Assessing the effectiveness of Madagascar's changing protected areas system: a case study of threatened Boraginales

James S. Miller and Holly A. Porter Morgan

Abstract Threat analyses of the Boraginales were conducted and used to assess the effectiveness of Madagascar's current and proposed protected area systems in conserving the threatened species of a group of plants widespread in Madagascar. Specimen locality data for 52 species of four families of Boraginales were analysed to provisionally assign species to IUCN Red List categories. Six species were excluded from these global analyses as they are non-native and introduced. IUCN's criterion B, analysis of geographical range, was found to be the most reliable means of estimating threat, and predicted future decline was found to overestimate threat. Twenty-six of the 46 native species of Boraginales were found to be threatened. Sixty-five percent of these have portions of their ranges in the 2002 protected areas system. When the protected areas system was expanded in 2006 the percentage of species with some protected populations increased to 78%. More than 93% would be protected if a series of proposed priority areas for plant conservation were protected. The implications of these analyses for the conservation of plant species in Madagascar are discussed.

Keywords Boraginales, conservation, IUCN Red List, Madagascar, protected areas

This paper contains supplementary material that can be found online at http://journals.cambridge.org

Introduction

Madagascar, the world's fourth largest island, lies c. 460 km off the south-west coast of southern Africa. It is a global conservation priority because of its exceptional combination of high species diversity and c. 90% species-level endemism amongst plants (Phillipson, 1994; Schatz, 2002) combined with high rates of deforestation that have left only c. 7% of the original vegetation intact (Green & Sussman, 1990; Myers et al., 2000). The flora of Madagascar remains poorly studied. Forty families, accounting for c. 20% of the flora, lack taxonomic treatments in the Flore de Madagascar (Schatz et al., 2000) and most available treatments are out of date. Recently revised families show that early accounts seldom recognize the full complement of species that are now documented in available collections.

Given the extent of deforestation in Madagascar it is clear that a significant proportion of the flora is threatened but present knowledge does not allow comprehensive identification of all threatened plant species. Protecting all threatened Malagasy plant species would require a comprehensive list of species and associated specimen data, which could then be analysed to identify those species at greatest risk of extinction. Knowledge of the distribution of species at risk could be used to identify the geographical localities most critical for protecting the greatest percentage of plant species. Unfortunately, as Schatz et al. (2000) concluded, this is not available for two-thirds of Malagasy plant families. Given this situation, priority areas for plant conservation can best be identified by the study of representative groups of species for which reliable taxonomy is available (Kremen et al., 2008).

Given the continuing rate of deforestation in Madagascar, Schatz et al. (2000) predicted the extinction of most threatened plant species that did not have part of their distribution in protected areas. Subsequent studies used percentage area of occupancy (AOO, defined as the area within the extent of occurrence, EOO, that is occupied by a taxon, where EOO is defined as the area contained within the shortest continuous imaginary boundary that can be drawn to encompass all the known sites of occurrence of a taxon, excluding cases of vagrancy; IUCN, 2001) inside and outside protected areas to calculate predicted future decline, a measure that can be applied under IUCN criterion A (Randrianasolo et al., 2002; Callmander et al., 2007). Madagascar has an extensive system of protected areas that has recently been expanded by the designation of an additional system of provisional protected areas. However, the original system protected only 1.7 million ha (c. 2.9% of terrestrial area) and the provisional system adds only 2.18 million ha, bringing the area protected in 2008 to 6.3% (Kremen et al., 2008) but still leaving many botanically significant areas unprotected.

Here we examine the species of Boraginales, a diverse order of flowering plants with 52 representatives in four families known from Madagascar and the Comoros Islands, which have related floras (Humbert, 1936), analysing available specimen data to assign species to threat categories

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(IUCN, 2001). Each species was assessed by analysis of its global distribution and the relative percentage of its distribution in currently and provisionally protected areas. A proposed series of priority areas for plant conservation were reviewed to determine their impact on the conservation of Boraginales. We thus use the Boraginales to assess the effectiveness of Madagascar's current and proposed protected areas systems.

