Short communication

# Historical and potential extinction of shrub and tree species through deforestation in the department of Antioquia, Colombia

Extinción histórica y potencial de especies de arbustos y árboles debido a la deforestación en el departamento de Antioquia, Colombia

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***Abstract***. *We assessed the expected historical and current species richness of shrubs and trees in the Department of Antioquia, northwest region of Colombia. We used the Fisher´s alpha value associated with the pooled dataset of identified species in 16 1-ha plots that were used to extrapolate the scaled species richness of the Antioquia Province under three different scenarios: 1) the entire region before deforestation began, assuming an original forest cover of around 92% of the entire province (excluding paramos, rivers, and lakes). 2) The forest cover in 2010. 3) The expected forest cover in 2100 assuming the observed deforestation rate between 2000 and 2010 as a constant. We found that, despite relatively low local and global losses of species, global extinctions in terms of number of species could be dramatically high due to the high endemism and deforestation rates.*

**Key words**: Andean mountains, endemism, Fisher´s alpha, tropical hotspots.

***Resumen***. *En este estudio, se evaluó la extinción histórica esperada y actual de arbustos y árboles en el Departamento de Antioquia, noroeste de Colombia. Para estimar la riqueza de especies, se empleó el valor del Alfa de Fisher asociado con el conjunto de especies plenamente identificadas provenientes de 16 parcelas de 1 ha a la escala del Departamento de Antioquia, bajo tres escenarios: 1) la region entera antes de que la deforestación iniciará, para lo cual asumimos un 92% del área total del Departamento (excluimos páramos, ríos y lagos). 2) La cobertura de bosques estimada a 2010. 3) La cobertura de bosques estimada a 2100 asumiendo como constante la tasa de deforestación estimada entre 2000 y 2010. Se encontró que a pesar de que la pérdida de especies a escala regional fue relativamente baja, los números asociados con la extinción de especies podrían en cambio ser bastante altos debido al alto endemismo y la alta tasa de deforestación.*

**Palabras claves**: Montañas de los Andes, endemismo, alfa de Fisher, centros de alta diversidad tropical.

The tropical Andes region has been widely recognized as a hotspot, which means an area with exceptional species richness and endemism that is experiencing a high loss of habitat (Myers *et al.*, 2000). This regional characteristic is also mirrored in Colombia, a country located in the northern portion of the Andean mountain ranges, where the remaining primary Andean forest vegetation covers around 25% (Armenteras *et al.*, 2003) and the dry forests cover nearly 5% (Chaves and Santamaría, 2006) of their original extent. This particular threat may be driving the modern flora of this region toward either local loss or global extinction of the species, many of which are likely still completely unknown.

In this study, we aimed to 1) estimate the historical and expected number of shrub and tree species in the region for different periods of time; 2) calculate the deforestation rate between 2000 and 2010; and 3) estimate the number of shrub and tree species that have gone and will go extinct in the Antioquia Province, northwest region of Colombia. The Antioquia Province is a geographical area that covers around 64,000 km$^2$. This province is mainly composed of the Central and Western Andean Cordilleras, but also includes some spots on the Caribbean and Choco-Darien side of the country. To characterize the shrub and tree diversity across the Antioquia Province, we established 16 1-ha plots at an average distance of 212.5 km (rank 44.5 km - 476.7 km) (Figure 1). The survey covered an altitudinal range between 50 and 2900 masl. All plots were 100 m x 100 m, except one plot that was 40 m x 250 m (Table 1). Each individual plant included in each plot was mapped, tagged and measured, including palms and tree ferns with a diameter at breast height that was (DBH) ≥ 10 cm. Near the central part of each plot, a 40 m x 40 m subplot (1600 m$^2$) was located. In this subplot, all the plants ranging between 1 cm ≤ DBH < 10 cm were tallied. Voucher collections were made for each unique species whenever there was any uncertainty

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of its identity. Taxonomic identifications were done by comparing specimens with herbaria material and with the help of specialists in some groups. All the samples were kept at the University of Antioquia's Herbarium (HUA). The plants that could not be identified by species were ruled out of the analysis (Pos *et al*., 2014).

