

TERRESTRIAL VERTEBRATE BIODIVERSITY IN PROTECTED AREAS AND INDIGENOUS TERRITORIES OF THE AMAZON BASIN

Final Report
October 2020

GORDON AND BETTY
MOORE
FOUNDATION



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Onychorhynchus coronatus

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ABSTRACT

The Amazon is the largest tropical forest in the world, the greatest and most complex freshwater system, and is renowned for extraordinary biodiversity concentrations and significant endemism for different taxonomic groups. The Amazon basin is home to more than 350 indigenous peoples whose rights to land have gradually been recognized by the Amazonian nations over the last 40 years. Indigenous territories and protected areas play an important role in the protection of the Amazon, a hugely important global contribution given that the critical ecosystem services of the Amazon benefit millions of people worldwide.

This study aims to demonstrate the incredible value of the Amazon basin in terms of biodiversity and the contribution of Protected Areas and Indigenous Territories, with emphasis on four groups of terrestrial vertebrates: amphibians, reptiles, birds and mammals. Based on geospatial information on the distribution of amphibian and mammalian species from IUCN and other sources, reptiles from Roll *et al.* (2017) and birds from BirdLife International, in this second report we estimate the number of expected species in the Amazon basin, and within existing Indigenous Territories and Protected Areas. To determine vertebrate diversity in South America and the Amazon basin, alpha-diversity was analyzed at a 1 km² scale. Additionally, to assess changes in species composition between sites, beta-diversity was analyzed at different scales within the Amazon basin. Finally, a complementary analysis was performed to determine the degree of similarity and representativeness in vertebrate species composition for the region.

Alpha-diversity analyses revealed a high concentration of amphibian species in the western Amazon (up to 138 species per km²), and this group has the lowest representation levels in indigenous territories and protected areas as compared to other terrestrial groups. For reptiles, species concentrations reach up to 184 species per km² in the Amazon, especially the central north and northwest of the basin. The areas of high concentration of birds in South America are mainly found in the Amazon basin reaching up to 596 species per km². For mammals, most of the sites with the highest concentration of species are found in the western Amazon, reaching up to 203 species per km². In all cases many of the species concentrations significantly overlap with the location of the conservation mosaics supported by the Gordon and Betty Moore Foundation. The Gordon and Betty Moore Foundation defines a conservation mosaic as a large landscape composed of protected areas, indigenous territories, and other land use types. This concept is based on an integrated landscape approach adopted by many conservation organizations. Meanwhile, geographic patterns of beta-diversity for amphibians, reptiles, birds and mammals show similar trends at all scales studied, with higher values towards the Andes and intermediate levels in the lowlands.

Collectively, the Protected Areas and Indigenous Territories contribute immensely to the conservation of the four vertebrate groups in the Amazon basin, since these conservation units are expected to harbor 1,188 species of amphibians, 947 species of reptiles, 2,454 species birds and 860 species of mammals: 94.67% of terrestrial vertebrates

of the Amazon, 53.91% of terrestrial vertebrates in South America and 14.92% of terrestrial vertebrates worldwide. National and Subnational Protected Areas alone are expected to harbor 5,183 species of terrestrial vertebrates (90.05% of terrestrial vertebrates in the Amazon, 51.28% of terrestrial vertebrates in South America and 14.19% of terrestrial vertebrates worldwide), including 1,058 amphibian species, 893 reptile species, 2,386 bird species and 846 mammal species. Whereas Indigenous Territories are expected to harbor 4,921 terrestrial vertebrate species (85.49% of terrestrial vertebrates of the Amazon, 48.68% of terrestrial vertebrates of South America and 13.48% of terrestrial vertebrates worldwide), including 939 amphibian species, 848 reptile species, 2,334 species of birds and 800 mammal species.

These analyses demonstrate that together Protected Areas and Indigenous Territories are expected to host the majority of terrestrial vertebrates of the Amazon basin, stressing the importance of their management through territorial planning, control and surveillance and effective management. Indeed, to date deforestation levels and environmental degradation rates are significantly lower in Protected Areas and Indigenous Territories than elsewhere in the Amazon. The analysis of representativeness at the country level also reveals that Protected Areas and Indigenous Territories in most Amazonian nations would house more than 70% of vertebrate species diversity, further underlining that the collective of Protected Areas and Indigenous Territories are located in strategic and efficient conservation sites. However, for amphibians and reptiles there are lower levels of species representativeness in Brazil, Colombia and Ecuador, compared to French Guiana, Peru, Suriname and Bolivia where levels are higher.

The vertebrate complementarity analysis for the Amazon basin shows that of the 254 cells covering this region, an estimated 112 cells would need to be protected to include all 100% of amphibian species, 87 cells for all reptile species, 66 cells for all birds and 46 cells for all mammal species. A comparison of the selected complementarity cells for the four vertebrate groups with the National Protected Areas, Subnational Protected Areas and Indigenous Territories in each country, demonstrated that independently the differing management unit categories fail to fully protect these cells, but when combined they manage to protect almost all of the cells, further highlighting their complementarity towards biodiversity conservation in the Amazon. Overall these analyses underline the commitment that Amazonian nations have already made towards biodiversity conservation in the Amazon through the formal designation of Protected Areas across the basin, and the recognition of large areas as Indigenous Territories. Together these conservation friendly management units amount to almost 50% of the basin and this study demonstrates that most terrestrial vertebrate biodiversity, almost 95%, is expected to occur within at least one of Protected Area or Indigenous Territory.

Key Words: Protected Areas, Indigenous Territories, amphibians, reptiles, mammals, birds, Gordon and Betty Moore Foundation



Lagidium viscacia

INTRODUCTION

Biodiversity or biological diversity are terms that define the variation in all the forms of life on planet earth (Gaston & Spicer 2004; Colwell 2009). This comprises the appearance, structure and function of genes, species and ecosystems, which are organized in spatial and temporal patterns (Gregorius *et al.* 2003; Colwell 2009; Minter *et al.* 2018). Species diversity, or the number of biological elements coexisting in a given area, is the most commonly used element for conservation purposes (Moreno 2001; Moreno *et al.* 2011; Socolar *et al.* 2015).

From a global perspective the tropics harbor the greatest biological diversity and endemism (Myers *et al.* 2000; Hoorn *et al.* 2010; Jenkins *et al.* 2013). The tropics cover just 10% of land, but harbor 91% of the world's birds, 83.2% of amphibians, 77% of mammals and 75% of plants and insects (PNUMA 2010; Barlow *et al.* 2018). The Amazon in the Neotropics has an enormous variety of habitats and aquatic and terrestrial species (Latrubesse *et al.* 2017). Unique characteristics such as the geographical barrier of the Andes and the variety of forests, wetlands and other habitats have resulted in extremely high levels of biodiversity and endemism in the Amazon (Valencia *et al.* 1994; Dirzo & Raven *et al.* 2003; Hutter *et al.* 2013; De Oliveira *et al.* 2016; Kolář *et al.* 2016).

The extraordinary concentration of species in the Amazon basin is mirrored by a diversity of crucial ecosystem services, such as timber, food, water, energy, nutrient recycling, and others (Foley *et al.* 2007; Tilman *et al.* 2011; Sobral *et al.* 2017; Horn *et al.* 2018), which benefit millions of people (Horn *et al.* 2018; Minter *et al.* 2018; Vieira *et al.* 2018), providing environmental services not only for the Neotropical region, but also for the world (Castro & Riega-Campos 2014).

The Amazon basin is also home to approximately 350 indigenous groups whose territories cover 28% of the basin in Bolivia, Brazil, Colombia, Ecuador, Peru and Venezuela (Prüssmann *et al.* 2017; Strelneck & Vilela 2017, RAISG 2019). High human cultural diversity within the indigenous territories (ITs) is associated with high biodiversity concentrations, and together with protected areas (PAs), play an important role in protecting the Amazon biome and the planet (RAISG 2016; Prüssmann *et al.* 2017; Strelneck & Vilela 2017). Together, we expect Protected Areas and Indigenous Territories to harbor high levels of biodiversity in the Amazon, given that globally Indigenous Territories (Jonas *et al.* 2014; Schleicher *et al.* 2017) and Protected Areas (Gray *et al.* 2016) contain significantly higher levels of biodiversity than areas outside those management units. Nevertheless, comprehensive studies regarding the representativeness and

effectiveness of ecosystems and biodiversity within Protected Areas or Indigenous Territories are missing (Chape *et al.* 2006; González-Maya *et al.* 2015), especially for the Amazon.

Anthropogenic activities outside conservation units in the Amazon are responsible for the loss of biodiversity at an unprecedented rate (Peres 1990, 2007; Foley *et al.* 2007; Hoorn *et al.* 2010; Canale *et al.* 2012; Laurance *et al.* 2014; Purvis *et al.* 2018). In the face of imminent and ongoing changes to Amazon forests and waterways, the need to identify priority biodiversity conservation is paramount. One approach is to identify areas with high concentration of species and endemism. For example, the “hotspots” proposed by Myers *et al.* (2000) have become a global conservation reference (Sloan *et al.* 2014; Roll *et al.* 2017), encouraging donors such as the Gordon and Betty Moore Foundation to implement conservation efforts in areas of high biodiversity and endemism, in particular with landscape and mosaic conservation strategies in the Amazon and beyond (Myers *et al.* 2000).

The Gordon and Betty Moore Foundation has implemented an Andes-Amazon Initiative, supporting biodiversity conservation efforts by communities, governmental authorities and non-governmental institutions for more than fifteen years (Gullison & Hardner 2018), implementing twelve conservation mosaics

distributed in Bolivia, Brazil, Colombia, Ecuador and Peru in areas with hypothesized high biodiversity concentrations (Castro & Riega-Campos 2014; Strelneck & Thais Vilela 2017)

For the design of informative scenarios regarding global biodiversity it is important to recognize that biodiversity varies across habitat types, as well as between different taxonomic groups such as amphibians, mammals, insects or plants (Wolters *et al.* 2006). It is therefore crucial to evaluate multiple taxonomic groups when considering spatial variations in biological diversity, especially when identifying priority conservation areas (Wolters *et al.* 2006; Quan *et al.* 2018). Similarly, for the Amazon basin it is crucial to understand to what extent existing conservation units (protected areas and indigenous territories) protect different taxonomic groups to complement our recognition of their global importance towards the mitigation of global climate change.

This study aims to demonstrate the incredible biodiversity value of the Amazon basin and the contribution of twelve conservation mosaics supported by the Gordon and Betty Moore Foundation (Wallace *et al.* 2020), as well as the effectiveness of existing conservation units (protected areas and indigenous territories) in conserving biodiversity, with an emphasis on the four terrestrial vertebrate groups: amphibians, reptiles, birds and mammals. In so doing, this

analysis intends to demonstrate the relevance of existing conservation efforts in the Amazon, as well as influence future decisions and actions in the conservation mosaics.

The added value of this assessment is that it attempts to project the overall biodiversity presence across the entire Amazon using a consistent approach and dataset. There is also an underlying premise by the conservation community that a protected area is the appropriate management and geographic unit to ensure biodiversity conservation. This assessment is one way of measuring how effective that management can be for biodiversity conservation.

GOALS & OBJECTIVES

Goal

Demonstrate the extraordinary value of the Amazon basin towards biodiversity conservation through analyses of four terrestrial vertebrate groups: amphibians, reptiles, birds and mammals.

Objective

Demonstrate the contribution of the conservation mosaics in the Amazon basin supported by the Gordon and Betty Moore Foundation, as well as the general importance of the effective management of protected areas and indigenous territories for biodiversity conservation in the Amazon.

Specific objectives

- Identify the vertebrate species expected to occur within existing protected areas and indigenous territories.
- Identify the most important geographical gaps in biodiversity protection in the Amazon basin.

Didelphis pernigra



STUDY AREA

The study area is the Amazon basin, the most extensive tropical forest and the largest freshwater hydrological system in the world, with particular emphasis on the conservation mosaics supported by the Gordon and Betty Moore Foundation (Table 1; Figure 1; Appendix). The Amazon basin is shared by nine countries (Brazil, Bolivia, Peru, Ecuador, Colombia, Venezuela, French Guiana, Guyana, and Suriname) and is inhabited by 33 million people including 350 indigenous groups (Prüssmann *et al.* 2017). These nine countries hold a total of 610 National Protected Areas covering 1,984,569 km² in the Amazon, with Indigenous Territories covering another 2,368,936 km² (Walker *et al.* 2014; RAISG 2019).

Table 1. Conservation Mosaics supported by the Gordon and Betty Moore Foundation in the Amazon Basin

Mosaic	Countries
Chiribiquete-Caqueta	Colombia
Yasuni-Pastaza	Ecuador, Peru
Yavari-Samiria	Peru
Ampiyacu	Peru
Upper Purus	Brazil, Peru
Madidi-Tambopata	Bolivia, Peru
Itenez-Rondonia	Bolivia, Brazil
Calha Norte	Brazil
Xingu	Brazil
Lower Rio Negro	Brazil
Upper Rio Negro	Colombia, Brazil
Madeira	Brazil





Figure 1: Location of the Conservation Mosaics supported by the Gordon and Betty Moore Foundation in the Amazon Basin. 1. Chiribiquete-Caqueta; 2. Yasuni-Pastaza; 3. Yavari-Samiria; 4. Ampiyacu; 5. Upper Purus; 6. Madidi-Tambopata; 7. Itenez-Rondonia; 8. Calha Norte; 9. Xingu; 10. Lower Rio Negro; 11. Upper Rio Negro; 12. Madeira

METHODS

To generate expected species lists for amphibians, reptiles, birds and mammals for the Amazon basin, we performed the following three steps: 1) taxonomic revision and update for terrestrial vertebrate species present in South America and the Amazon basin, 2) taxonomic species update according to the IUCN and Roll *et al.* (2017) and creation of new distribution polygons for amphibian, reptile and mammal species not evaluated by the IUCN, and 3) identification of expected species for the Amazon basin. This analysis is a fine-scale 1 km² effort which uses a standardized and updated dataset for all four terrestrial vertebrate groups across the Amazon. It cannot and should not replace on-the-ground field work to improve knowledge for individual protected areas and indigenous territories, but in the meantime, it does provide the best theoretical species lists available for each management unit.

Taxonomic revision and update for amphibians, reptiles, birds and mammals

In order to compare the number of species present in South America and the Amazon basin, we first standardized taxonomic species lists for each terrestrial vertebrate group. For taxonomic updates we used official taxonomic platforms for each vertebrate group: AmphibiaWeb (<https://amphibiaweb.org>), The Reptile Database (<http://www.reptile-database.org>), IUCN-BirdLife (<http://datazone.birdlife.org/species/requestdis>)

and South American Classification Committee (<http://www.museum.lsu.edu/~Remsen/SACCBaseline.htm>) for birds, and Mammal Diversity Database (<https://mammaldiversity.org>) and specific sources for mammals, as well as a global taxonomic source: the Taxonomic Information System IT IS (<https://www.itis.gov>). With the exception of mammals, these websites constantly update taxonomy, providing species lists for each country.

Additionally, to determine the taxonomy for amphibians and reptiles we consulted scientific articles and previously cited websites. For mammals firstly we constructed a species list for South America using recent species lists for Ecuador (Tirira 2018; Ron *et al.* 2019), Colombia (Ramírez-Chaves *et al.* 2016), Venezuela (Sánchez & Lew 2012), Argentina (Teta *et al.* 2018), French Guiana, Guyana, and Suriname (Lim 2016), Brazil (Paglia *et al.* 2012), and Bolivia (Aguirre *et al.* 2019) and the IUCN South America species list. We then complemented and updated taxonomies using the Mammal Diversity Database (2019), and Patton *et al.* (2015) for rodents, Rowe & Myers (2019) for primates and scientific articles published until December 2018 regarding newly described species.

Identification and taxonomic update of terrestrial vertebrate species in the Amazon basin and creation of distribution polygons for additional amphibians, reptiles and mammals

Geospatial information on amphibian, reptile and mammal species distributions was downloaded from the IUCN (IUCN 2018, <https://www.iucnredlist.org>) in November 2018, (reptiles in January 2019 from Roll *et al.* (2017)), and bird distributions were downloaded from BirdLife International, through the IUCN portal. Scientific names were updated using the updated taxonomic lists.

For amphibian, reptile and mammal species from the Amazon basin that were either not evaluated by the IUCN or were not considered in a threatened category, using scientific literature and webpages, we produced distribution polygons using Quantum GIS. Similarly, for newly described species we created distribution polygons with the geospatial Quantum GIS tool Concave Polygons, creating a 10 km buffer for species with only 1 or 2 records.

Nevertheless, in some cases, species and even genera, remain in taxonomic revision or require major research to confirm taxonomies, and therefore are lacking distributional polygons, underlining that this analysis will need to be updated into the future.

To finalize geospatial information for amphibians, reptiles and mammals, the new polygons were united with the geospatial information in Table 2, using the Quantum GIS tool Merge.

Analysis of alpha, beta, gamma diversity in the Amazon basin

i. Alpha-diversity species preliminary analysis for South America and Amazon basin

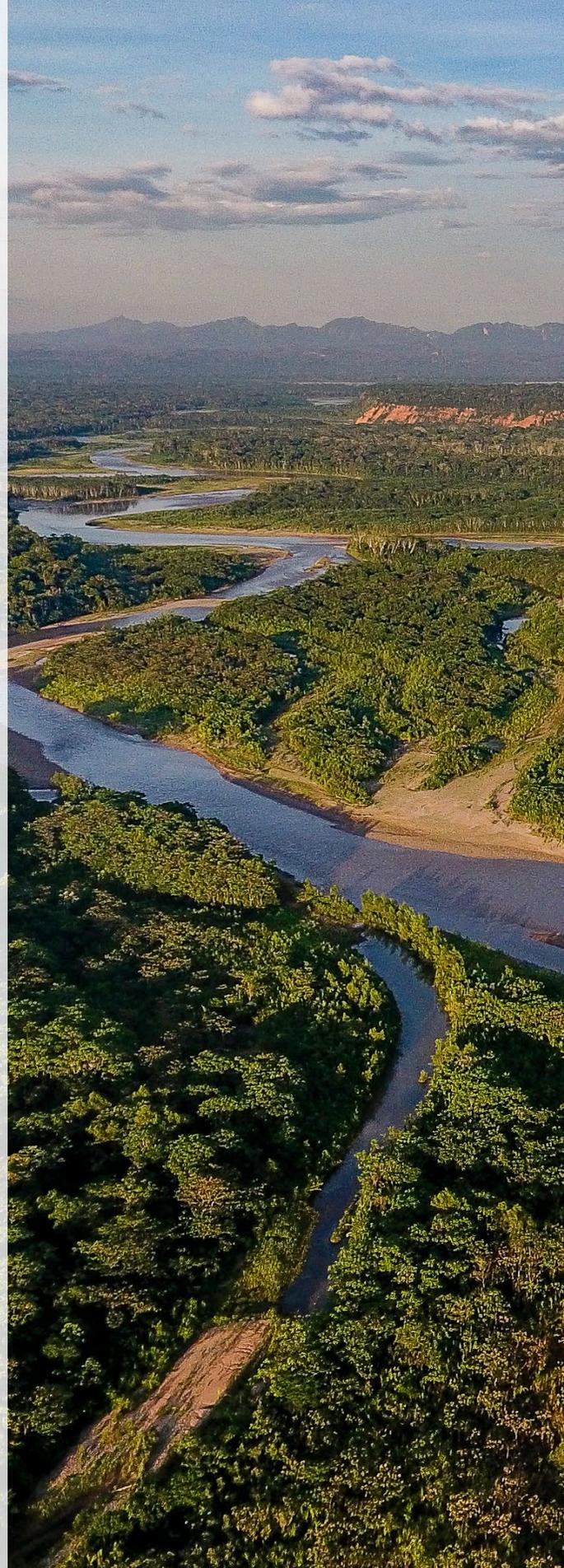
To determine the areas of greatest vertebrate diversity in South America and the Amazon basin we analyzed alpha-diversity. To date global efforts to determine species concentrations have used pixels of 10 km² or greater (Myers *et al.* 2000; Jenkins *et al.* 2013; Roll *et al.* 2017). Here we use a finer pixel size of 1 km².

Table 2. Number of Vertebrate Species in South America

Vertebrate Group	Geospatial Source	Number of Species
Amphibians	AmphibiaWeb	2,921
	IUCN	2,474
Reptiles	Roll <i>et al.</i> (2017)	1,977
Birds	BirdLife	3,564
	IUCN - BirdLife	3,625
Mammals	IUCN	1,258

Geospatial information on IUCN species distributions (using the geospatial information in Table 2) was projected on WGS 84/ World Mercator (EPSG:3395). Using the SAGA geoprocessing rasterize tool (Conrad *et al.* 2015), we generated raster data for each terrestrial vertebrate species using 1 x 1 km sized pixels, reclassifying values, where a value of 1 was assigned to pixels with presence, and 0 to those without presence.

Finally, using the geoprocessing raster calculator, we analyzed species distributions as a function of IUCN conservation state: Extinct (EX), Critically Endangered (CR), Critically Endangered & Possibly Extinct (CR PE), Critically Endangered & Extinct in the Wild (CR EW), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Data Deficient (DD) and Not Evaluated. For the alpha-diversity analyses we summed the different conservation status raster's, with the exception of the Extinct and Extinct in the Wild categories. Additionally, using the geospatial information in Table 5 (new polygons) and the Quantum GIS tools Spatial Join and Calculator, we generated the same information in Vector format. The alpha-diversity analysis was only performed in vector format for the Amazon basin, as the amount of information for South America was prohibitive for analysis within this report.





ii. Analysis of beta and gamma diversity at the level of the Amazon basin

To demonstrate changes in species composition between sites, we analyzed beta-diversity (β) at different spatial scales, using the geospatial data on the distribution of species from the four terrestrial vertebrate groups, following methods proposed by Rodríguez *et al.* (2019), defining the finest unit of analysis at 1 km², similar to that of our alpha-diversity analysis. Subsequently, to calculate beta-diversity (β), we divided the Amazon basin into four different sized grid cells: 2°x 2° (~ 200 × 200 km), 1°x 1° (~ 100 × 100 km), 0.5°x 0.5° (~ 50 × 50 km) and 0.25°x 0.25° (~ 25 × 25 km).

To estimate beta-diversity (β), we used the formula $\beta = \gamma / \text{mean } \alpha$, where γ is gamma-diversity, or, the number of species in the region, and α is alpha-diversity, or, the average number of species at the sites that make up the region. For this study, a region is one of the largest sized cells used to subdivide the Amazon basin. We used beta-diversity (β) because it is methodologically independent of alpha and gamma diversity (Baselga 2010; Rodríguez *et al.* 2019), allowing the comparison between taxa with a different number of species. Beta-diversity (β) was estimated for each vertebrate group at each spatial scale. Beta-diversity (β) includes values from 1, where every species is present in every cell (low beta-diversity). When beta-diversity (β) is equal to gamma-diversity (γ), every species in the region is only present at one site (greater beta-diversity).

