Diversity and Distributions, (Diversity Distrib.) (2004) **10**, 211–216

BIODIVERSITY RESEARCH

Modelling distribution patterns in a species-rich plant genus, *Anthurium* (Araceae), in Ecuador

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ABSTRACT

Modelling potential species distributions has become a powerful tool for botanists in recent years. Using herbarium specimen data and GIS desktop software, we modelled the potential distribution of 36 endemic and 47 non-endemic species of *Anthurium* (Araceae) in Ecuador based on mean annual temperature and humidity. Our results indicate the most important region for endemics in western Ecuador lies between the Andes and Coastal mountain ranges between 200 and 700 m, while for eastern Ecuador a belt of potential high diversity occurs directly along the foothills of the Andes under 1000 m. A very interesting result of this study highlights a site of predicted high species diversity at the borders of Guyas, Cañar, Bolivar, and Chimborazo, as well as sites within the Cordillera del Condor along the border with Peru. Potential richness for non-endemic *Anthurium* species was similar to that of endemics with the inclusion of a large area of Amazonian lowlands in the east of the country. Over 40% of the protected areas in Ecuador occur in the eastern Amazonian lowlands, an area of low diversity for *Anthurium* endemics. Overall, for areas with potential high concentrations of endemic species identified in this study, only 3.1% are within Ecuador's protected areas.

Keywords

Species distributions, endemics, Araceae, GIS, distribution modelling, endemic species diversity, national park system.

INTRODUCTION

Mapping the potential distribution of plant species is now within reach of many botanists, thanks to desktop modelling software and Geographical Information Systems (GIS)(Carpenter *et al*., 1993; Skov, 2000). The main requirements for mapping potential species distributions are environmental data at an appropriate scale (i.e. rainfall and temperature) and accurately geo-referenced collection data. Endemic species are by definition restricted in their distribution, and are often poorly represented by herbarium specimens. Areas of high endemic species diversity are frequently characterized by fragmented habitat and unique climatic and edaphic conditions (Gentry, 1986). The degree of endemism in an area is often used as a measure of conservation significance (Brooks *et al*., 2002), and thus predicting areas with potentially high concentrations of endemic species becomes especially valuable in Neotropical countries where vast areas remain unexplored. For example, fragmented habitats and variation in climatic conditions in the Andes Mountains contribute to the high levels of endemism found there (Gentry, 1986; Gentry *et al*., 1995), making them well suited as areas to model endemic species distributions.

Ecuador is among the most biologically diverse countries in the world, with more than 16,000 plant species (Jørgensen & León-Yánez, 1999). More than 4000 plant species are endemic to Ecuador, and at least 3000 of these are endangered (Valencia *et al*., 2000), and the overall proportion of species endemic to Ecuador is greater in the Andes (Borchsenius, 1997; Valencia *et al*., 2000; Kessler, 2002). The Amazonian lowlands have mostly rather widespread species, while much of the middle elevations of the north-eastern slopes of the Andes as well as the south-eastern slopes remain unexplored (Valencia *et al*., 2000).

The family Araceae is characterized by both high species diversity and local endemism (Croat, 1983, 1988, 1992), with two-thirds of the species believed to occur in tropical South America (Croat, 1979). Regions with differences in precipitation and temperature share relatively few species, and endemism is high in the Andean region at middle elevations on both slopes of the Andes (Croat, 1992, 1995). Ecuador is one of the richest areas in the world (Croat, 1995), and within Ecuador Araceae diversity is highest in the wettest sites at low to mid elevations, and lowest at dry lowland sites or higher elevation (Croat, 1992, 1995).

The genus *Anthurium* Schott is the largest in the Araceae. The Catalogue of Vascular Plants of Ecuador (Croat, 1999) reports

227 *Anthurium* species of which 145 species are endemic to Ecuador. *The Libro Rojo de Plantas Endémicas del Ecuador 2000* (Valencia *et al*., 2000) undertakes further analysis of the 4000 + endemic plant species and they include 143 endemic *Anthurium* species. Overall species diversity and endemic species diversity for *Anthurium* in Ecuador is higher in the Andean and Coastal regions than in the Amazonian regions, with the greatest concentration of species occurring between zero and 1500 m elevation (Fig. 2) (Croat, 1999). Recent surveys of the Cordillera del Condor along the Peruvian border indicate a high rate of endemism. The same is true of the Serrania de Cutucú further to the north.

Specimen data from the Missouri Botanical Garden's TROPICOS database was combined with climatic data to provide an invaluable resource for addressing questions such as: What are the distributions of endemic *Anthurium* species in Ecuador? Are there areas that have high levels of species richness, or so-called 'hotspots' for *Anthurium* endemics within Ecuador? and finally, are these 'hotspots' protected? This paper will attempt to answer these questions.

