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Diversity, threat, and conservation of reptiles from continental Ecuador

[1,2,3,5]Carolina Reyes-Puig, [4,6]Ana Almendáriz C., and [1,7]Omar Torres-Carvajal

[1]*Museo de Zoología, Escuela de Ciencias Biológicas, Pontificia Universidad Católica del Ecuador, Avenida 12 de Octubre 1076 y Roca, Casilla Postal 17-01-2184, Quito, ECUADOR* [2]*Sección de Herpetología, Instituto Nacional de Biodiversidad, Calle Rumipamba 341 y Av. De Los Shyris, Casilla Postal 17-07-8976, Quito, ECUADOR* [3]*Instituto de Zoología Terrestre, Universidad San Francisco de Quito USFQ, Colegio de Ciencias Biológicas y Ambientales COCIBA, Diego de Robles y Vía Interoceánica, 170901, Quito, ECUADOR* [4]*Instituto de Ciencias Biológicas, Escuela Politécnica Nacional, Casilla Postal 17-01-2759, Quito, ECUADOR*

***Abstract.*—Ecuador is one of the most reptile-diverse countries in the world, with 464 currently recognized species. Similar to other taxa, reptiles in Ecuador face important conservation challenges because of anthropogenic activities. Using distribution data of nearly 90% of the species of reptiles from continental Ecuador, as well as information on ecosystem protection status and anthropogenic activities, we present the first comprehensive quantitative study of reptile conservation in Ecuador. While species richness is higher in northwestern Ecuador and the central-northern Amazon, the conservation priority areas identified in this study also include the central Pacific coast, southwestern Ecuador, and the central-southern Amazon. Similar areas have been identified by previous studies as conservation gaps. Thus, our study reinforces the idea of protecting those areas to improve the conservation of biodiversity in continental Ecuador.**

Keywords. Conservation priority areas, endemism, importance, opportunity, species distribution models

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Introduction

Compared to other groups of terrestrial vertebrates, reptiles have been subject to relatively few conservation studies leading to the identification of either global or local threats. Similar to amphibians, some authors (e.g., Gibbons et al. 2000; Todd et al. 2010) conclude that reptiles face six significant threats at a global scale: habitat loss and degradation, introduced invasive species, pollution, disease, unsustainable use, and climate change; however, those studies are mostly descriptive and their sampling of taxa is poor. Only recently was the conservation of reptiles analyzed at a global scale. Based on a worldwide sample of 1,500 species (~14.6% of total), Böhm et al. (2013) concluded that nearly 20% of species of reptiles are threatened with extinction, whereas another 20% could not be evaluated because of lack of data (Data Deficient). Moreover, a recent global analysis of the distribution of terrestrial tetrapods including 99% of all species of reptiles revealed that reptiles are not as well represented as mammals and birds under current conservation schemes (Roll et al. 2017).

Tropical areas have been identified as facing the most dramatic rates of habitat loss, as well as having high percentages of threatened reptile species (Böhm et al. 2013). With an area of only 284,000 km^2, Ecuador is a tropical megadiverse country crossed by two biodiversity hotspots, Tumbes-Chocó-Magdalena and the Tropical Andes (Mittermeier et al. 2004; Myers et al. 2000). To date 464 species of reptiles have been recorded in Ecuador (Torres-Carvajal et al. 2017), which represents the highest reptile diversity in the world when considering species number per unit area. Nonetheless, a comprehensive, quantitative study of diversity and conservation of reptiles in Ecuador is lacking.

In this study, we generate species distribution models for nearly 90% of species of reptiles from continental Ecuador based on distribution data from collections and the literature to assess (i) general patterns of diversity and endemism, (ii) threats, and (iii) priority areas for their conservation.

Correspondence. [5]*carolina_reyes.88@hotmail.com*, [6]*ana.almendariz@epn.edu.ec*, [7]*omartorcar@gmail.com* (Corresponding author)

Materials and Methods

Data collection

We obtained locality data points for 406 species of reptiles from three local museum databases—Museo de Zoología at Pontificia Universidad Católica del Ecuador (QCAZ), Museo Ecuatoriano de Ciencias Naturales (MECN), Museo de Historia Natural Gustavo Orcés at Escuela Politécnica Nacional (MEPN)—, HerpNET, Global Biodiversity Information Facility (GBIF), as well as from the literature. We validated each data point in ArcMap v. 10.2 (ESRI 2013) and removed taxonomically incongruent records (e.g., localities along the Pacific coast for species known to occur exclusively east of the Andes). Duplicate points (for the same species), as well as points <2 km close to each other were also removed to avoid oversampling bias in the analyses.

