifragoides

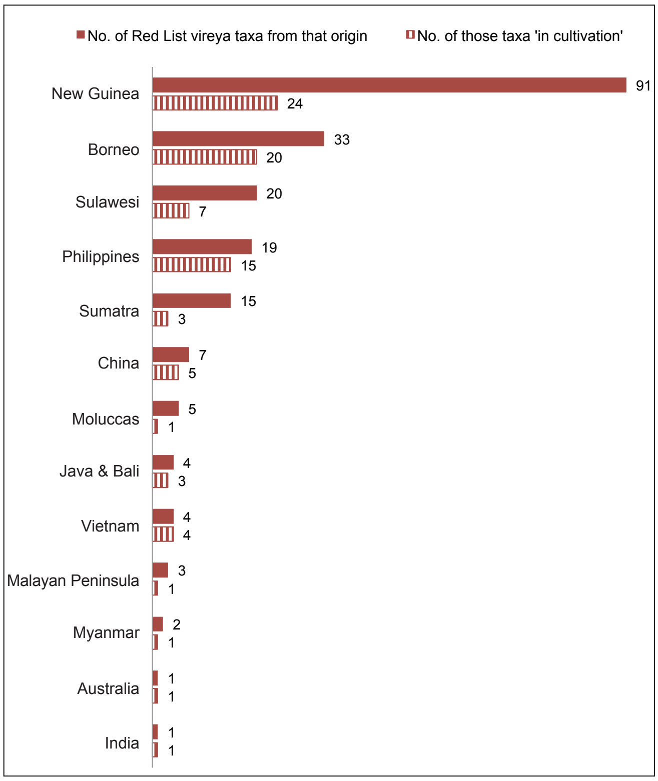

Fig. 5 Red List taxa in cultivation for geographic origins of *Rhododendron* subg. *Vireya* (Argent 2015): number of Red List taxa from each geographic origin 'in cultivation' in 2015.

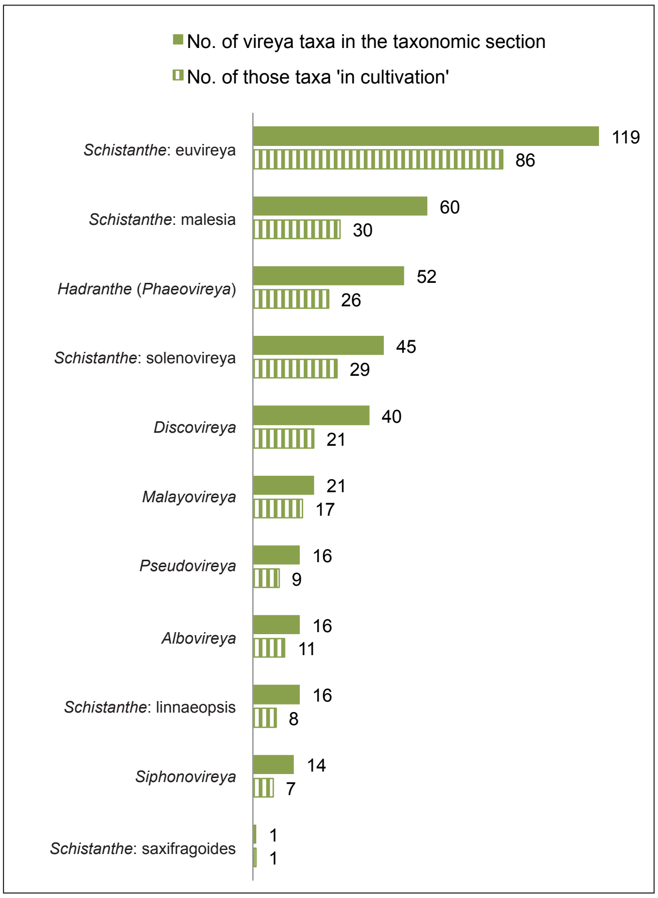

Fig. 6 Taxa in cultivation for taxonomic sections of *Rhododendron* subg. *Vireya* (Argent 2015): number of taxa 'in cultivation' in 2015.

