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ORIGINAL PAPER

Addressing target two of the Global Strategy for Plant Conservation by rapidly identifying plants at risk

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Abstract Target two of the 2002 Global Strategy for Plant Conservation (GSPC), "A preliminary assessment of the conservation status of all known plant species, at national, regional, and international levels" was not accomplished by its original 2010 target date and has therefore been included as a revised 2020 target, "An assessment of the conservation status of all known plant species, as far as possible, to guide conservation action." The most widely used system to estimate risk of extinction, the International Union for the Conservation of Nature Red List, provides conservation assessments for fewer than 15,000 plant species. Progress achieving Target two has been hampered by the large number of plant species and the difficulty assembling the data needed for Red List assessments. Two streamlined methods for identifying those plant species considered At Risk under the GSPC Target two are compared and contrasted. Both methods use readily available locality data from herbarium specimens to efficiently identify At Risk species and approximate the list of species that would be identified as threatened by Red List analyses. A comprehensive analysis of the native plant species of Puerto Rico using both streamlined methods identifies 570 of the 2,025 species at some risk of extinction. More efficient systems for assessing threat allow a more timely response to Target two, allow conservation efforts to be directed to the species that need attention, and the list of threatened plants can be used to identify priority areas for plant conservation.

Keywords Global Strategy for Plant Conservation · Endangered species · Extinction

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Introduction

A large percentage of the world's 250,000–420,000 plant species (Stebbins 1974; Prance et al. 2000; Thorne 2002; Govaerts 2001; Bramwell 2002; Joppa et al. 2010; Mora et al. 2011) are threatened by habitat loss or degradation, overexploitation, biological invasions, industrialization, pollution and accelerated climate change, with perhaps as many as 94,000–194,000 species at risk of extinction in the near future (Pitman and Jorgensen 2002). Unfortunately, efforts to conserve plant biodiversity are hindered by the lack of a comprehensive global inventory of plant species (Nic Lughadha 2004) and lack of sufficient data for assessment of the conservation status of each species (Brummitt et al. 2008; IUCN 2009). The lack of a comprehensive list of species at risk of extinction is one of the greatest impediments to future efforts to ensure their survival. Conversely, identifying or "greenlisting" species that are not of immediate conservation concern, the vast majority by all estimates, would allow further conservation studies to focus more efficiently on the species that most need attention to ensure their future survival.

The Global Strategy for Plant Conservation (GSPC) was adopted in 2002 at the sixth meeting of the Conference of the Parties to the Convention on Biological Diversity at The Hague in the Netherlands to explicitly address these challenges. The GSPC established five broad aims with 16 outcome-oriented targets designed to halt the current and continuing loss of plant diversity (GSPC 2002). Target one of the GSPC was the production of "A widely accessible working list of known plant species, as a step towards a complete world flora" and Target two was "A preliminary assessment of the conservation status of all known plant species, at national, regional and international levels" (GSPC 2002). Though some progress was made toward the 16 targets, none were fully realized by their proposed 2010 deadlines and the 2010 revision of the GSPC modified the targets and extended the deadlines for their accomplishment to 2020 (Convention on Biological Diversity 2010), extending Target two as "As assessment of the conservation status of all known plant species, as far as possible, to guide conservation action." A comprehensive list of species of conservation concern would help identify those species in need of further study and support development of management plans for their survival. Collectively, the geographic distributions of species of concern can help identify places where they are concentrated, priority areas for plant conservation (Hoffmann et al. 2008).

While there are multiple systems for assessing a species' risk of extinction, including NatureServe's conservation status assessments (www.natureserve.org), most widely used in North America, and CONABIO's system for Mexican plants and animals (SEMARNAT (Secretaría de Medio Ambiente y Recursos Naturales) 2002), only the IUCN's Red List, compiled by the International Union for the Conservation of Nature (IUCN 2001, 2008, 2009) has been widely used to complete global conservation assessments for species. The Red List is the product of a flexible system that may use any one of five criteria to assign each species to a category indicating whether it is extinct, of least concern, or included in one of three increasingly severe threatened categories, from vulnerable to endangered, or critically endangered (IUCN 2001). Assessments can be based on current status of species (e.g. calculated range statistics), take into account the past history of species (e.g. declines measured over ten or more years or three generations), or may speculate about future decline (IUCN 2001; Burgman et al. 2000).