Species distribution maps

We used Maxent, a technique based on the principle of maximum entropy, to construct species distribution models (SDMs) for those species ($n = 287$) with ≥ 10 locality data points (Elith et al. 2011; Phillips et al. 2006; Renner and Warton 2013). As predictor variables, we used species presence data (i.e., geographical coordinates) and bioclimatic variables from Worldclim 1.4 (http://www.worldclim.org), which are based on temperature and precipitation data at ~1 km^2 spatial resolution (Hijmans et al. 2005). After removing highly correlated ($r > 0.8$) variables, selected explanatory variables were Temperature Seasonality, Annual Precipitation, Precipitation Seasonality, and Minimum Temperature of Coldest Month. Additionally, we included the ombrothermic index, ombrothermic index of the driest bimonth, and the terrain ruggedness index, which have been used in previous studies of distributional patterns in the Andes (Killeen et al. 2007; Tovar et al. 2013). To construct the models, we set the convergence threshold to 0.00001, maximum iterations to 1,000, and the regularization parameter to 1. SDMs with AUC (Area Under Curve) values below 0.7 were discarded (Elith and Leathwick 2007). SDMs for those species with 5–9 locality data points were constructed in Bioclim (Busby 1991; type output: true/false). After removing highly correlated ($r > 0.8$) variables, selected explanatory variables were Annual Mean Temperature, Mean Diurnal Range, Temperature Seasonality, Maximum Temperature of Warmest Month, Minimum Temperature of Coldest Month, Annual Precipitation, Precipitation of Warmest Quarter, and Precipitation of Coldest Quarter.

The distribution of species with four localities ($n = 43$) and species with rejected SDMs (i.e., AUC < 0.7) was delimited with minimum convex polygons. For species with fewer than four localities ($n = 76$), a 1 km^2 buffer was constructed around their presence data points.

Conservation priority areas

To identify priority areas for the conservation of reptiles we employed the Toolbox developed by Ríos-Franco et al. (2013) for ArcMap. This method integrates three criteria—threat, importance, and opportunity. We used it to identify regions outside the National Protected Areas System (PANE for its initials in Spanish) with maximum threat and importance values that show opportunity to be considered as priority areas for the conservation of reptiles in continental Ecuador.

According to the threat criterion, those areas with human activities are the most vulnerable. We generated a raster file with values from 0 (non-threatened zones) to 1 (highly threatened zones) based on the results of a short survey to reptile experts that included questions on risks, distances and intensity of threats, such as roads, oil fields, mines, and human settlements (Appendix). Areas that are easy to access pose a major threat to species because they represent great opportunities for humans to exploit natural resources (Sanderson et al. 2002). For this reason, we also created a file with geographic information on human settlements, roads, navigable rivers and terrain slope. The toolbox calculates the access probability from each of these elements assuming that a single person walks at a maximum speed of three km/h on a flat terrain without road access (Ríos-Franco et al. 2013).

The importance criterion prioritizes areas based on richness, endemism, and threatened species and ecosystems. We generated richness, endemism, and threat maps by overlapping the distributions of (i) all species of reptiles included in this study (see Species distribution maps above), (ii) endemic species, and (iii) threatened species. Details on the threat status of the reptiles from Ecuador will be published elsewhere. To identify threatened ecosystems, we generated a raster file with values between 0 and 1, where values close to 1 correspond to natural ecosystems that are well represented within the PANE, and values close to 0 correspond to the opposite (i.e., threatened ecosystems). The importance criterion was summarized in a raster file with values of 0–1, where values close to 1 represent areas with high levels of species richness, endemism, threatened species, and threatened ecosystems.

