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

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Abstract

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

Keywords: species richness, diversity, anthropogenic activities, extinction, protected areas, populations, agriculture

Introduction

Dramatic changes in ecosystems due to human activities lead to habitat degradation, fragmentation and consequent biodiversity loss (Heywood, 1995; Kim and Byrne, 2006; Kim, 1998; Turner *et al.*, 2004), not to mention the effects on the ecosystem services (Worm *et al.*, 2006; Wohl *et al.*, 2012) that sustain human society. These changes are driven by a number of human activities, including the expansion of agricultural systems, grazing pressure, provoked and natural fires, oil and gas extraction, infrastructure development, and urban development (Jarvis *et al.*, 2010; Papeş and Gaubert, 2007; FAO, 1998). The most significant loss of biodiversity has taken place within the last decades, coinciding with rapid population and economic growth (Palmer *et al.*, 2004; Musser, 2005). A stable conservation system is necessary to preserve biodiversity, especially considering predicted rates of climatic changes (IPCC, 2007; Thomas *et al.*, 2004; Loarie *et al.*, 2009), which constitutes an additional pressure on ecosystems. Management practices and ecosystem conservation policies are key issues in the near and the long-term future (Burke *et al.*, 2009; Hagerman *et al.*, 2010; Jarvis *et al.*, 2008; Olfert and Weiss, 2006; Thomas *et al.*, 2004; Hitz and Smith, 2004).

NGOs, government conservation agencies and international research centers have engaged in activities with the aim of preserving species and genetic diversity in wild and natural habitats. Conservation policies and knowledge about biodiversity have increased over time, and the extent to which conservation actions preserve plant genetic diversity has increased (Maxted and Kell, 2009). However, further adjustments to approaches to conservation are needed, given the complexity of biodiversity (Kim and Byrne, 2006; Wilson *et al.*, 2006).

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

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

In this study, an assessment of the threat level and conservation status of South American flora is performed by means of spatial and statistical analyses, using seven immediate threat layers developed by Jarvis et al. (2010), combined with a representative set of occurrences of plants of South America from the Global Biodiversity Information Facility (GBIF), and using the distribution of protected areas in South America (UNEP and IUCN, 2009). These ~~R~~results can be used to improve conservation policies in the near future, ~~and~~ for the improvement of conservation practices, as well as to improve~~d~~ regional understanding of ecosystem and plant diversity threats from human activities.

Materials and methods

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

(1) Gather and assess the largest possible amount of publicly available data for the region (i.e. South America)

(2) Quantify the threat-level on a taxon-by-taxon basis for all species in the region for which data was available

(3) Perform a geographic analysis to compare the centers of plant diversity and the most threatened areas

(4) Determine the extent to which ~~current~~ protected areas in the region represent the sampled biodiversity and provide recommendations to the establishment of potential new sites to strengthen the existing protected area network.

Biodiversity data

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

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

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Given the known issues in the GBIF data, ~~signified~~ particular attention was given ~~to~~ to ensuring reliability of results. The entire set of occurrences corresponding to the *Plantae* kingdom (global dataset) was ~~queried~~ interrogated and then verified via a thorough coordinate verification process. Records (1) with ~~null~~ no reported latitude and/or longitude data, (2) belonging to sea plant species (based on their most superior clade or *Phylum*), (3) falling in the ocean ~~(using a high level detail land areas mask)~~, (4) with no ~~null~~ reported collection country names or falling in a wrong country according to the values reported in the database and their location within a global dataset (GADM, www.gadm.org), (5) with redundant information (belonging to the same taxon and having exactly the same coordinates), and/or (6) not falling within South America, were discarded during the process. The whole process was tracked to determine the degree to which the retrieved part of the GBIF database is incorrect and to determine the percent of sampled flora from the database that correspond to South America [see also Yesson *et al.* (2007)].

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

Threats data

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

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

Immediate threats assessment

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

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

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

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

4th quartile (top 25%) of the aggregate threat layer (calculated using all pixels in the region) to the total number of occurrences found in South America,

(3) The maximum horizontal (i.e. East-West) distance (HD) between two populations,

(4) The maximum vertical (i.e. South-North) distance (VD) between two populations,

(5) The value of each threat (*i*) corresponding to the most threatened population (MT_i). As opposed to the PTP, which provides an estimate of the geographic range extent that is under threat, the MT_i only provides an estimate of the most vulnerable population (i.e. focalized impact); and

(6) The value of each threat (*i*) corresponding to the least threatened population (LT_i).