METHODS

Study area

Continental Ecuador is situated on the Equator, on the West Coast of South America and covers approximately 275,000 km^2. It ranges from 1°30′ N to 5° S latitude and 75°20′ W to 81° W longitude and is traditionally divided into three natural regions: the Pacific Coastal region, the Andes Mountains, and the Amazon lowlands. The Andes Mountains are the dominant topographic feature of Ecuador, and occupy the central third of the country. The Andes of Northern and Central Ecuador are divided into two mountain ranges; the Eastern or 'Real' and the Western Cordilleras. Between the Western and Eastern cordilleras are a series of inter-andian valleys (Neill, 1999).

Methods

Fleming Skov generously made gridded climate data layers available. Data layers used for this project were humidity and temperature (1 km grid cell size) estimated from Digital Elevation Model topographic maps and mean annual temperatures from more than 100 weather stations in Ecuador (see Skov & Borchsenius, 1997 for further details). Specimen data for all collections in Ecuador for the genus *Anthurium* were downloaded from the Missouri Botanical Garden's Tropicos database and converted to a point theme using ArcView 3.2a. All analyses were done using ESRI's ArcView 3.2a Spatial Analyst software. The DOMAIN model for distribution modelling was applied to the collection data on a species by species basis using Fleming Skov's ArcView program which uses a point-to-point similarity metric (DOMAIN model) to quantify the similarity between two sites (Carpenter *et al*., 1993; Skov, 2000). The DOMAIN model is easily implemented, performs well with limited site data, and has successfully been used to model potential distributions of plant species (Carpenter *et al*., 1993; Guisan & Zimmermann, 2000; Skov, 2000; Funk & Richardson, 2002). The success rate of predictive models is greatly affected by the size of species occurrence points used in the models and increases as more site records are used, thus we selected all non-endemic species with at least 20 site records (Peterson, 2001; Stockwell & Peterson, 2001). However, endemic species are by their definition limited in distribution so we used all endemics with at least five site records to model their distributions (12 species with 5–9 records and 24 species with ≥ 10 records). A total of 83 species of *Anthurium* were analysed for potential distribution, of which 36 species are considered endemic to Ecuador.

Potential distribution grids for each *Anthurium* species were created and then reclassified to values of zero or one for unsuitable or suitable using the similarity index cutoff of 0–0.95 and 0.95–1.0, respectively. By eliminating all areas below 95% similarity we are assuming the 'core bioclimate' would contain those locations between 95 and 100 percentile limits and those locations whose grid value fall outside these limits would be considered areas of 'marginal bioclimate'. The cutoff point of 0.95 is based on other studies testing the DOMAIN model for plant and animal distributions (Carpenter *et al*., 1993; Funk & Richardson, 2002; Loiselle *et al*. in press). Adding all the grids using Spatial Analyst Map Calculator produced two grids or maps, one identifying the areas of highest diversity for the endemic species only, and the other with the same purpose for non-endemic species.

We used a set of collection data not used in the initial modelling to test the validity of our predicted distribution for both endemic and non-endemic *Anthurium* species. Due to the small number of collections available for most of the species, and based on the knowledge that Aroid species tend to be densely aggregated within any given site (Croat, 1995), we did not test our occurrence data on a species by species basis, but rather used a set of multiple species (43 collections representing 14 of the 36 endemic species used in the models). In addition, since our final predicted distributions (Fig. 1), are combinations of all the species used in the model, we feel this is a fair way of testing our results. We overlaid the test data on the predicted areas from our endemic species model and calculated the number of points correctly and incorrectly predicted as observed presence and absence values, respectively. Expected numbers were calculated as the number of test collections (43) multiplied by the proportionate area of land predicted from our model (Table 1). A chi-square test was used to assess model significance. The same procedure was done for the non-endemic species model, using a set of 261 collection points representing 35 of the 47 species used in our original model (Table 1). Potential distributions for areas of high concentrations of both endemic and non-endemic *Anthurium* species were highly significantly predicted in both models ($P < 0.001$).