The opportunity criterion identifies areas with potential to be established as areas of conservation priority. Since 2008 the Ecuadorian government established the "Socio Bosque" program (SBP) to pay farmers and indigenous communities that voluntarily protect their native forests. We overlapped the threat and importance raster files with an "opportunity" file containing SBP areas, as well as private reserves and remnant vegetation.

Results

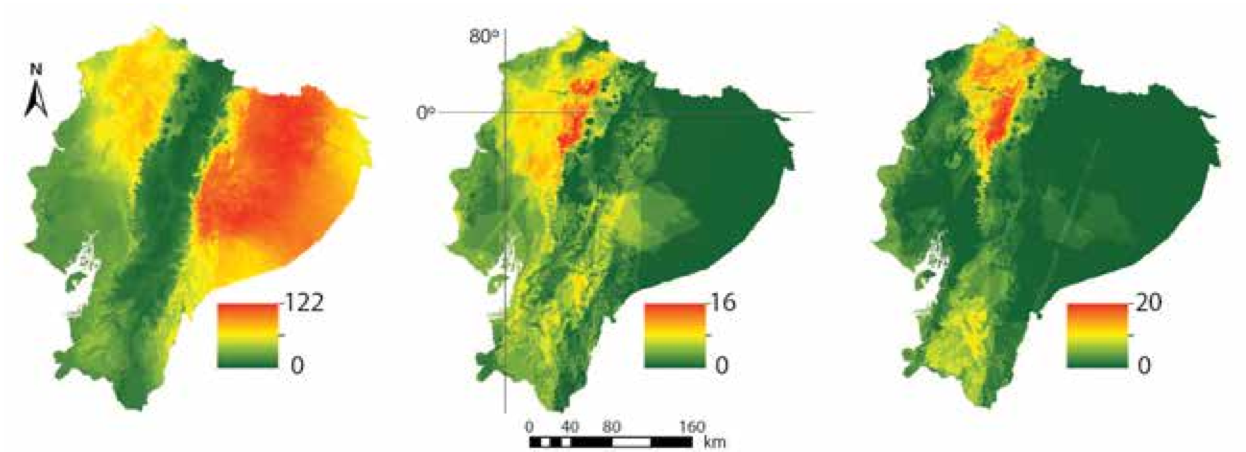

Figure 1. Maps of richness (left), endemism (center), and threat (right) for species of reptiles from continental Ecuador. Gradient values correspond to number of species.

Species richness, endemism and threat

Two regions in continental Ecuador have the highest numbers of species of reptiles. The most diverse region includes the central and northern Amazonian territories; however, northwestern Ecuador—Chocó and adjacent Andean slopes—is highly diverse as well (Fig. 1). Endemism is mostly concentrated in northwestern Ecuador, with large numbers of endemic species also present both on western and eastern Andean slopes. Similarly, the highest numbers of threatened species occur in northwestern Ecuador, followed by the Andes in southern Ecuador (Fig. 1).

Areas of conservation priority

The Pacific lowlands are more accessible to humans than any other regions in continental Ecuador. In contrast, according to the threat criterion, human activities that threaten reptiles are widespread mostly along the Andes and adjacent lowlands, with a slightly higher concentration in southern Ecuador (Fig. 2). The areas selected by the importance criterion based on species richness, endemism, and threat are described above; regarding threatened ecosystems, a large part of the Pacific lowlands, as well as Andean slopes in southern Ecuador are the least represented by the PANE. The central and southern Amazon include the areas with the greatest potential to be established as areas of conservation priority, most of them represented by SBP forests (Fig. 2).

Conservation priority areas were selected based on three of 12 possible solutions (Table 1). Accordingly, four areas were identified as the most important for the conservation of reptiles in continental Ecuador (Fig. 3): (1) the northwestern slopes of the Andes in Pichincha and Santo Domingo de los Tsáchilas provinces that include the Mindo-Nambillo Protected Forest, remnant Toachi-Pilatón vegetation, and SBP forest; (2) a central-south Amazonian area mostly in Morona Santiago province that includes remnant vegetation within the Kutuku and Shaimi cordilleras and SBP forest; (3) the southern