Boraginales

The order Boraginales comprises six families (Gottschling et al., 2005) including the four subfamilies of the formerly defined Boraginaceae elevated to familial rank, Cordiaceae, Ehretiaceae, Heliotropiaceae and Boraginaceae, along with the families Hydrophyllaceae and Lennoaceae that are nested within the traditionally broadly defined Boraginaceae (Luebert & Wen, 2008). All four families of the Boraginaceae s.l. are represented in Madagascar. The Hydrophyllaceae and Lennoaceae, except the South African endemic genus *Codon* L., are restricted to the Americas. A recent treatment of Boraginales for the Flore de Madagascar et des Comores (J. S. Miller, unpubl. data) is available as are treatments for many of the constituent genera (Miller, 2001a,b, 2002, 2003a,b, 2005). Fifty-two native and introduced species of Boraginales in the four families are known from Madagascar and the Comoros Islands. Species of Boraginales occur in a variety of habitats and many persist well in disturbed areas but they are most diverse in dry to seasonally dry vegetation (Gottschling et al., 2005).

Methods

A database containing information from all available herbarium specimens for the 52 species of Malagasy Boraginales was created in the geographical information system (GIS) *ArcGIS v. 9.2* (ESRI, Redlands, USA). A total of 928 localities were compiled from specimens examined from the following herbaria: British Museum of Natural History (BM), Royal Botanic Gardens, Kew (K), Missouri Botanical Garden (MO), Muséum National d'Histoire Naturelle, Paris (P), Parc Botanique et Zoologique de Tsimbazaza, Madagascar (TAN), Herbier du Service Forestier, FOFIFA, Madagascar (TEF), and Agricultural University, Wageningen (WAG). Herbarium specimens that did not have latitude and longitude values in their label data were georeferenced using Schatz & Lescot (2003). All specimen localities were expert validated and projected to an Albers projection with a World Geodetic System 1984 datum.

Threat analysis

Provisional assignment to Red List categories followed IUCN (2001) and was determined using EOO, AOO and field observations by JSM. Native species determined to be threatened were categorized as Critically Endangered (CR), Endangered (EN) or Vulnerable (VU), those species found not to be threatened as Least Concern (LC), and introduced species were not evaluated. The category Near Threatened was not used.

A species is assigned to the most serious threatened category for which it meets at least one of five quantitative criteria and any associated subcriteria (IUCN, 2001). Locality data from herbarium specimens can be used to assess threat under criterion B by calculating two spatial parameters from distribution data (Willis et al., 2003). To be thus categorized a species requires calculated values for either EOO or AOO below the category thresholds and must meet the requirements for at least two of the following subcriteria: (1) severe fragmentation or small number of locations, (2) continuing decline in distribution or population size, and (3) extreme fluctuation in distribution or population size (IUCN, 2001). Although herbarium data may also be used to categorize species under the criteria A and D, these criteria were not applicable for this study (see Discussion).

Specimen locality data were used to calculate EOO and AOO in *ArcGIS*. The thresholds for EOO and AOO applied to the values derived from the GIS analyses were: CR: EOO < 100 km^2, AOO < 10 km^2; EN: EOO $< 5{,}000$ km^2, AOO < 500 km^2; VU: EOO $< 20{,}000$ km^2, AOO $< 2{,}000$ km^2.

EOO was determined for all species for which at least three unique localities are known, and AOO was assessed for all native species. As areas of clearly unsuitable habitat may be excluded it is valid, for example, to remove a large water body from the EOO of a terrestrial species. The standard method for estimating EOO is the minimum convex hull, the smallest polygon that can be created that includes all of the specimen localities and has no angles that exceed 180 degrees (IUCN, 2008). To calculate EOO a script was written in *ArcGIS* that created minimum convex hulls, excluded those portions of the resultant polygons that covered water, and then calculated the area contained by each polygon.