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

The behavior of each of these variables was defined in order to calculate a single final value (index) that represents the level of threat and/or reflects the likelihood of a taxon being extinct in the near future. As PE, PTP, MT_i and LT_i increase, the taxon becomes more threatened either because it is not likely to be represented in areas other than South America, it has a considerable percent of threatened populations, or the levels of threat in its most and least threatened populations are considerably high (in this case the standardized value was used directly). As HD and VD increase, the taxon is less threatened because the geographical range of the taxon is broader, so it is less likely to be extinct by a single event (in this case the additive inverse is used). Although it is acknowledged that taxa with few, isolated and distant populations (i.e. with high HD and/or VD) are more vulnerable than taxa with many populations distributed uniformly across a large distance (i.e. with high HD and/or VD) and should be treated differently, such differences are partly accounted for by individual scores in threatened populations (MT_i and LT_i), and the PTP.

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

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

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

Geographic assessment of threats: In order to perform a spatially-explicit assessment of threats over South America, species richness (i.e. the number of different species) and sampling densities (i.e. the total number of samples) were calculated on each 0.5-by-0.5 degree cell (~50-by-50 km in the equator) in order to calculate the Menhinick diversity index (Whittaker, 1977) by dividing the former by the square root of the latter. ~~We use~~ ~~t~~The Menhinick index was used because, as opposed to simple species richness, it is less likely to be biased due to the differences in sampling sizes and efforts throughout the region (Whittaker, 1977).

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

Conservation status assessment

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

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

(1) A dataset containing the geographic distribution of protected areas of the region was retrieved from the World Database on Protected Areas (WDPA, publicly available at http://www.wdpa.org/) (UNEP and IUCN, 2009). The data retrieved consist~~s~~ed of polygons that show each of the protected areas (of all categories) in the region. Using this data in conjunction with the species occurrences (see above)~~.~~, t~~T~~he percent of

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

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

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

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

Results and discussion

Biodiversity data collation and cleaning

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

<INSERT TABLE 1 HERE>

Only 3.6% of the non-repeated records from the *Plantae* kingdom were used, indicating that data quality in large databases is a fundamental issue to be addressed when performing any analysis with such data (Robertson *et al.*, 2010; Graham *et al.*, 2008). The mean number of unique occurrences per taxon in South America was 31.4, with a standard deviation of 43.1, indicating that sampling distribution across species is highly heterogeneous, ranging between 1 and 1063 samples for a single taxon within the continental area. Some 6.6% of the taxa were reported in the database with only one occurrence (i.e. one single population) in the land areas of the continent, 3.7% with 2 populations, and 2.3% with 3 populations.

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

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

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

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

Immediate threats assessment

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

<INSERT FIGURE 1 HERE>

The most threatened areas *per se* are those in the last quartile of aggregate threat and mainly cover some highland areas in the Andes, particularly in Peru, the eastern plains in Colombia, and the very northern regions of Venezuela, where not even a single reserve has been established (Figure 2, right). There are some additional areas under considerable threat near the Brazilian Cerrado and in Paraguay and its borders with Argentina. In these areas, population presence varied substantially among the taxa, with 80.7% presenting less than 30% of the populations in a threatened area (above the 3rd quartile of the aggregate threat layer [Figure 2, left]); nevertheless, some 2% of the plant taxa presented more than 70% of their populations within some of these areas (Figure 2, left), indicating that although the entire taxon is not highly threatened, there is some risk of intensifying genetic loss. In addition, 173 plant taxa (out of 1,088 taxa that had only one population) had their single unique population within threatened areas. This indicates that under-sampled areas might coincide with high immediate threat areas, and that some additional sampling efforts should be done in order to better characterize the level of threat of certain groups of species. Likewise, the set of threats under analysis seem to affect 50% of the populations in most of the cases, and 18 entire genera (*Aerva*, *Catapodium*, *Chrysolepsis*, *Diectomis*, *Ecballium*, *Ginko*, *Ibicella*, *Kochia*, *Litchi*, *Lophospermum*, *Parapholis*, *Pelexia*, *Phlox*, *Potentilla*, *Pseudoscleropodium*, *Schoenocaulon*, *Scrophularia*, and *Taeniatherum*) had 100% of their populations within a high threat area. Nevertheless, these genera are not endemic to South America. In addition, there were 6 genera with up to 80% of their populations under high threat and with high rates of endemism (*Acca* [family *Myrtaceae*, PE=50%], *Bumelia* [family *Sapotaceae*, PE=40%], *Microlobius* [family *Fabaceae*, PE=75%], *Tetraplodon* [family *Splachnaceae*, PE=50%], *Hovenia* [family *Rhamnaceae*, PE=65%], and *Jaborosa* [family *Jaborosa*, PE=82%]).