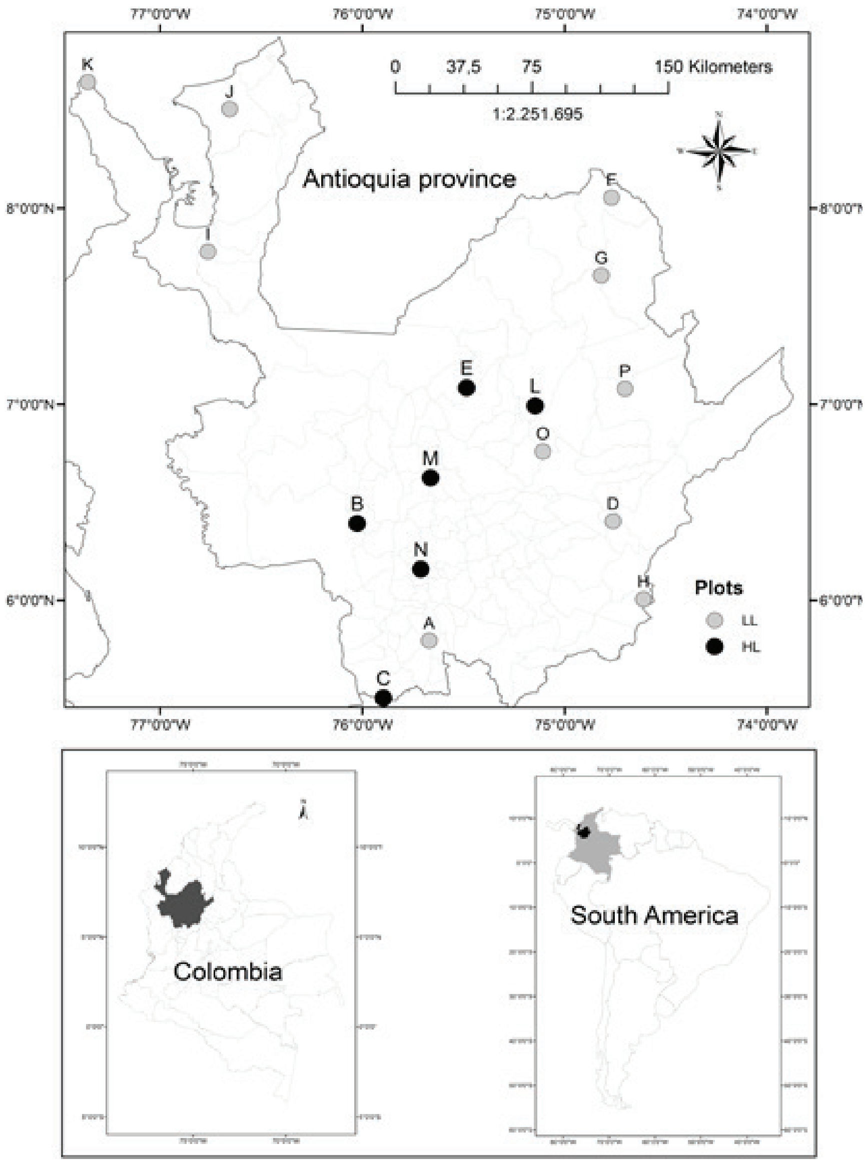


**Figure 1.** Geographical location of the Antioquia province in Colombia. Grey dots represent plots established below 1500 masl, while black plot represent those plots established over 1500 masl.