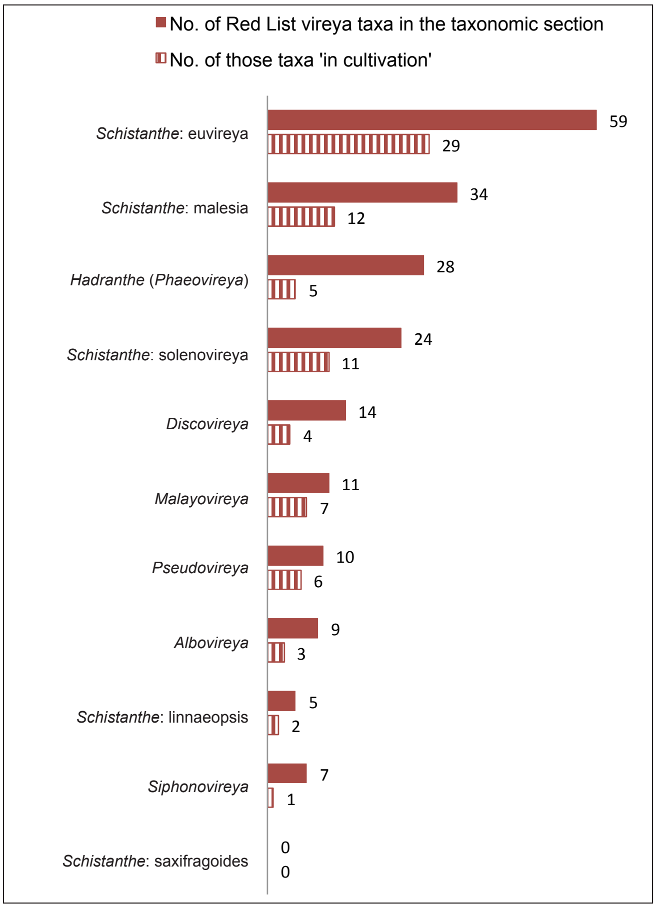

Fig. 7 Red List taxa in cultivation for taxonomic sections of *Rhododendron* subg. *Vireya* (Argent 2015): number of Red List taxa 'in cultivation' in 2015.

(100 %) and *Malayovireya* (81 %) have more than 75 % of taxa in cultivation. The greatest number of Red List taxa in cultivation (Fig. 7) are from *Schistanthe*: euvireya (29 taxa), followed by *Schistanthe*: malesia (12 taxa). No taxonomic section has more than 75 % of its Red List taxa in cultivation – the figures range from 64 % for *Malayovireya* to 14 % for *Siphonovireya*. Of the sections prioritised in the Red List analysis, *Schistanthe*: euvireya is in the best position (49 % of Red List taxa in cultivation), while *Schistanthe*: malesia (35 %) and *Hadranthe* (18 %) are poorly placed. All taxonomic sections are poorly placed with respect to average number of records per Red List taxon on the BGCI database (Table 7). *Siphonovireya* is in the worst position, with an average of 0.1 records per Red List taxon: five other sections have an average of less than 1.0, and three sections have an average of between 1.2 and 1.7.

Table 9 Geographic origins of *Rhododendron* subg. *Vireya* (Argent 2015) ranked according to 'not in cultivation' score.

Origin	'Not in cultivation' score = sum of ranking scores for four 'not in cultivation' factors (Table 8). Maximum score = 40
New Guinea	37
Sumatra	36
Sulawesi	32
Moluccas	31
Borneo	29
Philippines	21
China	19
Myanmar	18
Java & Bali	15
Malayan Peninsula	14
Vietnam	12
Australia	5
India	5
Lesser Sunda	0
Thailand	0
Taiwan	0

Table 8 Geographic origins of *Rhododendron* subg. *Vireya* (Argent 2015) ranked according to four 'not in cultivation' factors.