<INSERT FIGURE 2 HERE>

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

<INSERT TABLE 2 HERE>

There are threats that more significantly affect the flora of South America under analysis. Maximum values for accessibility ranged from 0.012 to 3, while minimum values ranged between similar values (0.012 to 2.639). In contrast, some threats such as oil/gas extraction exhibited much lower values (0 to 2.4 for maximums and 0 to 1.5 for minimums) due to their highly localized impacts. Fires, grazing pressure, accessibility and conversion to agriculture seem to account to most of the South American flora diversity losses, while infrastructure (airports and dams), oil/gas extraction, and recent conversion seem less likely to be involved in these losses and threats. It is also possible that some of the populations analyzed here are already extinct due to habitat destruction, habitat fragmentation and forest over-exploitation (Dodson and Gentry, 1991; Giam *et al.*, 2010; Feeley and Silman, 2010). In the long term (10-20 years), however, biodiversity can be much more threatened by population accessibility (including the construction of new roads) as this can cause community migration, forest clearing, and expansion of the agricultural boundary (Chomitz and Gray, 1996). Additionally, it is noted that although mining is known to be a more important problem than oil and gas extraction (Palmer *et al.*, 2010), the data of Jarvis et al. (2010) did not include such information and mining was thus not considered in the analyses. ~~It is expected l~~Levels of threat shown ~~here~~in this study are expected ~~-~~to be higher if mining activities were to be considered.

The threat index (i.e. cumulative threat) varied from 0.064 (6.4%, the least threatened, *Festuca rubra* L.) to 1.0 (100%, the most threatened, *Diplokeleba floribunda* N.E. Br.) (see Figure 3), and the observed distribution of this index showed significant variability, with most of the taxa presenting indices between 0.4 and 0.7. Some 13.7% of the total number of taxa under analysis showed indices above 0.8, while only 2.8% showed values below 0.3. Genera are more concentrated to the right (above 0.5% of extinction risk), but only few genera and taxa seem to have indices above 0.9.

<INSERT FIGURE 3 HERE>

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

A considerable area in the Amazon basin and southern part of the continent (almost all of Argentina) remains under-sampled, not sampled, or unrepresented in the GBIF *Plantae* database, where a very limited number of occurrences represent the plant diversity. These sampling deficiencies prevent us from performing a detailed analysis over the known diversity within South America. Knowledge gaps exist in Argentina and the Amazon, but are less prominent in the Andes, the Guyana shield and the Brazil Atlantic Forest (Figure 4). The greatest sampling densities were found across the Andes from Colombia to Bolivia, and particularly in Ecuador. There is some additional sampling in some parts of southeastern Paraguay, as well as some isolated areas in the French Guyana and Venezuela. Further study of biodiversity in those areas where data is not abundant would benefit this type of study and fill gaps in the current knowledge of plant diversity distribution.

<INSERT FIGURE 4 HERE>

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

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

<INSERT FIGURE 5 HERE>

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

Protected sites across the Andes (Figure 5c), at least geographically, seem to be useful in protecting vulnerable ecosystems and the taxa present in them (Sachs *et al.*, 2009; Bass *et* *al.*, 2010; Young *et al.*, 2002). Nonetheless, conservation is not only a question of establishing a set of reserves to preserve a set of plants, but also ensuring that the diversity within a taxon is preserved (Brooks *et al.*, 2006; Mittermeier *et al.*, 2003; Ricketts *et al.*, 2005). It is therefore critical not only that protected areas be well distributed throughout the region, but also that overall vulnerability is reduced in other parts of the region by means of sustainable development. Towards this end, conservation o~~r~~f plant diversity across South America can be enhanced via improved management and maintenance of "working landscapes" such as agricultural and urban frontiers, which were areas found to be under ~~greatest~~considerable threat for South American flora (Brooks *et al.*, 2006; Ricketts *et al.*, 2005; Wilson *et al.*, 2006).

Conservation status assessment

Interestingly, 82.3% of the assessed plant taxa were found to have at least one population within a protected site (Figure 2, right), and some 63.1% of the taxa were found to have up to 30% of their populations within a protected area. Less than 40% ~~of the populations~~ of ~~the~~ genera populations are conserved in most of the cases, although some exceptions were found. In some instances up to 90% of ~~the~~ genera populations are conserved, but these are usually limited geographical range genera. Importantly, 17.7% of the total number of taxa presented no populations within any protected area, and in some cases they are in areas that are under threat. These values could depict some potential deficiencies in conservation networks throughout the continent, although it could also be a sampling issue. While immediate (2-5 year) threat status seems to be considerable for a number of populations and taxa, in contrast, conservation status shows that plant diversity may be relatively well conserved. This paradox could be explained in two ways: there are protected sites under considerable threats so that the same populations are being threatened and conserved at the same time, or there are, separately, some very well conserved populations and some very threatened ones.