We used the Fisher's alpha index (± 1 SE) to estimate the expected species richness in the entire region (after Ter Steege *et al*., 2013). To calculate Fisher´s alpha, only those individuals (DBH ≥ 1 cm) that could be fully identified to the species level were employed. In total, there were 21,617 individuals (82% of the total) that belonged to 953 identified species (59% of the total). We only used fully-identified species to compare our estimates with the figures obtained from an intensive survey of the botanical vouchers historically collected from this region that are stored in the principal herbaria worldwide (Idárraga *et al*., 2011). We used Vegan 2.0-3 to calculate Fisher's alpha (Oksanen *et al*., 2012).

**Table 1.** Geographical characteristics of the 16 1-ha permanent plots established in this study.

| Plot: Municipality | Geographical coordinates | Precipitation (mm y$^{-1}$) | Altitude (m) | Number of species | Number of individuals |
|---|---|---|---|---|---|
| A: Támesis | 5°47´42" N<br>75°40'11" W | 1750 | 600 | 43 | 956 |
| B: Caicedo | 6°23´30" N<br>76°01'31" W | 2200 | 2600 | 122 | 2122 |
| C: Jardín | 5°30´04" N<br>75°53'44" W | 2250 | 2500 | 74 | 1705 |
| D: Maceo | 6°24'13" N<br>74°45'38" W | 2250 | 900 | 127 | 1483 |
| E: Valdivia | 7°05´05" N<br>75°29'03" W | 3500 | 2000 | 124 | 1853 |
| F: Caucasia | 8°03´21" N<br>74°46'05" W | 3250 | 400 | 76 | 785 |
| G: El Bagre | 6°00´22" N<br>74°36'38" W | 4250 | 700 | 148 | 1092 |
| H: Puerto Triunfo | 7°39'30" N<br>74°49'07" W | 2250 | 400 | 94 | 868 |
| I: Carepa | 7° 46`46" N<br>76° 45'52" W | 3250 | 50 | 107 | 668 |
| J: Necoclí | 8°30'26" N<br>76°39'27" W | 2000 | 55 | 125 | 1208 |
| K: Acandí (Chocó) | 8°65'14" N<br>77°35'44" W | 2750 | 250 | 100 | 843 |
| L: Anorí | 6°58´ N<br>75°09' W | 2400 | 1750 | 130 | 1409 |
| M: Belmira | 6°9,5"N<br>75°42'W | 2100 | 2950 | 52 | 1377 |
| N: Angelópolis | 6°35' N<br>75°32' W | 2400 | 2100 | 146 | 2577 |
| O: Amalfi | 7°4'47" N<br>74°42'6" W | 1920 | 1200 | 83 | 1257 |
| P: Segovia | 6°46´ N<br>75°04' W | 3500 | 600 | 206 | 1414 |

The letters correspond to Figure 1.

The Fisher´s alpha value associated with the pooled dataset of identified species in the 16 1-ha plots was employed to extrapolate the species richness (Ter Steege *et al*., 2013) on the scale of the Antioquia Province under three different scenarios: 1) the entire region before deforestation began, assuming an original forest cover of around 92% of the entire province (after excluding paramos, rivers, and lakes); 2) the forest cover in 2010; 3) the expected forest cover in 2100 assuming the observed deforestation rate between 2000 and 2010 as a constant. Both the forest cover in 2010 and the deforestation rates between 2000 and 2010 in the Antioquia Province were assessed using Landsat images with a spatial resolution of 30 m (ETM+ and TM sensors) from 2000, 2005 and 2010. Digital image processing and mapping of the forest cover were carried out using a semi-automated approach that integrates the CLASlite software (www.claslite.ciw.edu) and expert criteria.