From a comparative perspective, methodologically we considered eliminating cells that were partially outside the limits of the basin. However, this step left only 89 cells and so we elected to retain all 254 cells and consider those on the periphery as cells subject to border effects.

Contributions of Protected Areas and Indigenous Territories towards vertebrate biodiversity conservation in the Amazon basin

Geospatial data for the Amazon basin was downloaded from the SNAPP Western Amazon Group (Venticinque *et al.* 2016), and international limits from the Global Administrative Areas (GADM 2018) and updated geospatial data on National Protected Areas, Subnational Protected Areas and Indigenous Territories from the Amazon Network of Georeferenced Socio-environmental Information (Red Amazónica de Información Socioambiental Georreferenciada - RAISG) downloaded in May 2019 (Tables 3 & 4).

For each taxonomic group the analysis of expected species in the different conservation units was conducted by combining the Amazon basin limits and the distribution information for possible species (Table 2, from IUCN data), together with new information generated for amphibians, reptiles and mammals (new polygons), using the Quantum GIS tool Intersection.

Table 3. Protected Area sources for each country as considered by RAISG 2018.

Conservation Areas	Country	Source	Year
National Protected Areas	Bolivia	Servicio Nacional de Áreas Protegidas	2016
	Brazil	Instituto Socioambiental	2016
	Colombia	IDEAM	2012
		UAESPNN DTAO	2013
		UAESPNN DTSA	2012
	Ecuador	Ministerio del Ambiente (MAE)	2016
	French Guiana	Direction Régionale de l'Environnement de Guyane	2010
	Guyana	Ivokrama; Digital Chart World (DCW)	
	Peru	Ministerio del Ambiente	2016
	Suriname	Amazon Conservation Team (ACT)	2009
Venezuela	Rodriguez <i>et al.</i>	2014	
	Provita	2015	
Subnational Protected Areas	Bolivia	Gobierno Autónomo Departamental de Beni	2014
		Gobierno Autónomo Departamental de SCZ	2013
		Gobierno Municipal de Ixiamas	2009
		Gobierno Autónomo Departamental de Pando	2013
		Ministerio de Medio Ambiente y Agua	2012
	Brazil	Instituto Socioambiental	2016
	Ecuador	Ministerio del Ambiente (MAE)	2016
	Peru	Ministerio del Ambiente	2016

Table 4. Indigenous Territories sources for each country, as considered by RAISG 2018.

Country	Source	Year
Bolivia	Instituto Nacional de Reforma Agraria - INRA	2015
	Sistema Nacional de Información para el Desarrollo - SNID	
Brazil	Instituto Socioambiental	2016
Colombia	SIGOT	2015
Ecuador	Ecociência	2016
	MAE	2012
French Guiana	Direction Régionale de l'Environnement de Guyane	2007
Guyana	Indigenous Affair/Governo da Guyana	2009
Peru	Cultura-2016	2016
	ACPC, AIDSESP, CEDIA, COFOPRI-SERNANP, Disafilpa, Disafilpa - IBC, FECONABU - AIDSESP, FENACOCA - IBC, GOREL, IBC, IBC - ACPC, IBC - AIDSESP, IBC - Disafilpa, IBC - GOREU, IBC - PETT, MINAGRI, MINCU, Ministerio de Agricultura, ORPIO - AIDSESP, OTRAS, PETT - IBC, PETT, SERNANP-COFOPRI, Walsh Peru	
Suriname	Amazon Conservation Team (ACT)	2009
Venezuela	Ministerio del Poder Popular para la Salud, mapa,	2007
	OIPUS-OPIJKA-CIAG-UNEG	2008
	OIPUS-WATANIBA	2011
	HORONAMI	2014
	OIPUS-OPUHC-Wataniba-Provita	2014-2015
	Proyecto BABA	2014-2015
	ISA, HUTUKARA, WATANIBA, Comunidades, Tierra y Hábitat Yanomami Brasil-Venezuela; KUYUJANI, KUYUJANI ORIGINARIO, KUYUNU, WATANIBA, PROVITA	





Complementarity analysis for species diversity in the Amazon

The concept of complementarity analyses refers to the degree of similarity in species composition between sites using an algorithm that iteratively selects maximum biological diversity in the minimum number of areas, with the objective of achieving representativeness of one or several populations of all species in the most efficient manner for conservation purposes (Pressey *et al.* 1997; Gil & Moreno 2007). For the complementarity analysis of each vertebrate group we used a grid cell size of $2^{\circ} \times 2^{\circ}$ ($\sim 200 \times 200$ km), which for the Amazon basin amounts to 254 cells. In the complementarity analysis, similarly to the beta-diversity analyses, methodologically we considered eliminating cells that were partially outside the limits of the basin. However, this step left only 89 cells and so we elected to retain all 254 cells and consider those on the periphery as cells subject to border effects.

Using the Quantum GIS tool Spatial Attributes Union, we calculated whether each species was present or not in each $2^{\circ} \times 2^{\circ}$ cell. Subsequently, we calculated a matrix of cells versus species, allowing us to calculate total species in each cell. Using the total values for each cell, we selected the cell with the highest species richness and then eliminated the species present in that cell from the matrix, selecting in turn the cell with highest diversity. This process was repeated until all species in basin were included in the selection.

RESULTS

Identification and taxonomic update of terrestrial vertebrate species in the Amazon basin and creation of distribution polygons for additional amphibians, reptiles and mammals

Following consultation with the major data sources detailed above and considering additional amphibian, reptile and mammal species for which we generated new digitalized distribution polygons, we determined the total number of amphibian, reptile, bird and mammal species in South America as detailed in Table 5.

Alpha, beta and gamma diversity analyses for the Amazon basin

i. Alpha-diversity species analysis for the Amazon basin

Due to time constraints and the sheer number of 1 km² cells in South America, we conducted alpha-diversity species analysis at the scale of the Amazon basin, which do not differ significantly from maps included in previous reports

although these analyses include new information for species of amphibians, reptiles and mammals without previous distribution data (for comparison purposes, here we present both versions of each map).

A. Amphibians

Amphibian species richness for South America (Figures 2 & 3) highlights species concentrations per km² in the Amazon basin, especially the western Amazon where concentrations reach up to 138 species per km² (Figure 3). Due to their smaller range distributions, amphibians are the vertebrate group with the lowest level of representativeness within Protected Areas and Indigenous territories, and the twelve conservation mosaics supported by the Gordon and Betty Moore Foundation.

Our analysis highlights that the conservation mosaics are placed within the highest species concentrations of amphibian diversity per km² in South America, for example, Yasuni-Pastaza, Ampiyacu, Yavari-Samiria, and part of Upper Purus, Itenez-Rondonia and Madeira.

Table 5. Number of Vertebrate Species in South America (with new geospatial information)

Vertebrate Group	Source	New Digitalized Polygons	Total Number of Species with Geospatial Information
Amphibians	Amphibian Species of the World	388	2,807
Reptiles	Roll <i>et al.</i> (2017) & IUCN	154	2,138
Birds	IUCN-BirdLife	-	3,607
Mammals	IUCN & other sources	270	1,329*

*59 species from IUCN 2019



Several studies reported the western Amazon as an area with especially high amphibian species concentrations in South America (Duellman 1999; Finer *et al.* 2008; Jenkins *et al.* 2013; Roll *et al.* 2017). The origin of amphibian species diversification across the Amazon, and species diversification in general, has been the subject of several hypotheses (Hoorn & Wesselingh, 2010; Hoorn *et al.* 2010; Defler 2019). The Andes uplift was the crucial event leading to the evolution of Amazonian ecosystems and landscapes, and inevitably much of amphibian diversity. The Andes have nutrient-rich soils linked to high diversities of amphibians and mammals in the western Amazon, as new lineages formed along the length of the Andes each of which moving into the Amazon and contributing to lowland diversity (Antonelli *et al.* 2010; Hoorn *et al.* 2010), for example, the wide expansion of the dendrobatids (Santos *et al.* 2009; Antonelli *et al.* 2010). Nevertheless, vertebrate alpha-diversity has been influenced by a number of factors in the Amazon, and apparently these vary in importance for each family in each vertebrate group (Antonelli *et al.* 2010).

Another important factor for amphibian diversity, and perhaps diversification in the western Amazon, is the relatively stable climate in terms of humidity and seasonality as compared to the eastern Amazon (Hoorn *et al.* 2010). These factors, in combination with the small home ranges typical of amphibians may explain the restricted amphibian distributions in the western Amazon (Antonelli *et al.* 2010; Hoorn *et al.* 2010).

Vertebrate diversity is also evidenced by the large number of endemic species in the Amazon (Da Silva *et al.* 2005), principally Ecuador (150 species), northern Peru and Colombia (Olson *et al.* 1998; Duellman, 1999; Bass *et al.* 2010; González *et al.* 2018). Da Silva *et al.* (2005) defined eight areas of endemism importance for biodiversity in general, separated by the major rivers of the Amazon basin, again highlighting the western Amazon as especially important.

The areas with the highest concentration of threatened amphibians according to the IUCN also highlight the importance of the conservation mosaics supported by the Gordon and Betty Moore Foundation (Figure 4). Yasuni-Pastaza and Upper Purus protect areas with between 1 and 4 Critically Endangered (CR) species per km². Yavari-Samiria, Ampiyacu and part of Yasuni-Pastaza, Madidi-Tambopata and Upper Purus include areas with concentrations of Endangered (EN) species. Other conservation mosaics have concentrations of Vulnerable (VU) species, between 1 and 8 species per km² in Ampiyacu, Yavari-Samiria, Yasuni-Pastaza, Madidi-Tambopata and a small portion of Upper Purus, Lower Rio Negro, Calha Norte, Chiribiquete-Caqueta, Upper Rio Negro and Xingu. Given the overall importance of the Amazon for amphibian diversity, this analysis underlines the importance of the conservation mosaics supported by the Gordon and Betty Moore Foundation for amphibian conservation, including threatened species, especially considering that amphibians are globally particularly threatened (Young *et al.* 2004).

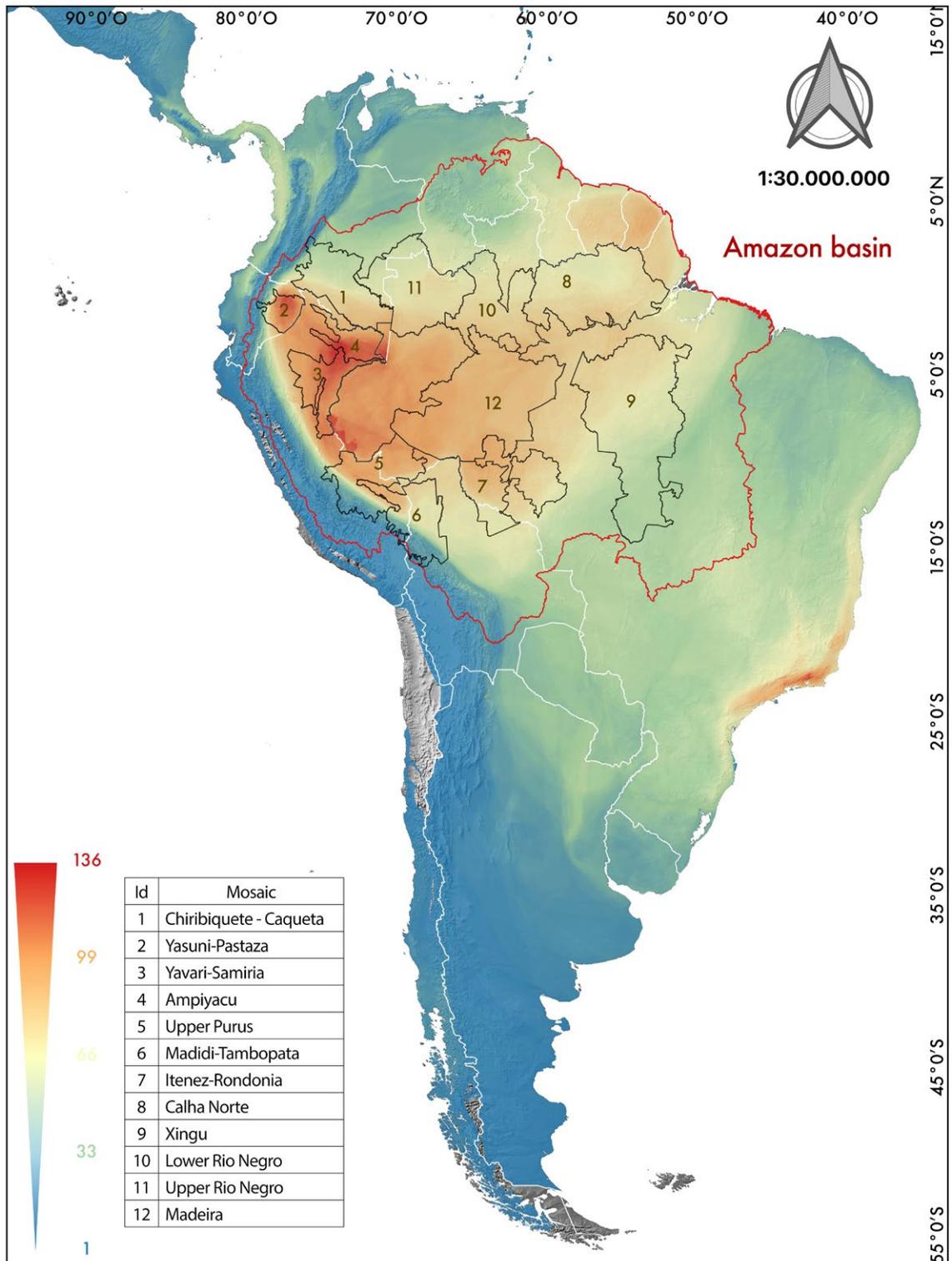


Figure 2: Amphibian Species Richness per km² in South America

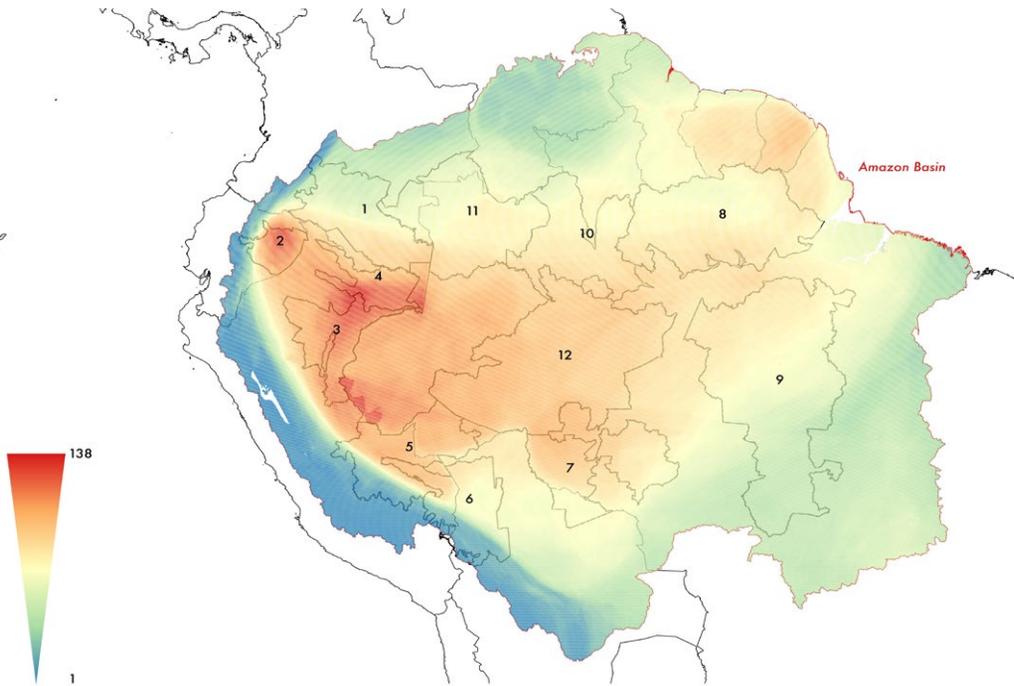
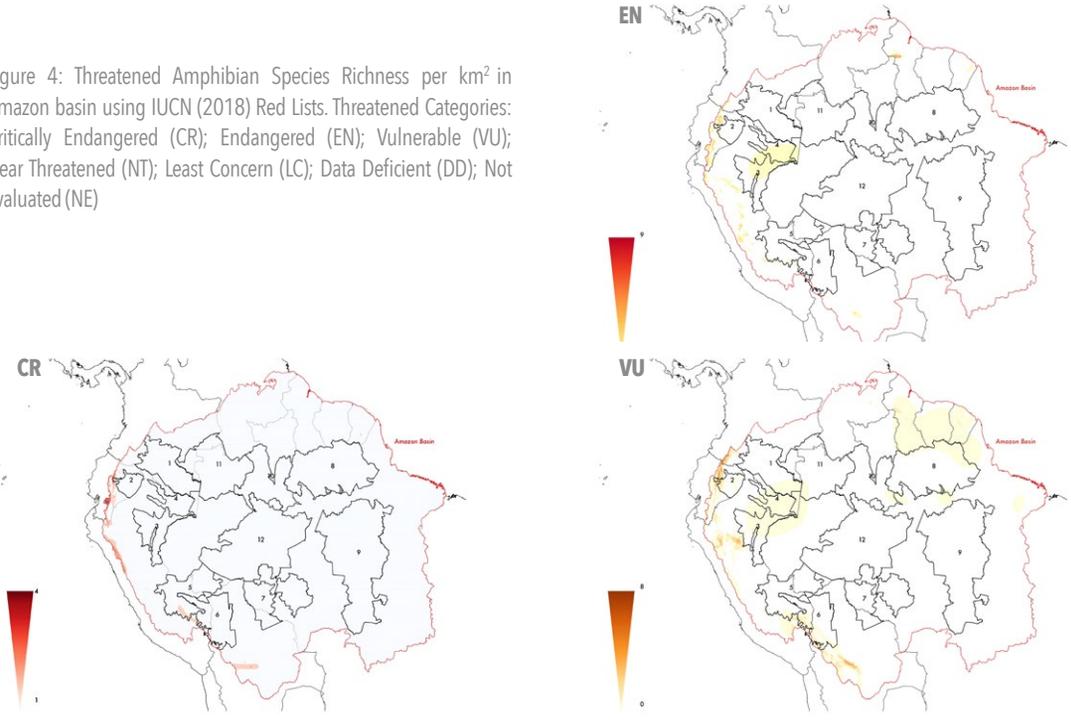
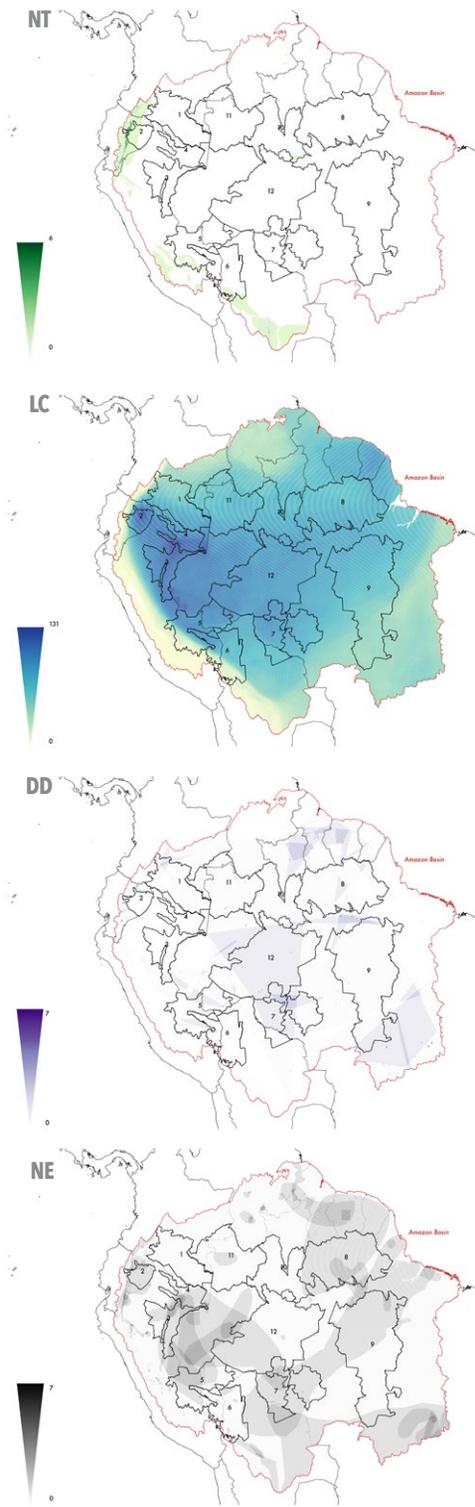


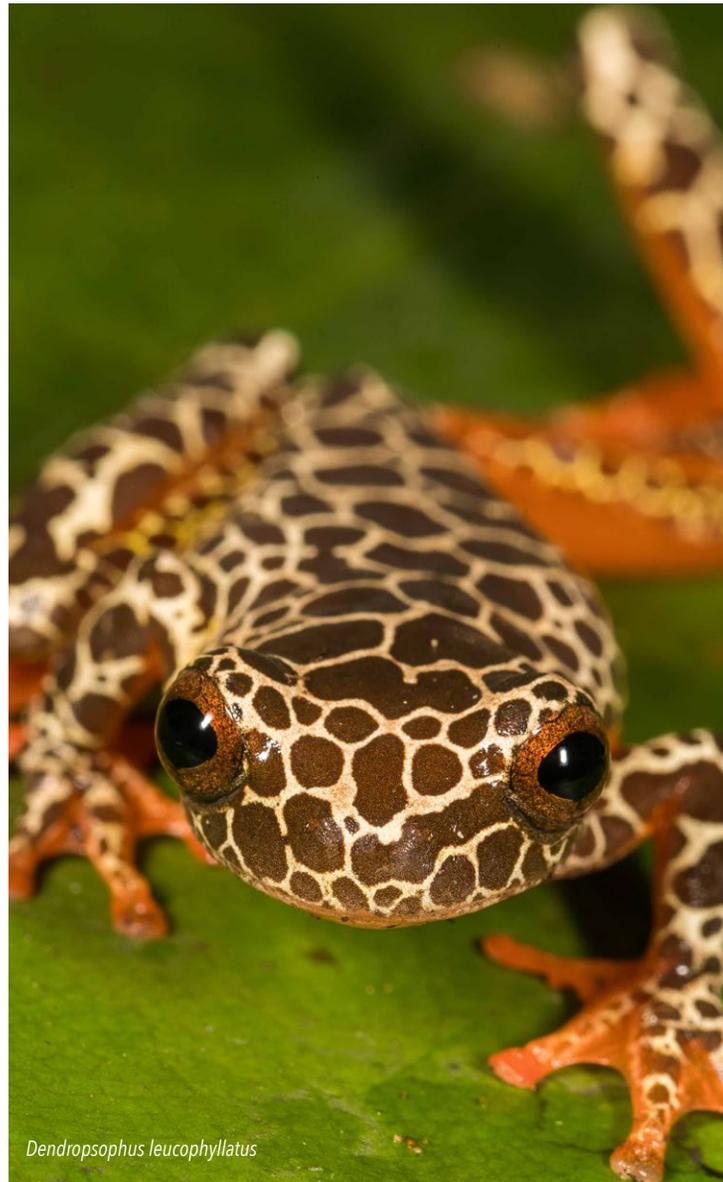
Figure 3: Amphibian Species Richness per km² in Amazon Basin

Figure 4: Threatened Amphibian Species Richness per km² in Amazon basin using IUCN (2018) Red Lists. Threatened Categories: Critically Endangered (CR); Endangered (EN); Vulnerable (VU); Near Threatened (NT); Least Concern (LC); Data Deficient (DD); Not Evaluated (NE)





◀ Figure 4 (cont.): Threatened Amphibian Species Richness per km² in Amazon basin using IUCN (2018) Red Lists. Threatened Categories: Critically Endangered (CR); Endangered (EN); Vulnerable (VU); Near Threatened (NT); Least Concern (LC); Data Deficient (DD); Not Evaluated (NE)



B. Reptiles

Most of the Amazon basin has a high concentration of reptile species (Figure 5). The highest concentrations of up to 184 species per km² are in northwestern Amazonia and northern central Amazonian Brazil. Again these areas highlight the importance of the twelve conservation mosaics supported by the Gordon and Betty Moore Foundation, including Calha Norte, Xingu, Itenez-Rondonia, Madeira, Yavari-Samiria, Ampiyacu, Upper Río Negro and Lower Río Negro, as concentrations for reptile diversity. We were unable to perform these analyses for reptiles in South America, however the polygons were derived from a global analysis that highlighted the highest concentration of South American reptile diversity in the Amazon (Roll *et al.* 2017).

