

| **Analysis of threats ~~of~~to South American flora and its implications for conservation**

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1 **Abstract**

2 South America houses a significant proportion of the world's plant diversity and
3 therefore merits conservation attention. However, ongoing habitat fragmentation,
4 degradation and destruction of natural habitats threaten biodiversity. A set of seven
5 threats to natural ecosystems derived from a previous study (Jarvis *et al.*, 2010),
6 combined with a dataset of occurrences from 16,339 species, and also with the World
7 Database of Protected Areas were used to analyze the patterns of threats to flora in South
8 America and its conservation. Species richness per ~50 km side cell ranged from 1 to
9 2,149 taxa, but with most of the areas presenting between 1 and 58 taxa. Population
10 accessibility, expansion of agriculture and grazing pressure were found to be the key
11 drivers of immediate extinction risk. A considerable (78.4%) number of species presented
12 at least one population under high threat due to the expansion and intensification of these
13 anthropogenic activities. In addition, some 13.8% of the analyzed species presented up to
14 80% of their populations at risk of extinction (high threat index). On the conservation
15 side, 82.3% of the analyzed taxa have at least one population occurring within a protected
16 site. However, it is important to note that for a protected area system to be effective and
17 efficient, the conservation of within-taxon genetic diversity is required. The expansion,
18 monitoring and strengthening of 24 existing protected areas holding up to 70% of South
19 American plant diversity is suggested; as is the revision of 7 additional sites where up to
20 200 species not currently conserved are present. Critical areas to monitor, expand and
21 strengthen are mainly located in the Ecuadorian and Colombian Andes, southern
22 Paraguay, the Guyana shield, southern Brazil, and Bolivia.

23 *Keywords:* species richness, diversity, anthropogenic activities, extinction, protected
24 areas, populations, agriculture
25
26

27 **Introduction**

28 Dramatic changes in ecosystems due to human activities lead to habitat degradation,
29 fragmentation and consequent biodiversity loss (Heywood, 1995; Kim and Byrne, 2006;
30 Kim, 1998; Turner *et al.*, 2004), not to mention the effects on the ecosystem services
31 (Worm *et al.*, 2006; Wohl *et al.*, 2012) that sustain human society. These changes are
32 driven by a number of human activities, including the expansion of agricultural systems,
33 grazing pressure, provoked and natural fires, oil and gas extraction, infrastructure
34 development, and urban development (Jarvis *et al.*, 2010; Papeş and Gaubert, 2007;
35 FAO, 1998). The most significant loss of biodiversity has taken place within the last
36 decades, coinciding with rapid population and economic growth (Palmer *et al.*, 2004;
37 Musser, 2005). A stable conservation system is necessary to preserve biodiversity,
38 especially considering predicted rates of climatic changes (IPCC, 2007; Thomas *et al.*,
39 2004; Loarie *et al.*, 2009), which constitutes an additional pressure on ecosystems.
40 Management practices and ecosystem conservation policies are key issues in the near and
41 the long-term future (Burke *et al.*, 2009; Hagerman *et al.*, 2010; Jarvis *et al.*, 2008; Olfert
42 and Weiss, 2006; Thomas *et al.*, 2004; Hitz and Smith, 2004).
43 NGOs, government conservation agencies and international research centers have
44 engaged in activities with the aim of preserving species and genetic diversity in wild and
45 natural habitats. Conservation policies and knowledge about biodiversity have increased
46 over time, and the extent to which conservation actions preserve plant genetic diversity
47 has increased (Maxted and Kell, 2009). However, further adjustments to approaches to
48 conservation are needed, given the complexity of biodiversity (Kim and Byrne, 2006;
49 Wilson *et al.*, 2006).

50 Moreover, in addition to improving the understanding of biodiversity and its processes,
51 improved understanding of the types of threats to which natural habitats are currently
52 subjected is also needed. The level at which these threats directly affect plant populations
53 needs to be assessed and accounted for in conservation policy making.

54 South America is a highly diverse area, estimated to contain up to 81,000 plant species of
55 vascular plant taxa and 4,200 vascular plant genera (Gentry, 1982; Myers *et al.*, 2000;
56 MEA, 2005; Ceballos and Ehrlich, 2006; Mittermeier *et al.*, 2003), which makes it a
57 source of rich ecosystem services for human use. Moreover, South American flora
58 features considerable rates of endemism (Jarvis *et al.*, 2010; Gentry, 1982; Gentry, 1992;
59 Midgley *et al.*, 2006; Brooks *et al.*, 2006), particularly for certain low migration and
60 endemic plant species of the Andes and the Amazon (Barthlott *et al.*, 2007; Barthlott *et*
61 *al.*, 2005; Mutke and Barthlott, 2005). All these factors complicate assessments of species
62 diversity (richness) or infra-species diversity (genetic variation within a taxon). Any
63 successful conservation strategy needs to be aware of and account for the particularities
64 of the region, its diverse landscapes, species extinction rates, current extent of *in situ*
65 conservation, and protected area distribution and connectivity (Jeffries, 2005; Sachs *et*
66 *al.*, 2009; Giam *et al.*, 2010).

67 In this study, an assessment of the threat level and conservation status of South American
68 flora is performed by means of spatial and statistical analyses, using seven immediate
69 threat layers developed by Jarvis *et al.* (2010), combined with a representative set of
70 occurrences of plants of South America from the Global Biodiversity Information
71 Facility (GBIF), and using the distribution of protected areas in South America (UNEP
72 and IUCN, 2009). ~~These R~~results can be used to improve conservation policies in the

73 near future, ~~and~~ for the improvement of conservation practices, as well as to improved
74 regional understanding of ecosystem and plant diversity threats from human activities.

75

76 **Materials and methods**

77 This paper ~~aimed~~ aims at prescribing to prescribe general recommendations ~~to~~
78 ~~conservation for conserving of~~ South American flora through a taxon-specific and
79 geographic analysis of threats level using publicly available biodiversity data, the
80 geographic distribution of immediate (2-5 years) threats arising from various
81 anthropogenic activities, and the locations of existing protected areas. More specifically,
82 the objectives were to:

- 83 (1) Gather and assess the largest possible amount of publicly available data for the
84 region (i.e. South America)
- 85 (2) Quantify the threat-level on a taxon-by-taxon basis for all species in the region for
86 which data was available
- 87 (3) Perform a geographic analysis to compare the centers of plant diversity and the
88 most threatened areas
- 89 (4) Determine the extent to which ~~current~~ protected areas in the region represent the
90 sampled biodiversity and provide recommendations to the establishment of
91 potential new sites to strengthen the existing protected area network.

92

93 *Biodiversity data*

94 Species occurrence data was obtained from the Global Biodiversity Information Facility
95 (GBIF, www.gbif.org). GBIF is a comprehensive ~~species occurrences~~ database that holds

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96 367 million records of species occurrences from 406 publishers (to date). Nearly 200
97 peer-reviewed publications have made use of its data in 2011 (GBIF, 2011). Although
98 sometimes imprecise and of limited geographic and taxonomic coverage [~~(see Yesson et~~
99 ~~al. (2007))~~] for a comprehensive assessment] and severely criticized by some authors
100 (Kim and Byrne, 2006), GBIF provides the most comprehensive and updated public
101 source of biodiversity information for research (GBIF, 2011; Guralnick and Hill, 2009).
102 With adequate treatment, GBIF data can be used with a high level of confidence to
103 analyze degree of conservation [~~(see Ramirez-Villegas et al. (2010))~~] and other
104 agriculture and biodiversity-related issues (Herrera Campo *et al.*, 2011; Huettmann *et al.*,
105 2011; Yesson *et al.*, 2007). In South America, GBIF data (particularly for the Andean
106 countries) show a high level of representativeness [~~(see Yesson et al. (2007))~~], and hence
107 it was the sole source of data for the present study.

108 Given the known issues in the GBIF data, ~~signified-particular~~ attention was given ~~to~~-to
109 ensuring reliability of results. The entire set of occurrences corresponding to the *Plantae*
110 kingdom (global dataset) was ~~queried-interrogated~~ and then verified via a thorough
111 coordinate verification process. Records (1) with ~~null-no reported~~ latitude and/or
112 longitude data, (2) belonging to sea plant species (based on their most superior clade or
113 *Phylum*), (3) falling in the ocean (~~using a high level detail land areas mask~~), (4) with no
114 ~~null-reported collection~~ country names or falling in a wrong country according to the
115 values reported in the database and their location within a global dataset (GADM,
116 www.gadm.org), (5) with redundant information (belonging to the same taxon and having
117 exactly the same coordinates), and/or (6) not falling within South America, were
118 discarded during the process. The whole process was tracked to determine the degree to

119 which the retrieved part of the GBIF database is incorrect and to determine the percent of
120 sampled flora from the database that correspond to South America [see also Yesson *et al.*
121 (2007)].

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122 An additional issue with the database is the taxonomical verification of specimens and
123 the synonyms of different species and even different genera (Kim and Byrne, 2006).
124 Given the large number of occurrences in the database, it would be complicated to track
125 all these occurrences and verify their taxonomy. GBIF data uses the Catalogue of Life
126 Annual Checklist (Bisby *et al.*, 2010), the International Plant Names Index (IPNI, 2008),
127 and the Index Fungorum database (CABI, 2010) as taxonomy sources. Whilst not perfect,
128 taxonomic and identification errors are likely to be random across the dataset and hence
129 unlikely to introduce bias in the results.

130

131 *Threats data*

132 Jarvis *et al.* (2010) developed a model to spatially map the threats to natural ecosystems
133 over a 2-5 year time frame. In their approach, Jarvis *et al.* (2010) consider the immediate
134 threat to a specific site within an ecosystem to be a function of the magnitude of the
135 current impact, the distance to ~~current~~ such impact and the sensitivity of the given
136 ecosystem to the threat. Jarvis *et al.* (2010) parameterized their model for 608 ecosystems
137 (from 9 major habitat types in South America) using expert knowledge ~~for 608~~
138 ~~ecosystems from 9 major habitat types in South America~~ and mapped out seven different
139 types of threats (see below) on a semi-continental (i.e. for South America) scale at a
140 spatial resolution of 30 arc-seconds (~1 km at the Equator). For further details the reader
141 is referred to Jarvis *et al.* (2010).