Red List assessments have been comprehensively completed for birds (BirdLife International 2008), mammals (Schipper et al. 2008), and amphibians (Stuart et al. 2008). However, much work remains to assess the more than 350,000 known plant species. The IUCN procedures require more data than what is readily available so fewer than 15,000 plant species had been Red Listed by 2011 (IUCN 2011). While many regional assessments have been completed (e.g. Golding 2002; Jorgensen and León-Yánez 1999; Valencia et al. 2000; León et al. 2006; Llamozas et al. 2003; Zona et al. 2007; Raimondo et al. 2009), most of these efforts have assessed species on a regional, rather than global, basis or only include those species identified as threatened. There are serious conceptual and practical problems in applying the system on a restricted geographic basis as opposed to the global distribution of a given species. Species that are uncommon, and possibly at risk of disappearance locally in one region, may be abundant with healthy populations in another. To date, the only taxonomically comprehensive efforts available for plants are for cycads (Donaldson 2003) and conifers (Farjon et al. 2006). What is desperately needed is a streamlined procedure for evaluation of conservation status that could produce credible results for large numbers of species using data that is readily available.

Population demographic data needed to evaluate species under IUCN's Criteria A, C, D(1), and E are seldom available for plants, so the most appropriate method for evaluating plant species is generally Criterion B (geographic range), as locality information from herbarium specimens can be used to calculate extent of occurrence (EOO) and area of occupancy (AOO) (Willis et al. 2003; Brummitt et al. 2008). EOO is defined as "the area contained within the shortest continuous imaginary boundary that can be drawn to encompass all sites of present occurrence of a taxon" and AOO is the calculated area actually occupied within this range (Cardoso et al. 2011). Species are categorized as threatened if either their EOO or AOO values fall below thresholds established by the IUCN, and if two or more additional subcriteria are met: (a) severe fragmentation or a small number of localities, (b) continuing decline in range, habitat, number of subpopulations, or number of individuals, or (c) extreme fluctuation in range, habitat, number of subpopulations, or number of individuals (IUCN 2001).

Both EOO and AOO can easily be calculated from specimen data and EOO is a good measure of range size, but interpretations of AOO are fraught with difficulties (Miller & Porter-Morgan 2011). Both statistics suffer from incomplete sampling, as available collection data only document known occurrences and absence of documentation does not mean that a species does not occur in suitable habitat. AOO is generally calculated by overlaying a grid on the known distribution and summing the area of cells with documented occurrence. These calculations are highly influenced by selection of grid size. Grid cells small enough so that a single cell does not exceed the Critically Endangered threshold require a very large number of collection localities to exceed the IUCN thresholds, but seldom are sufficient numbers of collections available, even for the most common species (Gaston and Fuller 2009), so calculation of meaningful AOO values from herbarium data is at best difficult. More than 500 collection-documented localities were necessary to reach the AOO of 2,000 km^2, threshold for threatened in the Red List in a survey of orchids and legumes from Madagascar, a number of collections that are never available, yet the conclusion that those species known from fewer than 500 localities were all threatened was a gross exaggeration (Rivers et al. 2011). For that reason, the first method tested here relies on EOO calculations. One further complication is the relationship between rarity or endemism and threat. While many species at risk of extinction have very restricted distributions and are rare (Pimm 1998), not all range-restricted species are rare and some may be locally abundant (Robbirt et al. 2006).

The greatest challenge to completing comprehensive conservation assessments is the lack of available data. Specimen data are scattered among numerous herbaria in many different locations, little of this information is available online, and only a small percentage of specimen records include the latitude and longitude coordinates required to calculate range statistics. Assembling this information and retrospectively georeferencing specimen records for large numbers of plant species is a daunting task so it has been accomplished comprehensively only for relatively small groups of species.

The GSPC does not specify a method for the conservation assessments needed to accomplish Target two. The present study compares two streamlined systems for conservation assessments developed at The New York Botanical Garden (hereafter, NY) and the Smithsonian Institution (hereafter, US), using simplified approaches to separate and identify species that are "At Risk," the aim of GSPC Target two. "At Risk" was specifically selected so as to not overlap with IUCN's nomenclature, as the methods are considered to be both an approach to GSPC Target two and also a first approximation of a list of species that would be identified as threatened with Red List assessments. The NY method uses EOO calculations under IUCN's Criterion B to rapidly separate "At Risk" species from those with calculated EOO values above the IUCN's 20,000 km^2 threshold for threatened. The US method (Krupnick et al. 2009) uses an approach to separate species that are geographically widespread, abundant, and documented by recent collections from those "At Risk". A comprehensive review of the flora of Puerto Rico compares the results of both methods.