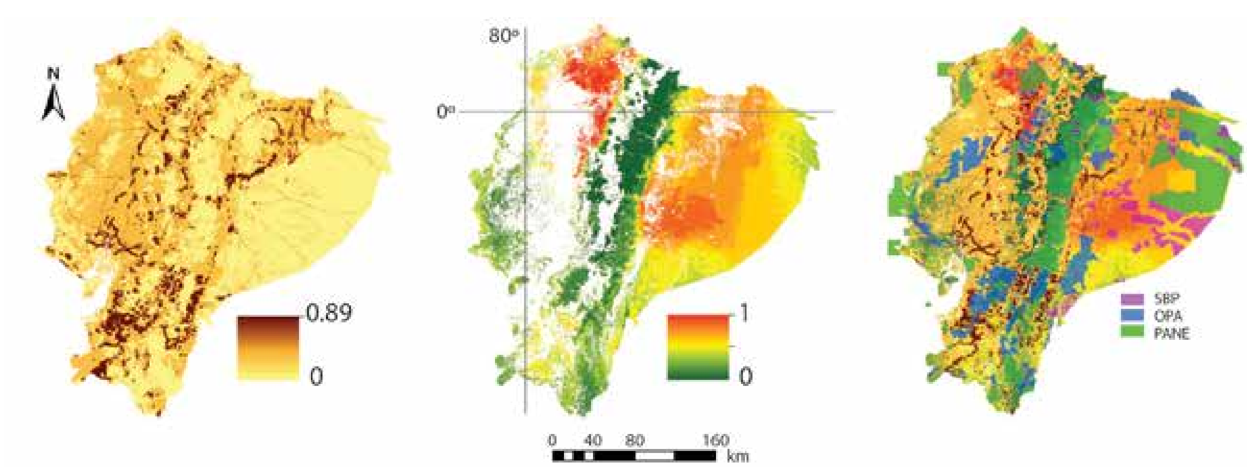

Figure 2. Maps of anthropogenic threat (left), importance (center), and opportunity (right), the three criteria used in this study to identify priority areas for the conservation of reptiles in continental Ecuador. SBP = Socio-Bosque protected forest, OPA = Other protected areas, PANE = National Protected Areas System.