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142 Seven different threats were thus considered for all further analyses; these included sub-
143 continental datasets for (1) population accessibility, (2) conversion to agriculture, (3)
144 fires, (4) grazing pressure, (5) infrastructure development, (6) oil and/or gas extraction
145 and (7) recent land use change, and a final aggregated threat layer comprising (i.e. mean
146 value) the results of the other threat layers. The threats data (both individual threats and
147 the aggregate threat) used [here](#) prescribe, in a scale from zero (0) to three (3), the degree
148 at which one pixel is likely to be threatened in the short-term future (2-5 years).

149

150 *Immediate threats assessment*

151 The extent to which biodiversity is currently threatened was assessed using the set of
152 seven anthropogenic and natural threats using two different approaches: (1) a taxon-by-
153 taxon assessment independent of [the](#) geographic space, and (2) a spatial approach to
154 compare [the](#) centers of plant diversity and the most threatened areas.

155

156 **Taxon- and genus-specific assessment:** When assessing each taxon and genus
157 (separately, see Figures 1, 3) for which at least one occurrence was available, each
158 occurrence of a taxon was assumed to be representative of at least one population of that
159 taxon. A set of calculations was then performed for each of the taxa in the database:

160 (1) The endemism (PE) of the taxon [was calculated](#) as the percent of populations (i.e.
161 single locations) occurring in South America to the total number of recorded
162 populations across the globe,

163 (2) The percent of threatened populations (PTP) was calculated as the percent of
164 populations occurring in areas where the value of the aggregate threat is above the

- 165 4th quartile (top 25%) of the aggregate threat layer (calculated using all pixels in
166 the region) to the total number of occurrences found in South America,
- 167 (3) The maximum horizontal (i.e. East-West) distance (HD) between two
168 populations,
- 169 (4) The maximum vertical (i.e. South-North) distance (VD) between two populations,
- 170 (5) The value of each threat (i) corresponding to the most threatened population
171 (MT_i). As opposed to the PTP, which provides an estimate of the geographic
172 range extent that is under threat, the MT_i only provides an estimate of the most
173 vulnerable population (i.e. focalized impact); and
- 174 (6) The value of each threat (i) corresponding to the least threatened population (LT_i).

175 Differences in scales between these six variables were standardized by dividing each by
176 its maximum possible value. In the case of threats, all were divided by 3, which is the
177 maximum value reported by Jarvis et al. (2010), in the case of PE and PTP the division
178 was done by 100, and in the case of HD and VD the division was done by the maximum
179 vertical and horizontal distances of the continent (7,505 and 5,170 km, respectively).

180 The behavior of each of these variables was defined in order to calculate a single final
181 value (index) that represents the level of threat and/or reflects the likelihood of a taxon
182 being extinct in the near future. As PE, PTP, MT_i and LT_i increase, the taxon becomes
183 more threatened either because it is not likely to be represented in areas other than South
184 America, it has a considerable percent of threatened populations, or the levels of threat in
185 its most and least threatened populations are considerably high (in this case the
186 standardized value was used directly). As HD and VD increase, the taxon is less
187 threatened because the geographical range of the taxon is broader, so it is less likely to be

188 extinct by a single event (in this case the additive inverse is used). Although it is
189 acknowledged that taxa with few, isolated and distant populations (i.e. with high HD
190 and/or VD) are more vulnerable than taxa with many populations distributed uniformly
191 across a large distance (i.e. with high HD and/or VD) and should be treated differently,
192 such differences are partly accounted for by individual scores in threatened populations
193 (MT_i and LT_i), and the PTP.

194 A threat index (TI) ~~is~~was finally calculated (Eqn. 1). To keep the TI calculation as
195 simple as possible, the additive effects of a set of equally weighted variables were used.
196 Although a more complex equation could be derived from the interactions between this
197 set of variables via a detailed calibration process, it was kept simple so that the result is
198 representative for the whole region, and to ensure it reflects at the same level the threats
199 being analyzed among species.

$$200 \quad TI = \frac{PE}{100} + \frac{PTP}{100} + \sum_{i=1}^7 \frac{MT_i}{3} + \sum_{i=1}^7 \frac{LT_i}{3} + \left(1 - \frac{HD}{7,505}\right) + \left(1 - \frac{VD}{5,170}\right) \quad [\text{Equation 1}]$$

201 Finally, the threat index (TI) is standardized to a scale from 0 to 1 by dividing each value
202 by the maximum value among all species.

203

204 **Geographic assessment of threats:** In order to perform a spatially-explicit assessment of
205 threats over South America, species richness (i.e. the number of different species) and
206 sampling densities (i.e. the total number of samples) were calculated on each 0.5-by-0.5
207 degree cell (~50-by-50 km in the equator) in order to calculate the Menhinick diversity
208 index (Whittaker, 1977) by dividing the former by the square root of the latter. ~~We use~~
209 ~~†~~The Menhinick index was used because, as opposed to simple species richness, it is less

210 likely to be biased due to the differences in sampling sizes and efforts throughout the
211 region (Whittaker, 1977).

212 The whole gridded dataset of the diversity index was then normalized by dividing each
213 cell's value by the maximum value amongst all data pixels. The total aggregate threat
214 was then calculated for each of those 0.5 degree cells by summing the threats of all the 1
215 km sub-cells that presented any data, and the resulting layer was normalized as with the
216 diversity index (this gives an indicator of both how much area is threatened and at what
217 level). An overlay (product) of the two layers was done and mapped to depict the areas
218 where species diversity is concentrated, and areas where this diversity is more likely to be
219 threatened in the near future.

220

221 *Conservation status assessment*

222 *In situ* conservation representativeness has been widely discussed and analyzed. Gap
223 analysis methods are usually applied to evaluate the representativeness of *in situ*
224 conserved biodiversity (Maxted *et al.*, 2008; Maxted and Kell, 2009; Scott and Schipper,
225 2006; Jarvis *et al.*, 2003; Fearnside and Ferraz, 1995)

226 Two simple analyses were performed in order to assess the conservation status of plant
227 species of South America:

228 (1) A dataset containing the geographic distribution of protected areas of the region was
229 retrieved from the World Database on Protected Areas (WDPA, publicly available at
230 <http://www.wdpa.org/>) (UNEP and IUCN, 2009). The data retrieved consisted of
231 polygons that show each of the protected areas (of all categories) in the region. Using
232 this data in conjunction with the species occurrences (see above), the percent of

233 populations (single locations) ~~was first identified~~ occurring within a protected area of
234 any kind for each taxon and genus separately was first identified. The conservation
235 status of the whole flora was then analyzed via a histogram for each taxonomic level
236 (i.e. taxon and genus).

237 (2) After that, a complementarity or reserve-selection analysis was performed, as
238 proposed by Rebelo (1994) and Rebelo and Siegfried (1992), ~~and~~ [fully analyzed by
239 Justus and Sarkar (2002)] in order to compare ~~the~~ a set of theoretically identified
240 points (i.e. those identified by the reserve-selection procedure) with the current
241 locations of protected areas ~~reported by UNEP~~ (explained above). The analysis of
242 complementarity for reserve selection is an iterative selection process in which ~~of~~
243 gridcells (squares of a given size) with large numbers of unique species are chosen as
244 “reserves”. In the complementarity analysis, the study area is divided in equally-sized
245 gridcells and a first gridcell is selected on the basis of its species richness (i.e. the
246 species-richest gridcell); species present in the first gridcell are then removed from all
247 other gridcells and the process repeated so that a second-richest gridcell (with species
248 not already in the first gridcell) is selected (Rebelo and Siegfried, 1992; Justus and
249 Sarkar, 2002). The process is completed after all the species are “virtually preserved”
250 (i.e. each species occurs at least once in at least one gridcell). In this study, the
251 software package DIVA-GIS, (Hijmans *et al.*, 2001) was used to perform the reserve-
252 selection process. Although it would have been optimal to perform this ~~procedure~~
253 analysis at the resolution of 0.5 degree, preliminary analyses with sub-sets of the
254 species in the dataset used in this paper suggested that computing resources were a
255 limitation and hence the resolution of 1 degree (~100 km at the Equator) was adopted.

256 Since the size of protected areas is commonly close to a 100 km (and larger in the
257 Amazon, for example), this larger gridcell size is expected to be more representative
258 of a “typical” protected area.

259 If the current protected area system does actually represent the diversity of plant species
260 in South America, it would be expected that (1) it covers all or the majority of gridcells
261 identified by the complementarity analysis, and (2) populations of a large proportion of
262 the species exist within protected areas.

263

264 **Results and discussion**

265 *Biodiversity data collation and cleaning*

266 At the time the GBIF database was queried, it held some 177,887,193 occurrences
267 including all the reported kingdoms. From those, 44,706,505 (25.1%) were reported as
268 being *Plantae*, and from these, 33,340,000 (74.5%) showed a value in the latitude and/or
269 longitude fields of the database (i.e. latitude and/or longitude values were different to “no
270 data”). After filtering, 12,860,281 occurrences, belonging to 61,801 terrestrial plant taxa,
271 were found to be correct at the two tested levels (i.e. continental, country) (Table 1).
272 After the full filtering process, 513,368 records (4%) belonging to 16,339 terrestrial plant
273 species and 2,805 genera were found to be located in South America.

274 **<INSERT TABLE 1 HERE>**

275 Only 3.6% of the non-repeated records from the *Plantae* kingdom were used, indicating
276 that data quality in large databases is a fundamental issue to be addressed when
277 performing any analysis with such data (Robertson *et al.*, 2010; Graham *et al.*, 2008).
278 The mean number of unique occurrences per taxon in South America was 31.4, with a

279 standard deviation of 43.1, indicating that sampling distribution across species is highly
280 heterogeneous, ranging between 1 and 1063 samples for a single taxon within the
281 continental area. Some 6.6% of the taxa were reported in the database with only one
282 occurrence (i.e. one single population) in the land areas of the continent, 3.7% with 2
283 populations, and 2.3% with 3 populations.

