Regional Red List assessment of tree species in upper montane forests of the Tropical Andes

NATALIA TEJEDOR GARAVITO, ADRIAN C. NEWTON and SARA OLDFIELD

Abstract The Tropical Andes are characterized by a high level of endemism and plant species richness but are under pressure from human activities. We present the first regional conservation assessment of upper montane tree species in this region. We identified 3,750 tree species as occurring in this region, of which 917 were excluded because of a lack of data on their distribution. We identified a subset of 129 taxa that were restricted to higher elevations (> 1,500 m) but occurred in more than one country, thus excluding local endemics evaluated in previous national assessments. Distribution maps were created for each of these selected species, and extinction risk was assessed according to the IUCN Red List categories and criteria (version 3.1), drawing on expert knowledge elicited from a regional network of specialists. We assessed one species, *Polylepis microphylla*, as Critically Endangered, 47 species as Endangered and 28 as Vulnerable. Overall, 60% of the species evaluated were categorized as threatened, or 73% if national endemics are included. It is recommended that extinction risk assessments for tree species be used to inform the development of conservation strategies in the region, to avoid further loss of this important element of biodiversity.

Keywords Biodiversity, conservation, extinction risk, flora, forest, threat

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Introduction

The IUCN Red List categories and criteria provide an authoritative approach for assessing species' risk of extinction (Rodrigues et al., 2006; Mace et al., 2008). The assessment criteria are based on population sizes and rates of decline, and the extent and decline of geographical ranges (IUCN, 2001). The IUCN Red List has been used to inform conservation policies and legislation, to support the identification of priority areas for conservation, and to prioritize species-based conservation actions (Hoffmann et al., 2008; Mace et al., 2008). Red List assessments also contribute to Target 2 of the Global Strategy for Plant Conservation, an initiative of the Convention on Biological Diversity, which refers to 'an assessment of the conservation status of all known plant species, as far as possible, to guide conservation action', to be achieved by 2020.

By 2008 the IUCN Red List database included a total of 8,324 tree species (Newton & Oldfield, 2008), most of which had been assessed > 10 years previously in *The World List of Threatened Trees* (Oldfield et al., 1998) or were included in assessments of the endemic tree species of Ecuador (Valencia et al., 2000; León-Yánez et al., 2011) and of Peru (León et al., 2006). Since 1998 > 2,500 tree taxa have been evaluated but fewer than half of these have been added to the Red List database (Newton & Oldfield, 2008), and many tree species have yet to be assessed. Progress has been limited by a number of factors, including the lack of appropriate data on the status and distribution of many species. Red List assessments of plant species often depend on the use of herbarium records (Brummitt et al., 2008; Rivers et al., 2011) and supporting data from geographical information systems (Nic Lughadha et al., 2005; Cicuzza et al., 2007) to identify the potential distribution of species and relevant threats, which are mainly of anthropogenic origin. Such data, however, are often limited in availability. Assessments have also been hindered by taxonomic confusion surrounding many taxa, and by a lack of resources to support the assessment process (Nic Lughadha et al., 2005; Hoffmann et al., 2008; Newton & Oldfield, 2008).

Red List assessments provide fundamental information on species' status and population trends, of relevance to both science and policy (Rodrigues et al., 2006; Mace et al., 2008; Stuart et al., 2010). Although some national assessments of vascular plants have been undertaken in the Andean region (e.g. Valencia et al., 2000), there has been no previous systematic assessment of the area's montane tree species. This unique region has c. 133 ecosystem types (Josse et al., 2009a,b), with high habitat diversity resulting from altitudinal and latitudinal gradients (Josse et al., 2003). Andean montane forests are a major conservation priority globally because of their biological richness and high level of endemism (Olson & Dinerstein, 1997; Bush

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et al., 2007). These forests also provide valuable ecosystem services, including those related to water quality and flow, the regulation of regional climate, and carbon capture and storage (Cuesta et al., 2009), and are considered to be amongst the least-known tropical ecosystems (Gentry, 1995; Ataroff & Rada, 2000; Bubb et al., 2004; Pitman et al., 2011). Andean montane forests are threatened by ongoing forest loss, fragmentation and degradation (Tejedor Garavito et al., 2012), and the potential effects of climate change (Cuesta et al., 2009; Feeley & Silman, 2010; Herzog et al., 2011).

Here we describe an assessment of the extinction risk of tree species in upper montane forests in the Tropical Andes, which was undertaken using the IUCN Red List categories and criteria (IUCN, 2001). Specifically, the assessment focused on those taxa that are restricted to the Tropical Andean region but are distributed in more than one country. The assessment thus focused on regional endemics but did not consider national endemics, to complement previous Red List assessments of vascular plants undertaken at the national scale (e.g. Bolivia, Meneses & Beck, 2005; Colombia, Calderón et al., 2002; Ecuador, León-Yánez et al., 2011; Peru, León et al., 2006; and Venezuela, Llamozas et al., 2003).

Scope and study area

The scope of this assessment was the Tropical Andes, in Argentina, Bolivia, Colombia, Ecuador, Peru and Venezuela, which represent most of the montane forests in the Andean region. The definition of upper montane forest for the purposes of this study includes cloud forest (Northern Andean, Yungas and BolivianTucuman forests) and seasonal (wet) forest at > 1,500 m altitude, with temperatures of 6–18°C and mean annual precipitation of > 1,000 mm, as described by Josse et al. (2009a,b). Our intention was to ensure that only tree species associated with upper montane forest were included in the assessment and, through a process of expert consultation, it was adjudged that a lower altitudinal limit of 1,500 m would achieve this. As noted by Bruijnzeel (2001) the transition from lower to upper montane forest coincides with the altitude where cloud condensation becomes most persistent; this typically occurs at elevations of 2,000–3,000 m on mountains in equatorial regions. Species composition also typically changes at about this altitude (Gentry, 1995; Josse et al., 2009a). However, this threshold varies geographically, occurring at lower elevations on small mountains on islands and further from the equator, and for this reason the more conservative altitudinal limit of 1,500 m was employed.