AOO represents the amount of suitable habitat actually occupied by a species and can be calculated by superimposing a grid of cells over the mapped specimen localities, scoring as occupied any grid cell in which at least one specimen locality occurs and summing the total area of all occupied grid cells (IUCN, 2008). For this study AOO was calculated using a 3×3 km grid (9-km^2 grid cells) following Callmander et al. (2007).

Protected areas analysis

To assess the effectiveness of Madagascar's current and proposed protected area systems in conserving the Boraginales the distribution of each species was analysed to

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determine the percentage of the AOO that occurs within three sets of conservation areas: (1) the original protected areas managed by the Madagascar National Parks (MNP), formerly known as the Association National de Gestion de Areas Protégées, (2) the additional areas that were provisionally protected between 2002 and 2006 via the Durban Vision process and had not received formal protection by 2008 (Kremen et al., 2008), and (3) a series of priority areas for plant conservation that were identified in 2004 by an expert group at MO and had not received provisional protection by 2006 (Fig. 1). Some of the areas identified in the MO analysis received provisional protection in 2005 and 2006.

The protected areas managed by MNP comprises Strict Nature Reserves, National Parks and Special Wildlife Reserves, all of which were established prior to 2003, hereafter referred to as MNP. For the purposes of this study, the MNP GIS layer included the original MNP protected areas plus any provisionally protected areas that had received fully protected status by 2008 (Kremen et al., 2008).

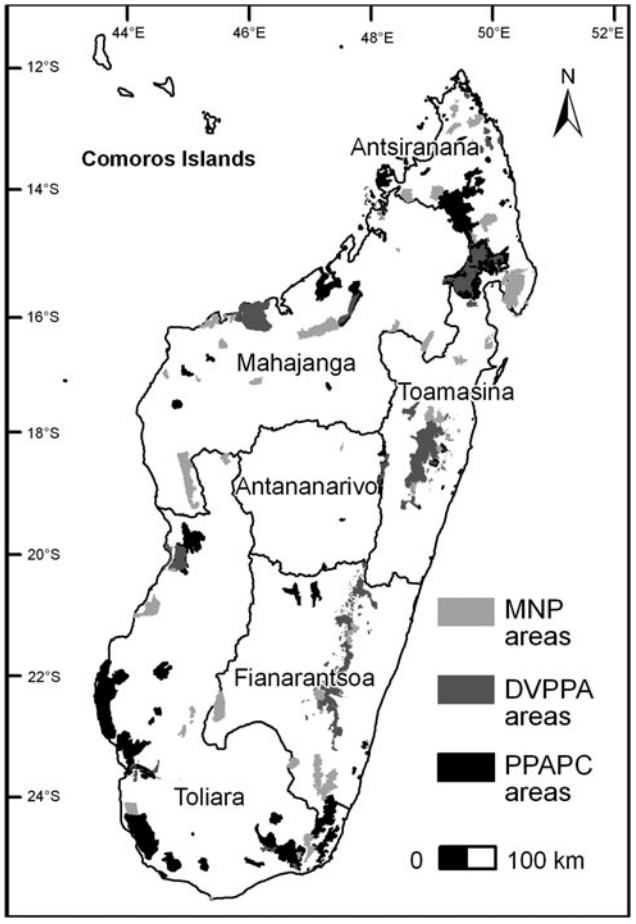

FIG. 1 Conservation areas in Madagascar: MNP (Madagascar National Parks' managed protected areas), DVPPA (Provisionally Protected Areas from the Durban Vision process), and PPAPC (proposed Priority Protected Areas for Plant Conservation from the Missouri Botanical Garden analysis; Rahari-mampionona et al. 2006).