284 Additional issues can arise from the primary biodiversity data such as the reliability of
285 geographic references (i.e. coordinates), the representativeness of the samples in the
286 database compared to the existing diversity, and the reliability of the taxonomic
287 identification (Barbet-Massin *et al.*, 2010; Feeley, 2010).

288 Errors in the database can lead to a bias in the results by shrinking or broadening the
289 geographic distribution of the species, which can also lead to differences in observed
290 species richness and therefore in the determination of diversity hotspots (Yesson *et al.*,
291 2007; Hill *et al.*, 2009). Additionally, since GBIF comprises different types of records
292 including herbarium specimens, genebank accessions, observations in field campaigns,
293 which are collected through time and do not account for species that migrate [~~see e.g.~~
294 Chen *et al.* (2009)], species numbers across the study area are in some cases gross
295 underestimates of real numbers of species, which in general are difficult to sample or
296 estimate (Barthlott *et al.*, 2007; GBIF, 2011).

297 Nevertheless, the analyses performed here aimed at the detection of major errors in the
298 database, and according to many standards [~~see Yesson *et al.* (2007)~~] they have
299 detected and removed the majority of errors and biases. Additional errors might be
300 randomly spread across the samples in the database and are therefore ~~less likely~~unlikely
301 to introduce important bias in the results presented. Strong focus towards the

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302 improvement of public biodiversity databases is suggested as a step to further narrow
303 uncertainties in ~~the~~any conservation-related analyses.

304

305 *Immediate threats assessment*

306 The percent of endemism ranged from 0.005 to 100%, with 50.8% of the species found in
307 South America presenting high rates of endemism (PE > 90%), and 28.3% taxa with
308 relatively low rates of endemism (PE < 30%, Figure 1). The remaining proportion of
309 species presented highly variable PE values, ranging from 30 to 90%. High rates of
310 endemism (25% of the genera presenting more than 90% of their populations and 18%
311 had all their populations only in South America) were also found ~~for genera~~at the genus
312 level.

313

<INSERT FIGURE 1 HERE>

314 The most threatened areas *per se* are those in the last quartile of aggregate threat and
315 mainly cover some highland areas in the Andes, particularly in Peru, the eastern plains in
316 Colombia, and the very northern regions of Venezuela, where not even a single reserve
317 has been established (Figure 2, right). There are some additional areas under considerable
318 threat near the Brazilian Cerrado and in Paraguay and its borders with Argentina. In these
319 areas, population presence varied substantially among the taxa, with 80.7% presenting
320 less than 30% of the populations in a threatened area (above the 3rd quartile of the
321 aggregate threat layer [Figure 2, left]); nevertheless, some 2% of the plant taxa presented
322 more than 70% of their populations within some of these areas (Figure 2, left), indicating
323 that although the entire taxon is not highly threatened, there is some risk of intensifying
324 genetic loss. In addition, 173 plant taxa (out of 1,088 taxa that had only one population)

325 had their single unique population within threatened areas. This indicates that under-
326 sampled areas might coincide with high immediate threat areas, and that some additional
327 sampling efforts should be done in order to better characterize the level of threat of
328 certain groups of species. Likewise, the set of threats under analysis seem to affect 50%
329 of the populations in most of the cases, and 18 entire genera (*Aerva*, *Catapodium*,
330 *Chrysolepis*, *Diectomis*, *Ecballium*, *Ginko*, *Ibicella*, *Kochia*, *Litchi*, *Lophospermum*,
331 *Parapholis*, *Pelexia*, *Phlox*, *Potentilla*, *Pseudoscleropodium*, *Schoenocaulon*,
332 *Scrophularia*, and *Taeniatherum*) had 100% of their populations within a high threat area.
333 Nevertheless, these genera are not endemic to South America. In addition, there were 6
334 genera with up to 80% of their populations under high threat and with high rates of
335 endemism (*Acca* [family *Myrtaceae*, PE=50%], *Bumelia* [family *Sapotaceae*, PE=40%],
336 *Microlobius* [family *Fabaceae*, PE=75%], *Tetraplodon* [family *Splachnaceae*, PE=50%],
337 *Hovenia* [family *Rhamnaceae*, PE=65%], and *Jaborosa* [family *Jaborosa*, PE=82%]).

338 <INSERT FIGURE 2 HERE>

339 Although some 78.4% of the plant taxa have at least one population within an area where
340 one or more threats are considerably high, there are differences in terms of each
341 individual species and threat, as well as in the non-linearities of the distribution of plant
342 diversity throughout the continent (distances between populations). Maximum distances
343 between populations of a single taxon ranged from 0 to 6,680 km for HD and to 7,360 km
344 for VD (Table 2).

345 <INSERT TABLE 2 HERE>

346 There are threats that more significantly affect the flora of South America under analysis.
347 Maximum values for accessibility ranged from 0.012 to 3, while minimum values ranged

348 between similar values (0.012 to 2.639). In contrast, some threats such as oil/gas
349 extraction exhibited much lower values (0 to 2.4 for maximums and 0 to 1.5 for
350 minimums) due to their highly localized impacts. Fires, grazing pressure, accessibility
351 and conversion to agriculture seem to account to most of the South American flora
352 diversity losses, while infrastructure (airports and dams), oil/gas extraction, and recent
353 conversion seem less likely to be involved in these losses and threats. It is also possible
354 that some of the populations analyzed here are already extinct due to habitat destruction,
355 habitat fragmentation and forest over-exploitation (Dodson and Gentry, 1991; Giam *et*
356 *al.*, 2010; Feeley and Silman, 2010). In the long term (10-20 years), however,
357 biodiversity can be much more threatened by population accessibility (including the
358 construction of new roads) as this can cause community migration, forest clearing, and
359 expansion of the agricultural boundary (Chomitz and Gray, 1996). Additionally, it is
360 noted that although mining is known to be a more important problem than oil and gas
361 extraction (Palmer *et al.*, 2010), the data of Jarvis *et al.* (2010) did not include such
362 information and mining was thus not considered in the analyses. ~~It is expected that~~ levels of
363 threat shown ~~herein this study are expected~~ to be higher if mining activities were to be
364 considered.

365 The threat index (i.e. cumulative threat) varied from 0.064 (6.4%, the least threatened,
366 *Festuca rubra* L.) to 1.0 (100%, the most threatened, *Diplokeleba floribunda* N.E. Br.)
367 (see Figure 3), and the observed distribution of this index showed significant variability,
368 with most of the taxa presenting indices between 0.4 and 0.7. Some 13.7% of the total
369 number of taxa under analysis showed indices above 0.8, while only 2.8% showed values

370 below 0.3. Genera are more concentrated to the right (above 0.5% of extinction risk), but
371 only few genera and taxa seem to have indices above 0.9.

372 **<INSERT FIGURE 3 HERE>**

373 Taxa that are more likely to become threatened in the near (2-5 year) future are about 5
374 times more frequently observed in South America than taxa that are less likely to become
375 threatened. This can be attributed to the sampling bias towards populated places and
376 agricultural lands, and to the fact that the most remote populations (the least threatened)
377 could be small-range endemic species in ecosystems that still remain untouched or are
378 very well preserved (Bass *et al.*, 2010). Threats to these taxa might be concentrated in a
379 few populations. However, not only the most endangered populations are taken into
380 account here. Species with very limited geographical distribution, or with high rates of
381 endemism (therefore likely to be quickly extinct) will certainly show a higher threat
382 index than those with very broad distributions or that are more likely to be represented in
383 ecosystems outside South America. A considerable amount of currently sampled
384 biodiversity was found to be significantly threatened. Locations of these plant
385 populations near to roads and near to the agricultural frontier make them more likely to
386 be extinct in the short term (Ricketts *et al.*, 2005; Young *et al.*, 2002). Geographic biases
387 in sampling could influence this assessment, as most collectors and botanists work along
388 roads, where accessibility is a significant threat to biodiversity. To address this issue, an
389 analysis across the different geographical zones of the continent was also performed.

390 A considerable area in the Amazon basin and southern part of the continent (almost all of
391 Argentina) remains under-sampled, not sampled, or unrepresented in the GBIF *Plantae*
392 database, where a very limited number of occurrences represent the plant diversity. These

393 sampling deficiencies prevent us from performing a detailed analysis over the known
394 diversity within South America. Knowledge gaps exist in Argentina and the Amazon, but
395 are less prominent in the Andes, the Guyana shield and the Brazil Atlantic Forest (Figure
396 4). The greatest sampling densities were found across the Andes from Colombia to
397 Bolivia, and particularly in Ecuador. There is some additional sampling in some parts of
398 southeastern Paraguay, as well as some isolated areas in the French Guyana and
399 Venezuela. Further study of biodiversity in those areas where data is not abundant would
400 benefit this type of study and fill gaps in the current knowledge of plant diversity
401 distribution.

402 **<INSERT FIGURE 4 HERE>**

403 The number of samples per gridcell ranged between one sample to 7,749 samples, with
404 most of the areas presenting between 1 and 138 samples per gridcell. Similarly, species
405 richness ranged from 1 to 2,149 taxa in a single gridcell, but with most of the areas
406 presenting between 1 and 58 taxa. The database does not seem to adequately capture the
407 complete picture of plant diversity in some areas (southern Argentina, Brazilian Amazon,
408 and some parts of Chile), and there seems to be spatial correlation in-between sampling
409 efforts and species diversity. Diversity in the Andes, however, appears to be adequately
410 represented and here the correlation between sampling and species is less clear,
411 indicating that as sampling efforts improve, the gross estimates of species richness that
412 can be derived from global public databases are much more robust. The most species rich
413 areas appear to be located from central Colombia to Bolivia and even some parts of
414 Paraguay (Brooks *et al.*, 2006).