We focused on tree species associated with moist, upper montane or cloud forests. Some species that are also associated with other types of vegetation were included in the assessment, however, because some species occur in more than one vegetation type. Trees are defined here as upright woody plants with a dominant above-ground stem at least 3 m in height (Körner, 1998), including palms and woody ferns. Bamboo species such as *Chusquea* spp. were excluded because they are considered tall grasses.

Methods

To support the assessment a series of workshops were held in Ecuador and Peru, involving at least two botanical specialists representing each country in the region (Argentina, Bolivia, Colombia, Ecuador, Peru and Venezuela). These specialists were affiliated with a range of institutions, including national herbaria, botanical gardens and conservation organizations, and provided expert knowledge throughout the assessment process.

During the first project workshop a consolidated list of the candidate tree species known to occur in the montane Tropical Andes was produced. This was based on the expert knowledge provided by the network of specialists that participated in the assessment, supported by data from a range of sources, including the Tropicos database (Missouri Botanical Garden, 2015), regional herbaria (Colombian National Herbarium, COL; Venezuelan National Herbarium, VEN; Bolivian National Herbarium, LPB; Herbarium of the Universidad Pontificia Católica in Ecuador, QCA; and San Marcos Herbarium of the Universidad Nacional Mayor de San Marcos, Peru, USM), regional floras, and personal databases. The nomenclature of taxa on the list was checked and revised using The Plant List (2010) to identify synonyms and those species unresolved taxonomically. The APG III system of the Angiosperm Phylogeny Group (2009) was followed for consistency in the names of species and families.

Geographical distribution data for each of the tree species were compiled, based primarily on vouchered records from herbaria. Sources of information included personal records of specialists involved in the assessment, the Tropicos database (Missouri Botanical Garden, 2015), regional herbaria, and the Global Biodiversity Information Facility (GBIF, 2015; Supplementary Table S1). A spatial database incorporating these data was created in *ArcGIS v. 10* (ESRI, Redlands, USA) and scrutinized to exclude points that were incorrectly georeferenced. Herbarium accessions for which location data were lacking were also excluded. The database was used to identify species occurring exclusively at ≥ 1,500 m, by overlaying data on a digital elevation model obtained from WorldClim (Hijmans et al., 2005; Fig. 1), with a grid space of 30 arc seconds (0.0083° or c. 1 km). To restrict the assessment to upper montane tree species, we excluded species for which there were any records below this altitude

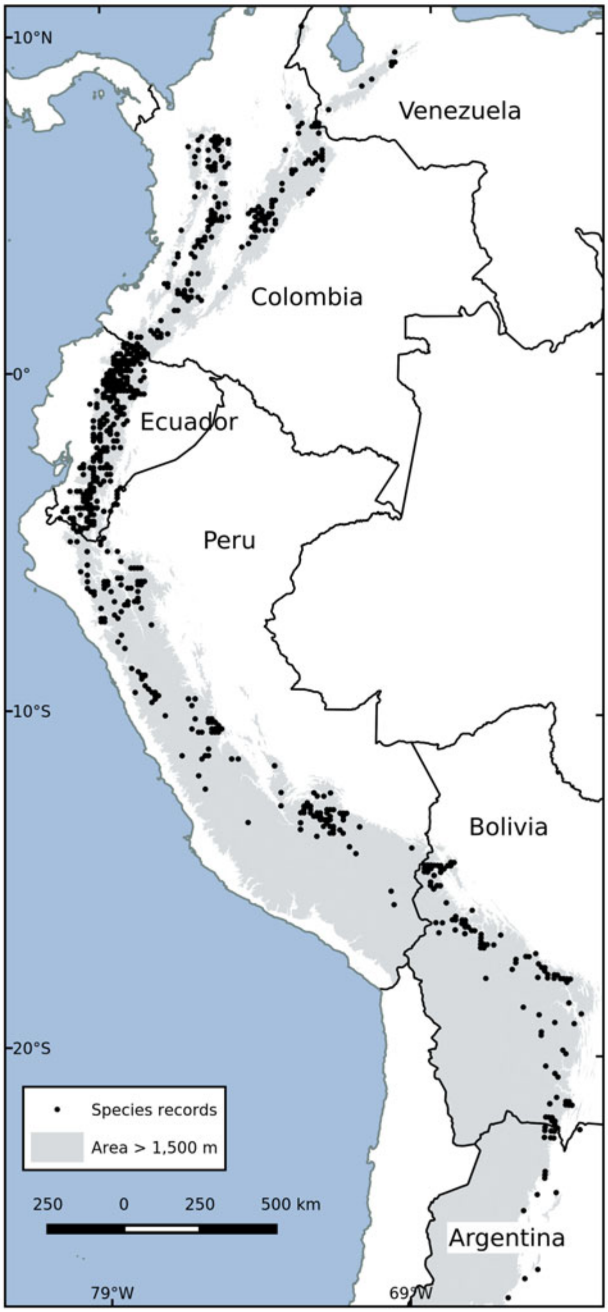

Fig. 1 Location of the study area in the tropical Andes. The shaded area indicates the distribution of upper montane forest at > 1,500 m altitude and the black circles the records of individual tree species.

threshold. These records were also used to identify species present in more than one country, which were the focus of this assessment. Distribution maps of each taxon that met these selection criteria were checked by the regional network of specialists, and revised if necessary.

The IUCN Red List criteria (IUCN, 2001) were applied to each taxon, with reference to the distribution maps created. These assessments were conducted by NTG, in consultation with the specialists. The criteria were applied following the IUCN Red List guidelines (IUCN Standards and Petitions Subcommittee, 2011). The process requires that all species are evaluated using all of the criteria (A–E) and assigned the highest appropriate category of threat (IUCN, 2001). Vagueness in the terms and definitions used in the IUCN Red List criteria represents a source of uncertainty in the results of assessments (IUCN, 2001), and therefore a number of the criteria were applied in different ways to examine the impact of this uncertainty on potential outcomes.