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

The reserve selection procedure identified 368 single 100km-side cells required to protect each of the 16,339 taxa under analysis; however, only ten cells, which intersected or contained 24 protected sites, were found to contain 70% of the analyzed taxa, and 20 cells contained 80% of the taxa (Figure 6). 77.7% of the selected cells contained or intersected in at least one national park, natural reserve, or indigenous territory, indicating that the protected area system of South America is ~~quite~~ highly effective in preserving ~~the~~ a ~~greatest~~ large amount of diversity ~~of~~ across the region. There were 48 cells that neither intersected nor contained any protected site, and these cells contained up to 317 taxa that are not being conserved at all in any of the protected areas (according to the GBIF database).

<INSERT FIGURE 6 HERE>

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

<INSERT TABLE 3 HERE>

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

<INSERT FIGURE 7 HERE>

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

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

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

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

Conclusions

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

Although the large sampling deficiencies over the Amazon make it difficult to draw conclusions on the protected areas over the basin, a more detailed database of species in the Amazon, or extrapolation algorithms (such as ecological niche modeling techniques) could be utilized to better estimate the Amazon's biodiversity using a limited set of data points, and thus enable threat analyses for the region [see e.g. Boyd (2012)].

It was found that despite the considerable region-wide threats to natural habitats, the conservation status of South American flora is relatively good. Some 82.3% of the analyzed taxa have at least one population occurring within some kind of protected site. Although there are political issues that surround conservation and there are difficulties ~~of~~ in the ~~adequately managing~~ management of public protected areas, especially in developing countries, the geographical distribution analyzed here appears to adequately represent the continental extent of plant diversity. There are, however, 17.7% taxa with no populations in any protected site. The expansion, careful monitoring and strengthening of 10 existing key sites that hold up to 70% of South American plant diversity, and the addition of 7 additional sites (where up to 200 species not currently conserved are present) is suggested. There are critical areas where the monitoring should be focused-- the Ecuadorian and Colombian Andes, southern Paraguay, and Bolivia-- which were found to have high threat likelihoods and considerable species richness and endemism.

Additional challenges in the form of fostering adequate and effective conservation policies and addressing the threat of climate change~~,~~ are also needed. However, it is critical to move swiftly to define the objectives of *in situ* conservation in order to better sustain biodiversity. Clear policies and governmental support on monitoring of habitats, as well as careful management of urban and agricultural expansion, are and will continue to be key issues in both the short-term (2-5 years) and long-term (20-50 years) future. Protected area systems not only need to adequately represent biodiversity, but also must have the necessary connectivity in order to sustain interactions between species (i.e.

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

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

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References

Armenteras, D., Gast, F. &Villareal, H. (2003). Andean forest fragmentation and the representativeness of protected natural areas in the eastern Andes, Colombia. *Biological Conservation* 113(2): 245-256.

Barbet-Massin, M., Thuiller, W. &Jiguet, F. (2010). How much do we overestimate future local extinction rates when restricting the range of occurrence data in climate suitability models? *Ecography* 33(5): 878-886.

Barthlott, W., Hostert, A., Kier, G., Küper, W., Kreft, H., Mutke, J., Rafiqpoor, D. &Sommer, J. H. (2007). Geographic Patterns of Vascular Plant Diversity at Continental and Global Scales. *Erkunde* 61(4): 305-315.

Barthlott, W., Mutke, J., Rafiqpoor, D., Kier, G. &Kreft, H. (2005). Global Centers of Vacular Plant Diversity. *Nova Acta Leopoldina* 92(342): 61-83.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Formatted: Spanish (Spain)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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Formatted: Spanish (Spain)

Jarvis, A., Touval, J. L., Schmitz, M. C., Sotomayor, L. &Hyman, G. G. (2010). Assessment of threats to ecosystems in South America. *Journal for Nature Conservation* 18(3): 180-188.

Jeffries, M. J. (2005). *Biodiversity and Conservation.* Abingdon, Oxdon.

Justus, J. &Sarkar, S. (2002). The principle of complementarity in the design of reserve networks to conserve biodiversity: a preliminary history. *Journal of Biosciences* 27(4): 421-435.

Kennedy, R. E., Townsend, P. A., Gross, J. E., Cohen, W. B., Bolstad, P., Wang, Y. Q. &Adams, P. (2009). Remote sensing change detection tools for natural resource managers: Understanding concepts and tradeoffs in the design of landscape monitoring projects. *Remote Sensing of Environment* 113(7): 1382-1396.

Kim, K. &Byrne, L. (2006). Biodiversity loss and the taxonomic bottleneck: emerging biodiversity science. *Ecological Research* 21(6): 794-810.

Kim, K. C. (1998).Biodiversity and environmental changes: a great challenge to humanity. In *roceedings of the 1st international symposium on the geoenvironmental changes biodiversity in the Northeast Asia*, 369-375 Seoul, Korea.