415 When calculating and normalizing the Menhinick diversity index (Figure 5B), some
416 centers of plant diversity were better identified. Due to the limited samples, most of the
417 areas in the continent still appear to have low diversity, but there are some additional
418 areas of high diversity in southern Venezuela, far eastern Brazil (South Atlantic coasts)
419 and southern Chile. The Andean highlands ~~continue were again found~~ to be the most
420 diverse areas, but the pattern of plant diversity seems to be better captured when using the
421 Menhinick index.

422 **<INSERT FIGURE 5 HERE>**

423 Aggregate threats to biodiversity seem to be the highest over the Peruvian Andes as well
424 as in the eastern region of Colombia, northern Venezuela, some parts of Chile, Paraguay,
425 the Paraguay-Brazil border, Argentina and Uruguay. There is a threat pattern in the
426 Andes that coincides with the plant diversity pattern, with additional significant threat
427 present in the Chocó region of Colombia (Pacific coast), the very southern portion of
428 Ecuador, and southeastern Venezuela, where a considerable area is under protection
429 (forest reserve *El Caura*, national park *Canaima*, forest reserve *Imataca*, *San Pedro* in
430 Venezuela and the indigenous area of *Raposa Serra do Sol* in Brazil) (Figure 5a,c). The
431 whole Andean mountain system seems to present the characteristics of high threat and
432 high diversity, indicating the need for conservation of biodiversity in these landscapes,
433 where anthropogenic activities are very likely to affect plant diversity. Additional areas
434 of conservation priority appear in southern Paraguay, northern Argentina, and the
435 Argentina border with Bolivia.

436 Protected sites across the Andes (Figure 5c), at least geographically, seem to be useful in
437 protecting vulnerable ecosystems and the taxa present in them (Sachs *et al.*, 2009; Bass *et*

438 *al.*, 2010; Young *et al.*, 2002). Nonetheless, conservation is not only a question of
439 establishing a set of reserves to preserve a set of plants, but also ensuring that the
440 diversity within a taxon is preserved (Brooks *et al.*, 2006; Mittermeier *et al.*, 2003;
441 Ricketts *et al.*, 2005). It is therefore critical not only that protected areas be well
442 distributed throughout the region, but also that overall vulnerability is reduced in other
443 parts of the region by means of sustainable development. Towards this end, conservation
444 of plant diversity across South America can be enhanced via improved management and
445 maintenance of “working landscapes” such as agricultural and urban frontiers, which
446 were areas found to be under ~~greatest~~considerable threat for South American flora
447 (Brooks *et al.*, 2006; Ricketts *et al.*, 2005; Wilson *et al.*, 2006).

448

449 *Conservation status assessment*

450 Interestingly, 82.3% of the assessed plant taxa were found to have at least one population
451 within a protected site (Figure 2, right), and some 63.1% of the taxa were found to have
452 up to 30% of their populations within a protected area. Less than 40% ~~of the populations~~
453 of ~~the~~genera populations are conserved in most of the cases, although some exceptions
454 were found. In some instances up to 90% of ~~the~~genera populations are conserved, but
455 these are usually limited geographical range genera. Importantly, 17.7% of the total
456 number of taxa presented no populations within any protected area, and in some cases
457 they are in areas that are under threat. These values could depict some potential
458 deficiencies in conservation networks throughout the continent, although it could also be
459 a sampling issue. While immediate (2-5 year) threat status seems to be considerable for a
460 number of populations and taxa, in contrast, conservation status shows that plant diversity

461 may be relatively well conserved. This paradox could be explained in two ways: there are
462 protected sites under considerable threats so that the same populations are being
463 threatened and conserved at the same time, or there are, separately, some very well
464 conserved populations and some very threatened ones.

465

466 The ~~highest-largest~~ number of plant populations (and therefore of species richness)
467 captured throughout the protected sites is located in the Andes, although there are other
468 areas that seem to preserve a considerable proportion of diversity in very different
469 ecosystems (southern Atlantic coasts of Brazil, areas in northern Guyana, French Guiana,
470 Suriname, and some areas in Chile and Argentina). Paraguay seems to be a very special
471 case, as it is reported to have both considerable diversity and considerable threats (Figure
472 5); moreover, it seems that the protected area system of Paraguay is not very well
473 distributed and rather small in area compared with other countries'. Small and isolated
474 protected sites in eastern Brazil, western Venezuela, the Guyana shield, Suriname and
475 central Colombia appear to capture a significant proportion of plant populations.

476 The reserve selection procedure identified 368 single 100km-side cells required to protect
477 each of the 16,339 taxa under analysis; however, only ten cells, which intersected or
478 contained 24 protected sites, were found to contain 70% of the analyzed taxa, and 20
479 cells contained 80% of the taxa (Figure 6). 77.7% of the selected cells contained or
480 intersected in at least one national park, natural reserve, or indigenous territory,
481 indicating that the protected area system of South America is ~~quite-highly~~ effective in
482 preserving ~~the-a-greatest-large~~ amount of diversity ~~of-across~~ the region. There were 48
483 cells that neither intersected nor contained any protected site, and these cells contained up

484 to 317 taxa that are not being conserved at all in any of the protected areas (according to
485 the GBIF database).

486 **<INSERT FIGURE 6 HERE>**

487 Assuming the database to be representative ~~of the~~ of the species and geographies of South
488 America, this study suggests clear policy prescriptions. In order to achieve greater
489 efficiency in the conservation of terrestrial plant species under analysis across South
490 America, and to ensure that the current threats to biodiversity will not continue to cause
491 genetic erosion and biodiversity loss, additional reserves and changes in the current
492 protection system are necessary. Areas currently under protection should be expanded
493 and managed to abate threats to conservation.

494 **<INSERT TABLE 3 HERE>**

495 There is a single site in southern Misiones province in Argentina (Figure 7, red squares)
496 that could potentially protect 114 taxa not represented in any other area, and in the very
497 north of Guyana where 20 additional taxa could be also conserved, along with some five
498 other sites, which would in total conserve an additional 198 taxa out of the 317 not
499 conserved (Figure 7, red squares). These new sites should be accompanied with a
500 clarification of the conservation effectiveness of all the key protected sites identified in
501 this study (Table 3), especially those in the Andes which currently hold a considerable
502 amount of plant diversity and that are under high threat from urban and agricultural
503 systems expansion. Strong policies for protected areas are necessary to adequately
504 preserve biodiversity throughout the continent, especially given the high rates of
505 endemism in the region (Figure 1).

506 **<INSERT FIGURE 7 HERE>**

507 There are additional issues that deserve close attention with regard to biodiversity
508 conservation, including the role of habitat disturbance in species transitions and
509 interactions, revision of conservation objectives, and the changes in standards of
510 conservation success (Hagerman *et al.*, 2010; Sachs *et al.*, 2009). Addressing these issues
511 is critical in order to better conserve biodiversity under current conditions. In addition,
512 there are significant threats within the protected area system, ~~so~~hence improved
513 monitoring and protection are requisites ~~to~~for avoiding continued biodiversity losses.
514 Automated monitoring systems using satellite data move the conservation community in
515 the right direction in terms of monitoring threats from land use changes (Kennedy *et al.*,
516 2009). The appropriate extension (size) of protected areas and the connectivity between
517 them are desirable characteristics within any protected area system (Galindo-Leal and
518 Camara, 2003). Establishing biological corridors would not only preserve current levels
519 of diversity but also improve resilience against the future impacts of climate change
520 (Hagerman *et al.*, 2010; Jarvis *et al.*, 2003; Jarvis *et al.*, 2008).

521 Threatened areas seem to surround a considerable number of protected areas (Figure 7,
522 right), although it was also observed that protected areas contain relatively large
523 proportions of the populations of medium and broad-range threatened species (not
524 shown). The new potential protected sites are in areas with considerable threat (especially
525 those located in Chile, Argentina and Paraguay).

526 Conservationists should also seek to improve ~~the~~ the current knowledge of the specific
527 landscape patterns occurring across the protected sites, most threatened areas, and when
528 possible, new potential protected sites. ~~-~~This would include the number of threatened
529 species and their habitat requirements (Galindo-Leal and Camara, 2003; Gentry, 1995;

530 Turner *et al.*, 2003) in order to better quantify ecosystem dynamics and critical
531 endangered ecosystems and hotspots (Jeffries, 2005; Sodhi and Ehrlich, 2010; McNeely
532 and Mainka, 2009). Land use changes are critical in certain regions of the Brazilian
533 Cerrado, where a substantial amount of biodiversity has been lost in recent decades
534 (Klink and Machado, 2005). There are additional problems in some areas of the
535 Colombian Amazon, where colonization is problematic for wild habitats (Fjeldså *et al.*,
536 2005; Armenteras *et al.*, 2003; Luteyn, 2002).

537

538 **Conclusions**

539 South America ~~is the home for houses~~ a significant proportion of the world's plant
540 diversity. The data presented in this paper ~~depicts~~ indicates that the region features high
541 rates of endemism, as well as a considerable (78.4% taxa) number of species under high
542 threat. Key drivers of threat are the expansion of agricultural al and grazinglivestock
543 systems, and increased population accessibility (colonization). Unsustainable practices
544 have led to significant fragmentation and loss of natural ecosystems and the ecosystem
545 services they provide. In some cases, forests are now only a fragment of what they were a
546 few centuries ago; while degradation trends are likely to continue and expand to new
547 areas. When analyzing the possible drivers of species extinction, most of South American
548 species were found not to be highly threatened; however, a notable 13.8% of the species
549 analyzed have up to 80% of their populations at risk of extinction (high threat index).