Two key measures used in the Red List process (Table 1), specifically in Criteria A and B, are the Extent of Occurrence and the Area of Occupancy, which are measures of the geographical range of a species. Extent of Occurrence is defined as the smallest polygon in which no internal angle exceeds 180° that contains all sites of occurrence. It is calculated using the minimum convex polygon around georeferenced data for species distributions. These calculations were performed using various packages in *R v. 2.14* (*dismo, rgdal, maps, maptools, mapdata*; R Development Core Team, 2011) and *ArcGIS v. 10*. The minimum convex polygon requires at least three points to be created. For species with fewer than three records, Extent of Occurrence was not calculated, namely *Citharexylum rimbachii, Crossothamnus gentryi, Diplostephium cinerascens, Dunalia trianaei, Joosia aequatoria, Polylepis microphylla, Ribes canescens* and *Tournefortia loxensis*. Following the IUCN Red List Guidelines (IUCN Standards and Petitions Subcommittee, 2011), this result was refined to calculate an Extent of Occurrence that excluded non-suitable habitats. This was achieved using a classified global land cover map for 2009 (GlobCover) produced by Arino et al. (2010), which was obtained from the MERIS imaging spectrometer, at a resolution of 300 m, to exclude non-forest land cover classes. The map was masked using the digital elevation model, to include areas ≥ 1,500 m. The Extent of Occurrence map was clipped with the GlobCover layer and then projected using the Mollweide (sphere) projection, to calculate the distribution area for each species.

Area of Occupancy is defined as the area occupied by a taxon, and is calculated using grid (raster) data at a scale appropriate to the taxon (IUCN, 2001). Area of Occupancy was calculated at two resolutions, with a 4 km^2 and a 100 km^2 grid cell, using various packages in *R v. 2.14*. Area of Occupancy was not calculated for the 14 species with ≤ 3 records.

Assessment under criterion A1 addresses a decline in population size where the sources of decline have ceased. This criterion was not applicable for any of the species assessed, because deforestation is ongoing (Tejedor Garavito et al., 2012). Criteria A2, A3 and A4 apply to species that have experienced a population decline of at least 30% over three generations (Table 1). Following the IUCN guidelines (v. 9.0) these criteria were applied by projecting or inferring trends, based on a decline in the Area of Occupancy, Extent

TABLE 1 Summary of IUCN Red List Categories and Criteria (IUCN, 2001)

Criterion	Critically Endangered	Endangered	Vulnerable	Qualifiers
A1 Reduction in population size	≥ 90%	≥ 70%	≥ 50%	Over 10 years or three generations in the past, where causes are reversible, understood & have ceased
A2–4 Reduction in population size	≥ 80%	≥ 50%	≥ 30%	Over 10 years or three generations in the past, future or a combination
B1 Small range (Extent of Occurrence)	< 100 km^2	< 5,000 km^2	< 20,000 km^2	Plus two of the following: (a) severe fragmentation/few localities (1, ≤ 5, ≤ 10), (b) continuing decline, (c) extreme fluctuation
B2 Small range (Area of Occupancy)	< 10 km^2	< 500 km^2	< 2,000 km^2	Plus two of the following: (a) severe fragmentation/few localities (1, ≤ 5, ≤ 10), (b) continuing decline, (c) extreme fluctuation
C Small and declining population	< 250	< 2,500	< 10,000	Mature individuals. Continuing decline either (1) over specified rates & time periods or (2) with (a) specified population structure or (b) extreme fluctuation
D1 Very small population	< 50	< 250	< 1,000	Mature individuals
D2 Very small range locations			< 20 km^2 or ≤ 5 locations	Potential to become Critically Endangered or Extinct within a very short time
E Quantitative analysis	≥ 50% in 10 years or three generations	≥ 20% in 20 years or five generations	≥ 10% in 100 years	Estimated extinction risk using quantitative models (e.g. population viability analyses)

of Occurrence and/or quality of habitat, by assuming a linear relationship between habitat loss and population reduction. Fifty and 100 years were used as the time periods to identify the population decline, given uncertainty about generation length.

Inferences from deforestation rates and the area of forest cover were used to estimate the percentage of forest loss over a period of 50 and 100 years that has occurred in the past (A2) or that may occur in the future (A3). Three scenarios were developed with the data available to explore various estimations of forest loss. For scenario 1, deforestation rates and the total forest area per country for 2010 were obtained from FAO (2010), which provides estimates of the percentage annual forest change during 2005–2010 as reported in national statistics. For scenario 2, the regional mean deforestation rate was calculated using values obtained from a review of the literature. A number of studies of forest loss have been undertaken within individual countries, primarily involving analysis of satellite remote sensing data, historical maps and documents. These are summarized by Tejedor Garavito et al. (2012), from which an overall mean deforestation rate was derived. This was used in conjunction with an estimate of the current total area of Andean montane forests > 1,500 m, derived from the GlobCover map. Scenario 3 used the deforestation rates from FAO (2010) with current total forest area derived from the GlobCover map. For all scenarios the area of forest loss per annum was calculated and then multiplied by 50 or 100, based on the assumption of constant deforestation rates throughout the 50- and 100-year periods. These values of deforestation rate were also used to calculate the percentage of forest loss during a 100–year period including past and future, for the A4 criterion (Table 1).

Criterion B addresses the geographical range of the species, based on the Extent of Occurrence and Area of Occupancy calculated as described above. The sub-criteria for criterion B were estimated using expert knowledge and the scientific literature, supported by reference to distribution maps. For example, areas of 25 x 25 km in which the species were present were used to define the number of locations, based on the distribution maps, and the occurrence of severe fragmentation was based on expert knowledge.

Criterion C addresses small population size and decline. This criterion was used only for species for which an estimate of the total population size was available, based on personal collections and field data. The information for most species is scarce. In every case where data were available, values of total population size exceeded the thresholds of the criterion.