RESULTS

Areas of potential distribution for endemic species

The maximum number of endemic species that potentially can be found in a grid cell was 20. We have identified three hotspot

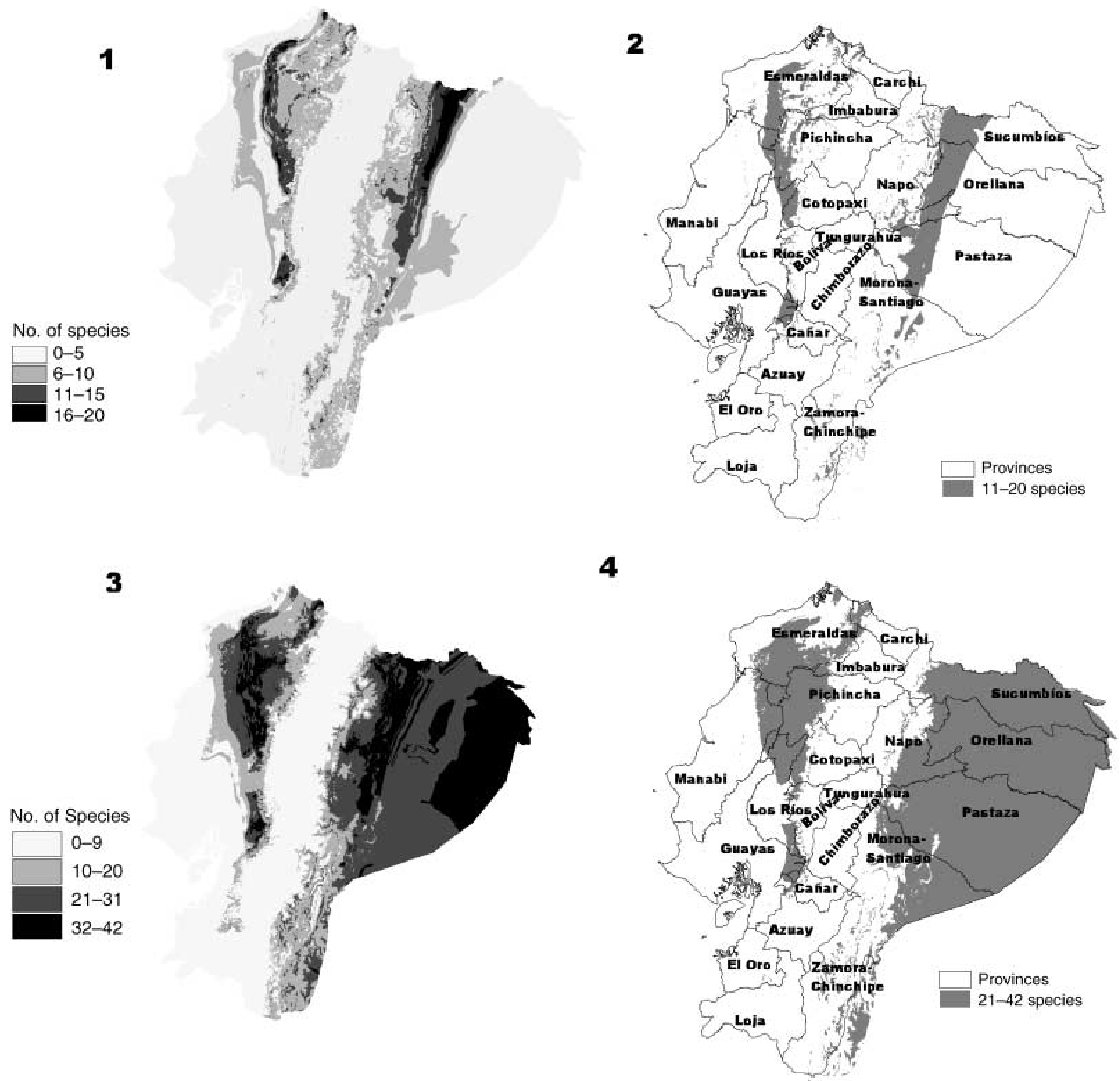

Figure 1 Potential distribution for species of *Anthurium* in Ecuador: (1) potential distribution of endemic species; (2) potential areas of high endemic species concentrations (a) in the western lowlands and foothills of Andes (b) foothills of the Andes in the east (c) border of Guayas, Los Ríos, Bolivar, Chimborazo, and Cañar (3) potential distribution of non-endemic species (4) potential areas of high non-endemic species distributions. A total of 36 endemic and 47 non-endemic species were used in modelling potential species distributions.