550 Although the large sampling deficiencies over the Amazon make it difficult to draw
551 conclusions on the protected areas over the basin, a more detailed database of species in
552 the Amazon, or extrapolation algorithms (such as ecological niche modeling techniques)

553 could be utilized to better estimate the Amazon's biodiversity using a limited set of data
554 points, and thus enable threat analyses for the region [see e.g. Boyd (2012)].
555 It was found that despite the considerable region-wide threats to natural habitats, the
556 conservation status of South American flora is relatively good. Some 82.3% of the
557 analyzed taxa have at least one population occurring within some kind of protected site.
558 Although there are political issues that surround conservation and ~~there are~~ difficulties ~~of~~
559 ~~in the adequately managing management of~~ public protected areas, especially in
560 developing countries, the geographical distribution analyzed here appears to adequately
561 represent the continental extent of plant diversity. There are, however, 17.7% taxa with
562 no populations in ~~any~~ protected site. The expansion, careful monitoring and strengthening
563 of 10 existing key sites that hold up to 70% of South American plant diversity, and the
564 addition of 7 additional sites (where up to 200 species not currently conserved are
565 present) is suggested. There are critical areas where the monitoring should be focused--
566 the Ecuadorian and Colombian Andes, southern Paraguay, and Bolivia-- which were
567 found to have high threat likelihoods and considerable species richness and endemism.
568 Additional challenges in the form of fostering adequate and effective conservation
569 policies and addressing the threat of climate change, are also needed. However, it is
570 critical to move swiftly to define the objectives of *in situ* conservation in order to better
571 sustain biodiversity. Clear policies and governmental support on monitoring of habitats,
572 as well as careful management of urban and agricultural expansion, are and will continue
573 to be key issues in both the short-term (2-5 years) and long-term (20-50 years) future.
574 Protected area systems not only need to adequately represent biodiversity, but also must
575 have the necessary connectivity in order to sustain interactions between species (i.e.

576 mammal and plant species), have the proper fragment sizes and the adequate funding that
577 allows their sustainability.

578 There are a variety of topics for which deeper analyses should be done, including
579 analyses of biotic interactions and composition, the economic sustainability of protected
580 sites and their monitoring, and necessary modifications under future climates (if, as
581 expected, species distributions become seriously affected).

582

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592

593 **References**

594

- 595 Armenteras, D., Gast, F. & Villareal, H. (2003). Andean forest fragmentation and the
596 representativeness of protected natural areas in the eastern Andes, Colombia.
597 *Biological Conservation* 113(2): 245-256.
- 598 Barbet-Massin, M., Thuiller, W. & Jiguet, F. (2010). How much do we overestimate
599 future local extinction rates when restricting the range of occurrence data in
600 climate suitability models? *Ecography* 33(5): 878-886.
- 601 Barthlott, W., Hostert, A., Kier, G., Küper, W., Kreft, H., Mutke, J., Rafiqpoor, D.
602 & Sommer, J. H. (2007). Geographic Patterns of Vascular Plant Diversity at
603 Continental and Global Scales. *Erkunde* 61(4): 305-315.
- 604 Barthlott, W., Mutke, J., Rafiqpoor, D., Kier, G. & Kreft, H. (2005). Global Centers of
605 Vascular Plant Diversity. *Nova Acta Leopoldina* 92(342): 61-83.

606 Bass, M. S., Finer, M., Jenkins, C. N., Kreft, H., Cisneros-Heredia, D. F., McCracken, S.
607 F., Pitman, N. C. A., English, P. H., Swing, K., Villa, G., Di Fiore, A., Voigt, C.
608 C. & Kunz, T. H. (2010). Global Conservation Significance of Ecuador's Yasuní
609 National Park. *PLoS ONE* 5(1): e8767.

610 Bisby, F. A., Roskov, Y. R., Orrell, T. M., Nicolson, D., Paglinawan, L. E., Bailly, N.,
611 Kirk, P. M., Bourgoin, T. & Baillargeon, G. (2010). Species 2000 & ITIS
612 Catalogue of Life: 2010 Annual Checklist. (Ed S. 2000). Reading, UK.

613 Boyd, I. L. (2012). The Art of Ecological Modeling. *Science* 337(6092): 306-307.

614 Brooks, T. M., Mittermeier, R. A., da Fonseca, G. A. B., Gerlach, J., Hoffmann, M.,
615 Lamoreux, J. F., Mittermeier, C. G., Pilgrim, J. D. & Rodrigues, A. S. L. (2006).
616 Global Biodiversity Conservation Priorities. *Science* 313(5783): 58-61.

617 Burke, M. B., Lobell, D. B. & Guarino, L. (2009). Shifts in African crop climates by
618 2050, and the implications for crop improvement and genetic resources
619 conservation. *Global Environmental Change* 19(3): 317-325.

620 CABI (2010). Index Fungorum. (Ed C. International).

621 Ceballos, G. & Ehrlich, P. R. (2006). Global mammal distributions, biodiversity hotspots,
622 and conservation. *Proceedings of the National Academy of Sciences* 103(51):
623 19374-19379.

624 Chen, I.-C., Shiu, H.-J., Benedick, S., Holloway, J. D., Chey, V. K., Barlow, H. S., Hill,
625 J. K. & Thomas, C. D. (2009). Elevation increases in moth assemblages over 42
626 years on a tropical mountain. *Proceedings of the National Academy of Sciences*
627 106(5): 1479-1483.

628 Chomitz, K. M. & Gray, D. A. (1996). Roads, Land Use, and Deforestation: A Spatial
629 Model Applied to Belize. *The World Bank Economic Review* 10(3): 487-512.

630 Dodson, C. H. & Gentry, A. H. (1991). Biological Extinction in Western Ecuador. *Annals*
631 *of the Missouri Botanical Garden* 78(2): 273-295.

632 FAO (1998). *The State of the World's Plant Genetic Resources for Food and Agriculture*.
633 Rome, Italy: FAO.

634 Fearnside, P. M. & Ferraz, J. (1995). A Conservation Gap Analysis of Brazil's Amazonian
635 Vegetation. *Conservation Biology* 9(5): 1134-1147.

636 Feeley, K. J. (2010). The conservation value of secondary forests for tropical nocturnal
637 bird species. *Animal Conservation* 13(1): 16-18.

638 Feeley, K. J. & Silman, M. R. (2010). Land-use and climate change effects on population
639 size and extinction risk of Andean plants. *Global Change Biology* 16(12): 3215-
640 3222.

641 Fjeldså, J., Álvarez, M. D., Lazcano, J. M. & León, B. (2005). Illicit Crops and Armed
642 Conflict as Constraints on Biodiversity Conservation in the Andes Region.
643 *AMBIO: A Journal of the Human Environment* 34(3): 205-211.

644 Galindo-Leal, C. & Camara, I. G. (2003). *The Atlantic Forest of South America:
645 biodiversity status, threats and outlook*. Washington D.C., USA: Island Press.

646 GBIF (2011). Global Biodiversity Information Facility: Annual Report 2011. (Eds S.
647 Alpanjiguly, T. Hirsch and A. M. Nielsen). Copenhagen, Denmark: Global
648 Biodiversity Information Facility.

649 Gentry, A. H. (1982). Neotropical Floristic Diversity: Phytogeographical Connections
650 Between Central and South America, Pleistocene Climatic Fluctuations, or an

Formatted: Spanish (Spain)

651 Accident of the Andean Orogeny? *Annals of the Missouri Botanical Garden*
652 69(3): 557-593.

653 Gentry, A. H. (1992). *Diversity and floristic composition of Andean forests*. Lima, Peru:
654 Univ. Nac. Mayor San Marcos, Memorias Museo Historia Natural.

655 Gentry, A. H. (1995). *Patterns of diversity and floristic composition in Neotropical*
656 *montane forests*. Bronx: New York Botanical Garden.

657 Giam, X., Bradshaw, C. J. A., Tan, H. T. W. & Sodhi, N. S. (2010). Future habitat loss
658 and the conservation of plant biodiversity. *Biological Conservation* 143(7): 1594-
659 1602.

660 Graham, C. H., Elith, J., Hijmans, R. J., Guisan, A., Townsend Peterson, A., Loiselle, B.
661 A. & The Neceas Predicting Species Distributions Working, G. (2008). The
662 influence of spatial errors in species occurrence data used in distribution models.
663 *Journal of Applied Ecology* 45(1): 239-247.

664 Guralnick, R. & Hill, A. (2009). Biodiversity informatics: automated approaches for
665 documenting global biodiversity patterns and processes. *Bioinformatics* 25(4):
666 421-428.

667 Hagerman, S., Dowlatabadi, H., Satterfield, T. & McDaniels, T. (2010). Expert views on
668 biodiversity conservation in an era of climate change. *Global Environmental*
669 *Change* 20(1): 192-207.

670 Herrera Campo, B., Hyman, G. & Bellotti, A. (2011). Threats to cassava production:
671 known and potential geographic distribution of four key biotic constraints. *Food*
672 *Security*: 1-17.

673 Heywood, V. H. (1995). *Global Biodiversity Assessment*. Cambridge, UK: Cambridge
674 University Press.

675 Hijmans, R. J., Guarino, L., Cruz, M. & Rojas, E. (2001). Computer tools for spatial
676 analysis of plant genetic resources data: 1. DIVA-GIS. *Plant Genetic Resources*
677 *Newsletter* 127: 15-19.

678 Hill, A., Guralnick, R., Flemons, P., Beaman, R., Wiecek, J., Ranipeta, A., Chavan, V.
679 & Remsen, D. (2009). Location, location, location: utilizing pipelines and services
680 to more effectively georeference the world's biodiversity data. *BMC*
681 *Bioinformatics* 10(0): 1-9.

682 Hitz, S. & Smith, J. (2004). Estimating global impacts from climate change. *Global*
683 *Environmental Change Part A* 14(3): 201-218.

684 Huettmann, F., Artukhin, Y., Gilg, O. & Humphries, G. (2011). Predictions of 27 Arctic
685 pelagic seabird distributions using public environmental variables, assessed with
686 colony data: a first digital IPY and GBIF open access synthesis platform. *Marine*
687 *Biodiversity* 41(1): 141-179.