Criterion D refers to cases where species have extremely small populations, with < 1,000 individuals. Based on consultation with experts, none of the species were identified to have < 1,000 individuals in total, and therefore no species was found to meet this criterion. Similarly criterion E was not applicable to these species, as no quantitative analysis of population viability had been performed on any species, because of a lack of sufficient data.

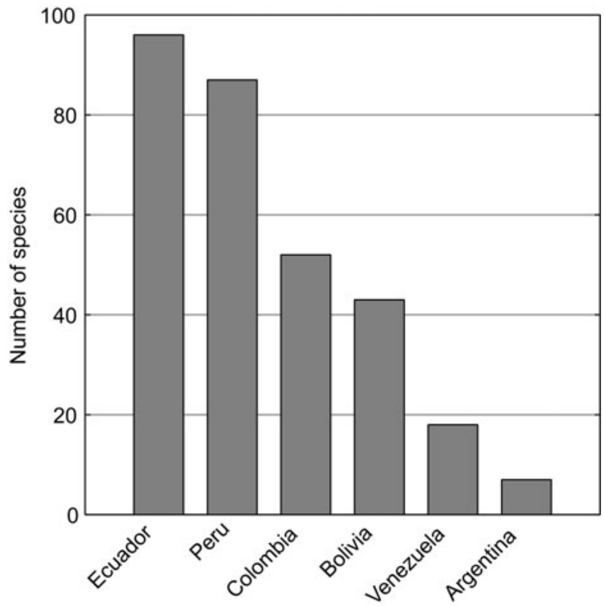

FIG. 2 Number of tree species per country assessed using the IUCN (2001) Red List categories and criteria.

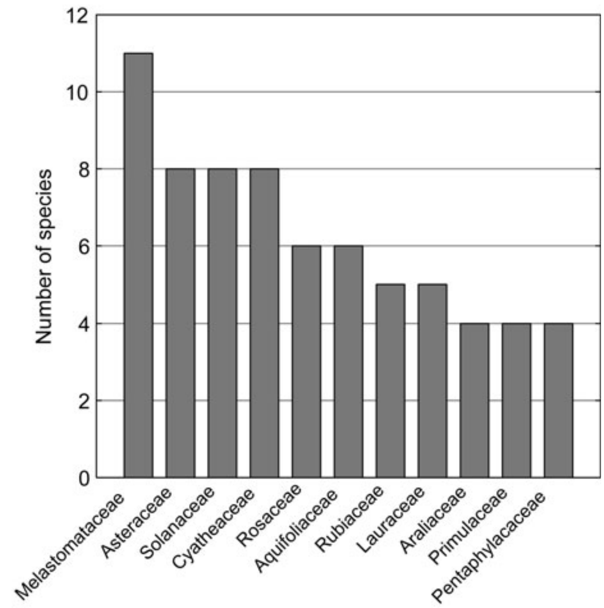

FIG. 3 The plant families included in the assessment with the largest numbers of tree species.

The Red List process is characterized by uncertainty, as many of the decisions are based on values that are inferred, estimated or projected (IUCN, 2001). The level of uncertainty was assessed by scoring each sub-criterion on a three-point scale, of high, medium or low uncertainty. Uncertainty in the information provided by experts was also assessed, by scoring the degree of uncertainty associated with applying each sub-criterion. For sub-criteria based on map analysis, uncertainty was scored according to the number of records that were available to carry out the evaluation.

Results

A total of 3,750 tree species were identified as occurring in the upper montane forests of the Andes. Of these, 917 species were excluded because no georeferenced records were located. Another 1,287 species were excluded because all of their records were within the boundaries of a single country. For 1,400 species, at least one record occurred below the 1,500 m threshold, and these were therefore excluded from subsequent analyses. Of the remaining 146 species, 17 were excluded during checking, as a result of taxonomic revision. Consequently, 129 taxa were evaluated according to the Red List categories and criteria. Ecuador was the country with most species and Argentina with fewest (Fig. 2). The family represented by the greatest number of species was Melastomataceae (11 species; Fig. 3). A total of 1,663 distribution records were obtained for these species. The number of records per species varied; 79 species had ≤ 10 unique records and four had > 50 unique records, with an overall mean of $12.9 \pm$ SD 11.4 records per species.

The Extent of Occurrence calculated without excluding unsuitable areas was $\leq 500,000$ km^2 for 102 species, and nine species had an Extent of Occurrence $\geq 1,000,000$ km^2 (Fig. 4a). Extent of Occurrence was $< 20,000$ km^2 for 26 species, 14 of which can be preliminarily categorized (under criterion B) as Vulnerable, 10 as Endangered and two as Critically Endangered according to IUCN thresholds. When unsuitable areas of habitat were excluded from the analysis (Fig. 4b) the Extent of Occurrence was reduced for all species. The mean reduction was $208,687 \pm$ SD 35,185 km^2, representing 82.5% of the original value. When unsuitable areas were excluded, 49 species had an Extent of Occurrence $< 20,000$ km^2; 30 of these can be categorized preliminarily (under criterion B) as Vulnerable, 17 as Endangered and two as Critically Endangered according to IUCN thresholds.

At a resolution of 4 km^2 (Fig. 5) all of the species had an Area of Occupancy of < 300 km^2 and would therefore be assigned a threat category of at least Endangered. Area of Occupancy was also calculated at a resolution of 100 km^2 to explore the implications of the choice of grid cell size on the categorization. The Area of Occupancy was $< 2,000$ km^2 for 96 species, 81 of which can be preliminarily categorized as Vulnerable and 15 as Endangered according to IUCN thresholds, without taking into consideration species with ≤ 3 records.