In September 2003, at the World Parks Congress in Durban, South Africa, Malagasy President Marc Ravalomanana announced his commitment to triple Madagascar's protected area system, and the effort to identify new protected areas has become known as the Durban Vision. This identified an additional 2.18 million ha that were granted provisional protected status between 2002 and 2006. Management of these provisionally protected areas will be handled by a number of government agencies, NGOs and other institutions. A number of these areas have subsequently been permanently protected and it is anticipated that all will be protected after management plans have been approved; these areas are hereafter referred to as the Durban Vision Provisionally Protected Areas (DVPPA) and include only those areas that are provisionally protected (Kremen et al., 2008).

The third set of areas was identified via an expert analysis conducted by a team from MO in 2004 using GIS to review present extent of vegetation, vegetation type, soils, climate, protected area boundaries, distributional data for several representative plant families and known distributions of threatened species. The existing vegetation was reviewed in one-degree grid squares, considering information from the data layers, as well as expert opinion, and a series of priority areas for plant conservation were identified that met at least one of the following criteria (Raharimampionona et al., 2006): (1) areas including primary vegetation of a type not present in the existing protected areas system; (2) areas including primary vegetation on soil substrates not represented in the existing protected areas; (3) areas with documented occurrence of significant numbers of endemic, newly discovered, threatened or unprotected species; (4) significant forested corridors connecting existing protected areas.

Although significant forested corridors were not selected for the specific types of vegetation or species that they would protect, as were other areas, they were perceived to be bold proposals that would contribute substantially to the preservation of biodiversity and environmental integrity in Madagascar. The 82 areas identified as priorities were presented to the Durban Vision team and were part of the materials used to delineate the provisionally protected areas, some of which have subsequently gained provisional protected status. Those that were provisionally protected are included in the DVPPA, while those still not provisionally protected are here called the Proposed Priority Areas for Plant Conservation (PPAPC).

Results

Threat analysis

The six non-native species were not evaluated and excluded from further analysis. Of the remaining 46 species, 28 are

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endemic and 18 have portions of their range in other countries but are established in Madagascar and considered part of the flora (Table 1). As the calculation of EOO requires a minimum of three unique specimen localities, EOO could not be determined for five species known from only 1–2 collections. For the 46 native species of Boraginales from Madagascar and the Comoros, the resultant provisional Red List assignments and their rationale are summarized in Table 1 and the Appendix. A total of 26 species (56.5%) are provisionally assigned threatened categories and will be submitted to the Red List authority, with six categorized as CR, 10 as EN and 10 as VU. Twenty species were categorized in the non-threatened category LC.

Of the 18 non-endemic species only *Cynoglossum cernuum* was assigned to a threatened category. Although it has a limited distribution outside Madagascar both the Malagasy and the Mauritian populations are small and occur in habitats under threat; this species was therefore categorized as VU. Ten species are weedy and persist well in highly disturbed areas and were therefore categorized as LC. The remaining seven non-endemic species were categorized as LC because they are reasonably widespread.

Although the threatened Boraginales are well distributed across the majority of lowland Madagascar, there are two distinct areas with high concentrations of threatened taxa. The first is along the south-west coast, around the town of Tulear. In this area just north of the Onilahy River and just outside the plant priority site named La table, St Augustin, Sept lacs, there are seven species. The low-canopy dry forests of this area are under threat from the production of charcoal to supply Tulear, and most of these forests have been significantly degraded, making protection of the remaining fragments a high priority. Seven threatened species, including four additional species not found north of Tulear, occur near the south-eastern tip of the country between the towns of Ambovombe and Amboasary. It includes the lower portion of the Mandrare corridor Andohahela plant priority area and extends west to just below the priority area Ampamalora. This area has been nearly completely deforested and only small fragments of degraded forest remain.