688 IPCC (2007). *IPCC Fourth Assessment Report: Climate Change 2007 (AR4)*. Geneva,
689 Switzerland: IPCC.

690 IPNI (2008). The International Plant Names Index. (Ed IPNI).

691 Jarvis, A., Ferguson, M. E., Williams, D. E., Guarino, L., Jones, P. G., Stalker, H. T.,
692 Valls, J. F. M., Pittman, R. N., Simpson, C. E. & Bramel, P. (2003). Biogeography
693 of Wild Arachis: Assessing Conservation Status and Setting Future Priorities.
694 *Crop Science* 43(3): 1100-1108.

695 Jarvis, A., Lane, A. & Hijmans, R. J. (2008). The effect of climate change on crop wild
696 relatives. *Agriculture, Ecosystems & Environment* 126(1-2): 13-23.

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- 697 Jarvis, A., Touval, J. L., Schmitz, M. C., Sotomayor, L. &Hyman, G. G. (2010).
698 Assessment of threats to ecosystems in South America. *Journal for Nature*
699 *Conservation* 18(3): 180-188.
- 700 Jeffries, M. J. (2005). *Biodiversity and Conservation*. Abingdon, Oxdon.
- 701 Justus, J. &Sarkar, S. (2002). The principle of complementarity in the design of reserve
702 networks to conserve biodiversity: a preliminary history. *Journal of Biosciences*
703 27(4): 421-435.
- 704 Kennedy, R. E., Townsend, P. A., Gross, J. E., Cohen, W. B., Bolstad, P., Wang, Y. Q.
705 &Adams, P. (2009). Remote sensing change detection tools for natural resource
706 managers: Understanding concepts and tradeoffs in the design of landscape
707 monitoring projects. *Remote Sensing of Environment* 113(7): 1382-1396.
- 708 Kim, K. &Byrne, L. (2006). Biodiversity loss and the taxonomic bottleneck: emerging
709 biodiversity science. *Ecological Research* 21(6): 794-810.
- 710 Kim, K. C. (1998). Biodiversity and environmental changes: a great challenge to
711 humanity. In *roceedings of the 1st international symposium on the*
712 *geoenvironmental changes biodiversity in the Northeast Asia*, 369-375 Seoul,
713 Korea.
- 714 Klink, C. A. &Machado, R. B. (2005). Conservation of the Brazilian Cerrado
715 Conservación del Cerrado Brasileño. *Conservation Biology* 19(3): 707-713.
- 716 Loarie, S. R., Duffy, P. B., Hamilton, H., Asner, G. P., Field, C. B. &Ackerly, D. D.
717 (2009). The velocity of climate change. *Nature* 462(7276): 1052-1055.
- 718 Luteyn, J. (2002). Diversity, adaptation, and endemism in neotropical Ericaceae:
719 biogeographical patterns in the Vaccinieae. *The Botanical Review* 68(1): 55-87.
- 720 Maxted, N., Dulloo, E., V Ford-Lloyd, B., Iriondo, J. M. &Jarvis, A. (2008). Gap
721 analysis: a tool for complementary genetic conservation assessment. *Diversity and*
722 *Distributions* 14(6): 1018-1030.
- 723 Maxted, N. &Kell, S. (2009). *Establishment of a global network for the in situ*
724 *conservation of crop wild relatives: status and needs*. Rome, Italy: FAO.
- 725 McNeely, J. A. &Mainka, S. A. (2009). *Conservation for a New Era*. Gland, Switzerland:
726 IUCN.
- 727 MEA (2005). *Millennium Ecosystem Assessment: Ecosystems and human well-being:*
728 *Biodiversity synthesis*. Washington, DC, USA: World Resources Institute.
- 729 Midgley, G. F., Hughes, G. O., Thuiller, W. &Rebelo, A. G. (2006). Migration rate
730 limitations on climate change-induced range shifts in Cape Proteaceae. *Diversity*
731 *and Distributions* 12(5): 555-562.
- 732 Mittermeier, R. A., Mittermeier, C. G., Brooks, T. M., Pilgrim, J. D., Konstant, W. R., da
733 Fonseca, G. A. B. &Kormos, C. (2003). Wilderness and biodiversity
734 conservation. *Proceedings of the National Academy of Sciences of the United*
735 *States of America* 100(18): 10309-10313.
- 736 Musser, G. (2005). The Climax of Humanity. In *Scientific American*, Vol. Sept. 2005, 44-
737 47.
- 738 Mutke, J. &Barthlott, W. (2005). Patterns of vascular plant diversity at continental to
739 global scales. *Biol. Skr.* 55: 521-531.
- 740 Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B. &Kent, J. (2000).
741 Biodiversity hotspots for conservation priorities. *Nature* 403(6772): 853-858.

Formatted: Spanish (Spain)

- 742 Olfert, O. & Weiss, R. M. (2006). Impact of climate change on potential distributions and
743 relative abundances of *Oulema melanopus*, *Meligethes viridescens* and
744 *Ceutorhynchus obstrictus* in Canada. *Agriculture, Ecosystems & Environment*
745 113(1-4): 295-301.
- 746 Palmer, M., Bernhardt, E., Chornesky, E., Collins, S., Dobson, A., Duke, C., Gold, B.,
747 Jacobson, R., Kingsland, S., Kranz, R., Mappin, M., Martinez, M. L., Micheli, F.,
748 Morse, J., Pace, M., Pascual, M., Palumbi, S., Reichman, O. J., Simons, A.,
749 Townsend, A. & Turner, M. (2004). Ecology for a Crowded Planet. *Science*
750 304(5675): 1251-1252.
- 751 Palmer, M. A., Bernhardt, E. S., Schlesinger, W. H., Eshleman, K. N., Foufoula-
752 Georgiou, E., Hendryx, M. S., Lemly, A. D., Likens, G. E., Loucks, O. L., Power,
753 M. E., White, P. S. & Wilcock, P. R. (2010). Mountaintop Mining Consequences.
754 *Science* 327(5962): 148-149.
- 755 Papeş, M. & Gaubert, P. (2007). Modelling ecological niches from low numbers of
756 occurrences: assessment of the conservation status of poorly known viverrids
757 (Mammalia, Carnivora) across two continents. *Diversity and Distributions* 13(6):
758 890-902.
- 759 Ramírez-Villegas, J., Khoury, C., Jarvis, A., Debouck, D. G. & Guarino, L. (2010). A Gap
760 Analysis Methodology for Collecting Crop Genepools: A Case Study with
761 *Phaseolus* Beans. *PLoS ONE* 5(10): e13497.
- 762 Rebelo, A. G. (1994). Iterative selection procedures: Centres of endemism and optimal
763 placement of reserves. *Strelitzia* 1: 231-257.
- 764 Rebelo, A. G. & Siegfried, W. R. (1992). Where Should Nature Reserves Be Located in
765 the Cape Floristic Region, South Africa? Models for the Spatial Configuration of
766 a Reserve Network Aimed at Maximizing the Protection of Floral Diversity.
767 *Conservation Biology* 6(2): 243-252.
- 768 Ricketts, T. H., Dinerstein, E., Boucher, T., Brooks, T. M., Butchart, S. H. M., Hoffmann,
769 M., Lamoreux, J. F., Morrison, J., Parr, M., Pilgrim, J. D., Rodrigues, A. S. L.,
770 Sechrest, W., Wallace, G. E., Berlin, K., Bielby, J., Burgess, N. D., Church, D. R.,
771 Cox, N., Knox, D., Loucks, C., Luck, G. W., Master, L. L., Moore, R., Naidoo,
772 R., Ridgely, R., Schatz, G. E., Shire, G., Strand, H., Wettengel, W.
773 & Wikramanayake, E. (2005). Pinpointing and preventing imminent extinctions.
774 *Proceedings of the National Academy of Sciences of the United States of America*
775 102(51): 18497-18501.
- 776 Robertson, M. P., Cumming, G. S. & Erasmus, B. F. N. (2010). Getting the most out of
777 atlas data. *Diversity and Distributions* 16(3): 363-375.
- 778 Sachs, J. D., Baillie, J. E. M., Sutherland, W. J., Armsworth, P. R., Ash, N., Beddington,
779 J., Blackburn, T. M., Collen, B., Gardiner, B., Gaston, K. J., Godfray, H. C. J.,
780 Green, R. E., Harvey, P. H., House, B., Knapp, S., Kumpel, N. F., Macdonald, D.
781 W., Mace, G. M., Mallet, J., Matthews, A., May, R. M., Petchey, O., Purvis, A.,
782 Roe, D., Safi, K., Turner, K., Walpole, M., Watson, R. & Jones, K. E. (2009).
783 Biodiversity Conservation and the Millennium Development Goals. *Science*
784 325(5947): 1502-1503.
- 785 Scott, J. M. & Schipper, J. (2006). *Gap analysis: a spatial tool for conservation planning*.
786 Sunderland: Sinauer.

787 Sodhi, N. S. & Ehrlich, P. R. (2010). *Conservation Biology for All*. Oxford, UK: Oxford
788 University Press.

789 Thomas, C. D., Cameron, A., Green, R. E., Bakkenes, M., Beaumont, L. J., Collingham,
790 Y. C., Erasmus, B. F. N., de Siqueira, M. F., Grainger, A., Hannah, L., Hughes,
791 L., Huntley, B., van Jaarsveld, A. S., Midgley, G. F., Miles, L., Ortega-Huerta, M.
792 A., Townsend Peterson, A., Phillips, O. L. & Williams, S. E. (2004). Extinction
793 risk from climate change. *Nature* 427(6970): 145-148.

794 Turner, W., Spector, S., Gardiner, N., Fladeland, M., Sterling, E. & Steininger, M. (2003).
795 Remote sensing for biodiversity science and conservation. *Trends in Ecology &*
796 *Evolution* 18(6): 306-314.

797 Turner, W. R., Nakamura, T. & Dinetti, M. (2004). Global Urbanization and the
798 Separation of Humans from Nature. *BioScience* 54(6): 585-590.