The origin of reptile diversification in the Amazon is contentious, especially due to the poorly studied situation of the group, with relatively few records across the region (Antonelli *et al.* 2010), which also limits our own analyses and highlights the particular need for targeted ecological and phylogeographic research. Studies have revealed a genetic divergence in the Late Miocene and Plio-Pleistocene (Antonelli *et al.* 2010), when different reptiles lineages appeared, reflecting an ecological partition in the Amazon environments probably linked to numerous large rivers and resulting separation (Antonelli *et al.* 2010; Riff *et al.* 2010). Again, there is significant reptilian endemism in the Amazon, for example in Ecuador there are 121 endemic species,

and in Amazonian Brazil 81 species of lizards (Trefaut 2005; Bass *et al.* 2010).

The areas with the highest concentration of IUCN recognized threatened reptile species highlight the importance of the twelve conservation mosaics supported by the Gordon and Betty Moore Foundation (Figure 6). Yasuni-Pastaza includes areas with between 1 and 4 Endangered (EN) reptiles per km², and areas with between 1 and 5 Vulnerable (VU) species per km² are found in all twelve mosaics, principally Calha Norte, part of Xingu, Madeira, Yavari-Samiria, Yasuni-Pastaza, Ampiyacu, Upper Río Negro and Lower Río Negro (with 4 to 5 VU species per km²). Critically Endangered (CR) reptiles are found in concentrations of just 1 species per km² in part of the Upper Purus and Chiribiquete-Caqueta, as well as close to the northern limits of the Upper Río Negro and Lower Río Negro. Near Threatened (NT) reptiles are found in the Upper Río Negro, Lower Río Negro, and parts of Madeira, Calha Norte, Madidi-Tambopata, Upper Purus, Yavari-Samiria, Ampiyacu and Chiribiquete-Caqueta (Figure 6), whilst Least Concern (LC) reptiles reach concentrations of up to 51 species per km² across the twelve mosaics. Together this data clearly demonstrates the contribution of the conservation mosaics towards the conservation of reptile diversity, as well as for the threatened reptiles of the Amazon.



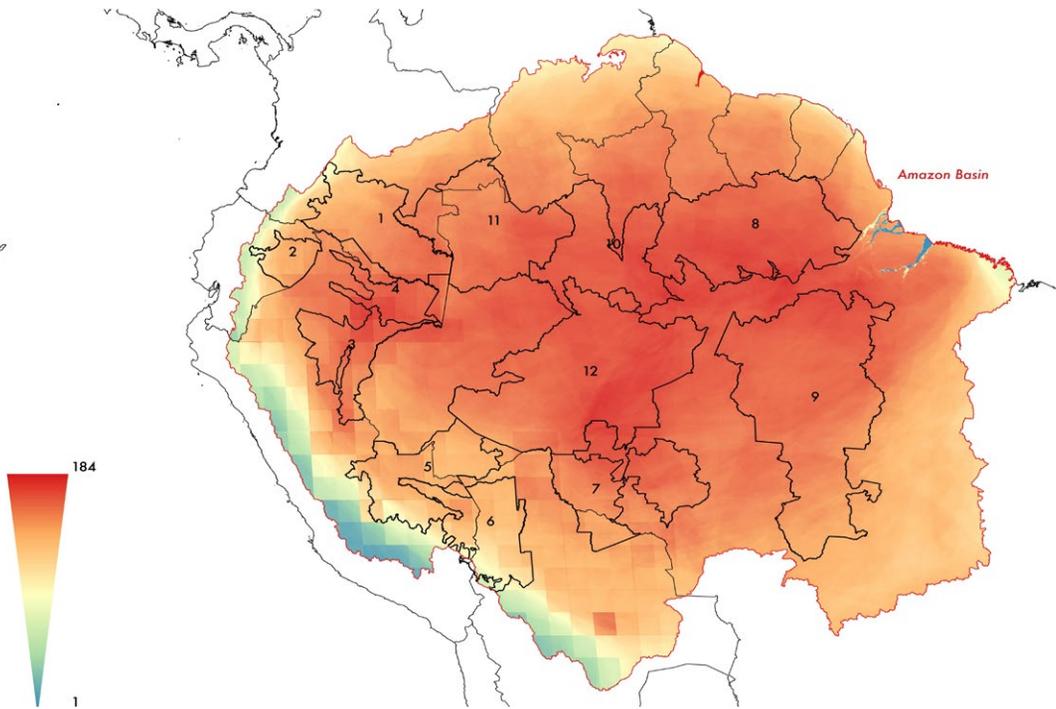


Figure 5: Reptile Species Richness per km² in Amazon Basin

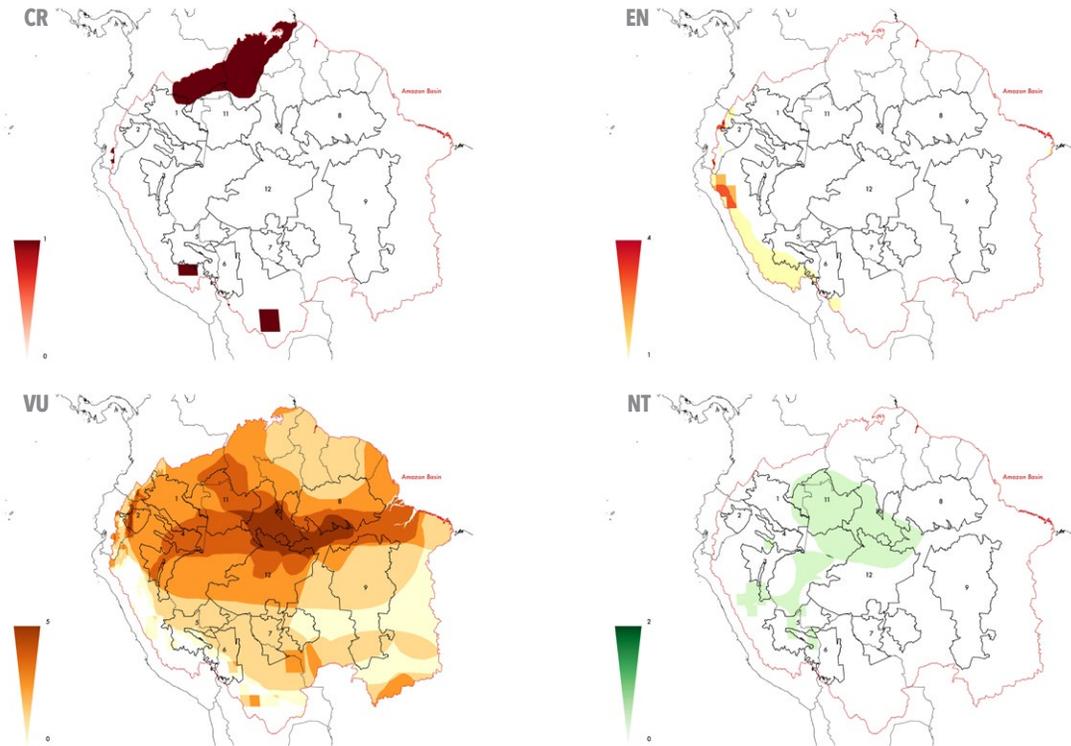


Figure 6: Threatened Reptile Species Richness per km² in Amazon basin using IUCN (2018) Red Lists. Threatened Categories: Critically Endangered (CR); Endangered (EN); Vulnerable (VU); Near Threatened (NT); Least Concern (LC); Data Deficient (DD); Not Evaluated (NE); Lower Risk/Conservation Dependent (LR/CD); Lower Risk/Least Concern (LR/LC).

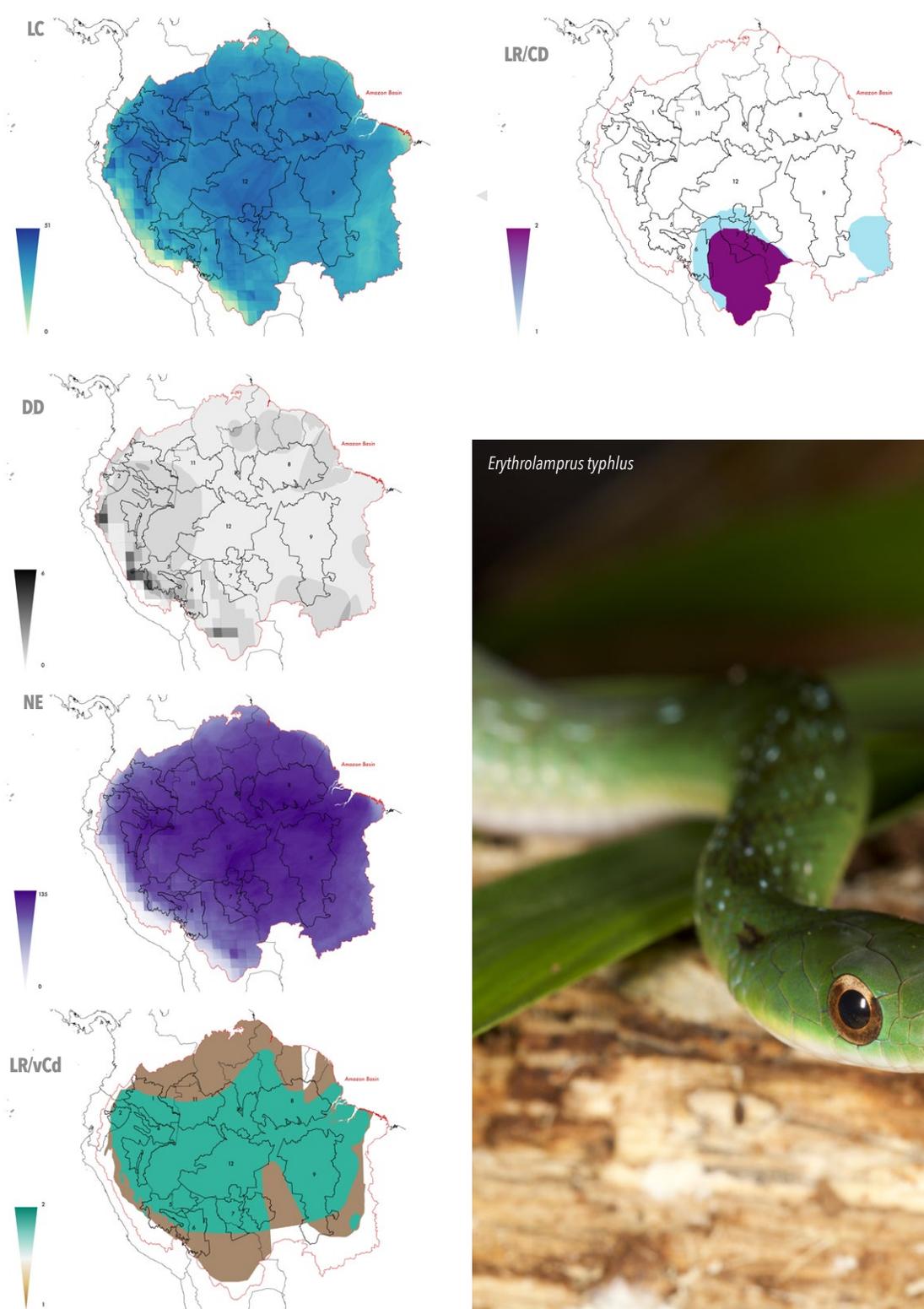


Figure 6 (cont.): Threatened Reptile Species Richness per km² in Amazon basin using IUCN (2018) Red Lists. Threatened Categories: Critically Endangered (CR); Endangered (EN); Vulnerable (VU); Near Threatened (NT); Least Concern (LC); Data Deficient (DD); Not Evaluated (NE); Lower Risk/Conservation Dependent (LR/CD); Lower Risk/Least Concern (LR/LC).

C. Birds

The majority of the areas with the highest concentration of bird species in South America are found in the Amazon basin (Figures 7 & 8). Once again, the areas with the highest concentrations of up to 596 species per km² are Amazonian, especially in the western Amazon, highlighting the importance of the Yasuni-Pastaza, Yavari-Samiria, Ampiyacu, Upper Purus conservation mosaics, and parts of the Madidi-Tambopata, Madeira, Calha Norte and Xingu conservation mosaics.

The Andean event is the predominant theory explaining bird diversification in the western Amazon (Antonelli et al. 2010). A study on patterns of bird species richness in South America showed greater diversity in the Andes towards Amazonian Ecuador, southeastern Peru and southern Bolivia in complex physiographical landscapes, a pattern that also responds to climatic fluctuations (Rahbek & Graves 2001). Another study suggested that Andean lineages of a group of Passeriformes dispersed to other geographic areas of the Neotropics, eventually leading to speciation events (Burns & Naoki 2004). Bates (2001) proposed that the concentrations in Guyana respond to marine influences that led to high endemism in northern South America. Similarly, coastal northern Brazil has many records of migratory birds from the

northern hemisphere, increasing species richness (Azevedo-Júnior 1998).

The areas with the highest concentration of threatened bird species according to the lower threatened IUCN categories (NT, LC) in South America are predominantly found in the Amazon (Figure 7), whereas Endangered and Vulnerable concentrations are predominantly concentrated outside the Amazon. In South America concentrations of Critically Endangered species reach 4 species per km² and are found in eastern Brazil and small portions of Bolivia, Ecuador, Argentina, Peru and Chile, and within the Madidi-Tambopata conservation mosaic.

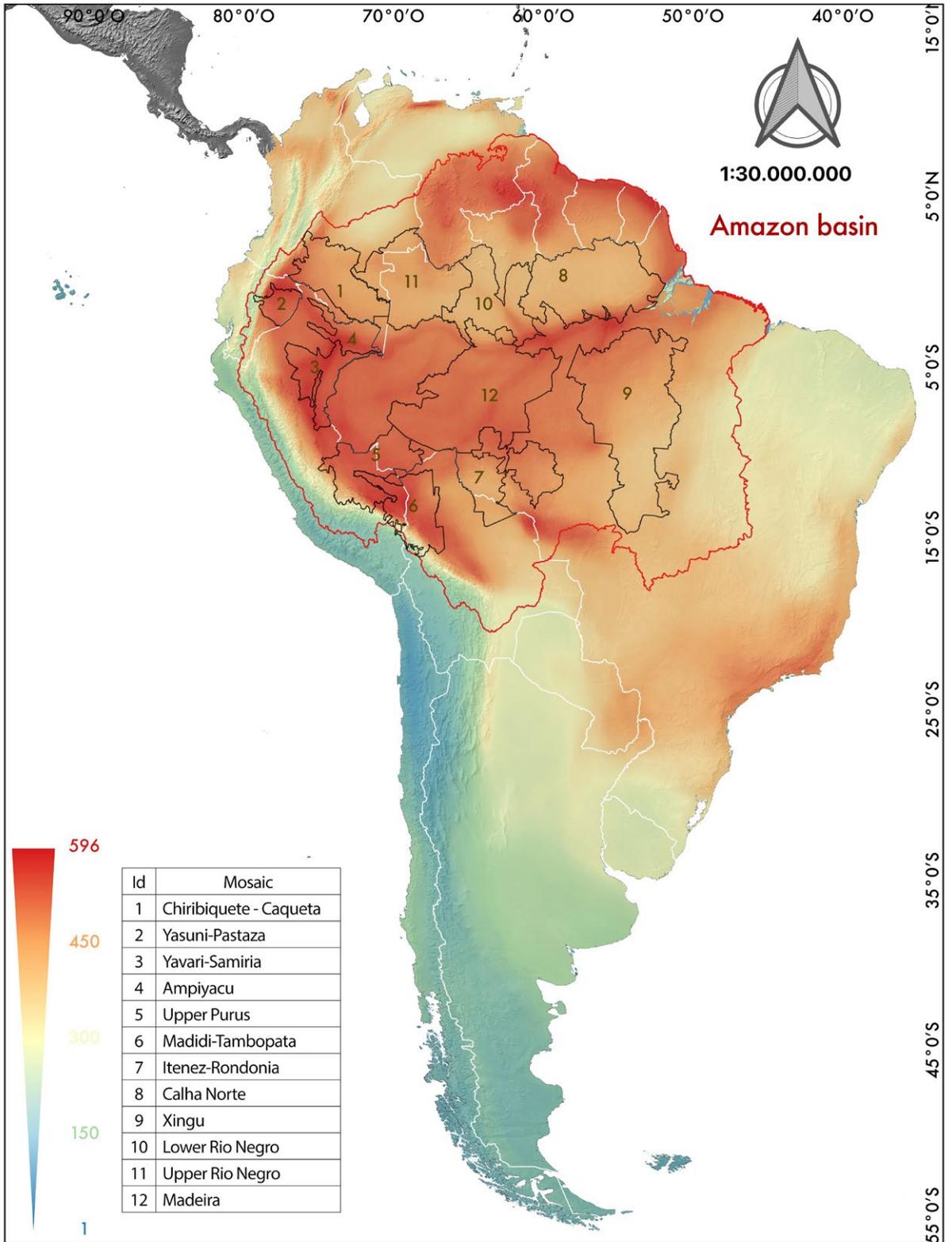


Figure 7: Bird Species Richness per km² in South America and Amazon basin

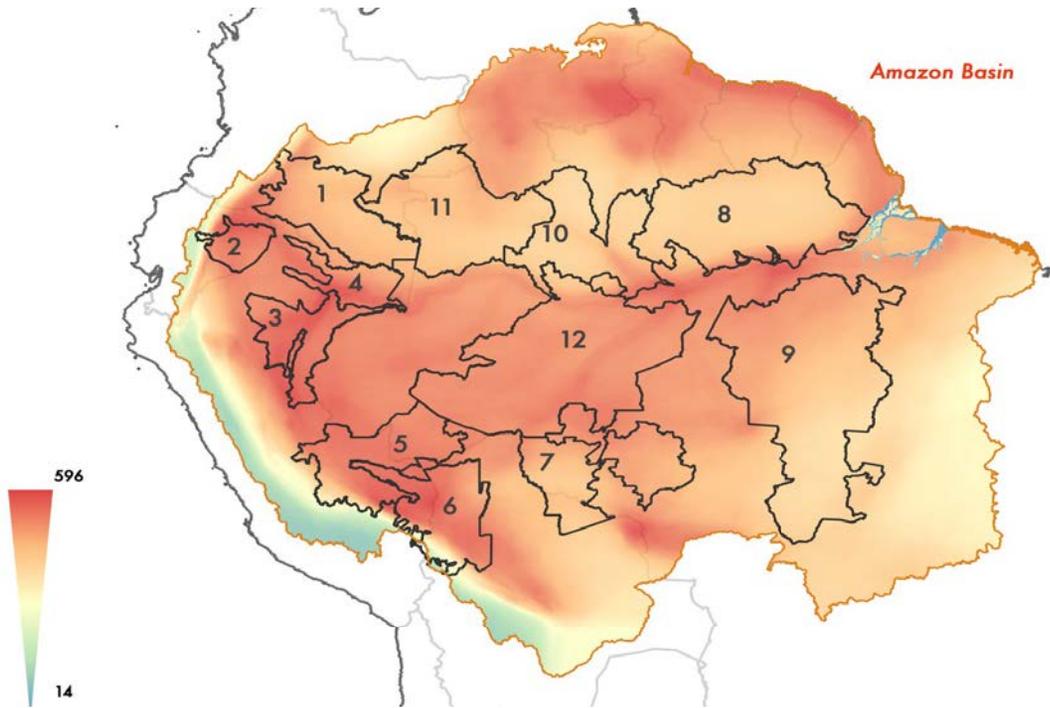


Figure 8: Bird Species Richness per km² in Amazon Basin

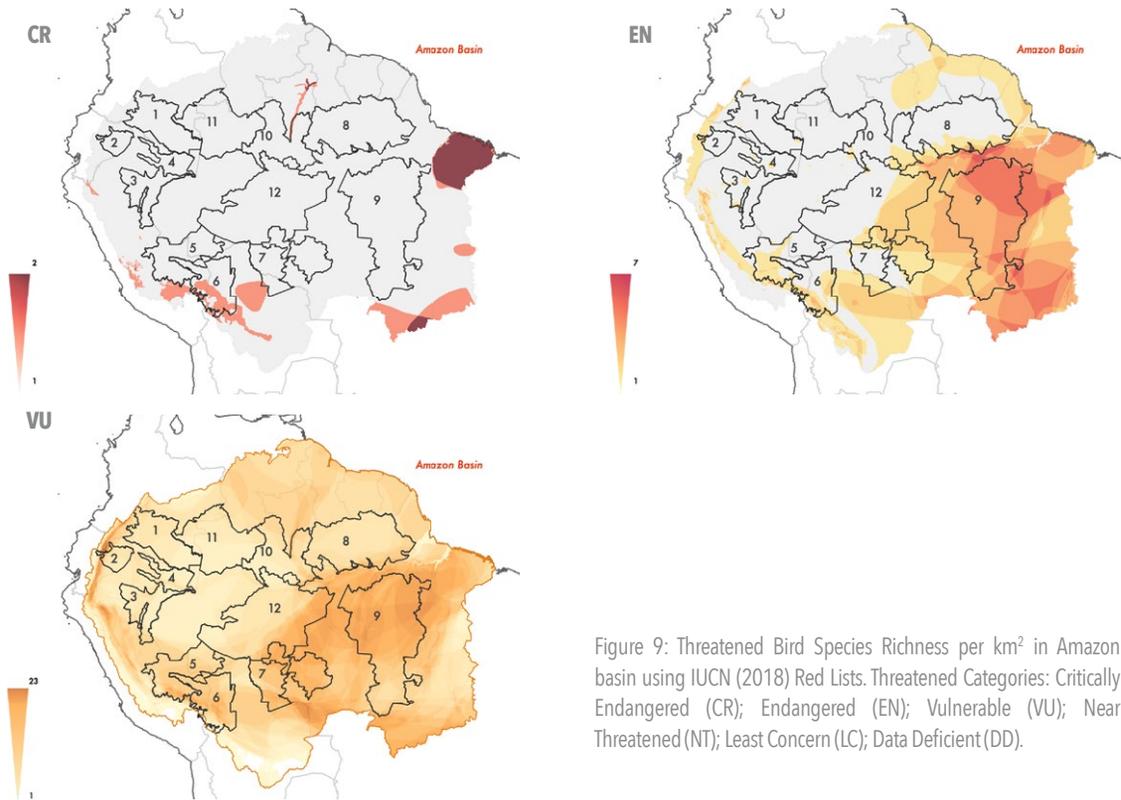


Figure 9: Threatened Bird Species Richness per km² in Amazon basin using IUCN (2018) Red Lists. Threatened Categories: Critically Endangered (CR); Endangered (EN); Vulnerable (VU); Near Threatened (NT); Least Concern (LC); Data Deficient (DD).