The flora of Puerto Rico includes 2,025 species of native seed plants (Acevedo-Rodríguez and Strong 2007, 2008), is well-known, and well documented by herbarium collections so it is ideal to test the two streamlined conservation assessment methods. Only 53 native Puerto Rican plant species have been considered threatened in the Red List (IUCN 2011; www.redlist.org), certainly an underestimate as only a small percentage of the flora has been evaluated. The primary objective of this study was to utilize the new rapid methods to assign every one of the 2,025 native species of seed plants from Puerto Rico into one of two categories, At Risk or Not At Risk; thereby completing a comprehensive analysis of the entire island's native flora.

Materials and methods

The NY Method: Herbarium specimen locality data were downloaded to a project geodatabase from the Global Biodiversity Information Facility (GBIF) (http://www.gbif.org/) and The New York Botanical Garden's Virtual Herbarium (http://sciweb.nybg.org/science2/VirtualHerbarium.asp) for 2,025 accepted seed plant species from the checklist for the Flora of the West Indies (http://botany.si.edu/antilles/WestIndies/) (Acevedo-Rodríguez and Strong 2008). The geodatabase was imported into ArcGIS 9.2 (ESRI 2007) and all specimens with geographic coordinates were projected to an Albers projection with a World Geodetic System 1984 datum. Extent of Occurrence (EOO) was calculated for all species with at least three unique known localities by creating a minimum convex polygon using the ArcGIS extension, Hawth's tools (Beyer 2007), the smallest polygon that encompasses all specimen localities and has no angles that exceed 180 degrees (IUCN 2008). Areas of unsuitable habitat, such as large bodies of water, were excluded from the EOO calculations using ArcGIS 9.2 (ESRI 2007; IUCN 2008)

All species with initially calculated EOO values above 20,000 km^2, the IUCN limit for the vulnerable category (IUCN 2001), were assigned to the "Not At Risk" category, assuming that inclusion of additional locality data could only increase the calculated EOO and document more widespread occurrence. For those species with initial calculated EOO values below the 20,000 km^2 threshold, or for which fewer than three known localities did not allow calculation of EOO values, the specimens that lacked geographical coordinates were georeferenced, assigning latitude and longitude values by using a combination of digital USGS maps and Google Earth. Collections of species with initial EOO values greater than 20,000 km^2 were not georeferenced as those species were already considered widespread. This avoids georeferencing the greatest percentage of specimens of widespread species and focuses the effort on the more limited numbers of collections of less common species, where additional locality data could change their conservation status. After georeferencing, EOO values were recalculated, and those species with EOO values above 20,000 km^2 were considered "Not At Risk" and if EOO's were still less than 20,000 km^2 species were categorized as "At Risk." Recalculating EOO values after georeferencing reduced the number of species known from three or fewer georeferenced collections by a third and allowed many species originally below the 20,000 km^2 threshold to be considered "Not At Risk." Using this assessment procedure, the "At Risk" category should include all species that would considered threatened under IUCN's criterion B1, but will likely also include a limited number of species that might have an EOO greater than 20,000 km^2 if more comprehensive specimen data were analyzed. However, it appears likely that all of the species that are considered "At Risk" are significantly range-restricted, and therefore of some conservation concern, even if additional localities might increase their EOO values beyond the 20,000 km^2 threshold.

The US Method: A U.S. National Herbarium database of 83,762 plant specimens of seed plant species native to Puerto Rico was compiled and analyzed using the methods outlined in Krupnick et al. (2009). The US four-step conservation assessment algorithm (Krupnick et al. 2009) makes use of temporal, spatial, and abundance data associated with herbarium specimens to provide a rapid and preliminary evaluation of the conservation status of a plant species. The categories "Potentially Extinct" and "Potentially Threatened" from Krupnick et al. (2009) were re-labeled here as "At Risk;" the "Not Threatened" category was re-labeled here as "Not At Risk." Like the NY method, the list of accepted species was derived from the checklist for the Flora of the West Indies and included the same 2,025 native species of seed plants.