Under criterion A, estimates of total forest loss since 1959 did not exceed the 30% threshold of the IUCN guidelines. Over a timescale of 100 years, however, this value was exceeded by a small margin (Table 2). The projected forest loss in the next 50 years reached the threshold at 30.8% (Table 3). The projected forest loss for the next 100 years,

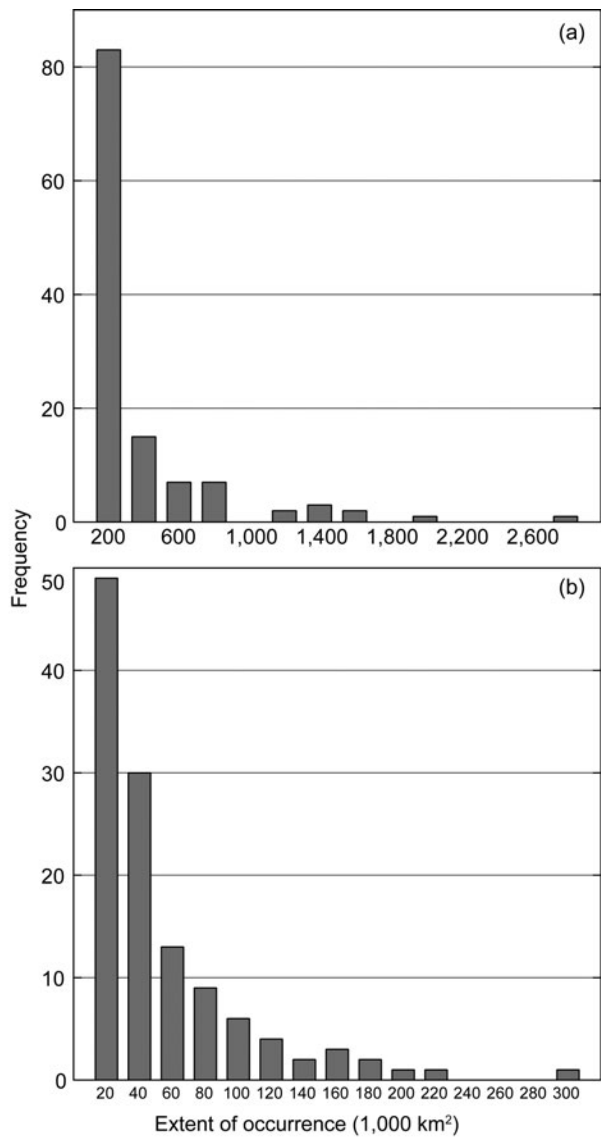

Fig. 4 Frequency distribution of the Extent of Occurrence, based on the minimum convex hull, of the tree species assessed: (a) using the full extent of the distribution, and (b) excluding unsuitable areas.

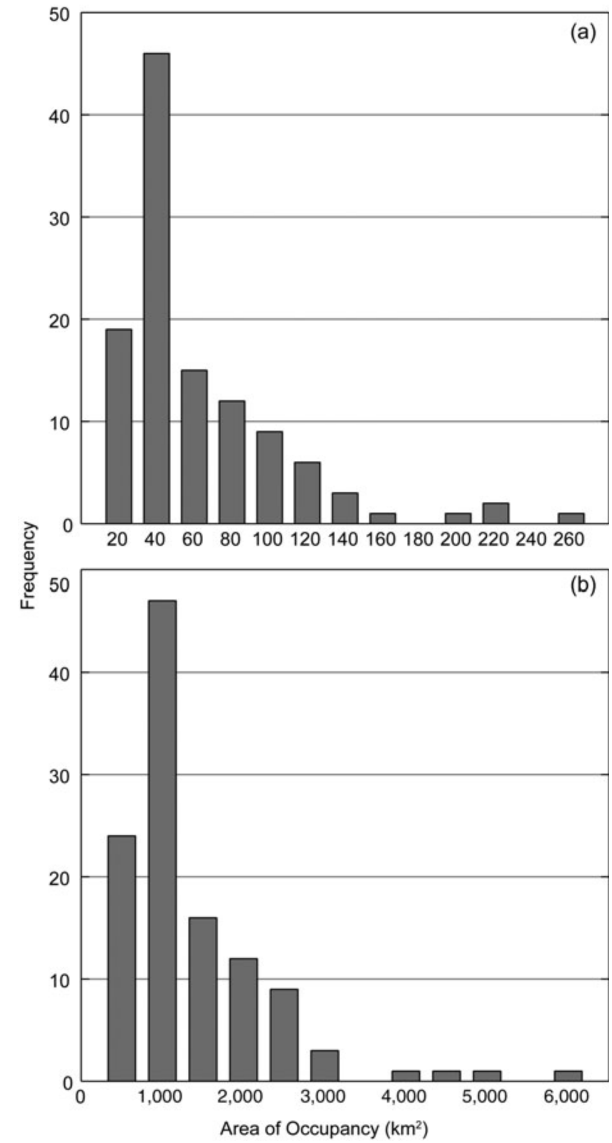

Fig. 5 Frequency distribution of the Area of Occupancy of the tree species assessed, at a grid cell size of (a) 4 km^2 and (b) 100 km^2.

using all three methods of calculation, was at least 30%, up to a maximum of 61.6%, depending on the method used (Tables 2 & 3). Projections indicate that if forests in Ecuador and Venezuela continue to be lost at the current rate, they may be lost in their entirety over the next 100 years.

For the A4 criterion the percentage forest loss during the interval from 50 years ago to 50 years in the future was estimated (Table 3). Results indicated that the forest loss during this timeframe could exceed the 30% threshold, which would qualify all species for categorization of at least Vulnerable under the Red List criteria (Table 4). In the case of future forest loss, all species would be categorized as Endangered according to this criterion. These results show the sensitivity of the overall results of the assessment, in terms of the number of species categorized as threatened, to assumptions about forest loss. For example under criterion A2 all of the species were categorized as Least Concern, based on a duration of 50 years, but all were categorized as Vulnerable under the assumption that deforestation has occurred at the same rate for the past 100 years. Similarly, under criterion A3 all species were categorized as either Least Concern or Vulnerable, depending on which of the three deforestation estimates was chosen. All species were categorized as Endangered under an assumption that deforestation rates associated with scenario 2 would continue for 100 years into the future (Table 4).