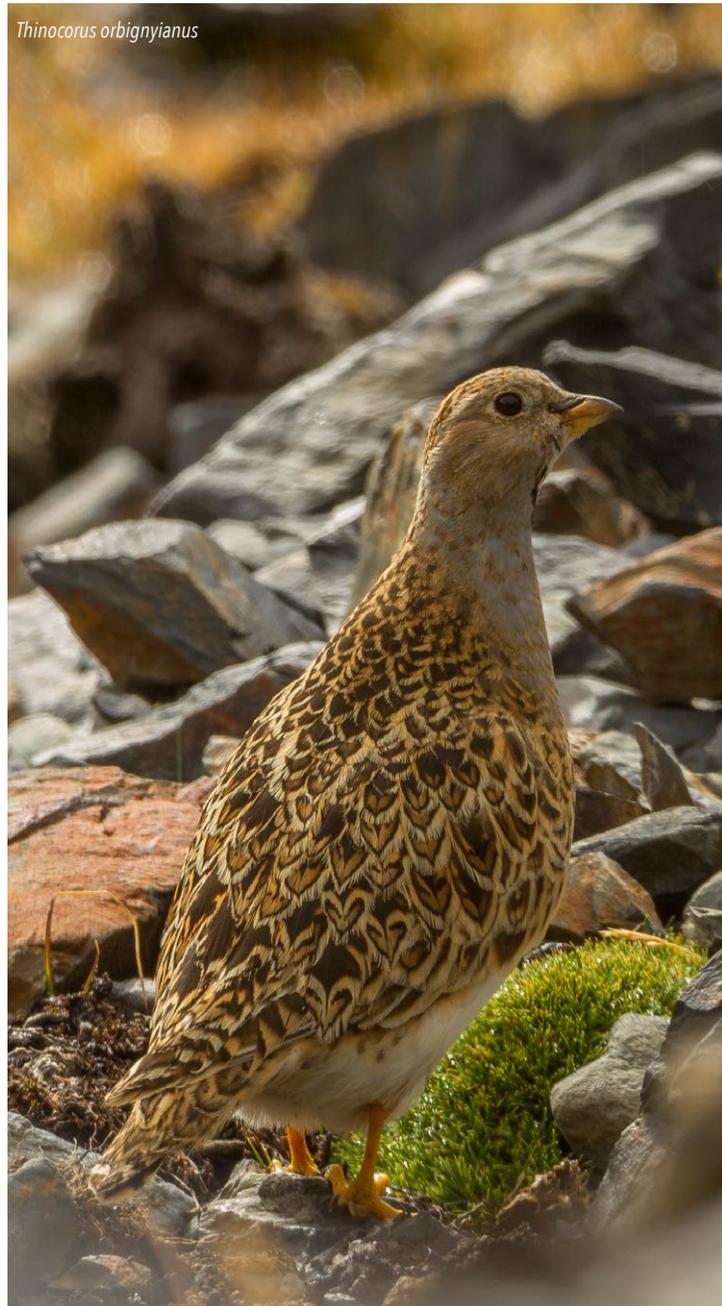
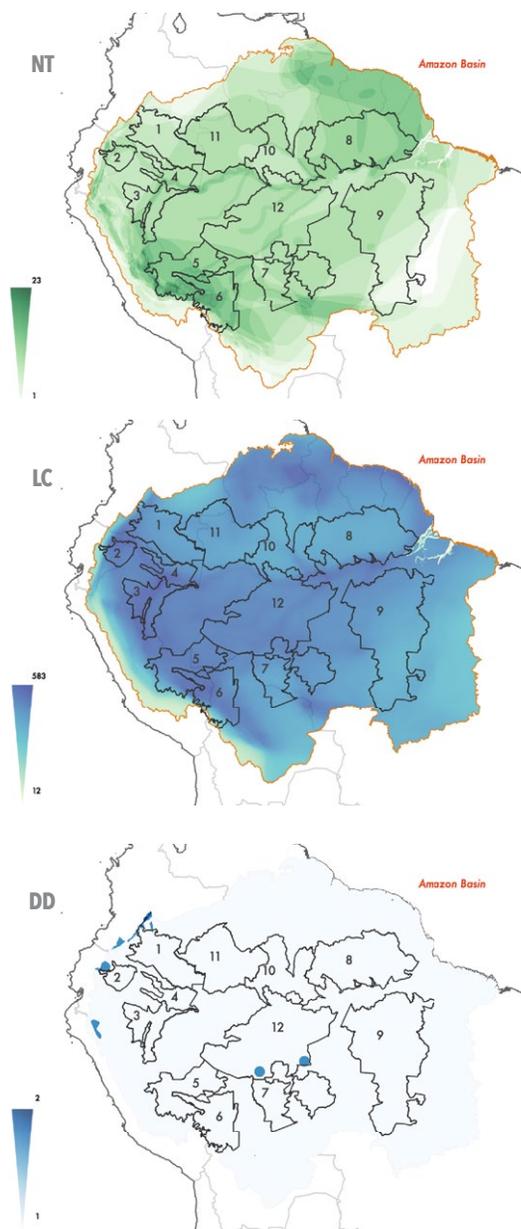


Figure 9 (cont.): Threatened Bird Species Richness per km² in Amazon basin using IUCN (2018) Red Lists. Threatened Categories: Critically Endangered (CR); Endangered (EN); Vulnerable (VU); Near Threatened (NT); Least Concern (LC); Data Deficient (DD).

D. Mammals

The majority of the areas with the greatest concentration of mammal species in South America are found in the Amazon basin (Figures 10 & 11). Again, the areas with the highest concentrations of up to 203 species per km² are Amazonian, especially in the western Amazon, highlighting the importance of the Yasuni-Pastaza, Yavari-Samiria, Ampiyacu, Upper Purus and Madidi-Tambopata conservation mosaics.

The high alpha-diversity of mammals in the western Amazon is also attributed to the rise of the Andes (Defler 2019), although the debate continues (Hoorn *et al.* 2010; Defler 2019). Compared to the eastern Amazon, the soils of the western Amazon in the Neogene are characterized by high nutrient levels (Hoorn *et al.* 2010), and soil richness is related to increased productivity and diversity. Tognelli and Kelt (2004) suggested that mammal species richness in South America is influenced by productivity and that this is reflected in a gradual gradient, with higher concentrations on the lower slopes of the eastern Andes in Bolivia, Perú and Ecuador, then the Amazonian plains, and then the Atlantic forests of Brazil. Higher productivity signifies increased resources for consumers, influencing population dynamics, and increasing the number of species that can co-exist (MacArthur 1972; Lennon *et al.* 2000; Defler 2019).

Similarly, high mammal species richness in northern South America may be biogeographically influenced by the ancient and

prominent Guinean Shield (Lim 2012), an elevated area that was relatively stable during the emergence of the Andes and Amazon in the Miocene, a period of significant environmental change, and influenced mammal diversification, principally bats, increasing endemism and functioning as a geographic barrier (Lim 2012; Lim & Tavares 2012). Other authors maintain that the Amazon is characterized by high rainfall for most of the year, which is related to high mammal species richness (Voss & Emmons 1996) and plant species richness (Gentry 1988; Pitman *et al.* 2002).

The areas with the highest concentrations of threatened mammals according to the IUCN (Figure 12) reveal that the Amazon is especially relevant for most threatened categories (LC, NT, VU, EN). Nevertheless, this is not the case for the Critically Endangered category (CR), with concentrations of up to 2 species per km² in Colombia, Brazil and small portions of Bolivia, Ecuador and Peru. The Chiribiquete-Caqueta conservation mosaic has small areas with concentrations of the most threatened species, although Itenez-Rondonia, and parts of Madeira, Xingu and Calha Norte have concentrations of Endangered (EN) mammal species. Vulnerable (VU) species are concentrated in Yavari-Samiria and Calha Norte, as well as concentrations of species in the LC, NT and DD categories.

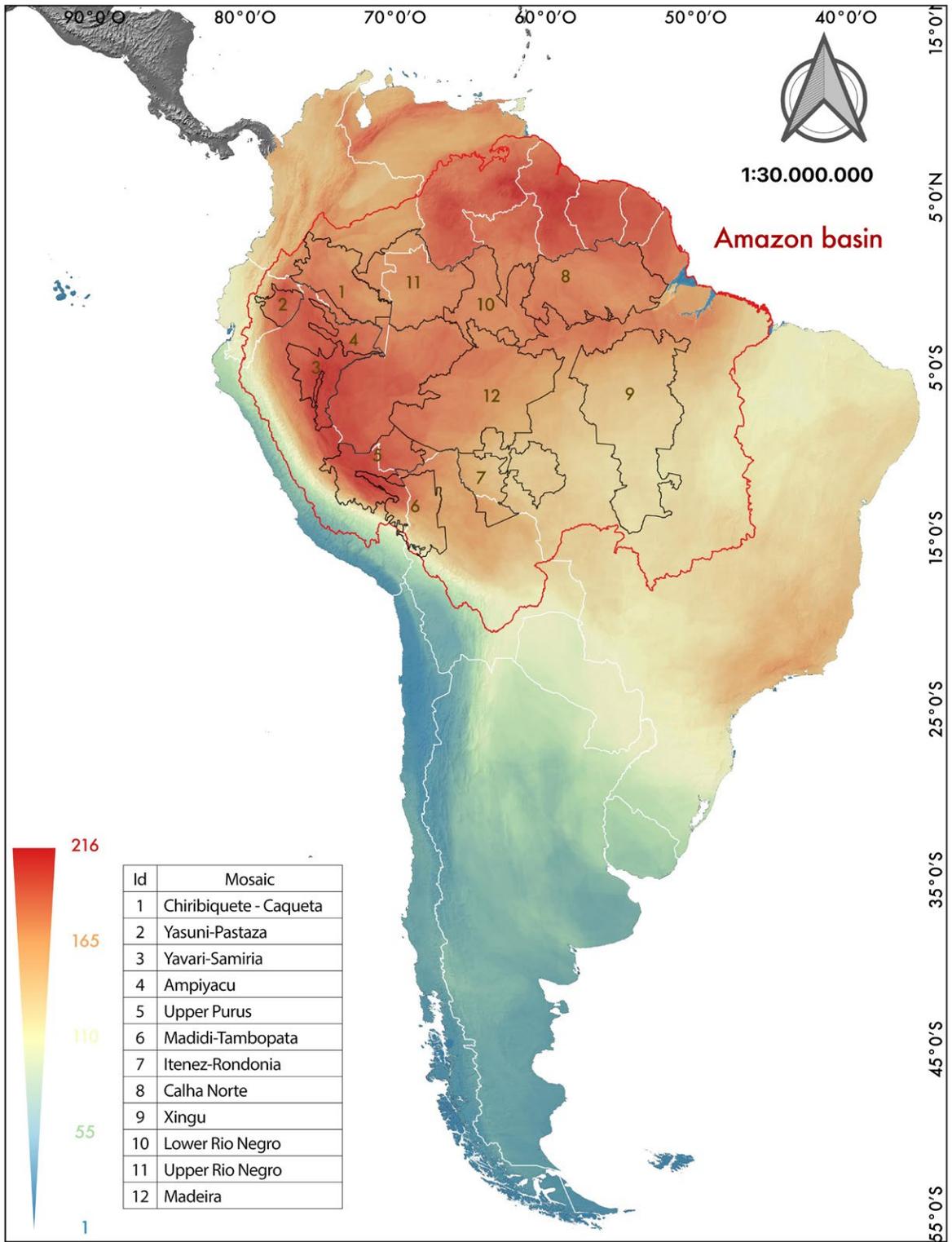


Figure 10: Mammal Species Richness per km² in South America

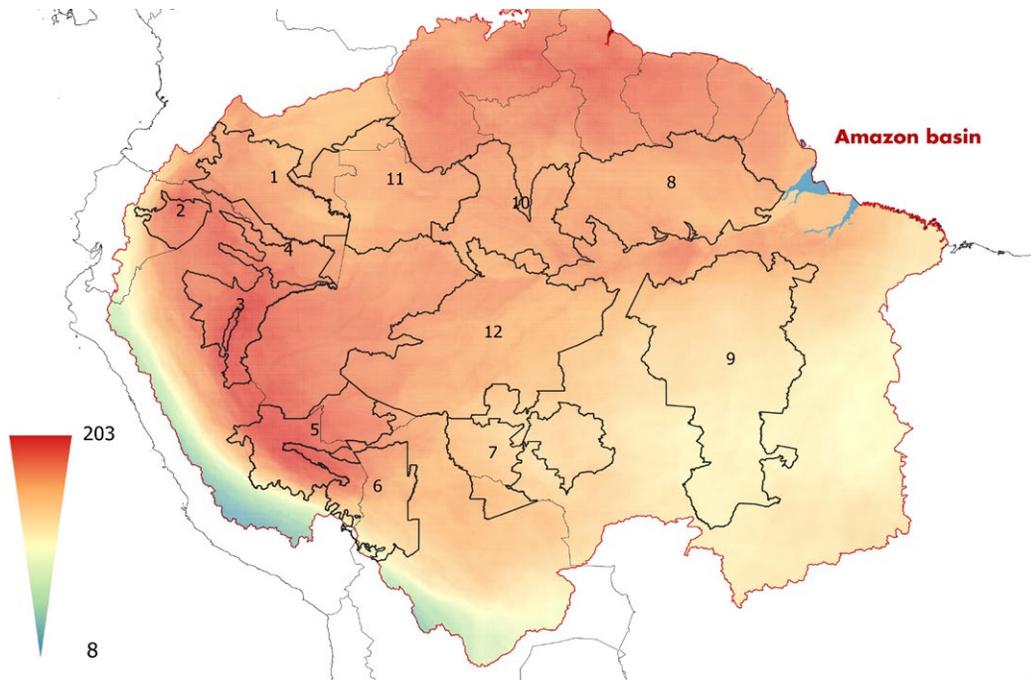
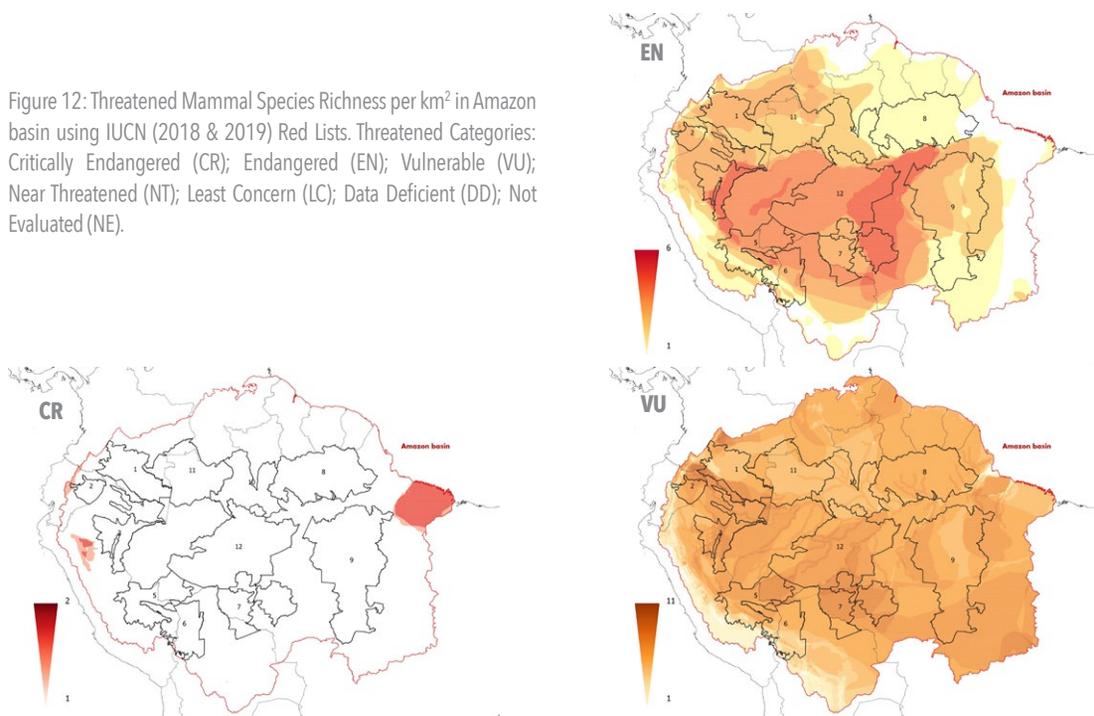
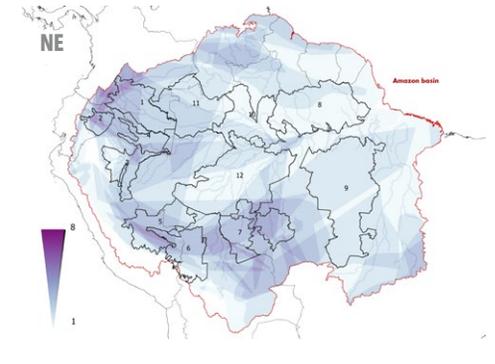
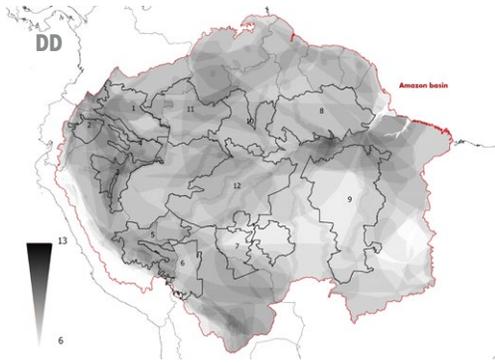
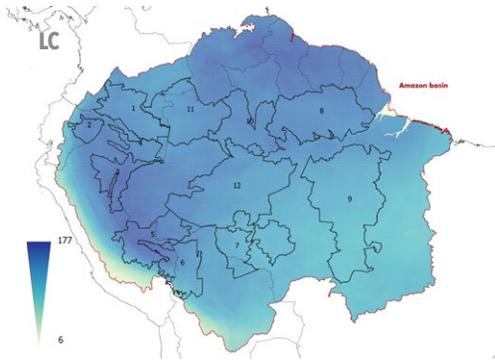
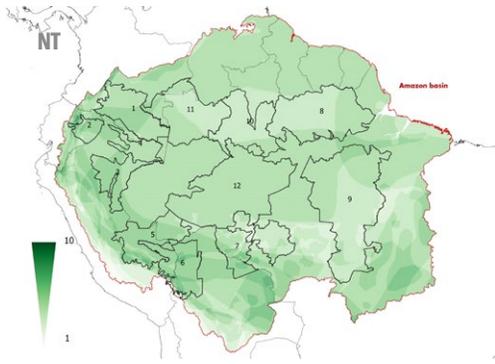


Figure 11: Mammal Species Richness per km² in Amazon Basin

Figure 12: Threatened Mammal Species Richness per km² in Amazon basin using IUCN (2018 & 2019) Red Lists. Threatened Categories: Critically Endangered (CR); Endangered (EN); Vulnerable (VU); Near Threatened (NT); Least Concern (LC); Data Deficient (DD); Not Evaluated (NE).



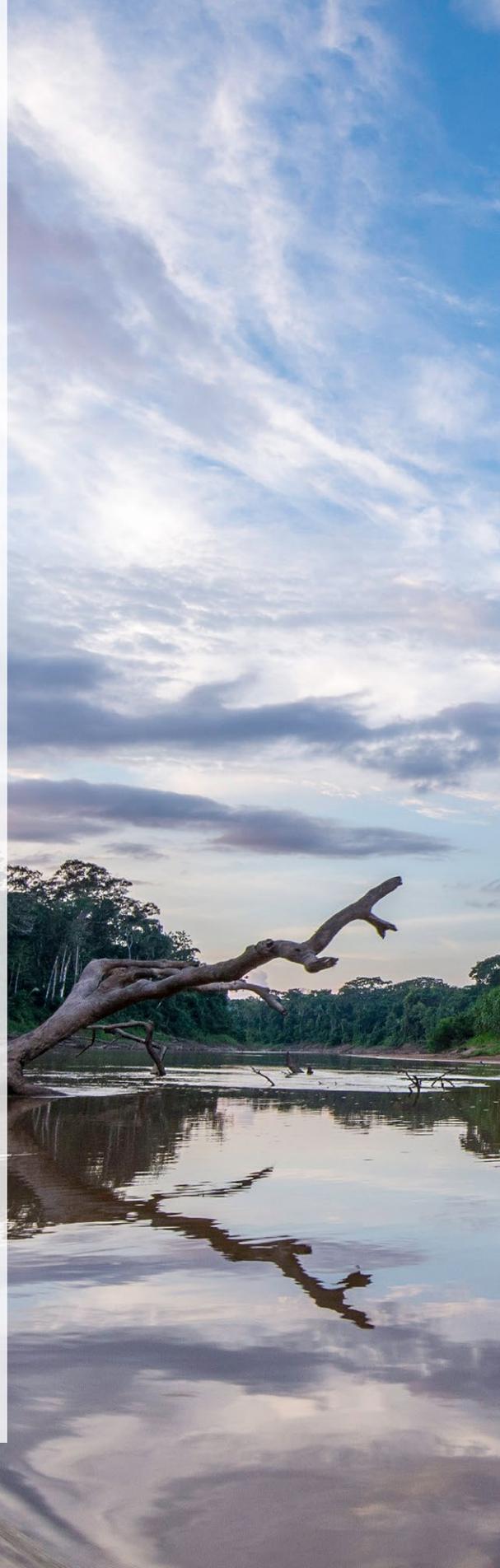


◀ Figure 12 (Cont.): Threatened Mammal Species Richness per km² in Amazon basin using IUCN (2018 & 2019) Red Lists. Threatened Categories: Critically Endangered (CR); Endangered (EN); Vulnerable (VU); Near Threatened (NT); Least Concern (LC); Data Deficient (DD); Not Evaluated (NE).