Protected areas analysis

Thirty-six of the 46 native species (78.2%) of Boraginales in Madagascar and the Comoros have some proportion of their range currently protected (Table 2). Twelve of the species, seven of which are endemics, have no part of their range in the MNP and DVPPA. Of the six species categorized as CR, three (*Cynoglossum birkinshawii*, *Heliotropium perrieri* and *Hilsenbergia angustifolia*) have no known localities within the MNP or DVPPA. Two species (*Tournefortia kirkii* and *Tournefortia puberula*) have c. 50% of their known range in protected areas and thus, although their AOO is below the threshold for EN, with half of their known localities protected they are considered VU and LC, respectively. Although the single locality attributed to *Cynoglossum tsaratananense* is within a protected area, this species has not been collected for nearly 80 years and is in an area that has been visited by botanists. It is therefore provisionally considered CR with the possibility of being extinct.

When the Malagasy protected area network was expanded to include the DVPPA the number of Boraginales species under protection increased. The original MNP areas contained 30 species with at least a single population within their boundaries. The addition of the DVPPA protected six additional endemic species (*Ehretia australis*, *Ehretia meyersii*, *Cordia lowryana*, *Cordia schatziana*, *Cynoglossum lowryanum* and *Hilsenbergia mortiana*), increasing the number of native species at least partially protected from 65.2 to 78.2%.

The promotion of the PPAPC to permanent protected areas status would further increase the proportion of Boraginales species that are protected. Six additional species would gain protection (*Cordia caffra*, *C. birkinshawii*, *Cynoglossum monophlebium*, *Heliotropium bacciferum*, *Hilsenbergia croatii* and *Trichodesma zeylanicum*); three are endemic and provisionally assigned to threatened categories. If the PPAPC are included in the Malagasy protected areas network, 43 of the 46 species (93.4%) would have a portion of their AOO inside one or more protected areas.

Discussion

This analysis categorizes 26 of the 46 species (56.5%) of Boraginales native to Madagascar and the Comoros as threatened. All but one of these threatened species is endemic. The percentage of threatened Boraginales is lower than that reported for other plant groups: 100% of several genera of Anacardiaceae (Randrianansolo et al., 2002), 91% of Pandanaceae in Madagascar (Callmander et al., 2007), and 92% of the endemic tribe Coleeae of the Bignoniaceae (Good et al., 2006). Boraginales have a lower percentage of endemism (61%) compared with the 90% or more predicted for the Malagasy flora as a whole. Within the Boraginales all but one of the non-endemic species are not considered threatened but 89% of the endemic Boraginales are threatened, a figure similar to endemic taxa in other studies.

IUCN thresholds for AOO under criterion B were found to either underestimate or overestimate threat for the majority of species assessed and therefore the calculated values were carefully considered. This fact is especially important because AOO has played a significant role in assigning species to threat categories, with almost 50% of the species for which Red List assessments had been

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TABLE 1 The 52 species of Boraginales known from Madagascar and the Comoros Islands (Fig. 1), with their status, extent of occurrrence (EOO), area of occurrence (AOO) and provisional IUCN Red List assignment.