The degree of uncertainty varied significantly among criteria (Table 5). In general, uncertainty was scored more

TABLE 2 Estimation of forest cover in the montane Tropical Andes from FAO (2010) and GlobCover (2009), and mean deforestation rates derived from FAO (2010) and from a review of quantitative estimates in the literature (Tejedor Garavito et al., 2012). The FAO data refer to forest cover at the national scale, whereas the GlobCover data relate specifically to upper montane forests.

Country	Current forest area, km^2 (FAO, 2010)	Current forest area, km^2 (GlobCover, 2009)	Annual change, % (FAO, 2010)	Annual change,% (Tejedor Garavito et al., 2012)*
Argentina	294,000	105,232	−0.8	−0.32
Bolivia	571,960	202,601	−0.53	−0.49
Colombia	604,990	100,905	−0.17	−0.64
Ecuador	98,650	46,800	−1.89	−0.75
Peru	679,920	314,113	−0.22	−0.75
Venezuela	462,750	13,315	−0.61	−1.08
Total	2,712,270	782,966	−0.46	−0.62

*Calculated from estimates for montane forests within individual countries

highly for criteria A, C and D than for criterion B, reflecting the importance of distributional data for conducting these assessments. The final categorization was based on the criterion with the lowest uncertainty level (mostly A2, B1 or B2; Table 5).

Based on our assessment one species, *Polylepis microphylla*, was categorized as Critically Endangered. In 2011 the authorities in Ecuador categorized the species as Critically Endangered within that country. Forty-seven species were categorized as Endangered and 28 as Vulnerable (Table 6). Five species were categorized as Data Deficient, including *Ilex maasiana*, for which there were only two records. *Allophylus coriaceus* may be categorized as Least Concern, as it has a large Extent of Occurrence, but more information is needed to assess this species. *Phenax laxiflorus* is a small shrub for which there was insufficient information to perform an assessment. *Cyathea catacampta* and *Prunus muris* are taxonomically unresolved. The 917 species that were excluded from the assessment because no georeferenced records were identified could also potentially be considered Data Deficient.

Discussion

Of the 129 tree species assessed using the IUCN Red List criteria, 76 were assigned a category of threat. Candidate species for which georeferenced records were available from only one country (n = 467) were excluded from the assessment. Sixty-four species were known to occur in more than one country but were not associated with georeferenced records, and were therefore excluded. Of the national endemic species, 199 had been evaluated previously at the scale of individual countries using the IUCN Red List criteria. Of these, 87 were included in the Red List database (IUCN, 2010), of which 84 were from Ecuador. Taking into consideration these previous assessments and the results of this research, 241 tree species in the upper montane Tropical Andes have been identified as threatened with extinction (Table 6; Tejedor Garavito et al., 2014).

The Tropical Andes is a global priority for conservation because of its high levels of species richness and endemism (Myers et al., 2000). Previous regional assessments of biodiversity in the Tropical Andes, such as those carried out by Brooks et al. (2002) and Myers et al. (2000), have found that of 45,000 plant species present in this biodiversity hotspot, 20,000 are endemic to the Andes. Of the 3,389 species of mammals, birds, reptiles and amphibians identified as present in the region, 1,567 were identified as endemic, 124 of which were considered threatened, with two bird species categorized as Extinct. According to Vié et al. (2009) a total of 62 mammal, 112 bird, and 442 amphibian species are threatened in the Andean region, representing 25, 42 and 47%, respectively, of the total number of species assessed. Young et al. (2001) found that the greatest population decline in amphibians in Latin America had occurred at > 1,000 m in the Tropical Andes in Venezuela, Colombia, Ecuador and Peru, with several species becoming locally extinct.

These values provide a basis for comparison with the 241 tree species that are endemic to the region and are also threatened, based on the results of this assessment and the national-scale assessments undertaken previously. When comparing these numbers, however, it should be noted that this assessment was limited to altitude > 1,500 m, whereas numbers for other species groups are for the entire Tropical Andean region, including lowland areas. The total of 241 threatened tree species may be considered a conservative estimate, as many taxa were excluded from this assessment.

Comparing our results with those of Newton & Oldfield (2008), the percentage of species identified as threatened in this assessment (59%) is higher than the mean value (45%) recorded in previous assessments in other locations. It is lower than the percentage of threatened species recorded in Mexican cloud forest (González-Espinosa et al., 2011) but the Mexican assessment included many local endemics, which were excluded from this assessment, suggesting that the level of threat to montane tree species in the Tropical Andes is at least comparable to that of Mexico. The principal threats are similar in the two regions, namely forest loss, degradation and fragmentation (González-Espinosa et al., 2011). Together, these results provide further evidence that tropical montane biodiversity is particularly threatened (Cincotta et al., 2000; Newton, 2007; Jarvis et al., 2010).

Although deforestation is the principal threat to many montane tree species, invasion of exotic species and overexploitation may also be affecting tree populations over the

TABLE 3 Estimation of forest loss in the Tropical Andean region during the past 50 years and projected for the next 50 years, based on the assumption of constant deforestation rates.

Country	Forest area in 1959 in km^2	Forest area in 2059 in km^2	% remaining in 2059	% loss in 2059
Scenario 1: estimates based on forest area and deforestation rates at the national scale, and not restricted to upper montane forests (FAO, 2010)				
Argentina	411,600	176,400	42.86	57.14
Bolivia	723,529	420,391	58.10	41.90
Colombia	656,414	553,566	84.33	15.67
Ecuador	191,874	5,426	2.83	97.17
Peru	754,711	605,129	80.18	19.82
Venezuela	603,889	321,611	53.26	46.74
Total	3,342,017	2,082,523	62.31	37.69
Scenario 2: Andean upper montane forest area (GlobCover, 2009) and mean deforestation rates for montane forest reported in the literature (Tejedor Garavito et al., 2012)				
Argentina	122,069	88,395	72.41	27.59
Bolivia	252,239	152,964	60.64	39.36
Colombia	133,195	68,616	51.52	48.48
Ecuador	64,350	29,250	45.45	54.55
Peru	431,905	196,321	45.45	54.55
Venezuela	20,471	6,158	30.08	69.92
Total	1,024,229	541,704	52.89	47.11
Scenario 3: estimates based on Andean upper montane forest area (GlobCover, 2009) and mean deforestation rates (FAO, 2010)				
Argentina	147,324	63,139	42.86	57.14
Bolivia	256,291	148,912	58.10	41.90
Colombia	109,482	92,328	84.33	15.67
Ecuador	91,026	2,574	2.83	97.17
Peru	348,665	279,560	80.18	19.82
Venezuela	17,375	9,254	53.26	46.74
Total	970,163	595,767	61.41	38.59