As mentioned previously, there are several theories to explain the origin of diversification for each of the four vertebrate groups (Antonelli *et al.* 2010), although it is widely accepted that Amazonian biodiversity is a result of more than one driving mechanism (Hoorn *et al.* 2010; Hoorn & Wesselingh 2010). Nevertheless, the emergence of the Andes in the Neogene, fundamentally changed the hydrology and climate of the entire continent, creating new evolutionary pressures on montane and lowland taxa (Tognelli & Kelt 2004; Antonelli *et al.* 2010). Historically, the extensive tropical forest of the Amazon has fragmented and undergone structural alterations, for example, marine incursions, geotectonic events, hydrology and wetland systems and climate fluctuations, which also created evolutionary pressures leading to extinctions or speciation (Antonelli *et al.* 2010; Hoorn *et al.* 2010; Lim 2012; Defler 2019). Collectively these mechanisms have led to the Amazon basin having the highest concentration of species in South America, and one of the highest in the world (Myers *et al.* 2000).

It is worth highlighting that the Amazon is also known for extremely high fish diversity. In the future it would be important to perform similar alpha-diversity analyses for fish to complete the first comprehensive assessment of vertebrate diversity for the Amazon.





ii. Beta diversity species analysis for the Amazon basin

Our results demonstrate that the geographical patterns of beta-diversity (β) for amphibians, reptiles, birds and mammals have similar tendencies for all scales examined, with high values towards the Andes and intermediate values in the lowlands of the western Amazon (Figure 13), indicating a higher changeover of species in these areas. Previous studies at different scales also indicated higher beta-diversity towards the Andes (Duellman 1999; Melo *et al.* 2009; Qian 2009). Rodríguez *et al.* (2019) also determined the importance of montane areas in México for beta-diversity for vertebrates, identifying that altitudinal differences is the most significant indicator in species composition divergence. Indeed, geographical differentiation is recognized as the most compelling explanation for historical isolation processes that led to species composition differences in these regions (Melo *et al.* 2009).

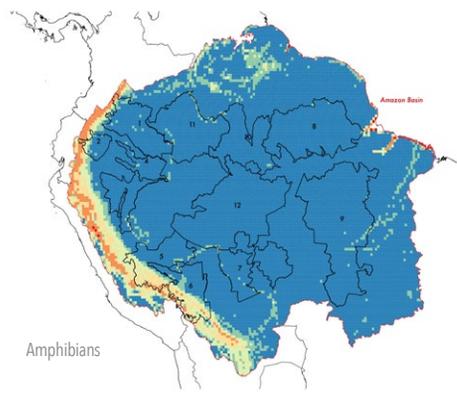
Amphibians had the highest beta-diversity, particularly along the Andes chain from Colombia to southern Bolivia (Figure 13). Previous studies have demonstrated that amphibians and reptiles have higher beta-diversity values than birds and mammals (Buckley & Jetz 2008; Qian 2009; Rodríguez *et al.* 2019), and species with lower dispersion capacities tend to have higher beta-diversity values (Qian 2009; Juen & De Marco 2011).

Previous studies have shown that beta-diversity (β) varies at different scales, indicating that species composition similarity increases with increase in the size of cell (MacNally *et al.* 2004; Lira-Noriega *et al.* 2007; Ochoa-Ochoa *et al.* 2014). In our study beta-diversity values for smaller scales differed to those at larger scales for reptiles, birds and mammals, following a similar pattern (Figure 13). Small cell analyses (25 x 25 km & 50 x 50 km) for these vertebrate groups showed intermediate beta-diversity values in the Andes, higher values on the Amapá coast of Brazil, and lower values for the rest of the Amazon. At broader spatial scales (100 x 100 km & 200 x 200 km), all three vertebrate groups present high beta-diversity in the Andes, with intermediate values in the eastern and northern Amazon, particularly for birds (Figure 13).

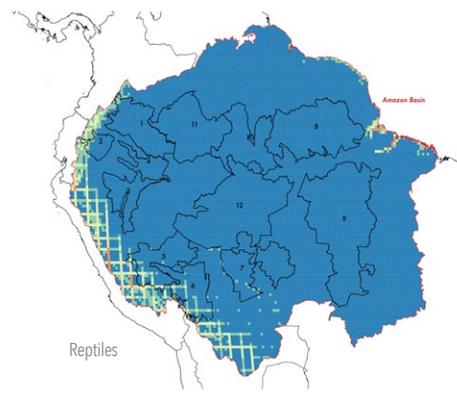
Contrastingly, amphibians have high beta-diversity values in the smaller cells, principally in the Andes, and lower values towards the eastern Amazon (Figure 13). The Andes also had higher beta-diversity values for the broader scale analyses, as well as in Venezuela, Guyana and the southeastern Brazilian Amazon.

Heterogeneous environmental effects are expected to increase with increasing scale, because larger sampling units tend to include a greater variability in environmental conditions (Qian 2009; Rodríguez *et al.* 2019). High beta-diversity values indicate significant habitat heterogeneity. Where habitats differ across a geography or gradient (temperature, humidity, altitude, etc.),

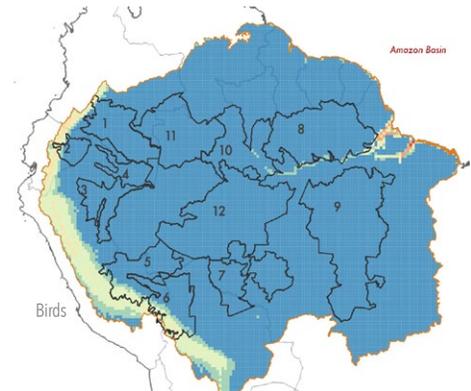
25 x 25 km Cells



Amphibians



Reptiles

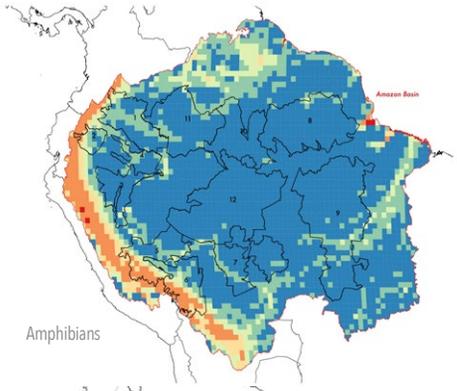


Birds

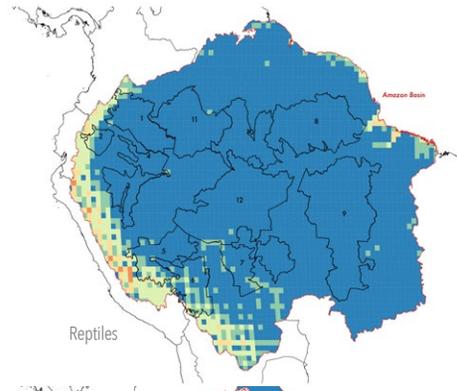


Mammals

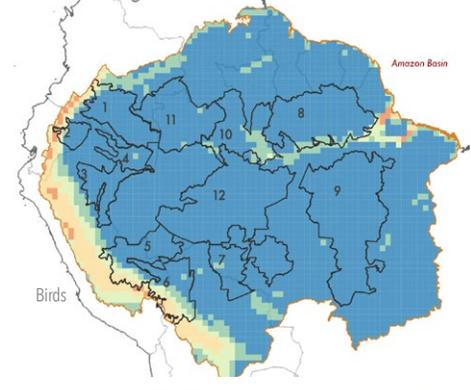
50 x 50 km Cells



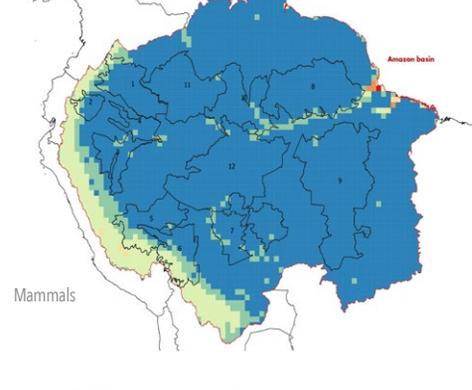
Amphibians



Reptiles



Birds

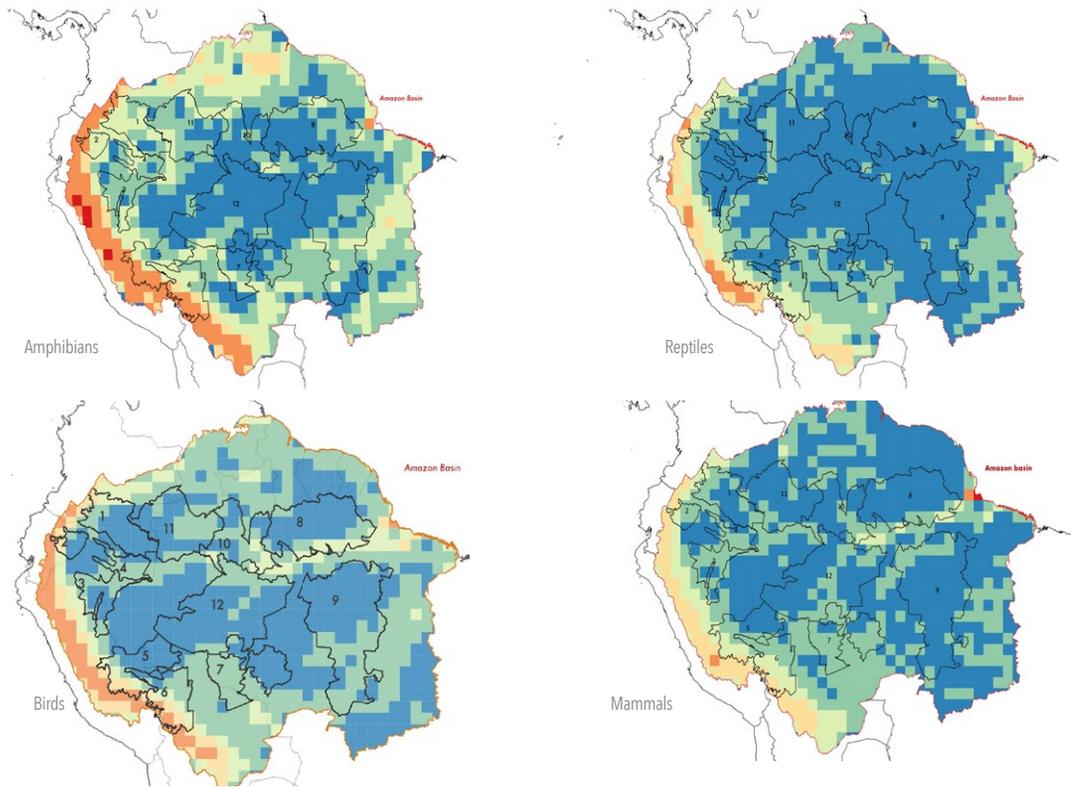


Mammals



Figure 13. Geographic patterns of beta-diversity (β) following Whittaker (1960) for amphibians, reptiles, birds and mammals at different spatial scales in the Amazon basin and twelve conservation mosaics supported by the Gordon and Betty Moore Foundation. 1. Chiribiquete-Caqueta; 2. Yasuni-Pastaza; 3. Yavari-Samiria; 4. Ampiyacu; 5. Upper Purus; 6. Madidi-Tambopata; 7. Itenez-Rondonia; 8. Calha Norte; 9. Xingu; 10. Lower Rio Negro; 11. Upper Rio Negro; 12. Madeira

100 x 100 km Cells



200 x 200 km Cells

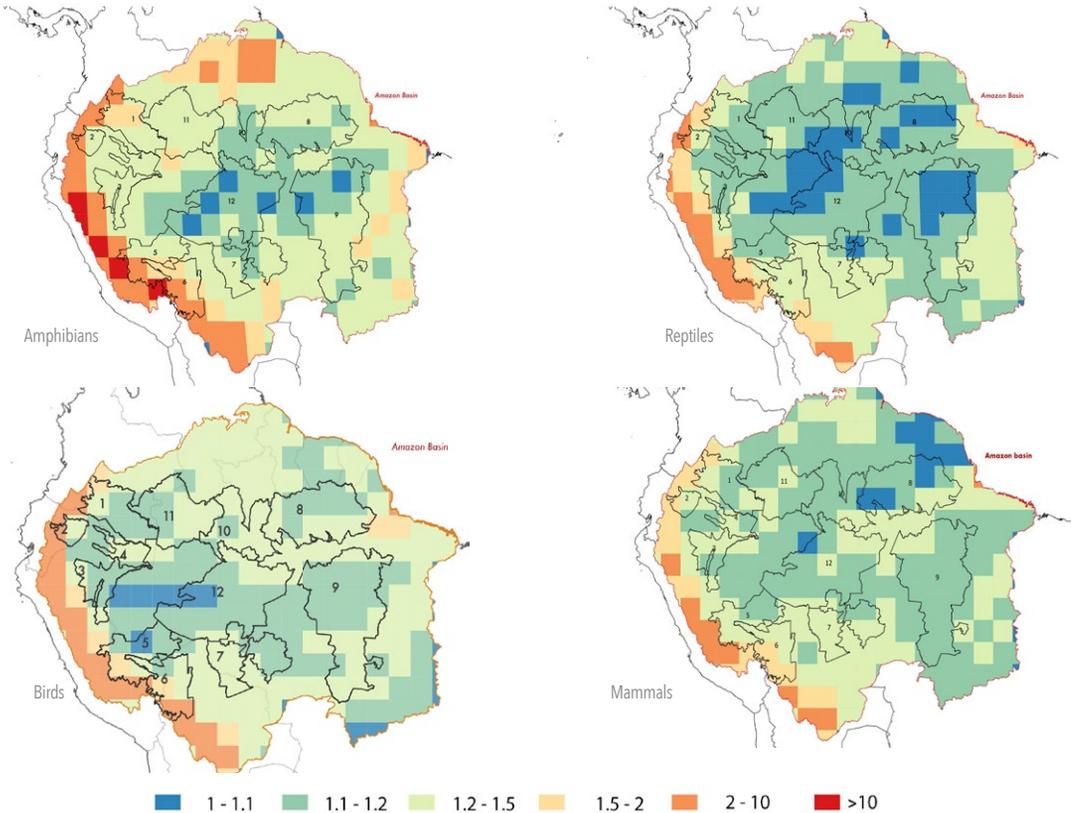


Figure 13 (cont.). Geographic patterns of beta-diversity (β) following Whittaker (1960) for amphibians, reptiles, birds and mammals at different spatial scales in the Amazon basin and twelve conservation mosaics supported by the Gordon and Betty Moore Foundation. 1. Chiribiquete-Caqueta; 2. Yasuni-Pastaza; 3. Yavari-Samiria; 4. Ampiyacu; 5. Upper Purus; 6. Madidi-Tambopata; 7. Itenez-Rondonia; 8. Calha Norte; 9. Xingu; 10. Lower Rio Negro; 11. Upper Rio Negro; 12. Madeira

biological communities tend to differ too, and these changes can be accentuated by other natural barriers, such as rivers, mountains, or soil types, or indeed anthropogenic factors such as forest fragmentation or variations in vegetation cover (Moreno 2001).

These analyses are relevant for conservation efforts as specific environmental variables can be used to predict beta-diversity, for example climate and temperature effects (Rodriguez *et al.* 2019), as well as predict the effects of climate change on the vertebrate groups studied here. For now these results help to highlight the conservation mosaics with high and intermediate beta-diversity for terrestrial vertebrates: Madidi-Tambopata, Upper Purus, Yasuni Pastaza, Chiribiquete-Caqueta, and small parts of Calha Norte, Yavari-Samiria, Lower Rio Negro, Lower Rio Negro and Xingu. For amphibian beta diversity the same eight conservation mosaics are the most important, and for reptiles the highest values were for Madidi-Tambopata, Upper Purus, Yasuni Pastaza and a small part of Yavari-Samiria. Birds have high and intermediate beta-diversity in Madidi-Tambopata, Upper Purus, Yasuni-Pastaza, Yavari-Samiria, Chiribiquete-Caqueta and Calha Norte, and for mammals the highest values are in Madidi-Tambopata, Upper Purus, Yasuni-Pastaza, Chiribiquete-Caqueta and Calha Norte.

At the broader scales (100 x 100 km & 200 x 200 km), the conservation mosaics with lowest beta-diversity (β), were Madeira and Xingu for amphibians, Madeira, Xingu, Calha Norte and part of Lower Río Negro and Upper Río Negro for reptiles, Madeira, part of Yavari-Samiria and Upper Purus for birds, and Calha Norte, Madeira and part of Lower Rio Negro for mammals. It is important to note that for the finer scale analyses (25 x 25 km & 50 x 50 km), reptile beta-diversity estimates are especially limited by the available data (Roll *et al.* 2017), although into the future the IUCN data also needs to be improved for amphibians and mammals.



Chloroceryle amazona

Contribution of protected areas and indigenous territories in the conservation of vertebrates in the Amazon basin

i. Number of expected species for four vertebrate groups in the protected areas and indigenous territories of the Amazon basin

Considering that 5,756 species of terrestrial vertebrates occur in the Amazon basin, we estimate that together National and Subnational Protected Areas (APs) and Indigenous Territories (TIs) host 5,449 amphibian, reptile, bird and mammal species. Birds have the highest number of expected species (2,454 species), followed by amphibians (1,188 species), then reptiles (947 species) and lastly mammals (860 species) (Figure 14).

We estimate that 5,183 of those species are found within the protected areas of the basin (Figure 14) including 2,386 species of birds, 1,058 species of amphibians, 893 species of reptiles and 846 species of mammals, showing a similar pattern to protected areas and indigenous territories combined.

The indigenous territories of the Amazon hold a total of 4,921 species of terrestrial vertebrates (Figure 14) including 2,334 species of birds, 939 species of amphibians, 848 species of reptiles and 800 species of mammals.

The existence of protected areas and indigenous territories is

fundamental for effective biodiversity conservation (Maxwell *et al.* 2016; Schleicher *et al.* 2019), as they mitigate against the major threats of habitat destruction and contamination.

The quantity of terrestrial vertebrate species expected to occur in Protected Areas and Indigenous Territories in the Amazon basin by country ranges from 1,160 to 3,128 species (Figure 15). In general, high numbers of species are protected within the conservation units of all countries, especially Peru (3,128 species), Brazil (2,589 species), Bolivia (2,364 species), and Ecuador (2,263 species), while other countries (Venezuela, Guyana, Suriname and French Guiana), protect between 1,160 and 1,667 species in their conservation units (Figure 15).

National and subnational protected areas in the Amazon basin protect 2,863 species in Peru, 2,495 species in Brazil, 2,342 species in Bolivia, 2,097 species in Colombia, 2,202 species in Ecuador 1,643 species in Venezuela, 1,296 species in Guyana, 1,180 species in Suriname and 1,157 species in French Guiana (Figure 15).