The US method for conservation assessment included four steps: Step one analyzes the age of collections to determine how recently occurrence is documented by available herbarium specimens. If a species has not been collected since 1900 it is considered to be "At Risk."

Step two aims to assess geographic distribution by determining if species are known from six or more natural locations. Location is defined here as the province or municipality level for Caribbean islands with an area greater than 9,000 km^2, or smaller individual islands are considered a single location. For the purposes of this study, political divisions were selected at the historical time of their greatest area in the past century: the 1970 map of Cuba, the 1922 map of the Dominican Republic, and the 1924 map of Haiti (see drawings of maps in Zanoni 1995). Species known from six or more locations are considered to be "Not At Risk", and remaining species documented from five or fewer locations continue on to step three.

Step three aims to assess rarity from abundance of available herbarium specimens, determining whether a given species is represented by less than or equal to the median number of specimens per species. The median number of specimens per species is 28 in the U.S. National Herbarium database. If a given species is known from 28 or fewer specimens, the species is considered to be "At Risk," and if known from more than 28 specimens, it is analyzed in step four.

Step four assesses decline of a species by determining whether the species is known from less than or equal to the median number of specimens collected since 1st January

1960. The median number of specimens collected since 1st January 1960 is seven in the U.S. National Herbarium database. The species remaining after the first three steps of analysis each are known from a large number of specimens (more than the median number), but from fewer than six locations. If the species is known from less than the median number of specimens collected since 1960, then the species may be in decline and is considered “At Risk.” Those taxa that are documented from more than the median number of recently collected specimens are considered to be “Not At Risk.”

Results

The NY analysis determined that 459, or 23 %, of the 2,025 native species of seed plants from Puerto Rico had calculated EOO values below 20,000 km^2 and were therefore considered “At Risk”. The remaining 1,566 species, or 77 %, of the native Puerto Rican flora, had a calculated EOO greater than 20,000 km^2 and were considered “Not At Risk.” Following the initial download of specimen locality data, 549 species had calculated EOO values below 20,000 km^2 and were considered “At Risk.” Following georeferencing, efficiently focused on only the limited number of specimens from species where new EOO calculations could change their categorical assignment, the number of “At Risk” species was reduced to 459, a reduction of 16 %. The US analysis determined that 367, or 18 %, of the 2,025 Puerto Rican native species were “At Risk,” as they have been collected from fewer than six islands or provinces, they were under-represented in herbarium collections, or they have not been recently collected. The remaining 1,658 species, or 82 %, of the Puerto Rican native species were either widespread or abundant and considered “Not At Risk.” In both analyses, 256 species were identified as “At Risk” and 1,455 species were “Not At Risk,” an 85 % agreement. The NY analysis identified 203 species as “At Risk” that were “Not At Risk” in the US analysis, and the US analysis identified 111 species as “At Risk” that were “Not At Risk” in the NY analysis. In total, there were 570 species, or 28 %, that were identified as At Risk in either or both analyses.

The species categorized as “At Risk” in these analyses appear to include all of those species that would be classified as threatened under IUCN’s criteria. However, the At Risk category in both analyses probably also includes some species for which additional specimen locality data might increase the calculated EOO beyond the 20,000 km^2 threshold or past the numerical thresholds used in the US method, moving a limited number of species into the “Not At Risk” category. Even if these species would not be considered threatened in a Red List assessment with more specimen data, they are likely range-restricted and therefore of conservation interest.

The results of the NY and US analyses were compared to the latest available IUCN Red List assessments (accessed November 18, 2011) to determine the congruence between those species considered “At Risk” with those assigned to the IUCN’s threatened categories. The NY analysis identified 47 of the 53 Red List threatened species (Table 1 in Appendix) as “At Risk.” The six not identified as “At Risk” include *Ilex sintenisii*, Red Listed as threatened, but recently considered a synonym of the widespread *Ilex obcordata* var. *obcordata* (Acevedo-Rodríguez and Strong 2008), a widespread species with an EOO well beyond the 20,000 km^2 threshold. Two more Red Listed species, *Halophila baillonis* and *Picrasma excelsa*, were considered threatened by IUCN based on regional assessments but their global distributions are widespread with EOOs much greater than 20,000 km^2. The other three species, *Guaiacum officinale*, *Guaiacum sanctum*, and *Mappia racemosa*, all considered “Not At Risk” in both the NY and US analyses, were listed as threatened by