long term (Gibson et al., 2011). Species such as *Polylepis* spp. have been exploited in the Andes (Jameson & Ramsay, 2007; Bellis et al., 2009; Gareca et al., 2010) and many species of this genus are now restricted to forest fragments. In Bolivia only 11% of the potential distribution area remains covered with *Polylepis* woodland (Gareca et al., 2010). Tree species of high commercial value, such as *Cinchona* spp., *Podocarpus* spp., *Zanthoxylum* spp. and *Ilex* spp., have also been subjected to overexploitation in the past, which is likely to have reduced their population sizes. *Cinchona* spp., for example, were particularly sought after for their medicinal properties until the 1950s (Cuvi, 2011), when a synthetic substitute for quinine was created. These species are still exploited by local communities and the forests continue to be degraded (Ayma-Romay & Padilla-Barroso, 2009) despite restrictions established by some countries to limit these activities. Populations of these species are further jeopardized by the fact that some have difficulty regenerating in transformed landscapes, as is the case for *Podocarpus* spp. (Ayma-Romay & Padilla-Barroso, 2009).

There are uncertainties associated with the application of the Red List categories and criteria (Akçakaya et al., 2000; Mace et al., 2008; Newton, 2010). There are particular challenges in applying the Red List to tree species because of the lack of accurate information on their status and distribution, and the uncertain taxonomic status of many taxa (Nic Lughadha et al., 2005; Newton & Oldfield, 2008). The results presented here should therefore be considered preliminary. The area of greatest uncertainty in this assessment was measurement error, which may be considered in relation to the so-called Linnean and Wallacean shortfalls (Whittaker et al., 2005). These refer to the inadequacy of taxonomic knowledge and distribution data available, respectively, to assess the species. This has been identified as a major constraint to conservation planning in tropical regions (Cayuela et al., 2009). Although data are increasingly being made available through digitized biological databases such as the Global Biodiversity Information Facility and the Tropicos database (Bachman et al., 2011), such data do not always provide an accurate indication of the full distribution of a species (Beck et al., 2013, 2014; Hjarding et al., 2014). The distribution of data for the species in this assessment (Fig. 1) indicates regional biases and gaps in collection efforts, many of which reflect variation in ease of access and botanical collection activity (Feeley & Silman, 2009). The general lack of distribution data is likely to have resulted in an underestimation of species' ranges (Feeley & Silman, 2009). Many of the rarest and most threatened species may be among

TABLE 4 Preliminary categorization of tree species in upper montane forests of the Tropical Andes, based on the IUCN Red List criteria, with criterion, timeframe, data, and number of species assigned to category.

Criterion	Timeframe, years[1]	Data[2]	Preliminary category[3]					
			CR	EN	VU	LC	NT	DD
A2	50 (P)	Scenario 1				129		
A2	50 (P)	Scenario 2				129		
A2	50 (P)	Scenario 3				129		
A2	100 (P)	Scenario 1			129			
A2	100 (P)	Scenario 2			129			
A2	100 (P)	Scenario 3			129			
A2	100 (P)	Expert knowledge		3	46			80
A3	50 (F)	Scenario 1				129		
A3	50 (F)	Scenario 2			129			
A3	50 (F)	Scenario 3				129		
A3	100 (F)	Scenario 1			129			
A3	100 (F)	Scenario 2		129				
A3	100 (F)	Scenario 3			129			
A3	100 (F)	Expert knowledge		5	42			82
A4	100 (B)	Scenario 1			129			
A4	100 (B)	Scenario 2			129			
A4	100 (B)	Scenario 3			129			
A4	100 (B)	Expert knowledge			6	1		122
B1 (EOO)[4]		Expert knowledge/Data		10	15	95		9
B1 (EOO)[5]		Expert knowledge/Data		17	31	72		9
B2 (AOO)[6]		Expert knowledge/Data		115				14
B2 (AOO)[7]		Expert knowledge/Data		15	81	19		14
C1					1			128
C2								129
D1								129
D2					1			128
E								129

[1]P, past; F, future; B, both

[2]Scenario 1, based on the calculation of forest loss using deforestation rates and national forest area by FAO (2010); Scenario 2, based on the calculation of forest loss using the regional mean deforestation rates from the literature and Andean forest area from GlobCover (2009); Scenario 3, based on the calculation of forest loss using deforestation rates from the FAO (2010) and Andean forest area from GlobCover (2009); Expert knowledge/Data, expert consensus and knowledge from the field

[3]CR, Critically Endangered; EN, Endangered; VU, Vulnerable; LC, Least Concern; NT, Near Threatened; DD, Data Deficient

[4]Based on the minimum convex hull area for each species

[5]Based on the GlobCover map area for each species

[6]Based on the Area of Occupancy at 4 km^2

[7]Based on the Area of Occupancy at 100 km^2

the least well known and may have been excluded from this assessment. As new distribution data become available as a result of future collection efforts the conservation status of such species should be reassessed.