Species (by Family)	Status[1]	EOO[2]	AOO[2]	Red List assignment[3]
Cordiaceae				
Coldenia procumbens L.	N	9,538 (VU)	63 (EN)	LC
Cordia africana Lam.	I			NE
Cordia caffra Sond.	N	90,684	270 (EN)	LC
Cordia dentata Poir	I			NE
Cordia lowryana J.S. Mill.	E	156,060	180 (EN)	VU
Cordia mairei J.S. Mill.	E	202,800	423 (EN)	LC
Cordia monoica Roxb.	N	49,310	72 (EN)	LC
Cordia myxa L.	N	313,402	459 (EN)	LC
Cordia schatziana J.S. Mill.	E	90,631	54 (EN)	EN
Cordia sinensis Lam.	N	236,571	180 (EN)	LC
Cordia subcordata Lam.	N	217,363	198 (EN)	LC
Varronia curassavica Jacq.	I			NE
Ehretiaceae				
Ehretia australis J.S. Mill	E	4,224 (EN)	54 (EN)	EN
Ehretia cymosa Thonn.	N	425,836	540 (VU)	LC
Ehretia decaryi J.S. Mill	E	1,061 (EN)	54 (EN)	EN
Ehretia meyersii J.S. Mill	E	963 (EN)	72 (EN)	EN
Ehretia obtusifolia J.S. Mill	N	1,164 (EN)	27 (EN)	LC
Ehretia phillipsonii J.S. Mill	E	11,701 (VU)	72 (EN)	EN
Ehretia seyrigii J.S. Mill	E	110,972	99 (EN)	VU
Hilsenbergia angustifolia J.S. Mill	E	NA	9 (CR)	CR
Hilsenbergia apetala J.S. Mill	E	17,657 (VU)	45 (EN)	EN
Hilsenbergia bosseri J.S. Mill	E	54,129	270 (EN)	LC
Hilsenbergia capuronii J.S. Mill	E	172,154	99 (EN)	VU
Hilsenbergia comorensis J.S. Mill	E	NA	18 (EN)	CR
Hilsenbergia croatii J.S. Mill	E	5,120 (VU)	72 (EN)	EN
Hilsenbergia darcyana J.S. Mill	E	239,645	72 (EN)	VU
Hilsenbergia labatii J.S. Mill	E	31,645	63 (EN)	VU
Hilsenbergia leslieae J.S. Mill	E	22,648	99 (EN)	VU
Hilsenbergia lowryana J.S. Mill	E	67,769	126 (EN)	EN
Hilsenbergia lyciacea J.S. Mill	N	35,882	198 (EN)	LC
Hilsenbergia moratiana J.S. Mill	E	19,019 (VU)	45 (EN)	EN
Hilsenbergia randrianasoloana J.S. Mill	E	23,514	36 (EN)	EN
Hilsenbergia schatziana J.S. Mill	E	4,345 (EN)	27 (EN)	EN
Heliotropiaceae				
Heliotropium arborescens L.	I			NE
Heliotropium bacciferum Forssk.	N	22,330	63 (EN)	LC
Heliotropium baclei DC.	N	74,573	36 (EN)	LC
Heliotropium curassavicum L.	N	137,804	54 (EN)	LC
Heliotropium indicum L.	N	507,019	234 (EN)	LC
Heliotropium ovalifolium Forssk.	N	446,782	279 (EN)	LC
Heliotropium perrieri J.S. Mill	E	NA	18 (EN)	CR
Heliotropium pterocarpum (DC. & A. DC.) Hochst. & Steud ex Bunge	I			NE
Heliotropium zeylanicum Lam.	I			NE
Tournefortia argentea L. f.	N	398,700	90 (EN)	LC
Tournefortia kirkii (I.M. Johnston) J.S. Mill	E	134,069	81 (EN)	VU
Tournefortia puberula Baker	E	182,527	324 (EN)	LC
Boraginaceae				
Cynoglossum birkinshawii J.S. Mill	E	61 (CR)	27 (EN)	CR
Cynoglossum cernuum Baker	N	48,087	90 (EN)	VU
Cynoglossum lanceolatum Forssk.	N	472,509	531 (VU)	LC
Cynoglossum lowryanum J.S. Mill	E	NA	9 (CR)	CR

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Table 1 (Continued)

Species (by Family)	Status[1]	EOO[2]	AOO[2]	Red List assignment[3]
Cynoglossum monophlebium J.S. Mill	E	12,054 (VU)	90 (EN)	VU
Cynoglossum tsaratananense J.S. Mill	E	NA	9 (CR)	CR
Trichodesma zeylanicum (Burm. f.) R. Br.	N	85,776	144 (EN)	LC