IUCN because they are economically useful, have been overharvested and possibly locally extirpated, and as a consequence have become rare throughout their range, even though they were once widespread. The results of the US analysis are congruent with the Red List results for all but 11 of the 53 threatened species. Five of the species identified in the NY analysis as "Not At Risk," but considered threatened by IUCN, were also identified as "Not At Risk" in the US analysis, *Ilex sintenisii*, *Guaiacum officinale*, *Guaiacum sanctum*, *Mappia racemosa*, and *Picrasma excelsa*, but six additional Red Listed species (*Chrysophyllum pauciflorum*, *Erythrina eggersii*, *Juglans jamaicensis*, *Maytenus cymosa*, *Tabernaemontana oppositifolia*, *Zanthoxylum flavum*) were also identified as "Not At Risk" in the US analysis because they are known from six or more locations. Therefore, with a few explainable exceptions, the results of the present analysis were found to have a high level of congruence with the IUCN assessments that have been completed.

Discussion

Both of the methods described in this paper were designed to streamline conservation assessments using readily-available data to achieve the GSPC Target two goal of identifying plant species that are vulnerable to extinction. They were designed to be efficient and use readily available herbarium specimen data to approximate the list of plant species that would be identified as threatened by IUCN, which also meets GSPC Target two by differentiating between species that are "At Risk" or "Not At Risk." Neither method is intended to replace IUCN's Red List procedures nor can they differentiate between and assign species to IUCN's critically endangered, endangered, or vulnerable categories. Both methods depend on analyses of geographic range, determined by several studies to be a core determinant for risk of extinction, with higher extinction risk associated with small ranges (e.g. Fischer and Blomberg 2010, Lee and Jetz 2010). The two methods use either GIS-based calculations of EOO from herbarium specimen data or temporal, spatial, and abundance data from herbarium specimens to rapidly complete global assessments.

The results of both analyses seem credible for several reasons. The NY analysis indicates that 23 % of the Puerto Rican flora is "At Risk," 18 % were identified in the US analysis, and 28 % of species were "At Risk" in one or both analyses, figures consistent with other efforts to estimate the world's threatened flora. The Sampled Red List Index (Brummitt et al. 2008) reviewed the conservation status of 7,000 plant species in a survey of selected plant families and found that approximately 20 % were threatened by IUCN standards, while Pitman and Jorgensen (2002) estimated that at least 27 % of the world's flora was endangered. Specimen locality data is scattered among the many herbaria in the world, and only a small percentage was readily available for these analyses. But while the inclusion of additional data could result in greater EOO values or numbers of locations, the number of "At Risk" species that would then change to exceed the "Not At Risk" threshold is probably small and it is likely that those species are still range restricted and hence of some conservation interest. While having the most comprehensive amount of locality available will certainly result in the most accurate assessment of a given species conservation status, Rivers et al. (2011) did demonstrate that a minimum of 15 collections resulted in informative conclusions from analysis with Criterion B in almost every case, so methods using available data, even if it is not complete, may have great utility in achieving Target two.

The two streamlined methods used here also produce results that differ from results expected from Red List analyses in limited instances. One unusual exception is wide-ranging species with EOO values above 20,000 km^2 that are uncommon throughout their range as a result of over-exploitation. Three Puerto Rican species identified as threatened in the IUCN Red List have EOO's above 20,000 km^2, yet they are locally rare, with population numbers reduced by exploitation. Another possible discrepancy may result from localities documented by older specimens no longer representing extant populations, hence the NY method may calculate an EOO that exaggerates the current range of species, but the US method incorporating age of collections in the analytical algorithm may compensate for this.