A second area of uncertainty relates to the application of Red List criteria to tree species (Rivers et al., 2011). Some previous assessments have been particularly dependent on the B1 and B2 criteria, reflecting a reliance on herbarium accession data for estimating Extent of Occurrence in plant species (Nic Lughadha et al., 2005). As noted by Gaston & Fuller (2009) there is some confusion in the literature regarding how Extent of Occurrence should be calculated. As demonstrated here, it varies markedly for curvilinear regions such as the Andes, depending on whether or not unsuitable areas are excluded. Although exclusion of unsuitable habitat was incorporated in the IUCN Red List Guidelines that were available when this assessment was conducted (IUCN Standards and Petitions Subcommittee, 2011), this guidance has since changed (IUCN Standards and Petitions Subcommittee, 2014), and this will affect the number of species considered at risk of extinction. A significant area of uncertainty in this assessment was the estimation of actual population size, as there are no inventory or population density data available for the majority of tree species in the region. Additional uncertainty arises from a lack of distribution data. Some of the species included in this analysis may also occur below the altitudinal threshold adopted. Such uncertainties highlight the need for increased

TABLE 5 Levels of uncertainty associated with IUCN Red List criteria in assessments of tree species in upper montane forests of the Tropical Andes, with the numbers of species for which each level of uncertainty applies.

	Uncertainty level		
Criterion	High	Medium	Low
A1 Reduction in population size	128	1	
A2 Reduction in population size[1]	98	20	11
A2 Reduction in population size[2]	129		
A3 Reduction in population size[3]	129		
A4 Reduction in population size[4]	129		
B1 Small range (Extent of Occurrence)[5]	30	6	94
B1 Small range (Extent of Occurrence)[6]	16	113	
B2 Small range (Area of Occupancy)[7]	47	58	24
B2 Small range (Area of Occupancy)[8]	45	44	40
B(a) Severely fragmented[9]	44	59	26
B(a) < 10 locations[9]	32	57	40
B(b) Continuing decline[9]	31	63	35
B(c) Extreme fluctuation	129		
C1 Number of mature individuals < 10,000	128	1	
C1 Continuing decline in the future > 10%	128	1	
C2 Small and declining population	128	1	
C2(ai) Number of mature individuals > 1,000	128	1	
C2(aii) % individuals in subpopulation is 100	128	1	
C2(b) Extreme fluctuation of number of individuals	128	1	
D < 1,000 individuals & Area of Occupancy < 20 km^2, or < 5 locations	129		
D2 Restricted Area of Occupancy & threatened such that taxon could become Critically Endangered or Extinct	128	1	
E Quantitative analysis	129		

[1]Based on expert knowledge
[2]Based on the three scenarios used to estimate the percentage of forest loss during a period of 50 ≤ 100 years in the past
[3]Based on the three scenarios used to estimate the percentage of forest loss during a period of 50–100 years in the future
[4]Based on the three scenarios used to estimate the percentage of forest loss during a period of 100 years, including past and future
[5]Based on the minimum convex hull and expert knowledge
[6]Based on the GlobCover map area for each species
[7]Based on the Area of Occupancy at 4 km^2, and expert knowledge
[8]Based on the Area of Occupancy at 100 km^2, and expert knowledge
[9]Based on expert knowledge

TABLE 6 Numbers of national endemic tree species categorized for the IUCN Red List in previous national-scale assessments (Calderón et al., 2002; Llamozas et al., 2003; Meneses & Beck, 2005; León et al., 2006; IUCN, 2010; León-Yánez et al., 2011) and numbers of species categorized in this study.

Country	Critically Endangered	Endangered	Vulnerable	Near Threatened	Least Concern	Data Deficient	Not evaluated	Total
Ecuador	2	36	52	9	5	1	61	166
Peru	9	31	15	2	3	10	50	120
Colombia	4	5	5	2	1	0	60	77
Bolivia		5	1			1	94	101
Argentina							3	3
Venezuela								0
Total endemics	15	77	73	13	9	12	267	467
No. of species categorized in this study	1	47	28	19	29	5		129
Total no. of tree species in the Tropical Andes	16	124	101	32	38	17	267	596

effort in field data collection to increase the accuracy of Red List assessments in the tropics (Cayuela et al., 2009; Pereira & Cooper, 2006). Results were also found to be sensitive to inferences relating to estimates of deforestation rate. Accurate estimates are available only for limited geographical areas and time periods, reflecting the availability of appropriate remote sensing imagery and historical data. The assumption that deforestation rates remain constant over time is likely to be incorrect, particularly in relation to future trends. There is therefore a need for further quantitative analysis and modelling of deforestation in the region (e.g. Soares-Filho et al., 2006), as such information is currently limited for the Andes (Tejedor Garavito et al., 2012).

The importance of expert judgement in the Red List process is recognized but it represents a further source of uncertainty (Possingham et al., 2002). Here, the degree of uncertainty from this source was assessed explicitly. Expert knowledge relating to criteria B1 and B2 had the lowest level of uncertainty, reflecting the fact that distribution data are typically the most readily available to experts undertaking assessments (Newton & Oldfield, 2008; Bachman et al., 2011). There was more uncertainty in estimates of population density and size, particularly for species with relatively few distributional records. A substantial number of taxa could not be evaluated because of a lack of sufficient data. Some of those species may be threatened, and therefore there is a need for further research to determine the conservation status of Data Deficient species (Butchart & Bird, 2009; Bland et al., 2012).

Overall, this assessment identified that the number of threatened trees in the Tropical Andean region is high relative to other groups of organisms such as mammals, birds and fish, and provides further evidence of the congruence of species richness, endemism and threat that occurs in this region. Threatened tree species should therefore be included in conservation plans in the region and prioritized for conservation action. Although the Tropical Andean region has been the focus of various conservation initiatives (e.g. BirdLife International and Conservation International (2005) have identified important areas for the conservation of birds, based on distributions of threatened species, and Conservation International have also supported the development of biodiversity corridors (Critical Ecosystem Partnership Fund, 2006) to support the conservation of endemic and threatened species), there has been little emphasis on tree species in such initiatives. We therefore recommended that extinction risk assessments for tree species, such as those described here, be used to inform the development of conservation plans and strategies in the region, to ensure that further losses of this important element of biodiversity are averted.

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