Ranking score	No. of Red List taxa 'not in cultivation'		Percentage of Red List taxa 'not in cultivation'		No. Data Deficient taxa 'not in cultivation'		Percentage of Data Deficient taxa 'not in cultivation'	
	Origin	No.	Origin	%	Origin	No.	Origin	%
10	New Guinea	67	Sumatra Moluccas	80	New Guinea	49	Sumatra	90
9	Borneo Sulawesi	13	New Guinea	74	Sulawesi	11	Moluccas	80
8	Sumatra	12	Malayan Peninsula	67	Sumatra	10	New Guinea Borneo	78
7	Philippines Moluccas	04	Sulawesi	65	Borneo	07	Sulawesi	75
6	China Malayan Peninsula	02	Myanmar	50	Philippines	04	Philippines	67
5	Java & Bali Myanmar	01	Borneo	39	Moluccas	04	China	50
4	Australia India Vietnam	0	China	29	China	02	Java & Bali Myanmar Vietnam	0
3			Java & Bali	25	Vietnam Myanmar Java & Bali	0		
2			Philippines	21				
1			Australia India Vietnam	0				
0: nil taxa for the factor	Lesser Sunda Thailand Taiwan		Lesser Sunda Thailand Taiwan		Australia India Lesser Sunda Malayan Peninsula Thailand Taiwan		Australia India Lesser Sunda Malayan Peninsula Thailand Taiwan	

Table 10 Taxonomic sections of *Rhododendron* subg. *Vireya* (Argent 2015) ranked according to four 'not in cultivation' factors.

Ranking score	No. of Red List taxa 'not in cultivation'		Percentage of Red List taxa 'not in cultivation'		No. Data Deficient taxa 'not in cultivation'		Percentage of Data Deficient taxa 'not in cultivation'	
	Section	No.	Section	%	Section	No.	Section	%
10	*Schistanthe*: euvireya	30	*Siphonovireya*	86	*Schistanthe*: euvireya	24	*Albovireya* *Discovireya* *Siphonovireya*	100 100 100
9	*Hadranthe*	23	*Hadranthe*	82	*Schistanthe*: malesia	18	*Schistanthe*: malesia	90
8	*Schistanthe*: malesia	22	*Discovireya*	71	*Hadranthe*	14	*Schistanthe*: solenovireya	79
7	*Schistanthe*: solenovireya	13	*Albovireya*	67	*Schistanthe*: solenovireya	11	*Hadranthe*	78
6	*Discovireya*	10	*Schistanthe*: malesia	65	*Albovireya* *Siphonovireya*	05 05	*Malayovireya* *Schistanthe*: linnaeopsis *Schistanthe*: euvireya	67 67 67
5	*Albovireya* *Siphonovireya*	06 06	*Schistanthe*: linnaeopsis	60	*Discovireya*	04	*Pseudovireya*	40
4	*Pseudovireya* *Malayovireya*	04 04	*Schistanthe*: solenovireya	54	*Pseudovireya* *Malayovireya* *Schistanthe*: linnaeopsis	02 02 02		
3	*Schistanthe*: linnaeopsis	03	*Schistanthe*: euvireya	51				
2			*Pseudovireya*	40				
1			*Malayovireya*	36				
0: nil taxa for the factor	*Schistanthe*: saxifragoides		*Schistanthe*: saxifragoides		*Schistanthe*: saxifragoides		*Schistanthe*: saxifragoides	

Table 11 Taxonomic sections of *Rhododendron* subg. *Vireya* (Argent 2015) ranked according to 'not in cultivation' score.

Taxonomic section	'Not in cultivation' score = sum of ranking scores for four 'not in cultivation' factors (Table 10). Maximum score = 40
Hadranthe (*Phaeovireya*)	33
Schistanthe: malesia	32
Siphonovireya	31
Schistanthe: euvireya	29
Discovireya	29
Albovireya	28
Schistanthe: solenovireya	26
Schistanthe: linnaeopsis	18
Pseudovireya	15
Malayovireya	15
Schistanthe: saxifragoides	0

Table 12 Geographic origins of *Rhododendron* subg. *Vireya* (Argent 2015) ranked according to Total score = Red List score (Table 3) + 'not in cultivation' score (Table 9).