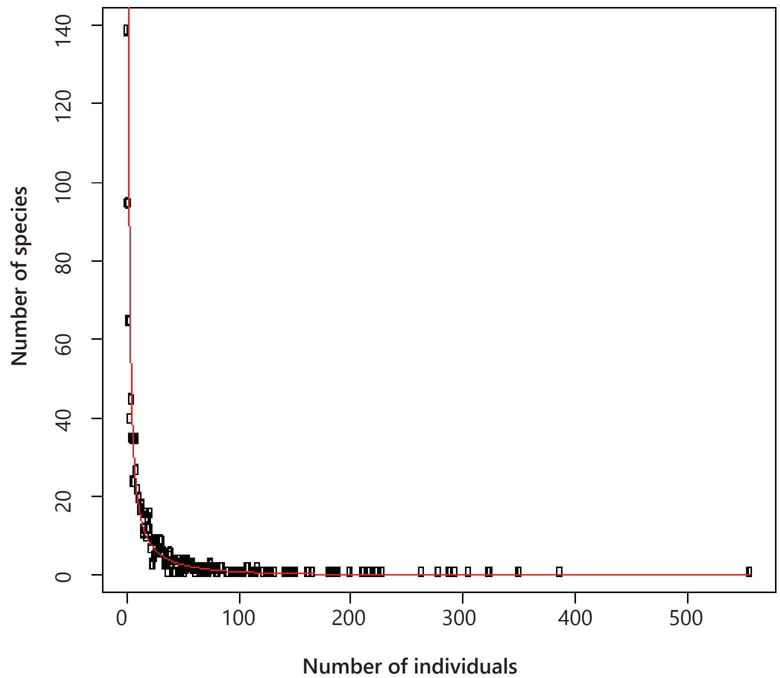


**Figure 2.** Fit of Fisher's log series to the relative species abundance pooled data of named species from 16 1-ha plots established in the northwest of Colombia. Open circles are the observed data. The continuous line represents the theoretical estimations of the log-series based on a Fisher's alpha of 203.95. The log series is defined by $\alpha = X^n/n$, where $\alpha$ = Fiher's alpha, n = number of individuals, and $X = n/(n+ \alpha)$ (see Oksanen *et al*., 2012).

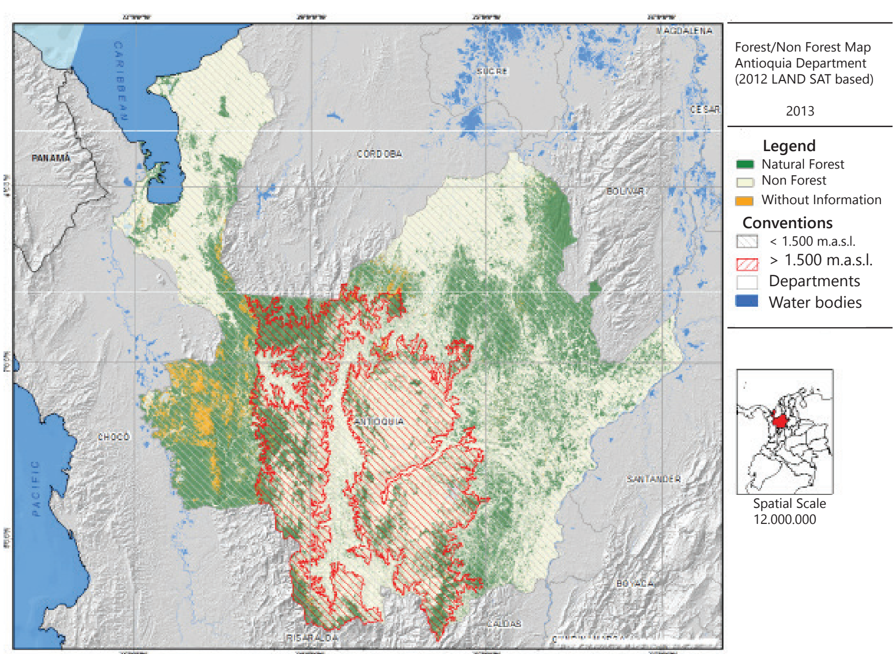


**Figure 3**. Forest cover of the Antioquia province at 2010.

**Table 2**. Total number of species estimated using Fisher's alpha under three different forest covers at three different times in the province of Antioquia, northwest region of Colombia.