Klink, C. A. &Machado, R. B. (2005). Conservation of the Brazilian Cerrado Conservación del Cerrado Brasileño. *Conservation Biology* 19(3): 707-713.

Loarie, S. R., Duffy, P. B., Hamilton, H., Asner, G. P., Field, C. B. &Ackerly, D. D. (2009). The velocity of climate change. *Nature* 462(7276): 1052-1055.

Luteyn, J. (2002). Diversity, adaptation, and endemism in neotropical Ericaceae: biogeographical patterns in the Vaccinieae. *The Botanical Review* 68(1): 55-87.

Maxted, N., Dulloo, E., V Ford-Lloyd, B., Iriondo, J. M. &Jarvis, A. (2008). Gap analysis: a tool for complementary genetic conservation assessment. *Diversity and Distributions* 14(6): 1018-1030.

Maxted, N. &Kell, S. (2009). *Establishment of a global network for the in situ conservation of crop wild relatives: status and needs.* Rome, Italy: FAO.

McNeely, J. A. &Mainka, S. A. (2009). *Conservation for a New Era.* Gland, Switzerland: IUCN.

MEA (2005). *Millennium Ecosystem Assessment: Ecosystems and human well-being: Biodiversity synthesis.* Washington, DC, USA: World Resources Institute.

Midgley, G. F., Hughes, G. O., Thuiller, W. &Rebelo, A. G. (2006). Migration rate limitations on climate change-induced range shifts in Cape Proteaceae. *Diversity and Distributions* 12(5): 555-562.

Mittermeier, R. A., Mittermeier, C. G., Brooks, T. M., Pilgrim, J. D., Konstant, W. R., da Fonseca, G. A. B. &Kormos, C. (2003). Wilderness and biodiversity conservation. *Proceedings of the National Academy of Sciences of the United States of America* 100(18): 10309-10313.

Musser, G. (2005).The Climax of Humanity. In *Scientific American*, Vol. Sept. 2005, 44-47.

Mutke, J. &Barthlott, W. (2005). Patterns of vascular plant diversity at continental to global scales. *Biol. Skr.* 55: 521-531.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B. &Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature* 403(6772): 853-858.

Formatted: Spanish (Spain)

Olfert, O. &Weiss, R. M. (2006). Impact of climate change on potential distributions and relative abundances of Oulema melanopus, Meligethes viridescens and Ceutorhynchus obstrictus in Canada. *Agriculture, Ecosystems & Environment* 113(1-4): 295-301.

Palmer, M., Bernhardt, E., Chornesky, E., Collins, S., Dobson, A., Duke, C., Gold, B., Jacobson, R., Kingsland, S., Kranz, R., Mappin, M., Martinez, M. L., Micheli, F., Morse, J., Pace, M., Pascual, M., Palumbi, S., Reichman, O. J., Simons, A., Townsend, A. &Turner, M. (2004). Ecology for a Crowded Planet. *Science* 304(5675): 1251-1252.

Palmer, M. A., Bernhardt, E. S., Schlesinger, W. H., Eshleman, K. N., Foufoula-Georgiou, E., Hendryx, M. S., Lemly, A. D., Likens, G. E., Loucks, O. L., Power, M. E., White, P. S. &Wilcock, P. R. (2010). Mountaintop Mining Consequences. *Science* 327(5962): 148-149.

Papeş, M. &Gaubert, P. (2007). Modelling ecological niches from low numbers of occurrences: assessment of the conservation status of poorly known viverrids (Mammalia, Carnivora) across two continents. *Diversity and Distributions* 13(6): 890-902.

Ramírez-Villegas, J., Khoury, C., Jarvis, A., Debouck, D. G. &Guarino, L. (2010). A Gap Analysis Methodology for Collecting Crop Genepools: A Case Study with *Phaseolus* Beans. *PLoS ONE* 5(10): e13497.

Rebelo, A. G. (1994). Iterative selection procedures: Centres of endemism and optimal placement of reserves. *Strelitzia* 1: 231-257.

Rebelo, A. G. &Siegfried, W. R. (1992). Where Should Nature Reserves Be Located in the Cape Floristic Region, South Africa? Models for the Spatial Configuration of a Reserve Network Aimed at Maximizing the Protection of Floral Diversity. *Conservation Biology* 6(2): 243-252.

Ricketts, T. H., Dinerstein, E., Boucher, T., Brooks, T. M., Butchart, S. H. M., Hoffmann, M., Lamoreux, J. F., Morrison, J., Parr, M., Pilgrim, J. D., Rodrigues, A. S. L., Sechrest, W., Wallace, G. E., Berlin, K., Bielby, J., Burgess, N. D., Church, D. R., Cox, N., Knox, D., Loucks, C., Luck, G. W., Master, L. L., Moore, R., Naidoo, R., Ridgely, R., Schatz, G. E., Shire, G., Strand, H., Wettengel, W. &Wikramanayake, E. (2005). Pinpointing and preventing imminent extinctions. *Proceedings of the National Academy of Sciences of the United States of America* 102(51): 18497-18501.