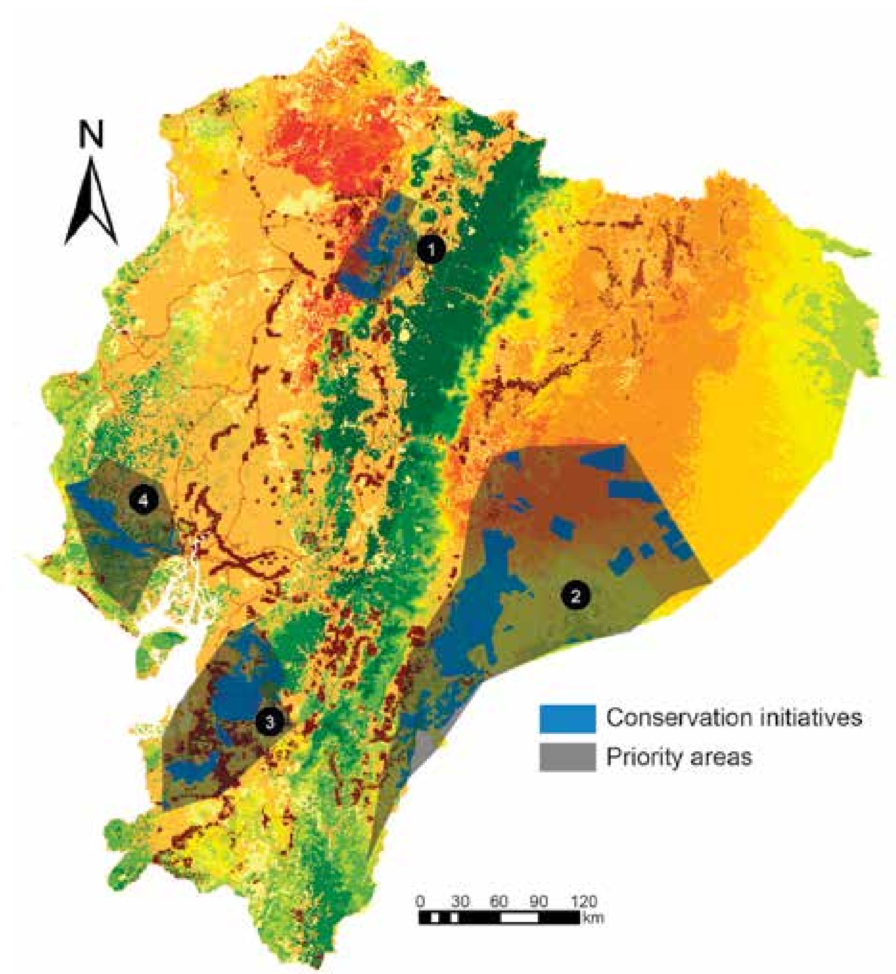

Figure 3. Map of priority areas for the conservation of reptiles in continental Ecuador.

Andean slopes and adjacent lowlands in Azuay and El Oro provinces that include the Molleturo and Mollepungo forests; and (4) the central Pacific coast in Manabí, Santa Elena and Guayas provinces that includes remnant vegetation in the Chongón-Colonche cordillera, as well as SBP areas.

Discussion

With three species per 2,000 km^2, Ecuador is the most reptile-diverse country in the world if country area is accounted for. The highest diversity of reptiles is located in the central and northern Amazon, as well as the Ecuadorian Chocó and adjacent Andean slopes. This pattern of species richness is concordant with other animal and plant taxa, both at local (Lessmann et al. 2014) and continental scales (Bass et al. 2010; Jenkins et al. 2013; Myers et al. 2000), which highlights the biological importance of these areas. Nonetheless, this pattern should not be taken as definitive because a considerable percentage of Ecuador's biodiversity has been discovered in recent years, and not necessarily from the most diverse regions. Nearly 10% of species of reptiles from Ecuador have been described or reported in this century. Of these, nearly 35% were discovered in southern Ecuador, which remains a largely undersampled area that has also been repeatedly identified as an area of conservation priority (this study; Cuesta et al. 2017; Lessmann et al. 2014; Tapia-Armijos et al. 2015).

Unlike other terrestrial vertebrates and plants (González-Palacios et al. 2015; Lessmann et al. 2014; Menéndez-Guerrero and Graham 2013), the conservation status and threats to reptiles from continental Ecuador remain poorly studied. For example, the IUCN Red List of Threatened Species (http://www.iucnredlist.org) lists ~25% of the species of reptiles from continental Ecuador (i.e., excluding the Galápagos islands), of which 17% are Data Deficient. Moreover, recent conservation-planning studies based on a variety of taxa do not include data on reptiles (Lessmann et al. 2016; Lessmann et al. 2014), with only one recent study including 112 species of reptiles for the first time (Cuesta et al. 2017). Here we present the first comprehensive quantitative study of reptile conservation in continental Ecuador including distribution data of nearly 90% of the species of reptiles from continental Ecuador, as well as information on ecosystem protection status and anthropogenic activities that might affect reptile populations negatively.

Table 1. Solutions to identify areas of conservation priority for reptiles from continental Ecuador. Selected solutions are marked with an asterisk.

Solution	Importance	Threat	Opportunity	State protected
A	High	High	yes	yes
B	High	High	no	yes
C*	High	High	yes	no
D*	High	Medium	yes	no
E	High	Medium	no	yes
F	High	Medium	yes	yes
G	Medium	High	yes	yes
H	Medium	High	no	yes
I*	Medium	High	yes	no
J	Medium	Medium	yes	yes
K	Medium	Medium	no	yes
L	Medium	Medium	yes	no

We identified parts of the northwestern slopes of the Andes, central-south Amazonian area, southwestern Andean slopes and adjacent lowlands, and the central Pacific coast as priority areas for the conservation of reptiles in continental Ecuador. These areas partially overlap with some of the Marxan-defined areas reported by Lessman et al. (2014) based on 809 species of amphibians, birds, mammals, and plants; and Cuesta et al. (2017) based on 744 species of amphibians, birds, reptiles (112 species), and plants. Thus, in addition to identifying those areas that are priorities for the conservation of reptiles, our study also supports the conservation of general areas that would benefit a larger number of animals and plants in continental Ecuador. Unfortunately, some of these areas are severely threatened. For example, Tapia-Armijos et al. (2015) reported that ~46% of southern Ecuador's original forests had been converted into pastures and other anthropogenic land cover types by 2008. Similarly, deforestation and extinction in western Ecuador has long been documented (Dodson and Gentry 1991). In conclusion, our study provides further evidence demanding the establishment of protected areas in certain regions of continental Ecuador that remain unprotected and under anthropogenic threat.