areas for endemic *Anthurium* species within Ecuador. The three hotspots were defined by those areas in the top 50 percentile (11–20 species) of overlap for all species, and are as follows: (1) the lowland and foothills in north-west Ecuador between the Andes and Coastal mountains as a 25 km wide belt extending from 1°5′ N, to 1°10′ S, running close to the Andes with an elevation range between 200 and 700 m; (2) lowland areas along the Andes in the east as a 35–50 km wide belt extending from the Colombian border in the north to 2°10′ S with an elevation that varies between 300 and 600 m; and (3) an area in the south central portion of Ecuador at the intersection of the provinces of Guayas, Los Ríos, Bolivar, Chimborazo, and Cañar, an area of 950 sq. km with an elevational range of 150–900 m (Fig. 1). Several discontinuous areas of smaller size, but with a high degree of potential species ranges overlap (> 10 species) occur in the north-western portion of Ecuador in the provinces of Esmeralda, Carchi, Pinchincha, and Imbabura at elevations between 50 and 2600 m, in the south-eastern portion of Ecuador in the Serrania de Cutucú in the Morona-Santiago province at elevations between 300 and 1800 m, and finally in the Zamora-Chinchipe province at the foothills of the Andes, in the Cordillera del Condor region at the Ecuador-Peruvian border (Fig. 1).

Table 1 Summary of significance tests for endemic species and non-endemic species models for *Anthurium* in Ecuador

	Endemic Species Model		Non-Endemic Species Model	
	Observed	Expected	Observed	Expected
Present	26	12	188	125
Absent	17	31	73	136
Total	43	43*	261	261†

*$\chi^2 = 22.66, P < 0.001$.
†$\chi^2 = 60.93, P < 0.001$.

Areas of potential distribution for non-endemic species

The areas of highest overlap in non-endemic species potential distributions (21–42 species) are over 78% larger than those for endemic species (Fig. 1). The areas of highest overlap mimic and include those of endemic species with the exception of the large area of Amazonian lowlands in the east of the country. If we look at those areas in the top 50% of species range overlap (21–42 species) the whole of the eastern Amazonian lowlands is included. Limiting the distribution to the top 25 percentile (32–42 species) still includes an area of *c.* 21,500 km^2 of eastern Amazonian lowlands.

DISCUSSION

High species diversity and local endemism characterize the Araceae in the Neotropics (Croat, 1983, 1988, 1992). Studies in Ecuador and Colombia show little overlap in species composition, even in regions of close proximity, particularly on opposite sides of the Andes (Croat, 1995). Overall species diversity and endemic species diversity for Araceae genus *Anthurium* in Ecuador is higher in the Andean and Coastal regions than in the Amazonian regions, with the greatest concentration of species occurring between zero and 1500 m elevation (Fig. 2) (Croat, 1999).

A summary of *Anthurium* endemic species taken from the Catalogue of Vascular Plants of Ecuador (Croat, 1999) shows the provinces with the highest number of endemic species as Pinchincha (59), Esmeraldas (42), and Cotopaxi (31). The data used in our study also had the highest number of endemic species in Pinchincha (30), Esmeraldas (15), and Cotopaxi (13). However, recent fieldwork in the province of Carchi suggests it will rank in the highest for endemic species, but is still poorly known. The results of this study are consistent with the characteristics of endemic Araceae species in the Neotropics, specifically the highest diversity was predicted at elevations between zero and 1000 m on both sides of the Andes in the northern to central portion of Ecuador (Fig. 1). The contribution that modelling adds is narrowing down the specific areas of potential species diversity below the provincial level, particularly for the western portion of the country. Our results indicate the most important region for endemics in western Ecuador occurs between the Andes and Coastal mountain ranges. While for eastern Ecuador a belt of potential high diversity occurs directly along the foothills of the Andes under 1000 m. A very interesting result of this study highlights a site for potentially high concentrations of endemic species at the borders of Los Ríos, Guyas, Cañar, Bolivar, and Chimborazo; all provinces with low numbers of known endemic species both from the Ecuador Catalogue (Croat, 1999) and collection data used in our study. Our results also indicate smaller areas with potential high concentrations of endemic species located in the northern border region between Esmeraldas and Carchi provinces, the region of the Cordillera del Condor, and the Serrania de Cutucú region of Morona-Santiago province (Fig. 1). The latter two areas appear particularly important as recent surveys of the Cordillera del Condor, along the Peruvian border, and the Serrania de Cutucú further to the north, indicate a high rate of endemism.