The conclusions of both methods presented here overlap in their conservation assessments, but also differ significantly in their predictions. Both methods identified 256 "At Risk" species, and these included all but 11 of the species that IUCN has listed as threatened, but 334 additional species were identified as "At Risk" in only one of the analyses, 203 in the NY study and 111 from the US review. It seems likely that all of the 334 species are in some sense range-restricted, as their calculated EOO values were below the threshold or they were known from a limited number of locations or only older collections not likely to represent extant populations. Puerto Rico is only 8,959 km^2, so the NY analysis automatically considered all endemic species to be "At Risk," as the area of the island is below IUCN's 20,000 km^2 threshold. While both methods probably overestimate the number of "At Risk" species because of the limited availability of specimen data, they are both conservative in the assignment of species to the "Not At Risk" category. The NY method is one of the possible first order approximations of IUCN's Criterion B, so the only species considered "Not At Risk" that may actually be IUCN threatened would be the very limited number of cases where once wide-ranging species have been extirpated throughout their ranges by human exploitation (three cases in this example). It is difficult to similarly assess the US method as it is not parallel to any of IUCN's approaches, but it is almost certainly also conservative assigning species to the "Not At Risk" category.

The methods presented here provide a global conservation assessment of the native flora of a tropical region. The two streamlined methods use readily-available data from online databases with GIS tools to separate "At Risk" species from those that are "Not At Risk" effectively 'greenlisting' widespread species, those are not of conservation concern at this time and allow conservation to focus on those species that need immediate attention.

Conclusions

The analyses described here were designed specifically to address Target two of GSPC a "An assessment of the conservation status of all known plant species, as far as possible, to guide conservation action" (Convention on Biological Diversity 2010). Both methods can provide efficient global conservation assessments for all species in a given flora using readily available specimen locality data. Both methods facilitate assessment of a greater numbers of species per unit effort, they are less time consuming and can be completed with available data, and are therefore more immediately responsive to providing valuable information that can help focus additional field studies relevant to those species at greatest risk. These methods for identifying plants "At Risk" are an efficient approach to Target two of GSPC and a means to move beyond the limited number of assessments completed for the Red List.

The results of the two analyses presented here are considered preliminary, both in the sense that additional information may be essential for confident conservation assessments and also that they can be a first step toward achieving IUCN Red List assessments in an efficient manner. It is clear that both methods probably overestimate the number of plant species "At Risk," but likely are still species of some conservation concern because of limited geographic distribution. There is a strong correlation between limited geographic distribution and likelihood of extinction (Pimm 1998), but Robbirt et al. (2006) also point out that not all range-restricted plants are at risk and that assessments must determine if they are locally abundant in healthy populations. For this reason, field studies may be required to confirm real risk of extinction. These methods are also considered a first step in that neither distinguishes the relative conservation priority that differentiates IUCN's threatened category into the subcategories critically endangered, endangered, and vulnerable, one of the most valuable assets of IUCN's system, so additional data, from further examination of additional collections or field observations are essential to identify priorities for conservation within the list of species generated by these two methods.

The GSPC Target two goal of a comprehensive list of "At Risk" plant species has enormous conservation value. Efficiently 'green-listing' wide-ranging species allows conservation efforts to focus on the species that most need attention to ensure their survival, targeting individual species for development of management plans and identifying areas where further field studies are needed to clearly identify priorities. The tools used to conduct these analyses can also map distributions of "At Risk" species and identify specific geographic places where threatened plants are concentrated. The places thus identified may be considered priority areas for conservation and possible candidate areas for protected status. Streamlined methods for preliminary global conservation assessments are thus an essential tool for achieving these goals and can be applied across other geographic regions to efficiently work toward the completion of Target two of GSPC.

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Appendix: Native Puerto Rican seed plant species categorized as at risk

See Table 1.

Table 1 The 77 species of native Puerto Rican seed plants currently assessed in IUCN's Red List with preliminary conservation assessments from the methods evaluated here

	2011 Red List	NY at risk	NY not at risk	US at risk	US not at risk
CR (Critically endangered)	20	20	0	20	0
EN (Endangered)	17	14	3	12	5
VU (Vulnerable)	16	13	3	10	6
Sum (=IUCN threatened)	53	47	6	42	11
NT or LR/nt (Near threatened)	4	2	2	3	1
LC or LR/lc (Least concern)	19	0	19	2	17
DD (Data deficient)	1	1	0	0	1
Sum	77	50	27	47	30

Ten additional species (8 = LC; 2 = DD) are included by IUCN in the current Red List, but they are considered exotic and not part of the native flora by Acevedo-Rodríguez and Strong (2007) and thus were not included in the assessments evaluated here

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