Origin	Total score Maximum score = 84
New Guinea	72
Sumatra	69
Sulawesi	65
Moluccas	55
Borneo	53
Philippines	50
China	48
Myanmar	40
Java & Bali	28
Vietnam	27
Malayan Peninsula	18
Australia	11
India	11
Lesser Sunda	0
Thailand	0
Taiwan	0

'Not in cultivation' analysis for subg. Vireya

The utility of the 'not in cultivation' analysis is illustrated by New Guinea, which is the origin of the greatest number of Red List taxa in cultivation, suggesting that it is well placed for *ex situ* conservation; however, New Guinea is also the origin of the greatest number of Red List taxa 'not in cultivation', indicating that it actually has a high priority for *ex situ* action. When geographic origins are examined for four 'not in cultivation' factors (Table 8), New Guinea, Borneo, and Sulawesi have the greatest number of Red List taxa 'not in cultivation', while New Guinea and Sulawesi have the greatest number of Data Deficient taxa 'not in cultivation'. By percentage, Sumatra and the Moluccas have the highest percentage of Red List taxa 'not in cultivation', and Sumatra and the Moluccas the highest percentages of Data Deficient taxa 'not in cultivation'. When the ranking scores for each origin, for the four factors, are summed, a 'not in cultivation' score is generated (e.g. the score for New Guinea is 10+9+10+8=37), showing that New Guinea and Sumatra have the highest scores, followed by Sulawesi and the Moluccas (Table 9).

When the same four 'not in cultivation' factors are applied to the taxonomic sections (Table 10), *Schistanthe*: euvireya has the greatest number of Red List taxa and Data Deficient taxa 'not in cultivation'. *Siphonovireya* and *Hadranthe* have the highest percentages of Red List taxa 'not in cultivation'. Three sections have 100 % of their Data Deficient taxa 'not in cultivation' (*Albovireya*, *Discovireya*, *Siphonovireya*). The sections with the highest 'not in cultivation' scores are *Hadranthe*, *Schistanthe*: malesia and *Siphonovireya* (Table 11), which therefore have the poorest representation in cultivation.

Ranking by Total Score

Total Score, which prioritises groups for *ex situ* conservation, shows that geographic origins New Guinea, Sumatra, and Sulawesi should be assigned highest priority (Table 12). These three origins are in the top three ranks for both component scores, and while New Guinea has more taxa than the other two origins, Sumatra and Sulawesi have high percentages of taxa in the factors that generate the component scores. Because these three origins are in the top ranks for both component scores, they take top priority for both *in situ* and *ex situ* conservation. In contrast, although the Philippines has a relatively high Red List score, its taxa are relatively well represented in cultivation, so it ranks sixth for Total Score and has a lower priority for *ex situ* conservation. Vietnam is similarly placed: good representation in cultivation reduces its ranking in Total Score compared with its Red List score. The origins with the lowest priority for *ex situ* conservation according to Total Score are India, Australia,

Table 13 Taxonomic sections of *Rhododendron* subg. *Vireya* (Argent 2015) ranked according to Total Score = Red List score (Table 5) + 'not in cultivation' score (Table 11).

Taxonomic section	Total score Maximum score = 80
Schistanthe: malesia	65
Hadranthe (*Phaeovireya*)	65
Schistanthe: euvireya	62
Siphonovireya	54
Schistanthe: solenovireya	51
Albovireya	49
Discovireya	46
Pseudovireya	38
Schistanthe: linnaeopsis	33
Malayovireya	31
Schistanthe: saxifragoides	0

and Malayan Peninsula, although only five taxa in total come from these origins.

For taxonomic sections, Total Score shows that *Schistanthe*: malesia and *Hadranthe* (*Phaeovireya*) are equal first ranked (and take the top two ranks in both component scores), followed by *Schistanthe*: euvireya (Table 13). Of the other taxonomic sections, *Discovireya* is as poorly represented in cultivation as *Schistanthe*: euvireya, but it has a much lower Red List score, and is only mid-ranked for Total Score. *Siphonovireya* has a lesser conservation issue than *Schistanthe*: solenovireya, but ranks more highly in Total Score because of poorer representation in cultivation. Using the Total Score method, the taxonomic sections with the lowest priority for *ex situ* conservation are *Malayovireya* and *Schistanthe*: linnaeopsis.