[1]N, native non-endemic; I, introduced; E, endemic
[2]Below thresholds for Critically Endangered (CR), Endangered (EN) or Vulnerable (VU)
[3]CR, Critically Endangered; EN, Endangered; VU, Vulnerable; LC, Least Concern; NE, not evaluated

completed in 2007 placed into those categories primarily on the basis of geographical measures under Red List criterion B (i.e. AOO and EOO; Gaston & Fuller, 2009). The calculated value for AOO is a function of the scale at which it is measured and, therefore, the chosen grid cell size can complicate the assessment process. In the Red List Guidelines (IUCN, 2008), the recommended size for AOO grid cells is 2×2 km, which would allow species known from one or two localities to be considered as CR. However, the paucity of collections from the Malagasy flora, only nine per 100 km^2 (Campbell & Hammond, 1989), means that most species are known from few grid cells and therefore have low AOO values and would not be known from sufficient numbers of collections to pass the threshold for EN. Schatz et al. (2000) used cells of 10×10 km to account for the low number of collections in Madagascar. This choice does not allow any species to be below the threshold to be listed as CR ($<$10 km^2) and therefore may seriously underestimate threat. The grid chosen for AOO calculations in our analysis was 3×3 km (for further discussion of AOO calculations, see Callmander et al., 2007). A size of 9 km^2 allows species known from a single locality to be below the threshold for CR but also means that a species must occupy at least 56 grid cells to surpass the EN threshold of 500 km^2 and 223 grid cells to surpass the VU threshold of 2,000 km^2. In the case of Malagasy Boraginales, only two species, *Cynoglossum lanceolatum* and *Ehretia cymosa*, are known from more than 56 collections and none are known from as many as 223 collections.

The potential use of predicted future decline for IUCN criterion A also merited careful consideration. Several studies of threat in Madagascar have used the results of similar protected areas analyses to infer likelihood of predicted future decline by calculating each species' AOO outside protected areas and dividing it by the species' total AOO (Schatz et al., 2000; Randrianansolo et al., 2002; Good et al., 2006). This method assumes that little primary vegetation will remain outside protected areas in the future and only those plants that occur within protected area boundaries will persist. This assumption may be reasonable for species that occur in moist primary forests but it overestimates the risk of extinction for species that are able to persist in disturbed habitats. In addition, many Boraginales occur in areas of dry forest that are currently outside protected areas but are not likely to disappear in the near future. For example, if predicted future decline were calculated for *Cordia myxa* and *E. cymosa*, their predicted declines would be 79 and 90% and they would be categorized as EN and CR, respectively. However, both species are common in highly disturbed and deforested areas and are provisionally assigned to the category LC. This illustrates the importance of having expert knowledge of the species being assessed, and predicted future decline as calculated by Schatz et al. (2000) was therefore considered to result in misleading assessments for many Boraginales.

The protected areas analysis determined that the current protected areas network (MNP and DVPPA) includes some portion of the range for 78.2% (36 of 46) of the Boraginales species of Madagascar. In addition, if the priority areas were included as part of the Malagasy protected areas system, then all but two (*Ehretia decaryi* and *H. perrieri*) of the endemic Boraginales would be protected, increasing the percentage protected to 93.4%. The increase in protection that would occur with the addition of the proposed protected areas demonstrates that these new areas afford more protection for species that occur primarily in dry forests, which are not well protected in the present protected areas system: a strong argument for the value of these areas to protect plant species diversity.

The majority of previous conservation assessments have focused primarily on species from wetter areas of Madagascar. Our analysis contributes a dataset for an Order that occurs predominantly in dry parts of the country. Although the 2009 Red List includes only 362 plant species for Madagascar, an additional 2,378 species have been provisionally evaluated by the Madagascar Plant Working Group. These assessments are, however, largely from families and genera that have the majority of their species diversity in wet forests (S. Andriambololonera, pers. comm.). Thus, we have demonstrated that the Boraginales are a useful model group for identifying those underrepresented habitats that are critical for protection of species that occur in dry forests and relatively open locations.