Indigenous territories contain between 1,132 species of terrestrial vertebrates in French Guiana and 3,038 species in Peru (Figure 15). In general, species numbers within indigenous territories in each country, present similar patterns to indigenous territories and protected areas combined, with Peru, Brazil, Ecuador, Colombia and Bolivia, having the highest numbers. It is also worth highlighting that the indigenous territories of Colombia,

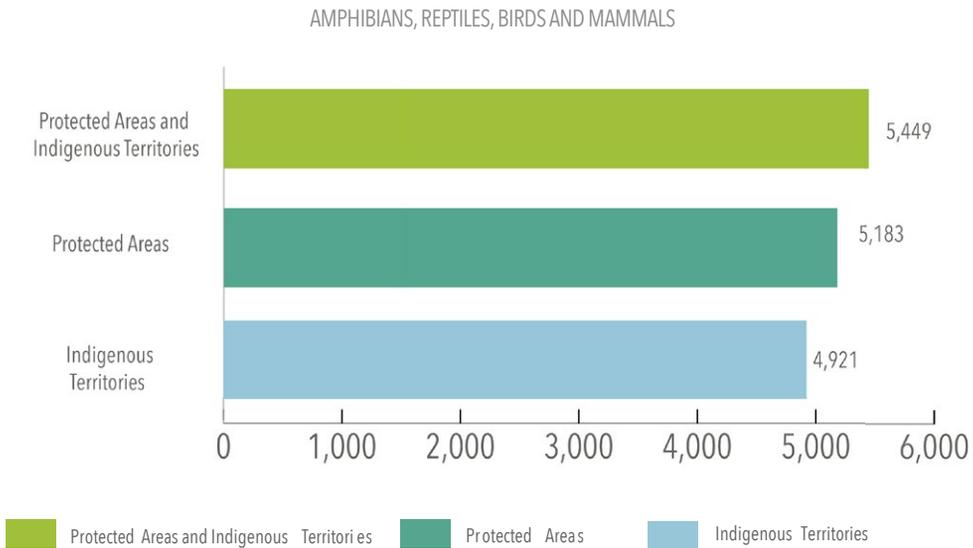
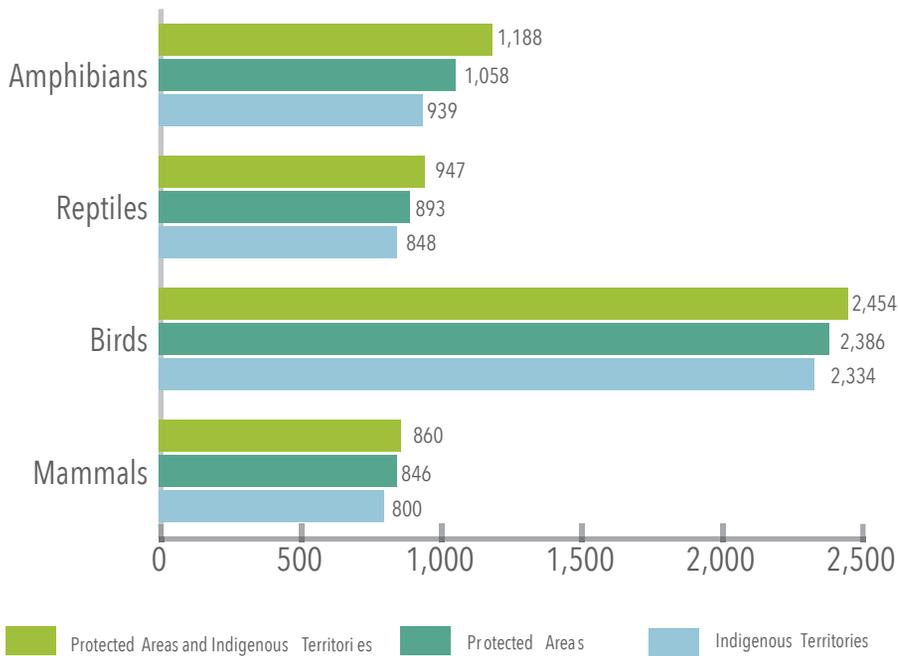


Figure 14 : Estimated number of terrestrial vertebrate species in conservation units (Protected Areas, Indigenous Territories, and both categories combined)



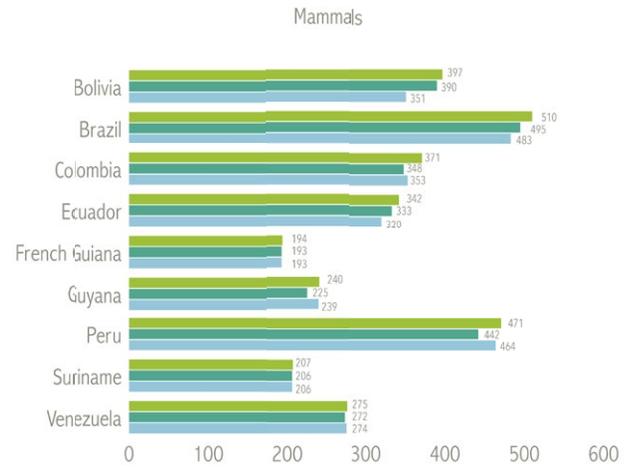
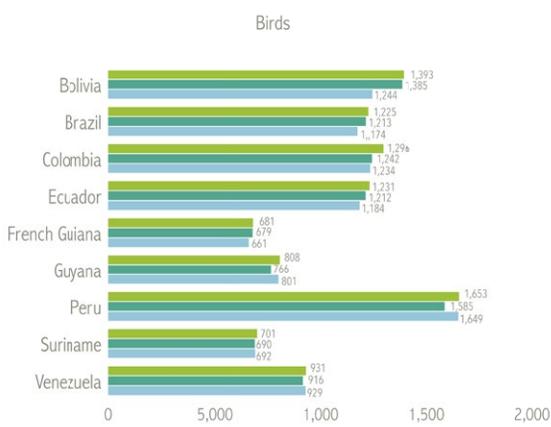
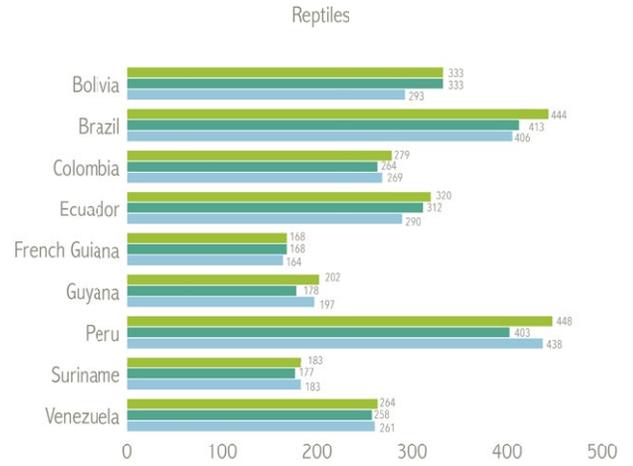
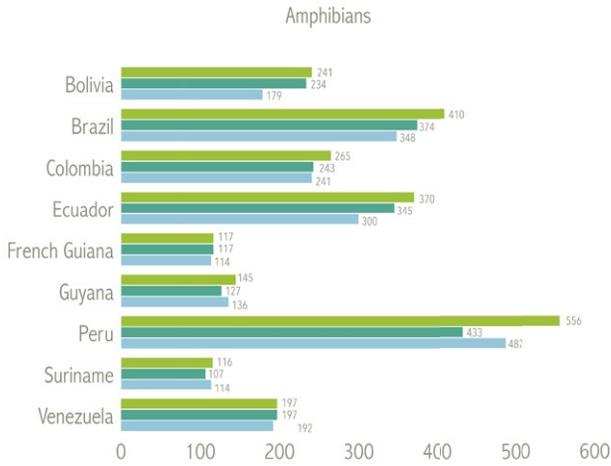


Guyana, Peru, Suriname and Venezuela hold more species than the protected areas in those countries (Figure 15).

Birds have the highest number of species within the protected areas and indigenous territories of the Amazon in all countries, ranging between 681 species in French Guiana and 1,653 species in Peru (Figure 15), with higher numbers in Bolivia, Colombia, Ecuador and Brazil, and less than 931 species in other countries. This pattern is typical for each vertebrate group with most reptile species in Brazil (444 species) and Peru (448 species), and most amphibians in Peru (547 species), Brazil (410 species) and Ecuador (370 species).

Protected areas and indigenous territories harbor most mammal species in Brazil (510 species), Peru (471 species) and Bolivia (397 species). Again, surprisingly indigenous territories harbor more mammal species than protected areas in Peru, Colombia, Venezuela and Guyana.

In general, protected areas protect more terrestrial vertebrate species than indigenous territories (Figure 15) with more species in countries with most Amazonian area like, Brazil, Bolivia and Colombia. Nevertheless, indigenous territories in Ecuador protect more amphibian and reptile species than protected areas. Indeed for reptiles this is the case in five of the nine countries. For birds, Indigenous Territories are potentially more important than Protected Areas in four countries: Peru, Venezuela, Guyana and Suriname (Figure 15). Here it is important to note that according to RAISG (2019) Protected Areas cover 11.9% (930,000 km²) of the Amazon, whereas Indigenous Territories cover 28.1% (2,190,000 km²).



■ Protected Areas and Indigenous Territories
 ■ Protected Areas
 ■ Indigenous Territories

Figure 15: Estimated number of terrestrial vertebrate species in conservation units (Protected Areas, Indigenous Territories, and both categories combined) by country.

Amphibians, reptiles, birds and mammals

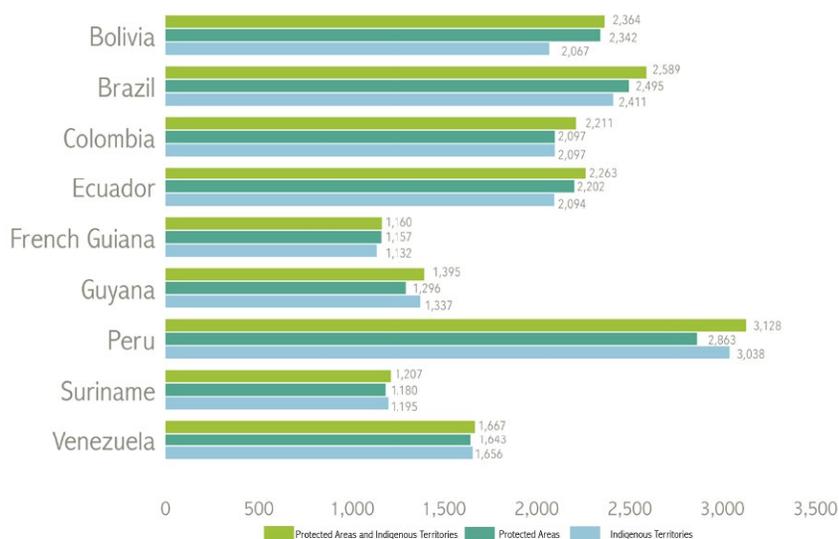


Figure 15 (cont.): Estimated number of terrestrial vertebrate species in conservation units (Protected Areas, Indigenous Territories, and both categories combined) by country.

ii. Representativeness of vertebrate species in Protected Areas and Indigenous Territories in the Amazon basin

We estimate that 5,449 species of amphibians, reptiles, birds and mammals are found within the National and Subnational Protected Areas (APs) and Indigenous Territories (TIs) of the Amazon basin, representing 94.67% of all terrestrial vertebrates in the Amazon (5,756 species), 53.91% of South America's (10,108 species) and 14.92% of the world's terrestrial vertebrates (36,513 species) (Figure 16). Together the conservation units protect more than 94% of the Amazon species of combined vertebrate group: 98.4% of mammals, 98.08% of birds, 91.94% of reptiles and 88% of amphibians (Figure 19).

The National and Subnational Protected Areas of the Amazon collectively protect 5,183 species of amphibians, reptiles, birds

and mammals, representing 90.05% of all Amazonian species for these groups and more than 50% of South American species (Figure 16). Collectively, protected areas harbor 96.8% of mammals, 95.36% of birds, 78.37% of amphibians and 86.7% of reptiles found in the Amazon basin (Figure 16). This data demonstrates that collectively the protected areas of the Amazon protect the vast majority of vertebrate biodiversity. Indeed, the protected area systems of the Amazon basin were developed with the implicit objective of protecting all Amazonian species (Schulman *et al.* 2007), which has become a more realistic goal given the recent tendency to expand the number of protected areas (Sala *et al.* 2000). Pringle (2017) suggests that despite management efforts many Protected Areas are poorly managed and ecologically damaged, often due to land titling conflicts and political corruption (Schleicher *et al.* 2019), or related to the time

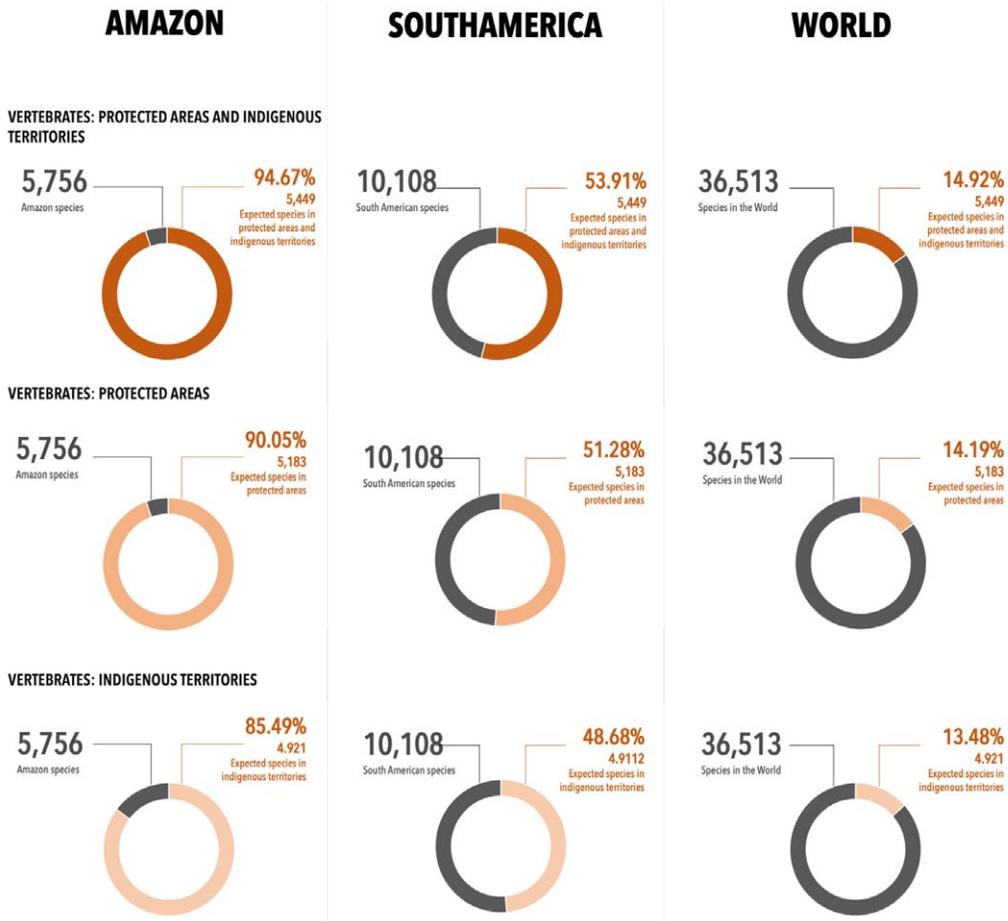


Figure 16: Representativeness of vertebrate diversity in conservation units: 1) Protected Areas and Indigenous Territories combined, 2) Protected Areas, 3) Indigenous Territories (compared with the number of species in the Amazon basin, South America and the world).

since their creation (Oliveira *et al.* 2017). Nevertheless, Schleicher *et al.* (2019) demonstrated that protected area implementation, especially stricter categories, help to reduce deforestation and degradation rates, directly attributable to control, vigilance and management, and other important factors.

The Indigenous Territories of the Amazon are also important for biodiversity conservation harboring 4,921 amphibian, reptile, bird and mammal species, representing 85.49% of the Amazon's, 48.68% of South America's and 13.48% of the world's

terrestrial vertebrate species (Figure 16). The representativeness analysis for each taxonomic group in indigenous territories indicate they are protecting 2,334 birds, 939 amphibians, 848 reptiles and 800 mammals, representing 69.56% of Amazonian amphibians, 82.33% of reptiles, 93.29% of birds, and 91.53% of mammals. Thus, 14.51% of vertebrate species are not expected in Indigenous Territories, and 9.95% of vertebrate species are not expected in Protected Areas, but amazingly only 5.33% of Amazonian vertebrates are not expected to occur in existing Protected Areas or Indigenous Territories. The Protected Areas

and Indigenous Territories cover 28% and 23.4% of the Amazon which covers 8,475,046 km² (RAISG 2019), and these units are evidently crucial for global biodiversity conservation.

Terrestrial vertebrate representativeness by country provides another lens with which to examine the effectiveness of the conservation units in the Amazon. For example, Protected Areas and Indigenous Territories in most countries contain more than 70% of the Amazonian species in each country (Figure 17), especially in the smaller countries such as Suriname (98.69%), Guyana (98.31%) and French Guiana (96.11%) that are entirely found within the Amazonian basin (RAISG 2019). The Guinean Shield has a large quantity of endemic species and encouragingly almost all of them are found within at least one conservation unit. This situation holds true when analyses are broken down for

each vertebrate group, for example, almost 100% of amphibian, reptile and mammal species in Suriname and French Guiana are found within Protected Areas and Indigenous Territories (Figure 18). Conservation units in Guyana protect 100% of bird species, whereas Suriname units protect 98% of birds, and in French Guiana units protect 94% of birds (Figure 18). This is especially impressive given the relatively small areas covered by Protected Areas (10,357 to 61,794 km²) and Indigenous Territories (7,068 to 31,671 km²) as compared to other countries, although Protected Areas cover 73.4% of French Guiana (RAISG 2019). These results suggest that protected area design has been extremely effective, complimented by commitments to indigenous people (RENFORESAP 2018). Indeed, French Guiana and Suriname have a high number of stricter protection Protected Areas, and in Suriname 72,000 km² of pristine tropical

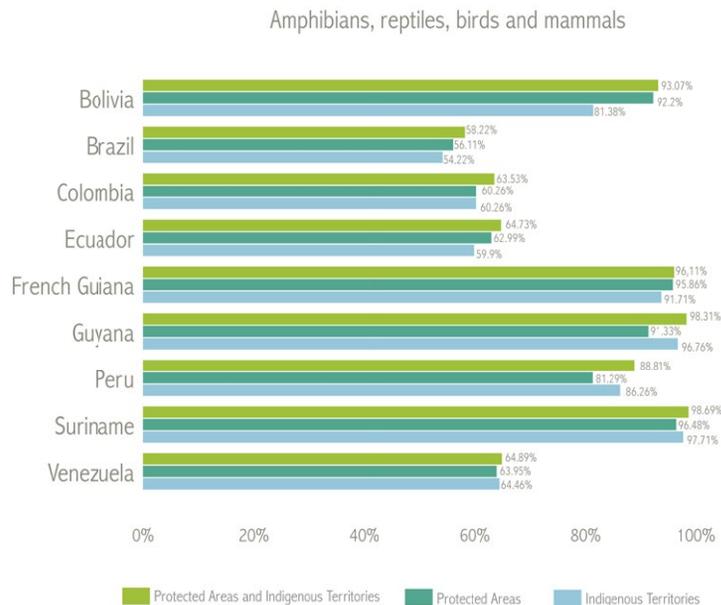


Figure 17. Representativeness of vertebrate diversity in conservation units by country for Protected Areas and Indigenous Territories combined, Protected Areas and Indigenous Territories (compared with the total number of vertebrate species by country).

forest were planned for conservation efforts (RedParques 2018), as well as a project to integrate the countries of the Guinean Shield improving management capacities, so as to increase the resilience of the forest and livelihood options of local people in a context of global climate change (RENFORESAP 2018).

The western Amazon in Bolivia, Colombia, Ecuador, Peru, and part of Brazil has the highest concentrations of terrestrial vertebrates in South America, and also have high percentages of this biodiversity expected to occur within Protected Areas and Indigenous Territories (Figure 17). Notably in Bolivia 93.07% of Amazonian terrestrial vertebrate species are found in these conservation units and in Peru this figure is 88.81%. This breakdown holds true for most of the individual vertebrate groups with 97% of Amazonian birds expected to occur in at least one Protected Area or Indigenous Territory in Bolivia and 88% for Peru (Figure 18). Similarly, 92% of Amazonian mammals are expected to occur in at least one Protected Area or Indigenous Territory in Bolivia and 91% for Peru. For amphibians 86% and reptiles 86% of Amazonian species are expected to occur in at least one Protected Area or Indigenous Territory in Bolivia, and in Peru 89% of amphibians and 90% of reptiles. Together these figures suggest that collectively the protected area and indigenous territory capital in the Bolivian and Peruvian Amazon have been placed in a strategic and efficient manner.

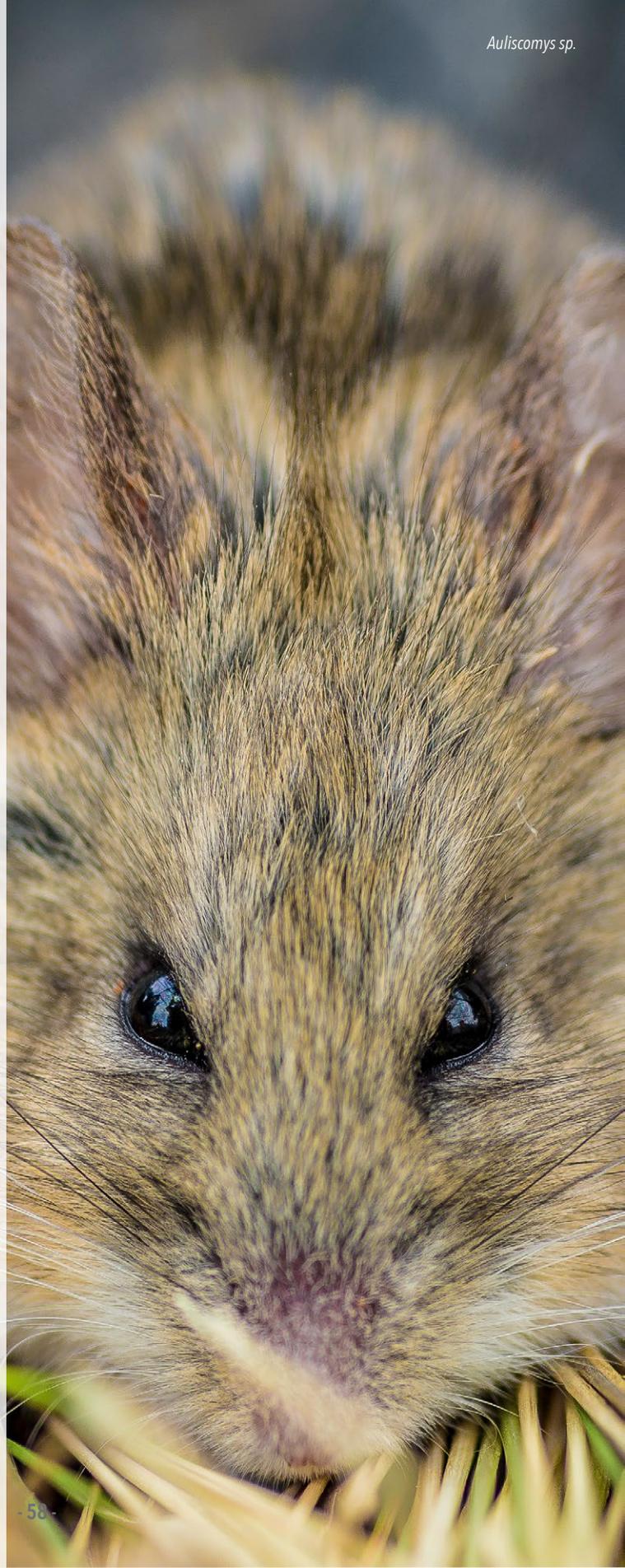




Figure 18: Representativeness of amphibians, reptiles, birds and mammals diversity in conservation units for Protected Areas and Indigenous Territories combined, Protected Areas and Indigenous Territories (compared with the total number of vertebrate species by country).

Peru has recently increased the number and area in conservation units (RENFORESAP 2018), with a relatively large area in Protected Areas (202,865 km²) and the largest number of Indigenous Territories in the Amazon covering 322,255 km² (RAISG 2019). Gullison and Hardner (2018) attribute this increase to significant political will and the correct designation of land towards conservation, along with improved capacity in governmental and non-governmental actors. In Bolivia, Protected Areas cover 207,227 km² and Indigenous Territories 187,431 km² (RAISG 2019), with relatively few, yet large, National Protected Areas, although few have been created since the end of the 20th Century. Non-governmental organizations have been especially important in providing technical support to Indigenous Territories, for example, the Tacana and Tsimane' have developed unparalleled capacity in the Amazon for the successful and sustainable management of natural resources (Gullison & Hardner 2018).

Thanks to the Protected Areas and Indigenous Territories deforestation and forest degradation rates in Peru have been relatively low (Blackman *et al.* 2017, Schleicher *et al.* 2017), further supporting the regional trend of low deforestation rates within Indigenous Territories (RAISG 2016; Blackman *et al.* 2017), stressing their importance towards biodiversity conservation in the Amazon. Bolivia and Peru have increased formally titled Indigenous Territory coverage, with more expected to be formally



recognized in years to come (Gullison & Hardner 2018).