799 UNEP & IUCN (2009). The World Database on Protected Areas (WDPA). (Ed UNEP-
800 WCMC). Cambridge, UK.

801 Whittaker, R. H. (1977). Evolution of species diversity in land communities.
802 *Evolutionary Biology* 10: 1-67.

803 Wilson, K. A., McBride, M. F., Bode, M. & Possingham, H. P. (2006). Prioritizing global
804 conservation efforts. *Nature* 440(7082): 337-340.

805 Wohl, E., Barros, A., Brunzell, N., Chappell, N. A., Coe, M., Giambelluca, T.,
806 Goldsmith, S., Harmon, R., Hendrickx, J. M. H., Juvik, J., McDonnell, J.
807 & Ogden, F. (2012). The hydrology of the humid tropics. *Nature Clim. Change*
808 advance online publication.

809 Worm, B., Barbier, E. B., Beaumont, N., Duffy, J. E., Folke, C., Halpern, B. S., Jackson,
810 J. B. C., Lotze, H. K., Micheli, F., Palumbi, S. R., Sala, E., Selkoe, K. A.,
811 Stachowicz, J. J. & Watson, R. (2006). Impacts of Biodiversity Loss on Ocean
812 Ecosystem Services. *Science* 314(5800): 787-790.

813 Yesson, C., Brewer, P. W., Sutton, T., Caithness, N., Pahwa, J. S., Burgess, M., Gray, W.
814 A., White, R. J., Jones, A. C., Bisby, F. A. & Culham, A. (2007). How Global Is
815 the Global Biodiversity Information Facility? *PLoS ONE* 2(11): e1124.

816 Young, K., Ulloa, C., Luteyn, J. & Knapp, S. (2002). Plant evolution and endemism in
817 Andean South America: An introduction. *The Botanical Review* 68(1): 4-21.

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Table 1 Cross-checking and verification of location data from the database

| Corrective procedure | Number of records | Percent from total | Percent from <i>Plantae</i> | Percent from non repeated terrestrial plant taxa |
|--------------------------------------|-------------------|--------------------|-----------------------------|--|
| +Records in the database | 177,887,193 | 100.0 | N/A | N/A |
| + <i>Plantae</i> records | 44,706,505 | 25.13 | 100.0 | N/A |
| +With coordinates | 33,340,000 | 18.74 | 74.58 | N/A |
| +Non repeated terrestrial plant taxa | 14,390,414 | 8.09 | 32.19 | 100.0 |
| -Wrong country | 128,419 | 0.07 | 0.29 | 0.89 |
| -Null country (not verifiable) | 780,536 | 0.44 | 1.75 | 5.42 |
| -Between 1 and 5km far from land | 497,078 | 0.28 | 1.11 | 3.45 |
| -More than 5km far from land | 120,389 | 0.07 | 0.27 | 0.84 |
| -Outside global boundaries | 3,711 | 0.00 | 0.01 | 0.03 |
| -Total records with errors | 1,530,133 | 0.86 | 3.42 | 10.63 |
| -Total good records | 12,860,281 | 7.23 | 28.77 | 89.37 |
| -Not in South America | 12,346,913 | 6.94 | 27.62 | 85.80 |
| -Total records for the assessment | 513,368 | 0.29 | 1.15 | 3.57 |

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Table 2 Descriptive statistics of variables used to calculate the threat index (among taxa)

| Variable | MEAN | SD ¹ | CV (%) ² | MIN | MAX |
|----------------------------------|---------|-----------------|---------------------|-------|---------|
| Maximum horizontal distance (km) | 1,860.1 | 1,377.6 | 74.1 | 0.000 | 6,684.6 |
| Maximum vertical distance (km) | 1,962.9 | 1,452.4 | 74.0 | 0.000 | 7,359.6 |
| Accessibility (MAX) | 1.527 | 0.573 | 37.5 | 0.012 | 3.000 |
| Accessibility (MIN) | 0.280 | 0.321 | >100 | 0.012 | 2.639 |
| Conversion to agriculture (MAX) | 0.731 | 0.607 | 83.0 | 0.000 | 2.827 |
| Conversion to agriculture (MIN) | 0.015 | 0.108 | >100 | 0.000 | 2.197 |
| Fires (MAX) | 1.192 | 0.905 | 75.9 | 0.000 | 2.992 |
| Fires (MIN) | 0.027 | 0.181 | >100 | 0.000 | 2.919 |
| Grazing Pressure (MAX) | 0.826 | 0.938 | >100 | 0.000 | 3.000 |
| Grazing Pressure (MIN) | 0.029 | 0.152 | >100 | 0.000 | 3.000 |
| Infrastructure (MAX) | 0.294 | 0.683 | >100 | 0.000 | 2.580 |
| Infrastructure (MIN) | 0.002 | 0.047 | >100 | 0.000 | 2.191 |
| Oil/Gas extraction (MAX) | 0.210 | 0.569 | >100 | 0.000 | 2.458 |
| Oil/Gas extraction (MIN) | 0.000 | 0.023 | >100 | 0.000 | 1.526 |
| Recent conversion (MAX) | 0.955 | 0.568 | 59.5 | 0.000 | 2.302 |
| Recent conversion (MIN) | 0.043 | 0.197 | >100 | 0.000 | 1.960 |
| Aggregate threat (MAX) | 0.491 | 0.208 | 42.4 | 0.008 | 1.811 |
| Aggregate threat (MIN) | 0.077 | 0.097 | >100 | 0.003 | 1.033 |
| Threat Index | 0.547 | 0.135 | 24.6 | 0.064 | 1.000 |

¹Standard deviation; ²Coefficient of variation

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Table 3 Top ten 100km side cells over South America where up to 70% of the taxa are concentrated, and corresponding official protected areas which these cells intersect

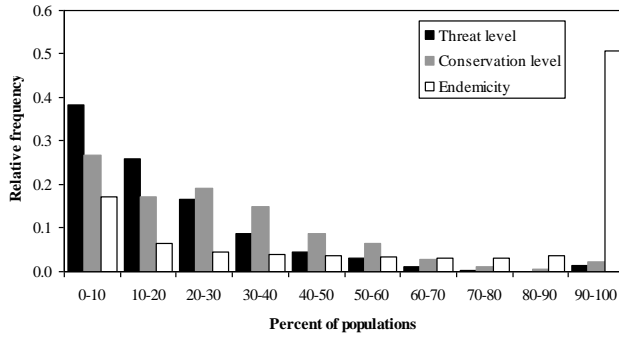
| Iteration | Taxa (N) | Unique taxa (N) | Intersected protected sites (N) | Corresponding Protected sites [ISO country]* |
|-----------|----------|-----------------|---------------------------------|---|
| 1 | 3615 | 3615 | 5 | -Cotacachi-Cayapas (ecological reserve) [ECU] |
| | | | | -Indigenous community Awá area [ECU] |
| | | | | -El Angel (ecological reserve) [ECU] |
| | | | | -Cayambe-Coca (ecological reserve) [ECU] |
| | | | | -Pululahua (geobotanical reserve) [ECU] |
| 2 | 2589 | 2147 | 4 | -Réserve naturelle des Nourages [GUF] |
| | | | | -Marais de Kaw [GUF] |
| | | | | -Parc Naturel Régional de Guyane [GUF] |
| | | | | -Mont Grand Matoury (national nature reserve) [GUF] |
| 3 | 3306 | 1406 | 3 | -Sumaco-napo Galeras (National Park) [ECU] |
| | | | | -Pululahua (geobotanical reserve) [ECU] |
| 4 | 2060 | 1022 | 1 | -Antisana (ecological reserve) [ECU] |
| | | | | -Cotapata national park [BOL] |
| 5 | 1349 | 763 | 4 | -Lago Ypoá national park [PAR] |
| | | | | -Ypacaraí national park [PAR] |
| | | | | -Macizo Acahay natural monument [PAR] |
| 6 | 2071 | 702 | 1 | -Río Pilcomayo national park [ARG] |
| | | | | -Allapahuayo Mishana national reserve [PER] |
| 7 | 2189 | 567 | 1 | -Rio Nare [COL] |
| 8** | 2177 | 438 | 1 | -Podocarpus national park [ECU] |
| 9 | 1096 | 349 | 2 | -Noel Kempff-Mercado national park [BOL] |
| | | | | -Serra de Ricardo Franco (state park) [BRA] |
| 10 | 2671 | 284 | 2 | -Yasuní National Park [ECU] |
| | | | | -Cuyabeno production reserve [ECU] |

850 *ECU: Ecuador, GUF: French Guiana, BOL: Bolivia, PAR: Paraguay, ARG: Argentina, PER: Peru, COL:

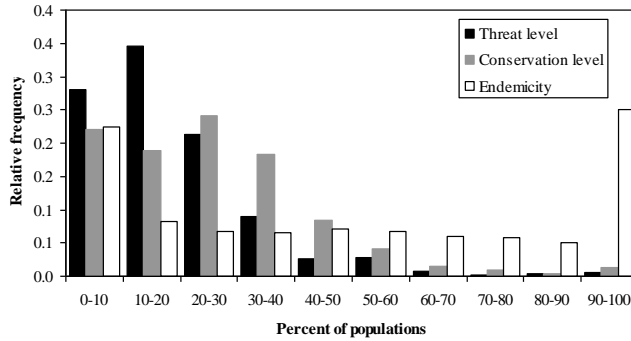
851 Colombia, BRA: Brazil; **Only a very small portion of the protected site was intersected (<5% area)

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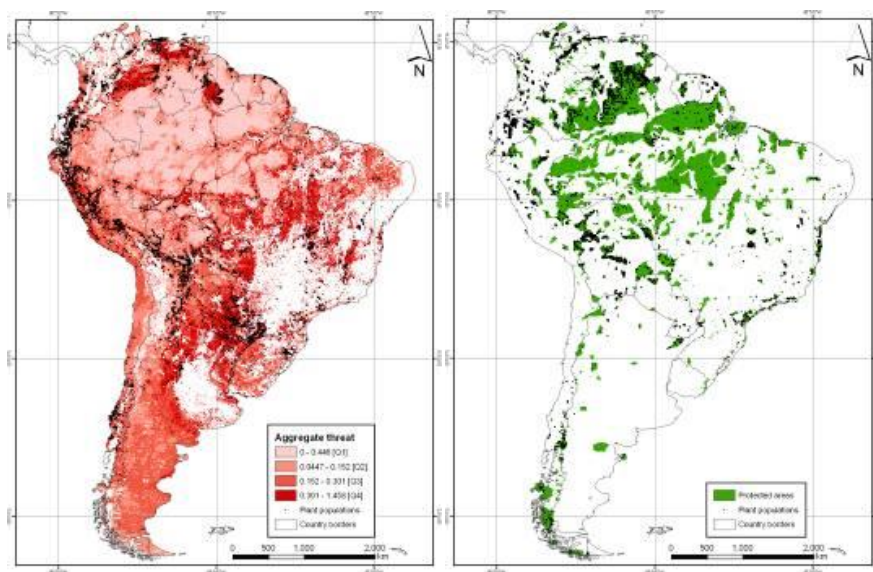


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863 **Figure 1** Rates of endemism (white bars), conservation (grey bars) and threats (black
864 bars). (A) for individual species, and (B) for genera. Relative frequency represents the
865 fraction of species or genera under analysis in each class.