Target 2 of The Global Strategy for Plant Conservation is a 'preliminary assessment of the conservation status of all

TABLE 2 Percentage of area of occupancy (AOO) of the 46 species of native Boraginales protected within MNP (Madagascar National Parks' managed protected areas), DVPPA (Provisionally Protected Areas from the Durban Vision process), and PPAPC (proposed Priority Protected Areas for Plant Conservation from the Missouri Botanical Garden analysis; Raharimampionona et al., 2006), the percentage of each species' AOO that is protected by MNP and DVPPA combined, and the percentage of AOO that would be protected if the PPAPC were given full protected status.

Species (by Family)	MNP	DVPPA	PPAPC	% protected (MNP + DVPPA)	% protected incl. PPAPC
Cordiaceae					
C. procumbens	14.3	0	0	14.3	14.3
C. caffra	0	0	13.3	0	13.3
C. lowryana	0	20	15	20	35
C. mairei	17	2.1	6.4	19.1	25.5
C. monoica	12.5	12.5	0	25	25
C. myxa	13.7	7.8	5.9	21.5	27.4
C. schatziana	0	16.7	0	16.7	16.7
C. sinensis	5	5	15	10	25
C. subcordata	4.5	0	9	4.5	13.5
Ehretiaceae					
E. australis	0	16.7	0	16.7	16.7
E. cymosa	8.3	1.7	6.7	10	16.7
E. decaryi	0	0	0	0	0
E. meyersii	0	25	37.5	25	62.5
E. obtusifolia	33.3	0	0	33.3	33.3
E. phillipsonii	25	0	0	25	25
E. seyrigii	27.3	0	27.3	27.3	54.6
H. angustifolia	0	0	0	0	0
H. apetala	80	0	0	80	80
H. bosseri	6.7	0	13.3	6.7	20
H. capuronii	9	0	9	9	18
H. comorensis	0	0	0	0	0
H. croatii	0	0	2.5	0	12.5
H. darcyana	12.5	0	12.5	12.5	25
H. labatii	42.8	0	0	42.8	42.8
H. leslieae	27.3	18.2	9	45.5	54.5
H. lowryana	7	0	7	7	14
H. lyciacea	13.6	9	9	22.6	31.6
H. moratiana	0	20	20	20	40
H. randrianasoloana	25	0	0	25	25
H. schatziana	33.3	33.3	0	66.6	66.6
Heliotropiaceae					
H. bacciferum	0	0	14.3	0	14.3
H. baclei	25	0	0	25	25
H. curassavicum	0	0	0	0	0
H. indicum	15.4	7.7	3.8	23.1	26.9
H. ovalifolium	9.7	3.2	9.7	12.9	22.6
H. perrieri	0	0	0	0	0
T. argentea	20	10	10	30	40
T. kirkii	44.4	0	11	44.4	55.4
T. puberula	41.7	8.3	0	50	50
Boraginaceae					
C. birkinshawii	0	0	33.3	0	33.3
C. cernuum	20	0	0	20	20
C. lanceolatum	13.6	6.8	6.8	20.4	27.2
C. lowryanum	0	100	0	100	100
C. monophlebium	0	0	12.5	0	12.5
C. tsaratananense	100	0	0	100	100
T. zeylanicum	0	0	6.3	0	6.3

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known plant species' by 2010 (Brummitt et al., 2008). The research described here contributes to meeting this unfulfilled goal by utilizing herbarium data from a well-curated dataset and a GIS to calculate several spatial measures to provisionally assign species to Red List categories. Boraginales is one of the first plant groups well represented in dry forests and more open areas to be assessed in this manner for Madagascar. It is imperative that a variety of life forms in a variety of habitats are included in conservation assessments to gain a truly representative survey of threats to Malagasy biological diversity and the areas most important for its protection. This conservation assessment is a step towards our goal of building a set of exemplar taxa that can be used to inform conservation decisions in Madagascar.

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Appendix

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Biographical sketches

James S. Miller studies the systematics of Boraginales (Boraginaceae) with an emphasis on how information on plant systematics can inform conservation. Holly A. Porter Morgan uses geographical information systems and botanical data to develop geospatial models that can facilitate plant conservation and management.

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