Robertson, M. P., Cumming, G. S. &Erasmus, B. F. N. (2010). Getting the most out of atlas data. *Diversity and Distributions* 16(3): 363-375.

Sachs, J. D., Baillie, J. E. M., Sutherland, W. J., Armsworth, P. R., Ash, N., Beddington, J., Blackburn, T. M., Collen, B., Gardiner, B., Gaston, K. J., Godfray, H. C. J., Green, R. E., Harvey, P. H., House, B., Knapp, S., Kümpel, N. F., Macdonald, D. W., Mace, G. M., Mallet, J., Matthews, A., May, R. M., Petchey, O., Purvis, A., Roe, D., Safi, K., Turner, K., Walpole, M., Watson, R. &Jones, K. E. (2009). Biodiversity Conservation and the Millennium Development Goals. *Science* 325(5947): 1502-1503.

Scott, J. M. &Schipper, J. (2006). *Gap analysis: a spatial tool for conservation planning.* Sunderland: Sinauer.

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

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

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

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

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

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

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

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

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

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

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

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

Corrective procedure	Number of records	Percent from total	Percent from *Plantae*	Percent from non repeated terrestrial plant taxa
+Records in the database	177,887,193	100.0	N/A	N/A
+*Plantae* 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

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

[1] Standard deviation; [2] Coefficient of variation

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] -Antisana (ecological reserve) [ECU]
4	2060	1022	1	-Cotapata national park [BOL]
5	1349	763	4	-Lago Ypoá national park [PAR] -Ypacaraí national park [PAR] -Macizo Acahay natural monument [PAR] -Río Pilcomayo national park [ARG]
6	2071	702	1	-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]

*ECU: Ecuador, GUF: French Guiana, BOL: Bolivia, PAR: Paraguay, ARG: Argentina, PER: Peru, COL: Colombia, BRA: Brazil; **Only a very small portion of the protected site was intersected (<5% area)

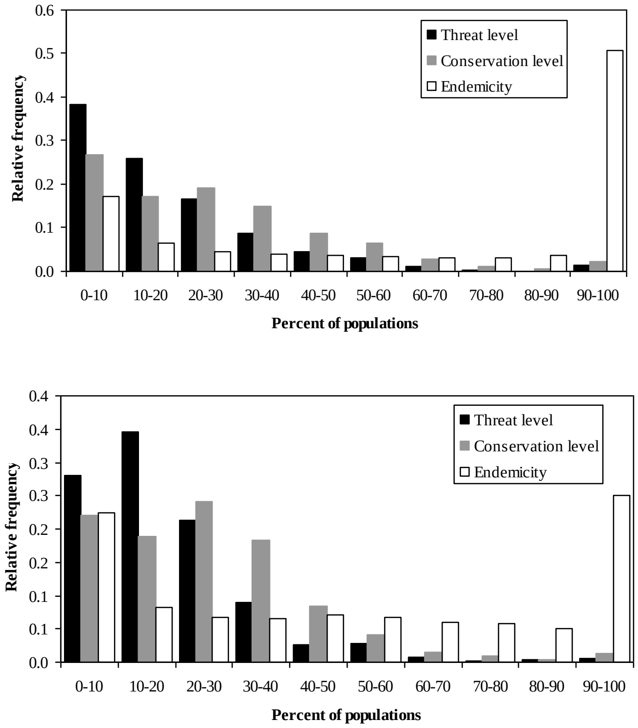

Figure 1 Rates of endemism (white bars), conservation (grey bars) and threats (black bars). (A) for individual species, and (B) for genera. Relative frequency represents the fraction of species or genera under analysis in each class.