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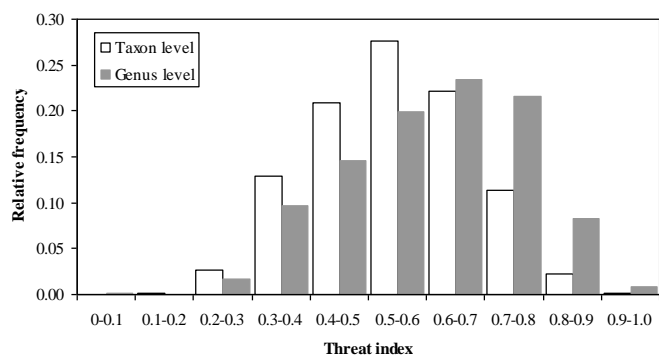
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880 **Figure 2** Spatial distributions of threats and protected areas. (A) Aggregate threat and (B)
881 protected areas. Black dots in (A) show populations occurring in the last quartile (top
882 25%), and black dots in (B) show populations occurring within protected areas.

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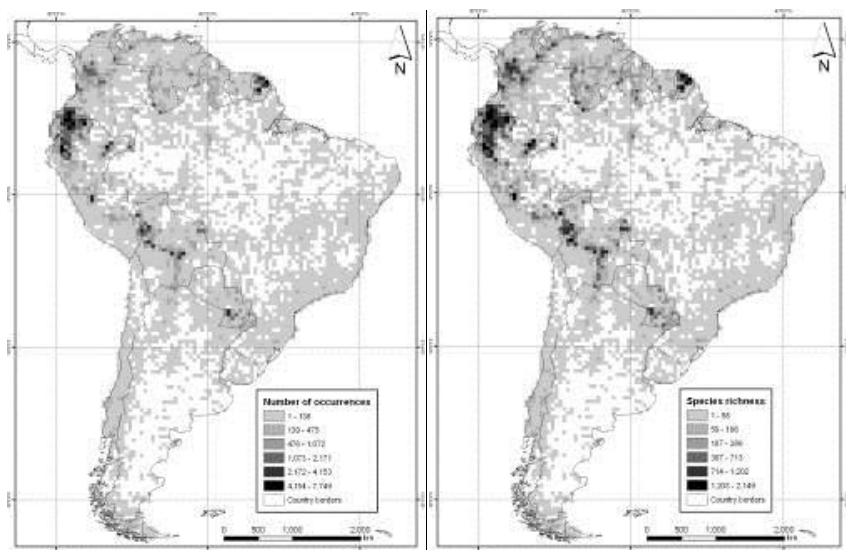


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898 **Figure 3** Distribution of the threat index (TI) among taxa (white bars) and genera (grey
899 bars). Relative frequency represents the fraction of the set of taxa under analysis
900 belonging to each class of the index.

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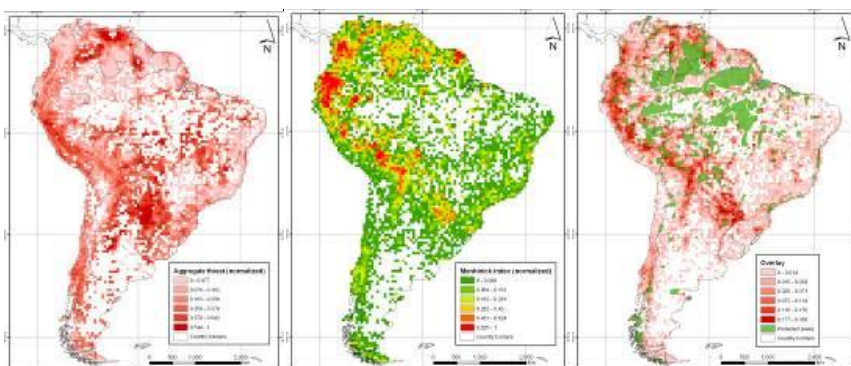
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916 **Figure 4** Sampling densities (left) and species richness (right) calculated for each 0.5-by-
917 0.5 degree cells.

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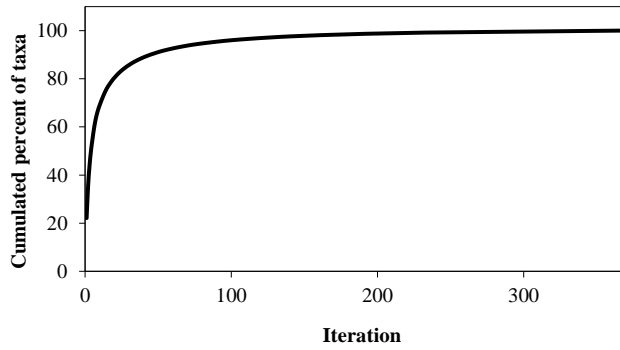
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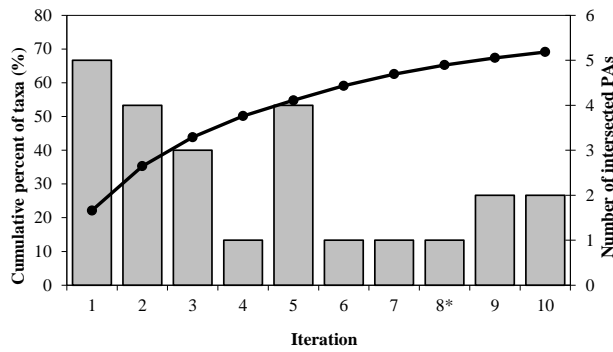
930 **Figure 5** Regional threat status analyses. (A) Normalized sum of aggregate threat, (B)
931 normalized Menhinick index and (C) product between A and B, overlaid with protected
932 areas. White areas are those where no threat or no species data was reported.
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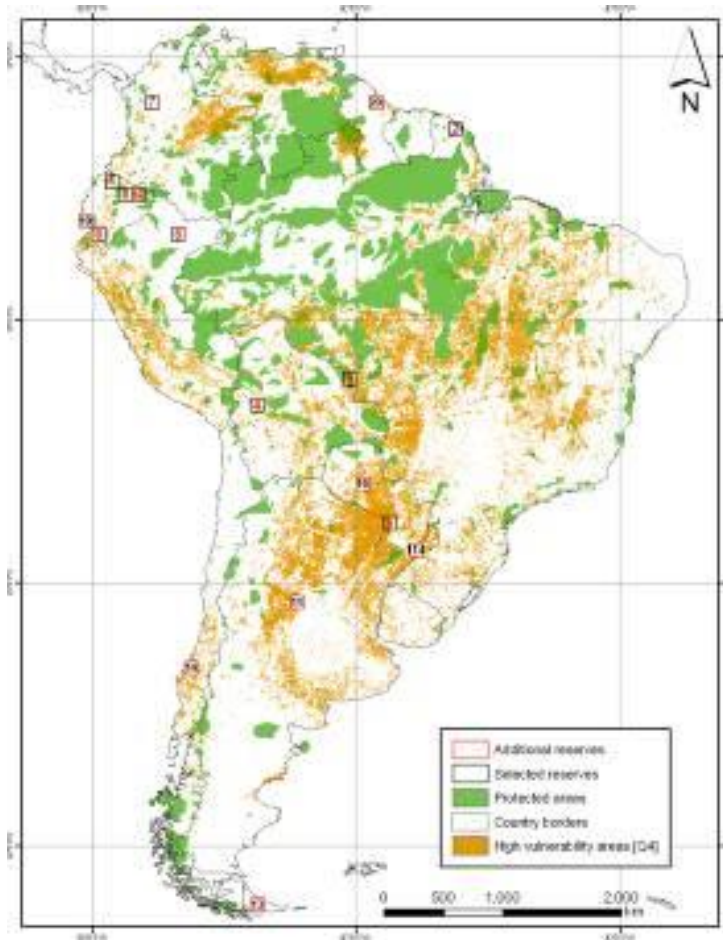


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940 **Figure 6** Reserve selection process. (A) With no limit in iterations (total 368), and (B)
941 with a limit of 10 iterations (see also Table 3). Each iteration represents a single 100 km
942 side cell. The continuous line represents the cumulated percent of taxa that would be
943 protected in each of the cells. In (B) the bars represent the number of protected sites that
944 are contained or intersected by each of the gridcells. *Intersects only a small part (<5%
945 area) of a protected area.

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951 **Figure 7** Nationally and internationally protected areas (green) according to WDPA and
952 IUCN (2009), black squares are reserves containing up to 70% of South American plant
953 diversity (labels show the selection order to match with Table 3); red squares are the
954 likely new areas where additional unique taxa could be conserved (labels show the
955 respective number of taxa) overlaid with high aggregate threat areas (4th quartile)