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Carolina Reyes-Puig graduated in biological and environmental sciences from Universidad Central del Ecuador in 2012 and received a Master's degree in conservation biology from the Pontificia Universidad Católica del Ecuador in 2015. She was curator of the Herpetology Section of the Instituto Nacional de Biodiversidad (INABIO) for almost two years, and is now an assistant professor and researcher at the Museo de Zoología and Instituto de Zoología Terrestre of the Colegio de Ciencias Biológicas y Ambientales, Universidad San Francisco de Quito (USFQ). Her interests include taxonomic relationships of morphological characters in cryptic species of Ecuadorian herpetofauna and the spatial analysis of distribution models for species conservation.

Ana Almendáriz is a researcher and the Curator of Herpetology at the Institute of Biological Sciences at the Escuela Politécnica Nacional in Quito, Ecuador. A native of Quito, Almendáriz holds an undergraduate degree in biology and a Master's degree in conservation and management of natural resources. She conducts research on amphibians and reptiles throughout Ecuador and has published extensively in her field.

Omar Torres-Carvajal graduated in biological sciences from Pontificia Universidad Católica del Ecuador (PUCE) in 1998, and in 2001 received a Master's degree in ecology and evolutionary biology from the University of Kansas under the supervision of Dr. Linda Trueb. In 2005 he received a Ph.D. degree from the same institution with the thesis entitled "Phylogenetic Systematics of South American Lizards of the Genus *Stenocercus* (Squamata: Iguania)." Between 2006–2008 he was a postdoctoral fellow at the Smithsonian Institution, National Museum of Natural History, Washington DC, USA, working under the supervision of Dr. Kevin de Queiroz. He is currently Curator of Reptiles at the Zoology Museum QCAZ of PUCE and a professor at the Department of Biology in the same institution. He has published more than 60 scientific papers on taxonomy, systematics, and biogeography of South American reptiles, with emphasis on lizards. He is mainly interested in the theory and practice of phylogenetic systematics, particularly as they relate to the evolutionary biology of squamates.

Appendix 1. Reptile conservation survey: risks, distances, and intensity of threats

1) On a scale from 1 to 10, where 10 is the worst, how bad do you think a primary road is for reptiles?

2) On a scale from 1 to 10, where 10 is the worst, how bad do you think a secondary road is for reptiles?

3) On a scale from 1 to 10, where 10 is the worst, how bad do you think a tertiary road is for reptiles?

4) Imagine that you were to trace a straight line, perpendicular to a road, as far as you think that road has a negative impact on reptiles. How far would you go for a primary road?

0–5 m	10 m	50 m	100 m	500 m	1 km

5) Imagine that you were to trace a straight line, perpendicular to a road, as far as you think that road has a negative impact on reptiles. How far would you go for a secondary road?

0–5 m	10 m	50 m	100 m	500 m	1 km

6) Imagine that you were to trace a straight line, perpendicular to a road, as far as you think that road has a negative impact on reptiles. How far would you go for a tertiary road?

0–5 m	10 m	50 m	100 m	500 m	1 km

7) On a scale from 1 to 10, where 10 is the worst, how bad do you think a mining area is for reptiles?

8) On a scale from 1 to 10, where 10 is the worst, how bad do you think an oil-well area is for reptiles?

9) In your opinion, what is a mine's ratio of negative impact for reptiles?

0–5 m	10 m	50 m	100 m	500 m	1 km

10) In your opinion, what is an oil-well's ratio of negative impact for reptiles?

0–5 m	10 m	50 m	100 m	500 m	1 km

11) On a scale from 1 to 10, where 10 is the worst, how bad do you think livestock husbandry and agriculture is for reptiles?

12) If you were to define a ratio of negative impact for reptiles, where livestock/agriculture facilities represent the center, how far would you go?

0–5 m	10 m	50 m	100 m	500 m	1 km