In contrast the representativeness values for Amazonian terrestrial vertebrates within Protected Areas and Indigenous Territories in Brazil, Colombia, Ecuador and Venezuela are significantly lower at less than 63.5% in Colombia, 64.8% in Venezuela, 64.7% in Ecuador and lowest in Brazil at 58.2% (Figure 17). This analysis also contrasts with the total number of species in Protected Areas and Indigenous Territories in Brazil, which is very high, especially for reptiles and mammals (Figure 15). The Brazilian Amazon covers 5,239,647 km²

representing 61.5% of the country (RAISG 2019), including by far the greatest portion of the Amazon basin, and with 19.8% or 1,037,074 km² dedicated to Protected Areas and 22.2% or 1,156,900 km² to Indigenous Territories. The overall size of the Amazon in Brazil may best explain the lower percentages of Amazonian biodiversity in protected areas, and this pattern holds true for the individual vertebrate groups, with extremes of just 37.14% of Amazonian amphibians in Brazil found within the Protected Areas and Indigenous Territories, and 52.86% of reptiles.

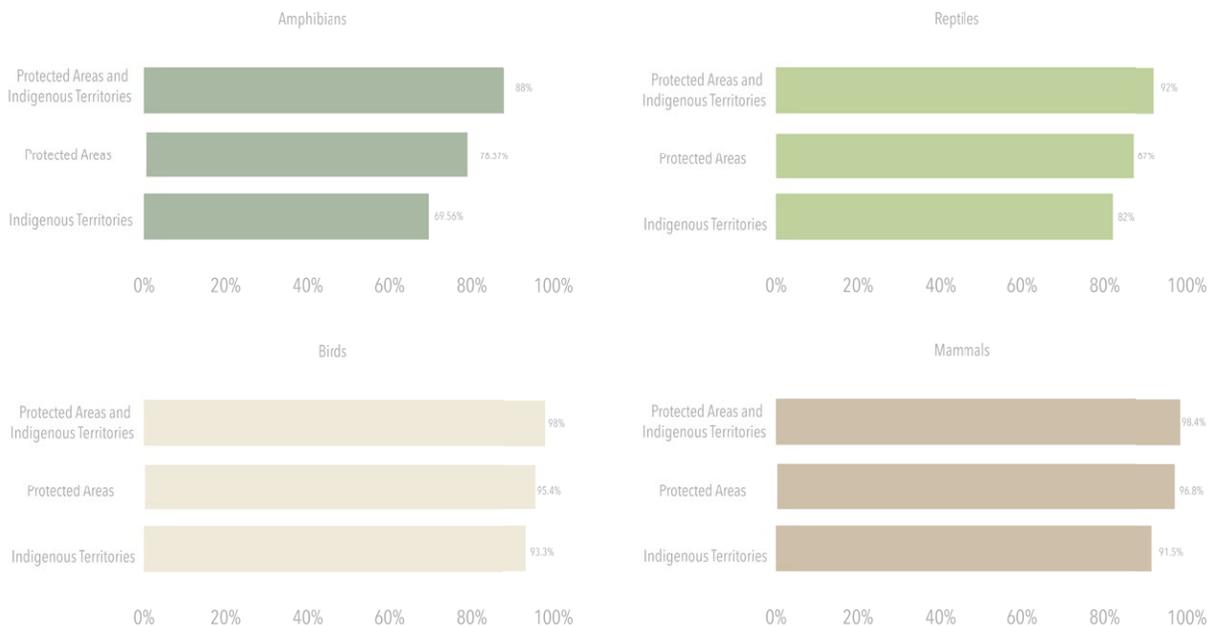


Figure 19: Representativeness of amphibians, reptiles, birds and mammals in the Amazon basin in Protected Areas (National and Subnational), Indigenous Territories and Protected Areas and Indigenous Territories combined.

Possibly the high deforestation rates in large parts of the Brazilian Amazon (INPE 2012; Oliveira *et al.* 2017; González *et al.* 2018; Gomes *et al.* 2019) may have limited protected area creation and indigenous territory recognition, for example, in southeastern Amazonian Brazil along the Arc of Deforestation. Furthermore, deforestation projections into the future in central and eastern Amazonian Brazil are significant, as are the risks of drought (Soares *et al.* 2006; Malhi *et al.* 2008; Gomes *et al.* 2019).

Mammals and birds have the lowest levels of representativeness in Protected Areas and Indigenous Territories of Venezuela, Brazil, Colombia and Ecuador: 66% of Amazonian birds in Venezuela, 68% in Brazil and Colombia, and 73% in Ecuador, and 86% of Amazonian mammals in Ecuador, 72% in Venezuela and 74% in Brazil and Colombia. The Protected Areas and Indigenous territories of Ecuador protect 64% of the country's Amazonian reptile and amphibians. Eastern Ecuador and northern Peru are the only parts of South America where the centers of species richness overlap for the four vertebrate groups (Bass *et al.* 2010).

The representativeness of Amazonian vertebrates in Venezuela is also striking in a country with large extensions of Protected Areas (249,109 km²) and Indigenous Territories (326,521 km²), larger than Bolivia and Peru (RAISG 2019). Colombia also has relatively low representativeness values and the third most endemic species (Swenson 2001), suggesting a need for a new phase

of protected area creation in the Colombian Amazon. However, the possibilities for new protected area creation in Ecuador, Venezuela, Colombia and Brazil maybe limited by a proliferation of threats such as hydroelectric dams, mining, mechanized agriculture and intensive livestock expansion, hydrocarbon exploitation, or other extractive industries (Finer *et al.* 2008; Kröger & Lalander, 2016; Latrubesse *et al.* 2017; González *et al.* 2018). For example, the renowned Yasuni National Park is the largest Protected Area in the Ecuadorian Amazon covering 14% of the Ecuadorian Amazon, whereas hydrocarbon concessions cover 79% (Bass *et al.* 2010). The western Amazon is also threatened by hydrocarbon extraction in Colombia, Peru, Brazil and Bolivia (Finer *et al.* 2008).

Several authors have argued for the expansion of the Protected Area and Indigenous Territory capital in the Amazon to increase representativeness, protect significant portions of threatened and endemic species, improve climate change adaptation, increase connectivity and landscape permeability for species or ecosystems through the creation of corridors or restoration of fragments, or promote sustainable use of land and resources to ensure biological flow (Da Silva *et al.* 2005; Schulman *et al.* 2007; Gonzalez *et al.* 2018; RENFORESAP 2018; Metzger *et al.* 2019). The lower levels of representativeness for amphibians and reptiles is explained by their relatively small distributional ranges,

especially amphibians, which results in lower concentrations at few places (Jenkins *et al.* 2013), and it is therefore difficult to capture total diversity in Protected Areas.

Nevertheless, the National Protected Areas of the nine countries of the Amazon basin have the highest representativeness of species for the four vertebrate groups (Figure 18). Protected Areas were more important than Indigenous Territories for amphibians in all nine countries. Nevertheless, six countries (Peru, Guyana, French Guiana, Colombia, Suriname and Venezuela) have higher mammal representativeness in Indigenous Territories, three countries (Peru, Guyana and Suriname) have higher reptile representativeness in Indigenous Territories, and four countries (Peru, Guyana, Venezuela and Suriname) have higher bird representativeness in Indigenous Territories.

Beyond the examples in Peru and Bolivia, there are several other recent studies that demonstrate that Indigenous Territories and sustainable management efforts reduce deforestation rates and protect high levels of biodiversity (Nepstad *et al.* 2006; Schleicher *et al.* 2017; Schuster *et al.* 2019). Indeed, indigenous people are actively defending their lands from incursions from third parties including agriculture (Nepstad *et al.* 2006). For example, the Kayapo people have successfully defended their ancestral lands from colonists and cowboys trying to invade their territory (Zimmerman *et al.* 2001), maintaining deforestation rates close

to zero (Schwartzman *et al.* 2000; Zimmerman *et al.* 2001).

In part, the importance of the Indigenous Territories can be explained by the fact that they are more numerous than Protected (RAISG 2019), for example, in Brazil there are 140 Amazonian Protected Areas, but more than 350 Indigenous Territories (RAISG 2019). Peru has more than 2,500 Indigenous Territories, although they tend to be rather small in comparison with those in other countries in the Amazon.



Complementarity analyses for species diversity in Amazon basin

The complementarity analysis for terrestrial vertebrates in the Amazon basin revealed that from the 254 cells in the region, a total of 112 cells would be necessary to include 100% of Amazonian amphibian species, 87 cells for 100% of Amazonian reptiles, 66 cells for 100% of Amazonian birds, and 46 cells for Amazonian mammals (Figure 20). The highlighted cells in the complementarity analysis for terrestrial vertebrates are spread amongst the nine countries of the Amazon basin, with cells running along the eastern slopes of the Andes mountain chain, as well as the mountainous zone of the northern Amazon, and lowland floodplain cells in the western, southern, eastern and central Amazon. Although this is the first study for the entire Amazon basin, many of the areas highlighted as important in this complementarity analysis were highlighted in our alpha-diversity analysis, as well as in previous studies (Duellman 1999; Ceballos & Ehrlich 2006; Jenkins *et al.* 2013; Roll *et al.* 2017; González *et al.* 2018).

A comparison of the selected cells in comparison with the distribution of National Protected Areas, Subnational Protected Areas and Indigenous Territories the majority of these complementarity cells when Protected Areas in general and

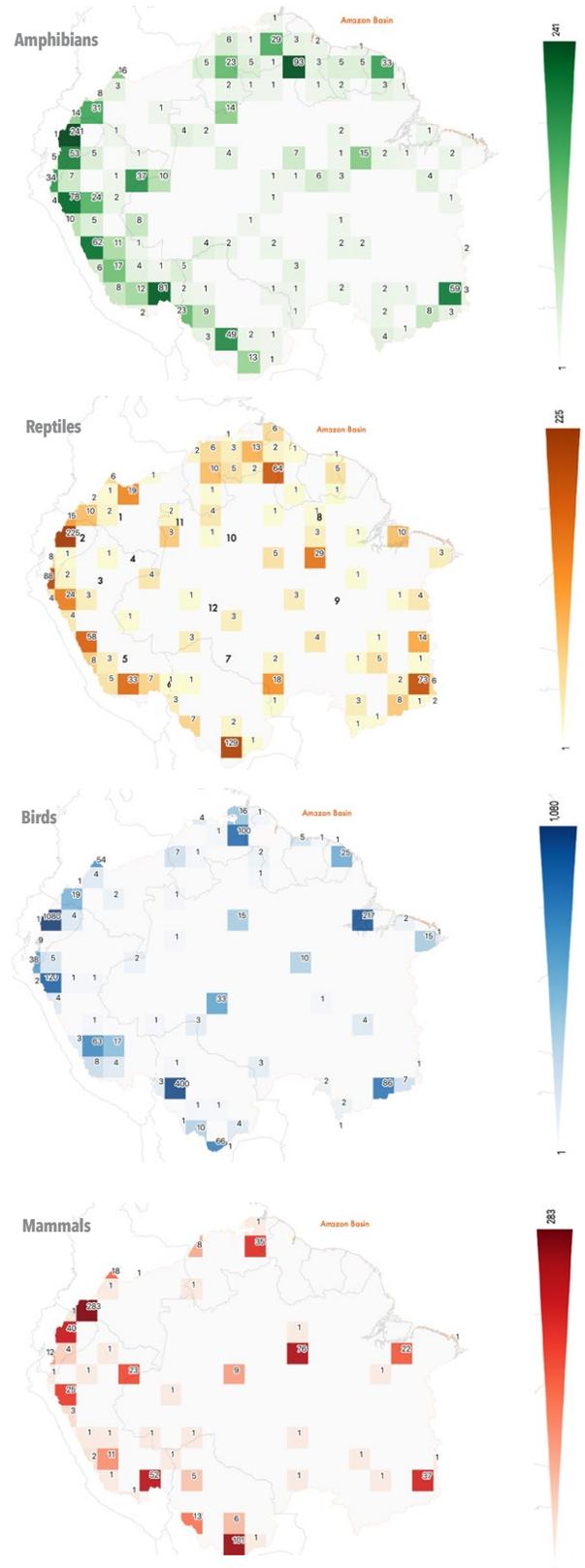
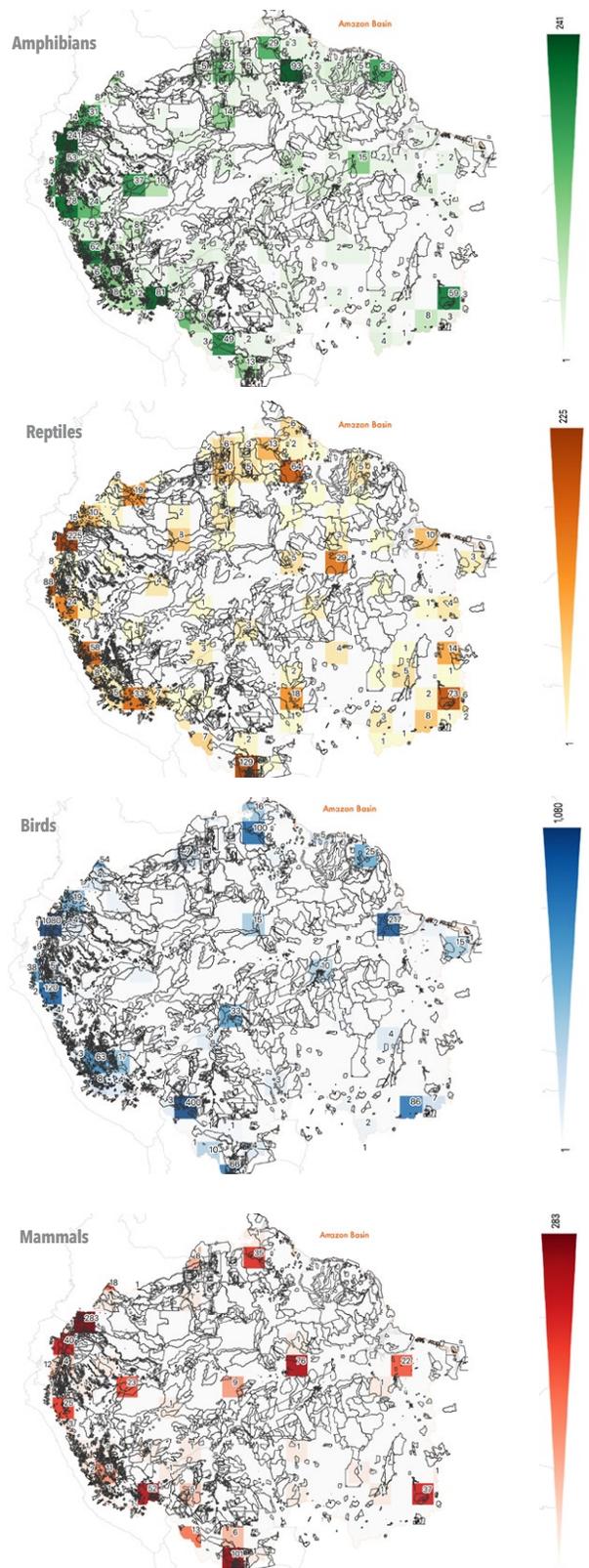


Figure 20: Complementarity analysis and efficient cell selection for maximum species richness for amphibians, reptiles, birds and mammals in the Amazon basin.

Indigenous Territories are combined (Figure 21), once again highlighting the effectiveness of existing conservation units in biodiversity conservation. For each vertebrate group a few cells only partially overlapped with Protected Areas and Indigenous Territories (Figure 21), for example, five cells for amphibians (93, 81, 59, 15, 10), six cells for reptiles (65, 8, 7, 4, 2, 1), six cells for birds (400, 120, 100, 86, 12, 10), and five cells for mammals (89, 76, 26, 22, 13).

Comparing the highest value complementarity cells for each vertebrate group with the distribution of Protected Areas (National and Subnational) and then separately with the distribution of Indigenous Territories (Figure 22), showed that Protected Areas protect a greater quantity of priority cells than Indigenous Territories. For example, for amphibians, for 16 priority cells in southeastern and southern Amazonia there is no overlap with Indigenous Territories, whereas 10 priority cells in northern, southeastern and western Amazonia have no overlap with Protected Areas. For reptiles, birds and mammals there are up to seven priority cells that do not overlap with Protected Areas, as compared to between 7 and 15 cells that do not overlap with Indigenous Territories, principally in northern, western and southeastern Amazonia (13 priority bird cells with no overlap with Indigenous Territories and

Figure 21: Complementarity analysis and efficient cell selection for maximum species richness for amphibians, reptiles, birds and mammals in relation to the distribution of all Protected Areas and Indigenous Territories in the Amazon basin.



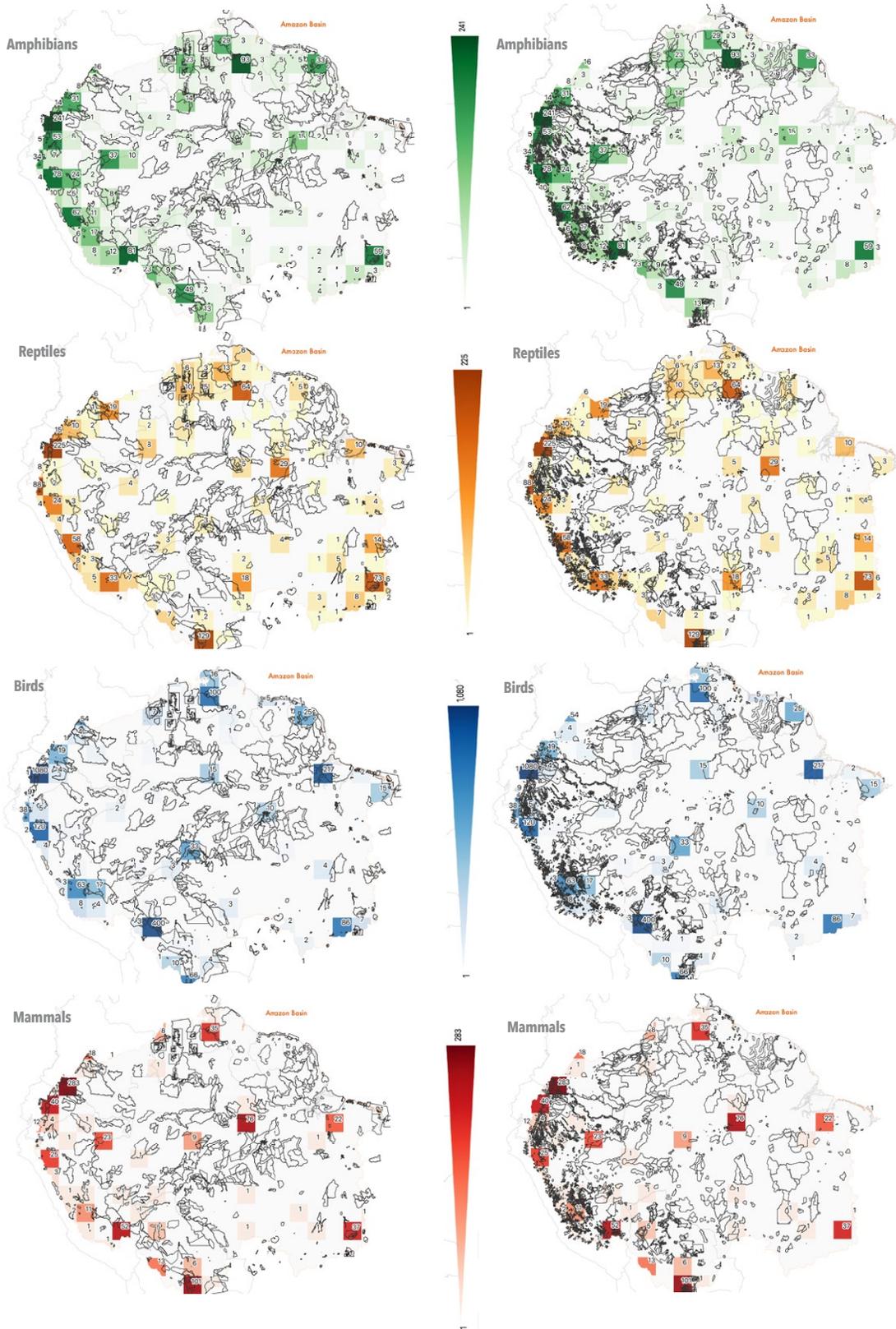


Figure 22: Complementarity analysis and efficient cell selection for maximum species richness for amphibians, reptiles, birds and mammals in relation to the distribution of National Protected Areas, Subnational Protected Areas and Indigenous Territories in the Amazon basin.

seven not in Protected Areas; 15 priority reptile cells with no overlap with Indigenous Territories and seven not in Protected Areas; seven priority mammal cells not in Protected Areas and Indigenous Territories). A closer look at Colombia and Ecuador highlights the complementarity that the combination of Protected Areas and Indigenous Territories play in the conservation of terrestrial vertebrate diversity in the Amazon, where Protected Areas do not completely cover all of the highest priority complementarity cells, but adding in Indigenous Territories provides significantly better coverage (Figures 21-22). This pattern is relevant across the basin and is also reflected in our representativeness analyses (Figures 16-19).

An analysis of the contribution of National Protected Areas versus Subnational Protected Areas and Indigenous Territories revealed that National Protected Areas harbored most terrestrial vertebrate species (5,103 species), and the Subnational Protected Area and Indigenous Territory categories added further species not found in the National Protected Areas, 94 and 252 species respectively (Table 6).

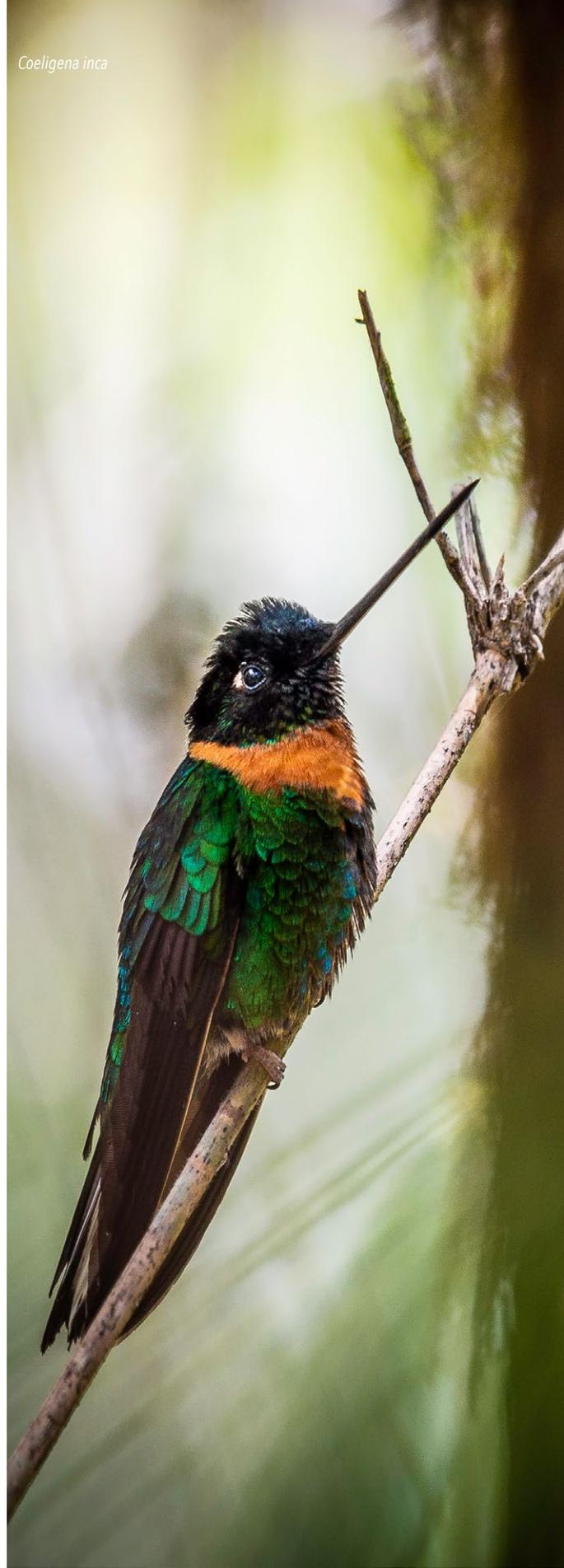


Table 6. Cumulative complementarity analysis for amphibians, reptiles, birds and mammals in National Protected Areas, Subnational Protected Areas and Indigenous Territories in the Amazon basin.