| Period | Observed woody species in Antioquia: 2881 | | | Endemic species: 158 | | | |
|---|---|---|---|---|---|---|---|
| | Initial forest cover (km$^2$) | Final forest cover (km$^2$) | Fisher´s alpha | $S_i$ estimated | $S_f$ estimated | $S_l$ ($S_i$ - $S_f$) | $S_e$ |
| -2000 | 58,166.82 | 21,469.4 | 203.95 | 4377 | 4173 | 192 | 11 |
| 2000-2010 | 21,469.4 | 18,573.1 | 203.95 | 4173 | 4144 | 28 | 2 |
| 2010-2100 | 18,573.1 | 4988.6 | 203.95 | 4144 | 3876 | 253 | 15 |

$S_i$: Initial number of estimated species; $S_f$: Final number of estimated species; $S_l$: Estimated number of locally lost species; $S_e$: Estimated number of extinct species. Total number of observed and endemic species for the entire Antioquia Province based on Idarraga *et al.* (2011).

The regional endemism of the shrubs and trees was calculated according to Idárraga *et al.*(2011). The total number of both extinct and locally lost species, at the province level, was calculated by the difference between the estimated number of species under the different forest covers according to the three reference scenarios. The total number of species was estimated as follows: $S = \alpha * \ln(1 + N/\alpha)$, where S = number of species, N = total number of individuals, and $\alpha$ = Fisher's alpha. The total number of extinct species was calculated by multiplying the number of species lost by the proportion of endemic species. The remaining species were classified as locally lost.

The average number of individuals with a DBH ≥ 1 cm per hectare was of 7,282. The Fisher´s Alpha value for the entire data set was of 203.95 (± 7.4). There were not significant differences (Chi square = 2880, df = 2856, $P > 0.05$) between the observed species relative abundances that came from the identified species in the 16 1-ha plots and the expected species relative abundances as estimated by Fisher´s log-series (Figure 2). The annual deforestation rate between 2000 and 2010 was 1.45% and the remaining cover of natural forest in the entire region in 2010 was 18,573 km$^2$, which equals 29.4% of the entire territory of the Antioquia province (Figure 3).

The total number of shrub and tree species expected for the entire region before deforestation began was 4,377; the total number of shrub and tree species expected in 2010 was 4,144; the total number of shrub and tree species expected in 2100 was 3,876 (Table 1). The total number of known shrub and tree species in 2010 was 2,881 (Idárraga *et al.*, 2011), which represents 69.5% of the total number of expected species in the entire region. For 2010, we expected a total of 234 shrub and tree species to be lost, 13 of which should have gone extinct. For 2100, we expected another 268 species to disappear from the region, 15 of which should have gone extinct as well (Table 2).

Our total estimate of 0.3% (13 of 4377 species) species that went extinct in 2010 was very much in line with the 78 out of 20,000 (0.39%) plant species defined as extinct or threatened for the entire tropical Andes by Brooks *et al.* (2002). On the other hand, our estimates for extinct species in 2010 were twelve fold the estimates in the Amazon basin in Ecuador, where the authors considered a similar geographic area (67,000 km$^2$) and a similar percentage of endemism (5.6%) (Pitman *et al.,* 2002). Assuming the rate of habitat loss by deforestation calculated between 2000 – 2010 as a constant, the percentage of globally and locally lost species for the entire province of Antioquia between 2010 and 2050 will be 0.073%, which is much lower than the 23% estimated under the worst-case scenario for the Brazilian Amazon basin for 2050 (Hubbell *et al.,* 2008) and also lower than the 5-9% estimated by Feeley and Silman (2009) for the same region and time. The main reason for such a big difference resulted from the fact that we assessed extinction rates for a geographical province where we knew that most species occur elsewhere (Idarraga *et al.,* 2011), rather than for an (almost) entire biogeographic region. However, it will remain true if and only if the habitat loss does not occur anywhere outside of the Antioquia Province for a longer period, which is not the case (Hansen *et al.,* 2013). Habitat loss through deforestation in places outside of the study region will facilitate the extinction of locally lost species.

