Impacts of Habitat Transformation on Amphibian and Reptile Communities in a Heterogeneous Andean Landscape

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Abstract

The Andean region of Colombia is recognized for its exceptional biodiversity and high levels of endemism, particularly among amphibians and reptiles. However, this region faces significant challenges due to habitat loss and fragmentation driven by agricultural activities, urbanization, and livestock farming. This study evaluates the effects of habitat alterations on herpetofaunal communities within the Sumapaz province, focusing on three habitat types: secondary Andean forests, coffee plantations, and open areas associated with low-intensity livestock farming. We also compiled a comprehensive inventory of 85 species based on fieldwork conducted (2021-2022) and biodiversity databases, recognizing 35 amphibians and 50 reptiles for the region. We found that forests support the highest richness and diversity of species, while open areas exhibited greater reptile abundance. Crops showed lower biodiversity but demonstrated potential as secondary habitats for certain species. These findings highlight the importance of preserving forested areas and designing mixed-use landscapes to promote biodiversity and maintain ecological functions. This study provides a baseline for future conservation strategies in the Sumapaz region.

Keywords: Agroecosystems, habitat use, biodiversity conservation, anthropic disturbance, herpetofauna inventory.

Introduction

In Colombia, Andean ecosystems have undergone significant transformation, particularly in sub-Andean and Andean forests. Today, only 39.5% of their original area remains as natural ecosystems, while the remaining 60.5% has been altered [1]. The Andean region is home to approximately 53% of the country's total herpetofauna species [2], including around 317 endemic species [3,4]. This high level of biodiversity and endemism makes the region one of the top global priorities for herpetofauna conservation [5–7].

One of the most significant threats to amphibian and reptile community assemblages is land use alteration for human activities, such as urbanization or agricultural purposes. This practices often leads to the loss and degradation of forest habitats, leaving only fragmented remnants within heavily disturbed ecosystems. [8,9]. Given their ecological traits, amphibians and reptiles display diverse responses to environmental disturbances, with potential positive or negative effects on the richness and abundance of herpetofaunal species [9]. Both amphibians and reptiles are significantly affected by urbanization; however, amphibian richness is more heavily impacted by activities such as deforestation and forestry, whereas reptiles are more affected by increased livestock intensity [10]. As a result, habitat alterations resulting from human activity significantly influence the composition, structure, and dynamics of amphibian and reptilian communities, thereby affecting ecological interactions in the ecosystem [11–13].

Different strategies have been proposed to reduce and mitigate the impacts of habitat loss and fragmentation due to changes in land use on species diversity [8,14,15]. Thus, it has been proposed that some agroecosystems can protect wildlife species in human-modified landscapes, maintaining both species diversity and the economic benefits of crops [16]. For example, coffee plantations have been suggested as biodiversity-friendly land uses with relatively low environmental impact [17–19]. Nonetheless, the effects of landscape-scale transformations and human activities on herpetofaunal community assemblages remain largely unknown in Colombia.

Similarly, knowledge about the herpetofauna in Colombian Andes and the Sumapaz province, where agricultural activities, livestock farming, and urbanization are integral parts of the landscape remains limited. This area of great conservation importance lacks comprehensive data on amphibian and reptile species composition and ecology [20]. Such knowledge is fundamental to the evaluation of the impacts of land-use alterations on herpetofaunal communities and the formulation of effective conservation strategies [19].

For all reasons mentioned above, we evaluated the changes in species richness and abundance of amphibians and reptiles in three different habitats with different degrees of anthropic intervention in the Eastern Cordillera of Colombia: secondary Andean forests (named hereafter simply as forest, the most conserved habitats remaining in the region today, representing the closest approximation to a natural assemblage currently found in the area), crops (specifically coffee plantations, which dominate the agroforestry activities in the region), and open areas (primarily associated with low-intensity livestock farming activities in the region). All these areas are spatially interconnected, with varying degrees of connectivity between natural and human-altered landscapes.

In addition, we compiled historical and current records of the species present in the Sumapaz province to consolidate an inventory that will serve as a starting point for the establishment of conservation strategies for the Sumapaz river basin herpetofauna.

Materials and Methods

Study area

We carried out fieldwork in the municipalities of Tibacuy, Nilo and Viotá located in the Sumapaz province in Cundinamarca, Colombia, between 645 and 1840 m elevation (Figure 1). The region has a mostly humid mountain climate in combination with dry enclaves, typical of the middle lands of the Magdalena basin. The study area is characterized by secondary Andean forest and agroecosystems in a heterogeneous matrix where it is possible to find forest reserve areas and private properties used for mixed crops and livestock farming [21]. We conducted the study in three habitat types: forest (11 localities), with scattered trees over five meters high, where advanced plant regeneration processes are evident; shaded coffee crops (6 localities) and open areas (9 localities) used as pastures for permanent livestock.