Group	Spatial Unit Category	Number of Additional Species	Cumulative Species Richness
Amphibians	National Protected Areas	1,013	1,013
	Subnational Protected Areas	45	1,058
	Indigenous Territories	130	1,188
Reptiles	National Protected Areas	870	870
	Subnational Protected Areas	23	893
	Indigenous Territories	54	947
Birds	National Protected Areas	2,386	2,386
	Subnational Protected Areas	14	2,400
	Indigenous Territories	54	2,454
Mammals	National Protected Areas	834	834
	Subnational Protected Areas	12	846
	Indigenous Territories	14	860
Vertebrates	National Protected Areas	5,103	5,103
	Subnational Protected Areas	94	5,197
	Indigenous Territories	252	5,449

Whilst complementarity analyses serve as a useful baseline with which to establish conservation priorities into the future, they do not reflect ecological processes, or inform us about minimum viable populations of species (Jacinto-Flores *et al.* 2017). Complementarity analyses prioritize areas where many species overlap, sometimes considered ecological transition zones (Lombard 1995), and therefore, at least for a portion of species, perhaps not priority areas from a minimum viable population perspective, although this debate is ongoing (Araújo 2002; Kati *et al.* 2004).



CONCLUSIONS

To conclude, the Protected Areas and Indigenous Territories of the Amazon cover almost half of the basin, representing a magnificent and globally unprecedented conservation achievement over the last three decades. This study underlines this poorly recognized contribution by demonstrating that from the perspective of biodiversity conservation, collectively this existing conservation collateral is estimated to include populations of almost 95% of terrestrial vertebrate species of the Amazon, 54% of terrestrial vertebrate species in South America and 15% of terrestrial vertebrate species worldwide. National and Subnational Protected Areas alone are expected to harbor 5,183 species of terrestrial vertebrates, amounting to 90% of terrestrial vertebrates in the Amazon. Similarly, indigenous Territories are expected to harbor 4,921 terrestrial vertebrate species, representing 85.49% of terrestrial vertebrates of the Amazon.

The analysis of representativeness at the country level also reveals that Protected Areas and Indigenous Territories in most Amazonian nations would house more than 70% of vertebrate species diversity, further underlining that the collective of Protected Areas and Indigenous Territories are located in strategic and efficient conservation sites. These analyses stress the importance of the sustainable management Protected Areas and Indigenous Territories into the future.

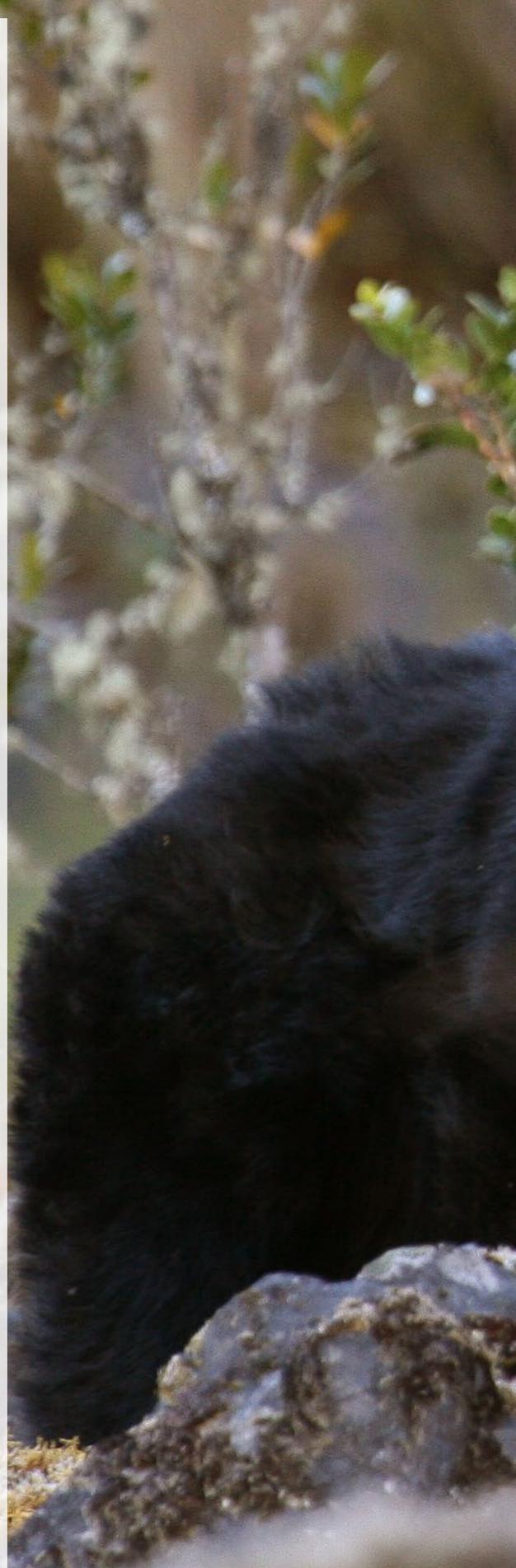
Overall these analyses underline the commitment that Amazonian nations have already made towards biodiversity conservation in the Amazon through the formal designation of Protected Areas across the basin, and the recognition of large areas as Indigenous Territories. Nevertheless, most of these conservation units are chronically underfunded and many are under threat from the development of the Amazon. Furthermore, recent studies suggest that between 60% and 80% of the Amazon's original forest cover must be retained in order to retain the climate regulation functions for the region (Lovejoy & Nobre 2018). Thus, these results are also bittersweet. The protection of almost 95% of terrestrial vertebrate biodiversity is truly extraordinary, however, in the face of threats and the global climate change challenge in order to ensure this accomplishment a sustainable finance stream for the Protected Areas and Indigenous Territories of the Amazon must be established, as well as further mechanisms to increase the percentage of original forest cover under protection.



RECOMMENDATIONS FOR FUTURE STUDIES

Evaluations regarding the effectiveness of Protected Areas and Indigenous Territories in the Amazon, as well as the contribution of the twelve conservation mosaics supported by the Gordon and Betty Moore Foundation, could be improved through the following actions:

- Given that the Amazon basin is the largest freshwater system in the world, it will be important to update our analyses to include fish as the fifth and final vertebrate group. This would provide further weight to these analyses as a unique and complete study of vertebrate diversity in the Amazon and would also allow the incorporation of further spatial lenses, in particular that of watersheds and basins. Given the ongoing advances in GIS and spatial data on Amazonian watersheds by the Amazon Waters Initiative in which WCS and the Gordon and Betty Moore Foundation have both been key players, it would seem logical to take advantage of that synergy and prioritize those studies as soon as possible. The very recent publications of a complete species list for Amazonian watersheds (Dagosta & De Pinna 2019), and patterns of fish diversity across basins (Oberdorff *et al.* 2019), would now allow us to adapt our methodologies to include fish in these analyses.
- A second priority would be to update our alpha, beta and gamma-diversity analyses for amphibians, reptiles, birds, mammals and the terrestrial vertebrates in general for the entire South America





continent which would further highlight our unique fine-scale analysis, provide geographic context regarding the importance of the Amazon basin, and identify biodiversity concentrations at the continental scale.

- Thirdly, we recommend an additional analysis concentrating on endemic species richness including representativeness and complementarity.
- A fourth future analysis should concentrate on identifying the most profitable areas for potential new protected area creation in the Amazon basin from the perspective of biodiversity conservation, both in terms of adding species protected within at least one Protected Area or Indigenous Territory, ensuring ecosystem coverage, and guaranteeing adequate local and regional connectivity.
- Fifthly, our database would permit analyses to identify specific variables regarding environmental heterogeneity as predictors of beta-diversity for amphibians, reptiles, birds and mammals at the different analysis scales considered herein. These analyses may help identify the possible impacts of climate change on populations of these vertebrate species.

- Another pathway to improve future analyses, would be to use confirmed locality information to develop predictive distribution models for species for which current IUCN information and distributions from other sources (Roll *et al.* 2017) are considered weak, particularly for some amphibian, reptile and mammal species.
- These analyses could also be run for protected areas systems as official units of management, for example, all the government run areas in the Peruvian Amazon, or a regional network of conservation areas in Loreto, or the protected areas of Colombia.
- Finally, apart from the Protected Areas, Indigenous Territories and conservation mosaics supported by the Gordon and Betty Moore Foundation, it would also be interesting to include the biodiversity conservation contribution of other types of conservation unit such as forestry concessions or RAMSAR sites in the Amazon basin.



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Appendix

Indigenous Territories and protected areas in the conservation mosaics supported by the Gordon and Betty Moore Foundation. Category: IL= Indigenous Land; SP= Strict Protection; SU= Sustainable Use

Conservation unit Name	Type	Category	Mosaic	Country	Hectares
Ampiyacu Native Communities	Indigenous Land	IL	Ampiyacu	Peru	367.459
Ampiyacu-Apayacu	State Park	SU	Ampiyacu	Peru	435.465
Bajo Putumayo	State Park	SU	Ampiyacu	Peru	370.606
Majijuna Kichwa	State Park	SU	Ampiyacu	Peru	392.272
Medio Putumayo	State Park	SU	Ampiyacu	Peru	370.606
Yaguas	National Park	SP	Ampiyacu	Peru	872.136
Nhamunda Mapuera	Indigenous Land	IL	Calha Norte	Brazil	1.050.000
Paru d'Este	Indigenous Land	IL	Calha Norte	Brazil	1.535.500
Trombetas Mapuera	Indigenous Land	IL	Calha Norte	Brazil	3.971.000
Tumucumaque	Indigenous Land	IL	Calha Norte	Brazil	1.535.500
Ti Kaxuyana-Tunayana	Indigenous Land	IL	Calha Norte	Brazil	
Faro	State Forest	SU	Calha Norte	Brazil	635.936
Grao Para	Ecological Station	SP	Calha Norte	Brazil	4.245.819
Jari	Ecological Station	SP	Calha Norte	Brazil	227.126
Maicuru	Biological Reserve	SP	Calha Norte	Brazil	1.173.217
Paru	State Forest	SU	Calha Norte	Brazil	3.612.914
Trombetas	State Forest	SU	Calha Norte	Brazil	3.172.978
Aguas Negras	Indigenous Land	IL	Chiribiquete-Caqueta	Colombia	17.818
Anduche de Andoque	Indigenous Land	IL	Chiribiquete-Caqueta	Colombia	60.350
Chiribiquete	National Park	SP	Chiribiquete-Caqueta	Colombia	2.792.233
Coropoya	Indigenous Land	IL	Chiribiquete-Caqueta	Colombia	3.878
El Quince	Indigenous Land	IL	Chiribiquete-Caqueta	Colombia	1.278
El Triunfo	Indigenous Land	IL	Chiribiquete-Caqueta	Colombia	194
Guayabal	Indigenous Land	IL	Chiribiquete-Caqueta	Colombia	610
Huitora	Indigenous Land	IL	Chiribiquete-Caqueta	Colombia	64.890
Jerico - Consaya	Indigenous Land	IL	Chiribiquete-Caqueta	Colombia	8.364
La Teofila	Indigenous Land	IL	Chiribiquete-Caqueta	Colombia	1.684
Llanos del Yari	Indigenous Land	IL	Chiribiquete-Caqueta	Colombia	199.867
Mesai	Indigenous Land	IL	Chiribiquete-Caqueta	Colombia	7.114
Miriti Parana	Indigenous Land	IL	Chiribiquete-Caqueta	Colombia	1.549.277
Monochoa	Indigenous Land	IL	Chiribiquete-Caqueta	Colombia	265.375
Niñeras	Indigenous Land	IL	Chiribiquete-Caqueta	Colombia	2.496
Nonuya de Villazul	Indigenous Land	IL	Chiribiquete-Caqueta	Colombia	265.976
Paez del Libano	Indigenous Land	IL	Chiribiquete-Caqueta	Colombia	442
Porvenir- Kananguchal	Indigenous Land	IL	Chiribiquete-Caqueta	Colombia	530
Puerto Naranjo - Peñas Rojas - Cuerazo El Diamante	Indigenous Land	IL	Chiribiquete-Caqueta	Colombia	2.914
Puerto Sabalo y Los Monos	Indigenous Land	IL	Chiribiquete-Caqueta	Colombia	216.291
San Miguel	Indigenous Land	IL	Chiribiquete-Caqueta	Colombia	173
Yaigoje-Apaporis	National Park	SP	Chiribiquete-Caqueta	Colombia	1.060.082

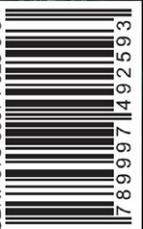
Conservation unit Name	Type	Category	Mosaic	Country	Hectares
Igarape Lourdes	Indigenous Land	IL	Itenez-Rondonia	Brazil	186.000
Pacaas Novos (TI)	Indigenous Land	IL	Itenez-Rondonia	Brazil	280.000
Rio Guapore	Indigenous Land	IL	Itenez-Rondonia	Brazil	116.000
Roosevelt	Indigenous Land	IL	Itenez-Rondonia	Brazil	230.826
Sete de Setembro	Indigenous Land	IL	Itenez-Rondonia	Brazil	297.870
Uru-Eu-Wau-Wau	Indigenous Land	IL	Itenez-Rondonia	Brazil	1.867.120
Zoro	Indigenous Land	IL	Itenez-Rondonia	Brazil	355.789
Guajara-Mirim	State Park	SP	Itenez-Rondonia	Brazil	216.568
Itenez	State Forest	SU	Itenez-Rondonia	Bolivia	1.389.025
Pacaas Novos	National Park	SP	Itenez-Rondonia	Brazil	769.801
Rio Cautario	Extractive Reserve	SU	Itenez-Rondonia	Brazil	220.218
Amana	Sustainable Development Reserve	SU	Lower Rio Negro	Brazil	2.313.000
Anavilhanas	National Park	SP	Lower Rio Negro	Brazil	350.018
Jau	National Park	SP	Lower Rio Negro	Brazil	2.272.270
Poranga-Conquista	Sustainable Development Reserve	SU	Lower Rio Negro	Brazil	76.936
Rio Negro	Sustainable Development Reserve	SU	Lower Rio Negro	Brazil	103.086
Rio Negro Setor Norte	State Park	SP	Lower Rio Negro	Brazil	257.422
Rio Negro Setor Sul	State Park	SP	Lower Rio Negro	Brazil	86.601
Unini	Extractive Reserve	SU	Lower Rio Negro	Brazil	833.352
Balata-Tufari	National Forest	SU	Madeira	Brazil	802.023
Canutama	State Forest	SU	Madeira	Brazil	150.589
Canutama (Resex)	Extractive Reserve	SU	Madeira	Brazil	197.986
Humaita	National Forest	SU	Madeira	Brazil	468.790
Igapo Acu	Sustainable Development Reserve	SU	Madeira	Brazil	394.622
Ituxi	Extractive Reserve	SU	Madeira	Brazil	776.940
Juma	Sustainable Development Reserve	SU	Madeira	Brazil	589.611
Água Preta/Inari	Indigenous Land	IL	Madeira	Brazil	139.763
Caititu	Indigenous Land	IL	Madeira	Brazil	308.062
Camicua	Indigenous Land	IL	Madeira	Brazil	58.159
Diahui	Indigenous Land	IL	Madeira	Brazil	47.354
Ipixuna	Indigenous Land	IL	Madeira	Brazil	215.362
Novo de Janeiro	Indigenous Land	IL	Madeira	Brazil	229.000
Seruini/Mariene	Indigenous Land	IL	Madeira	Brazil	144.971
Tenharim do Igarape Preto	Indigenous Land	IL	Madeira	Brazil	87.413
Tenharim Marmelos	Indigenous Land	IL	Madeira	Brazil	497.521
Matupiri	State Park	SP	Madeira	Brazil	513.747
Matupiri (RDS)	Sustainable Development Reserve	SU	Madeira	Brazil	179.083
Medio Purus	Extractive Reserve	SU	Madeira	Brazil	604.290
Piagacu Purus	Sustainable Development Reserve	SU	Madeira	Brazil	1.008.167
Rio Amapa	Sustainable Development Reserve	SU	Madeira	Brazil	216.109
Rio Madeira	Sustainable Development Reserve	SU	Madeira	Brazil	283.117
Tapaua	State Forest	SU	Madeira	Brazil	881.704

Conservation unit Name	Type	Category	Mosaic	Country	Hectares
Bahuaja Sonene	National Park	SP	Madidi-Tambopata	Peru	1.095.910
Ixiamas	State Forest	SU	Madidi-Tambopata	Bolivia	47.950
Leco Apolo	Indigenous Land	IL	Madidi-Tambopata	Bolivia	60.145
Los Amigos	Private Conservation Area	SU	Madidi-Tambopata	Peru	145.686
Madidi	National Park	SP	Madidi-Tambopata	Bolivia	1.266.333
Manuripi	State Park	SU	Madidi-Tambopata	Bolivia	743.171
Pilon Lajas	Indigenous Land	IL	Madidi-Tambopata	Bolivia	353.996
Tacana I	Indigenous Land	IL	Madidi-Tambopata	Bolivia	386.595
Tacana II	Indigenous Land	IL	Madidi-Tambopata	Bolivia	343.982
Tambopata	National Reserve	SU	Madidi-Tambopata	Peru	278.873
Alto Purus	National Park	SP	Upper Purus	Peru	2.501.793
Cazumba Iracema	Extractive Reserve	SU	Upper Purus	Brazil	730.794
Chico Mendes	Extractive Reserve	SU	Upper Purus	Brazil	970.570
Macaua	National Forest	SU	Upper Purus	Brazil	176.348
Manu	National Park	SP	Upper Purus	Peru	1.701.033
Madre de Dios	Indigenous Land	IL	Upper Purus	Peru	871.092
Mashco Piro	Indigenous Land	IL	Upper Purus	Peru	2.929
Murunahua	Indigenous Land	IL	Upper Purus	Peru	475.850
Purus	Indigenous Land	IL	Upper Purus	Peru	197.674
San Francisco	National Forest	SU	Upper Purus	Brazil	21.147
Alto Rio Negro	Indigenous Land	IL	Upper Rio Negro	Brazil	7.999.000
Medio Rio Negro I	Indigenous Land	IL	Upper Rio Negro	Brazil	1.776.140
Medio Rio Negro II	Indigenous Land	IL	Upper Rio Negro	Brazil	316.194
Kichwa	Indigenous Land	IL	Yasuni-Pastaza	Ecuador	108.000
Sapara	Indigenous Land	IL	Yasuni-Pastaza	Ecuador	423.303
Tagaere Taromenani	Indigenous Land	IL	Yasuni-Pastaza	Ecuador	700.000
Waorani	Indigenous Land	IL	Yasuni-Pastaza	Ecuador	821.108
Yasuni	National Park	SP	Yasuni-Pastaza	Ecuador	1.027.300
Matses	National Park	SU	Yavari-Samiria	Peru	422.544
Nanay-Chambira-Pintayacu	State Park	SU	Yavari-Samiria	Peru	954.635
Pacaya Samiria	National Park	SU	Yavari-Samiria	Peru	2.181.296
Tamshiyacu Tahuayo	State Park	SU	Yavari-Samiria	Peru	421.731
Yavari Tapiche	Indigenous Land	IL	Yavari-Samiria	Peru	1.170.286

Conservation unit Name	Type	Category	Mosaic	Country	Hectares
Altamira	National Forest	SU	Xingu	Brazil	689.012
Iriri	State Forest	SU	Xingu	Brazil	44.493
Rio Iriri	Extractive Reserve	SU	Xingu	Brazil	398.938
Rio Xingu	Extractive Reserve	SU	Xingu	Brazil	303.841
Riozinho do Anfrizio	Extractive Reserve	SU	Xingu	Brazil	736.640
Apyterewa	Indigenous Land	IL	Xingu	Brazil	773.470
Arara	Indigenous Land	IL	Xingu	Brazil	274.010
Arawete	Indigenous Land	IL	Xingu	Brazil	940.901
Badjonkore	Indigenous Land	IL	Xingu	Brazil	221.981
Batovi	Indigenous Land	IL	Xingu	Brazil	5.159
Bau	Indigenous Land	IL	Xingu	Brazil	1.540.930
Cachoeira Seca do Iriri	Indigenous Land	IL	Xingu	Brazil	734.027
Capoto Jarina	Indigenous Land	IL	Xingu	Brazil	634.915
Kararao	Indigenous Land	IL	Xingu	Brazil	330.838
Kayapo	Indigenous Land	IL	Xingu	Brazil	3.284.005
Koatinemo	Indigenous Land	IL	Xingu	Brazil	378.834
Kuruaya	Indigenous Land	IL	Xingu	Brazil	166.784
Menkragnoti	Indigenous Land	IL	Xingu	Brazil	4.914.255
Panara	Indigenous Land	IL	Xingu	Brazil	499.740
Pequizal do Naruvotu	Indigenous Land	IL	Xingu	Brazil	27.980
Serra do Cachimbo	Biological Reserve	SP	Xingu	Brazil	342.478
Serra do Pardo	National Park	SP	Xingu	Brazil	445.392
Terra do Meio	Ecological Station	SP	Xingu	Brazil	3.373.110
Trincheira Bacaja	Indigenous Land	IL	Xingu	Brazil	1.650.939
Wawi	Indigenous Land	IL	Xingu	Brazil	150.300
Xingu	Indigenous Land	IL	Xingu	Brazil	2.642.003
Xipaya	Indigenous Land	IL	Xingu	Brazil	178.724



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