According to the Fisher's alpha value of 203.95 that was calculated for the 16 plots employed in this study to sample the 2,881 species currently available in the herbaria, we would have had to survey 34,858 ha of forests, which roughly represent 278. 3 × 106 individuals. Then, assuming the estimated total number of species in 2010 as a reference (4144), in this region, there would still be 1,263 (30.5%) species awaiting collection of the hypothetical 13,246.7 × 106 individuals (≈ 18,573.1 $km^2$ of forests) not yet sampled. This figure appears quite reasonable if we take into account that, within the 26,493 individuals sampled in the 16 plots, there were 10 new species reported for the Antioquia region, 5 of them classified as new species. Therefore, in order to get 1,263 new records for the entire region, we would only need one new record for each 10.5 × 106 individuals (≈1440.3 ha) sampled. Indeed, it shows that Fisher´s alpha could underestimate rather than overestimate the expected total species richness (see also Ter Steege *et al.,* 2013), a desirable property for a conservative assessment.

On large biogeographical scales, the log-series has been seen as the steady-state distribution of relative species abundance originated from small population sizes under random-walk processes (Hubbell, 2001, 2013). The Neutral Theory (*sensu* Hubbell, 2001) supports our view of a continuous species increase with the sample size due to the occurrence of many rare species (Hubbell *et al.,* 2008). Although our analysis does not allow us to know how many of the still unrecorded plants in Antioquia would be unknown species for science, we can ensure that the 13 woody species expected to have gone extinct in 2010 must have been scaled many times by coupled extinctions with other plant growth forms, microbial, and animal species. In particular, the risk of extinction increase for all those endemic species with small and restricted geographic ranges (i.e. Pounds *et al.,* 2006). We also do not know if many rare species in the Antioquia Province are abundant elsewhere, which would contradict the fit of the log-series to either larger datasets or larger geographic areas, as compared to those surveyed here.

The approach employed in this study did not allow us to account for the spatial structure of the individual populations, and we assumed a scattered species distribution across the entire range of the geographical province of Antioquia, according to the historical collection of botanical vouchers (Idarraga *et al.,* 2011). However, plant species are patchily distributed in space (Condit *et al.,* 2000) and vary in their relative abundance, as was shown here. Clustering species may certainly increase the risk of local loss and global extinction of those individuals located close to deforestation hotspots, particularly if they are locally rare (*sensu* Rabinowitz, 1981). The fact that deforestation in the Antioquia Province is actually highly concentrated in the middle lowlands of the Magdalena and Urabá areas, which are the more diverse areas within the region (A. Duque, unpubl.data.), poses serious threats for increasing species loss and extinction in this region. Since some of the main drivers of habitat loss in these areas are land-use change to pastures, illegal crops and illegal mining, the fate of the persistence of many species in this region is uncertain due to the absence of political willingness to work on these major social and economical issues.

Overall, this study combined non-spatial explicit information from a plant catalogue (Idárraga *et al.,* 2011) with a plot survey and a deforestation assessment to estimate the historical and potential risk of extinction for shrub and tree species in an environmentally complex neotropical region. Our estimates of the expected number of species for the entire region employing Fisher's alpha index, in proportion, were very much in line with those recently presented for the Amazon basin (Ter Steege *et al.,* 2013). However, we had the relative advantage of having a recent survey of botanical vouchers from this region that covered the most important national and international herbaria of the world, to compare the estimates with the observed data. Finally, we knew that our estimates of the endemism in the region were far from perfect, but they still seemed to be a more robust metric than data on threatened species (Pitman and Jørgensen, 2002). However, we hope that our results will help to promote similar studies in other regions as well as the implementation of regional programs of forest management and conservation. As stated before, curtailing deforestation is a major and necessary step to avoid species extinction and loss of diversity.

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