Vireya collections

Of the 245 vireya taxa in cultivation, the largest collection is held at Royal Botanic Garden, Edinburgh (222 taxa), followed by New Zealand (151 taxa) and Dublin Botanic Garden (81). Edinburgh also holds the largest collection of Red List taxa, with 66 of the 80 taxa that are in cultivation, while New Zealand holds 33 Red List taxa and Dublin has 12. Royal Botanic Gardens, Kew holds only eight vireya taxa, including two Red List taxa, and is not a significant collection. There are 23 taxa in cultivation that are not held at Edinburgh; seven are in New Zealand and 22 are recorded at BGCI. Wild-source material is present for 218 of the 245 taxa in cultivation (89 %), including 67 of the 80 Red List taxa (84 %). Further analysis is needed to examine the taxonomic, geographic, and wild-source characteristics of these collections.

Additional taxa

The present study has recorded more taxa than the 400 considered in the Red List assessments (Gibbs et al. 2011, Argent 2015). Argent (2015) describes, but does not assess, four taxa of which one is in cultivation (*R. rugosum* var. *laeve*, Borneo) and three are not in cultivation (*R. atrichum* ssp. *dendrolepis*, Borneo; *R. gaultherifolium* ssp. *expositum*, New Guinea; *R. suaveolens* forma *roseum*, Borneo). He also describes 15 named natural hybrids of which seven are from Borneo, three from New Guinea, and five from other locations. Eleven of the hybrids are in cultivation, and nine have wild-source accessions. Also recorded in cultivation were another 40 wild-collected taxa, comprising 26 hybrids, six 'aff.' taxa and eight forms of species that are named as cultivars. Most of these taxa came from New Guinea (26), with seven from Borneo, and the remainder from other locations. None of the additional taxa was considered in the Red List assessments, so they were noted but not included in this analysis. Any that are deemed valid taxa will be placed in an appropriate position in a future Red List revision.

Limitations to this study

Several potential limitations to this study should be noted. Any analysis of a Red List assumes a robust Red List process in the first instance, and while the IUCN assessment categories require data on habitat, extent, threats and current degree of protection (Gibbs et al. 2011), some weaknesses of the 2011 assessment have been noted (MacKay 2013a, Ma et al. 2014). The difficulty of assembling the knowledge in one place at one time has been recognised (Oldfield 2010, Cires et al. 2013), and several iterations of a Red List assessment may be needed.

A second potential limitation is the range of data used to define taxa as 'in cultivation'. We used the online BGCI database (which contains 1 359 957 records of 498 053 taxa at 1 146 sites, bgic.org acc. 18 Aug. 2016) as a measure of taxa in cultivation in general, and the BGCI (2012) study to focus the comparison on the largest collections identified by that survey. Although the BGCI (2012) survey covered 304 botanic gardens world-wide, it did not cover every international collection, and it was not strongly representative of the countries of origin for vireya as it included only two sites in Southeast Asia (and seven in Australia). Further research should target additional vireya collections that may be relevant to a conservation programme.

The third possible limitation relates to the taxonomic analysis, which compared sections of different sizes, and highlights the tension between conservation of species diversity (e.g. the broad range of taxa in *Schistanthe*: euvireya) vs less common characters (e.g. the few taxa in *Siphonovireya*) (Paton 2009, Kozlowski et al. 2012, Castañeda-Álvarez et al. 2015). Such comparison hinges on the robustness of the sections, whereby small groups that are distinct could merit a high priority for conservation. Although recent molecular research largely supports most of the current taxonomic groupings (even though views differ on their ranking (Craven et al. 2008, 2011, Goetsch et al. 2011)), additional molecular research is needed to clarify these issues further.

Two further aspects should be noted. Firstly, as the New Zealand data were acquired over a range of time, it is possible that some accessions are no longer extant. Conversely, there may be further accessions in other collections that are yet to be discovered. Secondly, although some herbarium specimens have been assembled from the two largest New Zealand collections and identified by the authors, accessions in other New Zealand collections reported here have not been verified by any of the authors.