Areas of potential high species diversity for non-endemic *Anthurium* species are similar to those of endemics, but include a large portion of Amazonian lowlands in the far eastern portion of the country (Fig. 1). Based on past studies, the Amazonian lowlands below 500 m do not have high species diversity for the Araceae (Croat, 1995, 1999), yet our results modelled this region as high in potential non-endemic species diversity (32–42 species). One explanation for this disparity may be in the data used in the study, a summary of which can be seen in Table 2. It is interesting to note that in the case of non-endemics the distribution of species appears evenly distributed between both sides

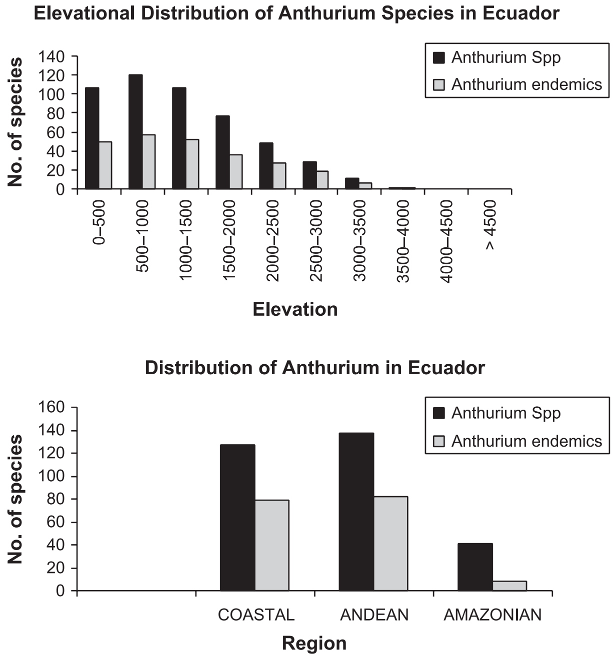

Figure 2 Distribution of *Anthurium* species in Ecuador. Numbers for *Anthurium* species were taken from the Catalogue of Vascular Plants of Ecuador (Croat, 1999) and plotted according to (1) elevation and (2) natural regions.

Table 2 Distribution of species used to model *Anthurium* in Ecuador, in relation to the Andes Mountains

	Eastern/ Andean	Western/ Andean	East/West/ Andean	Andean only	Total
Endemics	4	24	7	1	36
Non-endemics	17	13	17	0	47
Total	21	37	24	1	83

of the Andes, while six times the number of endemic species used occurs only on the western side of the Andes. As mentioned earlier, the provinces with the highest number of endemic species occur in north-western Ecuador. The DOMAIN procedure used to model these data uses a point-to-point similarity index to assign a value to a site based on its proximity in the environmental space of the most similar record (Carpenter *et al.*, 1993), and as such our potential distribution maps may reflect some degree of collection bias. That said however, it still appears that overall our results are similar to the known distribution of *Anthurium* in Ecuador, particularly for endemics, and add valuable components by not only identifying specific areas where these species may be found, but novel areas that may not be well known. Indeed, based on field experience of one of the authors, the area of highest species diversity and highest endemism for Araceae is the wettest part of the country in north-west Ecuador in the northern border area of Esmeraldas and Carchi provinces, congruent with one of the areas highlighted in our study. Finally, model testing showed highly significantly predicted areas of presence for our test data when applied to our modelled distributions (Table 1).

Protected areas and recommendations for conservation

The degree of endemism for an area is often used to prioritize conservation sites (Myers *et al.*, 2000; Knapp, 2002; Young *et al.*, 2002). The Andes Mountains in particular are associated with high levels of endemism (Gentry, 1986; Gentry, 1995). Total land area of potential high endemic diversity modelled in this study equalled *c.* 23,700 km^2. Over 40% of the protected areas in Ecuador occur in the eastern Amazonian lowlands, an area of low diversity for *Anthurium* endemics. When we look at the areas with potential high concentrations of endemic species identified in this study, only 735 km^2 or *c.* 3.1% of the total area is within Ecuador's protected areas broken down as follows: north-west Ecuador, 270 km^2 (1.1%), north-east Ecuador, 430 km^2 (1.8%), Cordillera del Condor region, 35 km^2 (0.2%). There is no protection afforded to the area with potential high concentrations of endemic species in the south central portion of Ecuador at the intersection of the provinces of Guayas, Los Ríos, Bolivar, Chimborazo, and Cañar. Of the 36 endemic species analysed in this study 22 (61%) have been collected in protected areas within Ecuador, whereas 47 (98%) of non-endemic species used in this study have been found within protected areas. So while it may not be possible to extend protection to all of the areas identified in this study, increased protection even in smaller areas may result in preserving high numbers of endemic species since Aroid species tend to be densely aggregated within any given site (Croat, 1995).

ACKNOWLEDGEMENTS

We wish to thank Fleming Skov for giving us the climate data grids used in this study, as well as his scripts for the DOMAIN model incorporated into ArcView. We also thank David Richardson, A. Townsend Peterson, and an anonymous reviewer for insightful comments on this manuscript.

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