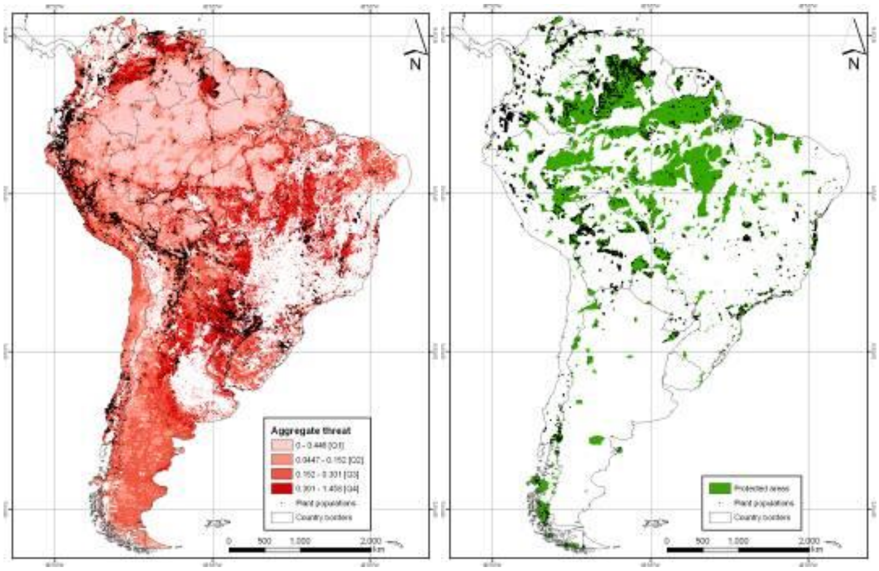

Figure 2 Spatial distributions of threats and protected areas. (A) Aggregate threat and (B) protected areas. Black dots in (A) show populations occurring in the last quartile (top 25%), and black dots in (B) show populations occurring within protected areas.

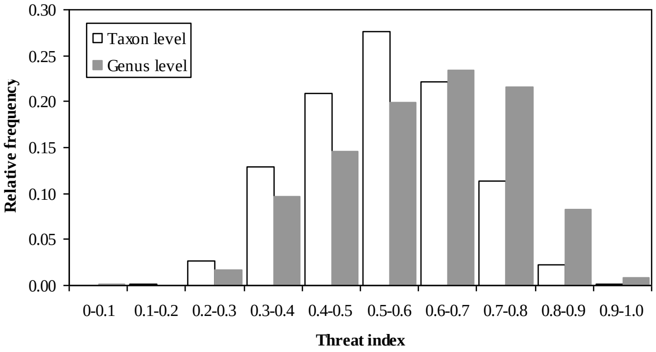

Figure 3 Distribution of the threat index (TI) among taxa (white bars) and genera (grey bars). Relative frequency represents the fraction of the set of taxa under analysis belonging to each class of the index.

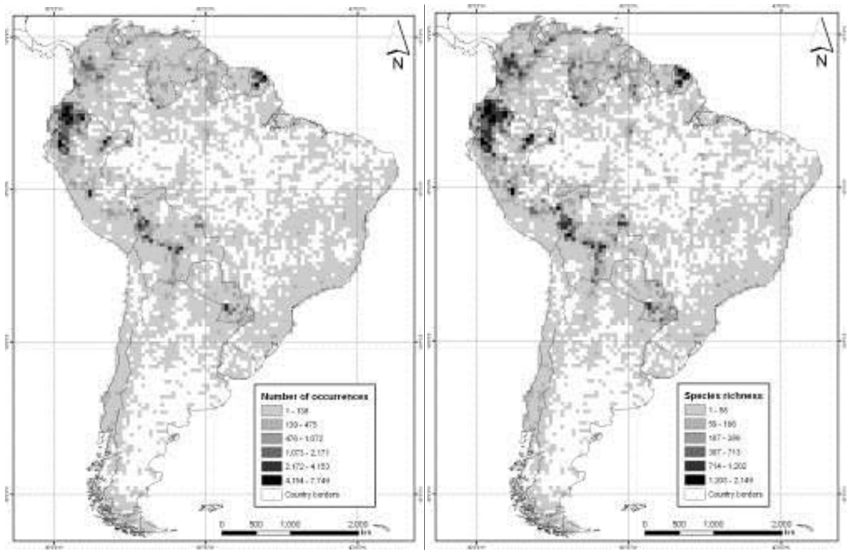

Figure 4 Sampling densities (left) and species richness (right) calculated for each 0.5-by-0.5 degree cells.

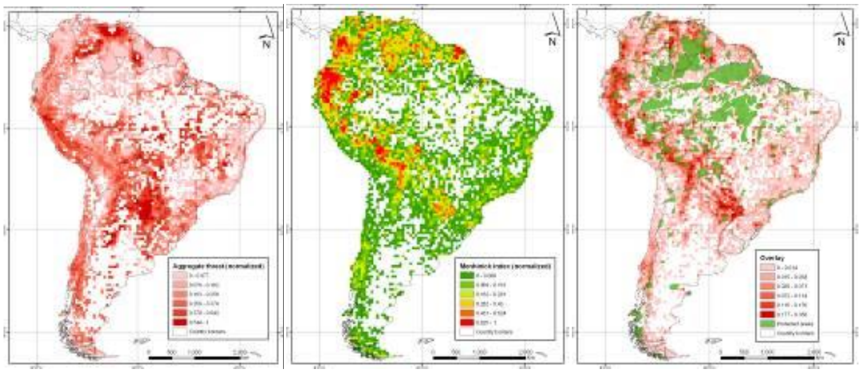

Figure 5 Regional threat status analyses. (A) Normalized sum of aggregate threat, (B) normalized Menhinick index and (C) product between A and B, overlaid with protected areas. White areas are those where no threat or no species data was reported.