CONCLUSIONS

Analysis of the Red List for *Rhododendron* subg. *Vireya* shows that the highest priority for *ex situ* conservation should be assigned to New Guinea, Sumatra, and Sulawesi, and the taxonomic sections *Schistanthe*: malesia, *Hadranthe* (*Phaeovireya*), and *Schistanthe*: euvireya. Although two other origins (Borneo, the Philippines) have reasonably high numbers of Red List taxa, they are better represented in cultivation and have fewer Data Deficient taxa, and hence have a lower priority for *ex situ* conservation. One section, *Pseudovireya*, has a high percentage Red Listed; however, Data Deficiency is low and percentage in cultivation is high, so this section also has a lower priority for *ex situ* conservation.

Of the 400 vireya taxa, 245 are in cultivation, with the largest collection at Edinburgh which holds 91 % of the taxa in cultivation. The collections investigated have several strengths (a substantial range of taxa and Red List taxa, wild-source accessions, and reasonable representation of some geographic origins); however, they also have weaknesses. These include poor representation of some priority geographic and taxonomic groups, and poor security in cultivation, as shown by an almost universally low average number of records on the BGCI database. Our analysis shows that there is considerable work needed to achieve Target 8 of the Global Strategy for *Rhododendron* subg. *Vireya* and our research provides a sound basis for further development. We propose six priorities and actions for conservation:

1. Taxa from New Guinea, Sumatra, and Sulawesi, and the taxonomic sections *Schistanthe*: malesia, *Hadranthe*, and *Schistanthe*: euvireya should have highest priority for *ex situ* conservation. Increasing the number of accessions in cultivation is a key task; activities should include propagation and dispersal of existing accessions, as well as acquisition of new accessions.
2. Mitigation of the risk of the limited number of collections should be addressed. The need for an international network of collections was identified at the Species Conservation Workshop of 2013 (MacKay 2013a) and a group should be formed to advance this initiative for subg. *Vireya*. Decisions are needed on the number and location of sites required world-wide, including collections in countries of origin, as well as the range of taxa to be held at each site.
3. As New Zealand collections appear to be significant world-wide, the potential role of New Zealand collections for *ex situ* conservation should be further investigated.
4. The true threat status of the 113 Data Deficient taxa should be investigated. Only 26 are in cultivation and bringing the remainder into cultivation is desirable, as are the field work and research needed to clarify their Red List assessment.
5. Because our Red List assessment also informs *in situ* conservation, an investigation should be undertaken into current *in situ* programmes for New Guinea, Sumatra, and Sulawesi (involving the countries of Indonesia, Malaysia, and Papua New Guinea). The taxonomic sections *Schistanthe*: malesia, *Schistanthe*: euvireya and *Hadranthe* attained the highest Red List scores in our analysis, suggesting a high priority for *in situ* conservation; however, the sections vary in their geographic characteristics. *Hadranthe* are almost all from New Guinea and so any *in situ* programme there would be likely to capture those taxa. The other two sections are spread across several islands and countries, making an *in situ* investigation somewhat harder to focus.
6. A policy framework for a global *ex situ* conservation plan for *Rhododendron* subg. *Vireya* must be developed to support the previous recommendations. Decisions are needed on the balance between acquiring more accessions of taxa already in cultivation and searching out taxa that are not in cultivation. A process to investigate Data Deficient taxa should be identified and an international procedure for propagation and distribution established. These activities should take place within international regulations such as the Nagoya Protocol, or New Zealands strict plant import regulations. The role of some countries may be limited to certain aspects, e.g. New Zealand could export accessions to other collections; however, cannot easily import additional taxa.

Rhododendron subg. *Vireya* is a large plant group with taxa from a wide range of habitats and niches in Southeast Asia, and as such provides an instructive example for conservation planning. Management of conservation of one of the larger genera of flora of Southeast Asia will advance the whole conservation cause in this region. Our method has combined an analysis of the Red List with an analysis of the incidence of taxa in cultivation, to identify geographic origins and taxonomic sections that should have priority for *ex situ* conservation, and to focus conservation effort on the most urgent groups of taxa within the subgenus. We have proposed six conservation priorities and actions. Any *ex situ* conservation plan should be embedded into an overall (*in situ* and *ex situ*) conservation strategy, yet to be formulated, with this analysis providing a useful component for development of that strategy.

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