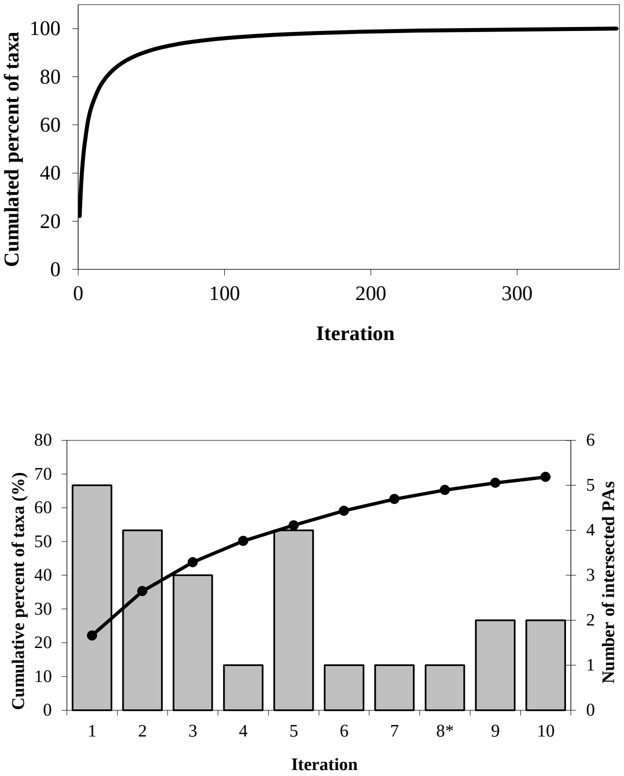

Figure 6 Reserve selection process. (A) With no limit in iterations (total 368), and (B) with a limit of 10 iterations (see also Table 3). Each iteration represents a single 100 km side cell. The continuous line represents the cumulated percent of taxa that would be protected in each of the cells. In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

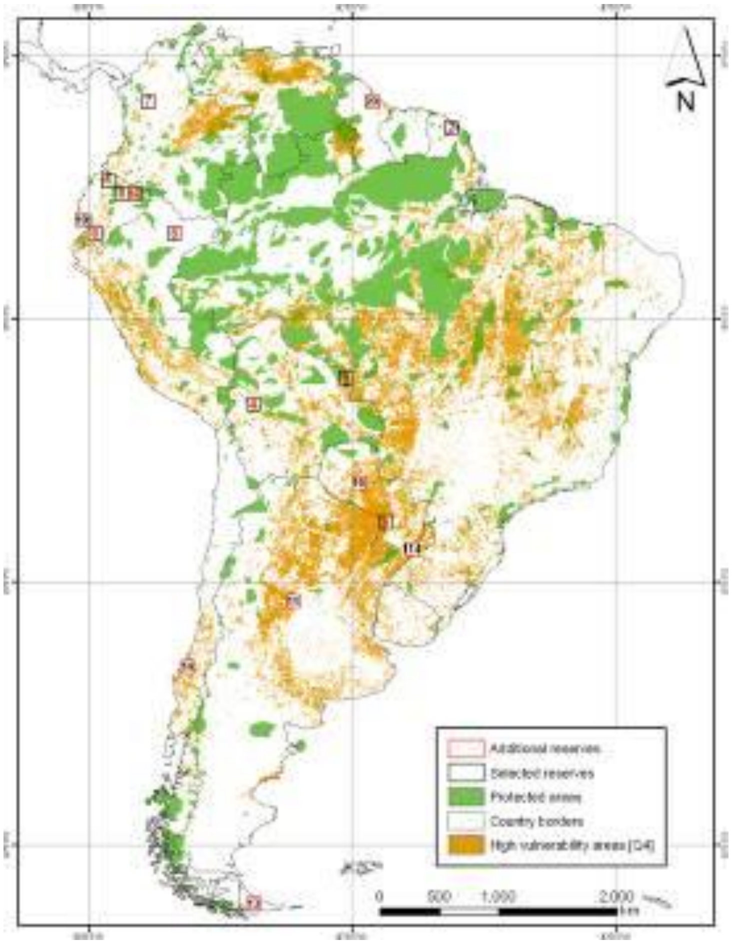

Figure 7 Nationally and internationally protected areas (green) according to WDPA and IUCN (2009), black squares are reserves containing up to 70% of South American plant diversity (labels show the selection order to match with Table 3); red squares are the likely new areas where additional unique taxa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