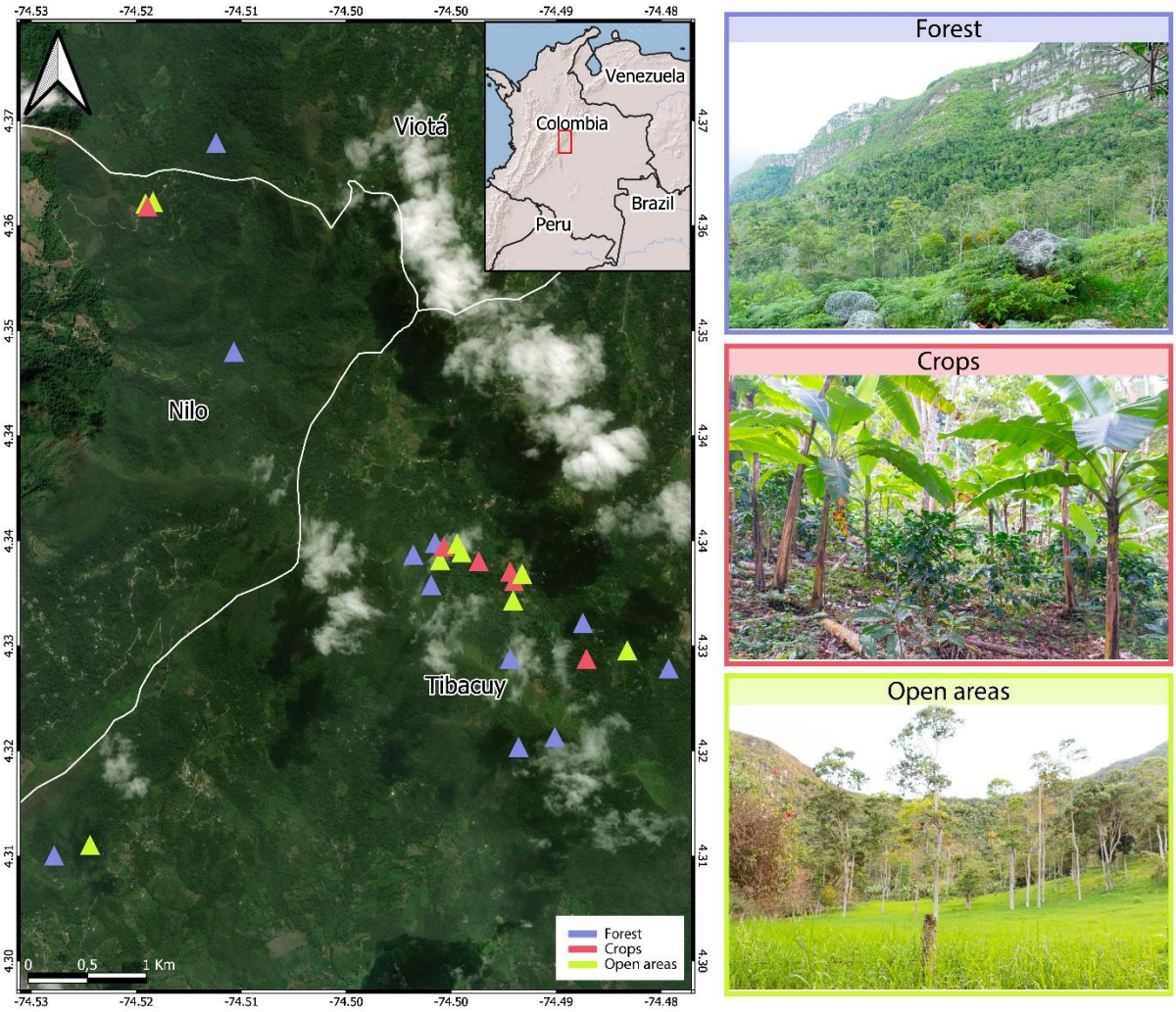

Figure 1. Map of Study Area in the Eastern Cordillera of the Andes, Colombia. The figure shows the locations of fieldwork within the municipalities of Tibacuy, Nilo, and Viotá, situated in the Eastern Cordillera of the Andes, Cundinamarca, Colombia. Field sites encompass a heterogeneous matrix of diverse habitat types, including secondary forest, shaded coffee plantations, and open pastures.

Data collection

We conducted a total of eight field trips (three effective sampling days each) between June of 2021 and July of 2022 to cover the rainy and dry seasons in the region. During the sampling phase, we used the technique of visual and auditory encounter surveys (VES) for a limited time and fixed band transects (2 X 50 m) in which each encounter was counted individually for abundance estimation during a sampling event [22]. We carried out sampling between 8:00 and

12:00 and between 18:00 and 22:00 h, surveying microhabitats suitable for amphibians and reptiles such as vegetation, ponds, streams and leaf litter, with a maximum limit of 5 m from the ground [23]. During all the sampling phase, data as habitat, body measurements and photographic records for all individuals were collected on the site of observation. The individuals were released at the same location where they were captured.

In addition to the field trips conducted in 2021 (33 species, 153 individuals), historical records from surveys between 2015 and 2019 (51 species, 455 individuals, of which 24 species were not reported in 2021) were also included in the analysis. These records were collected by the authors of this study and the herpetology group of Universidad Nacional de Colombia (Herpetos UN) following the VES methodology described above. Finally, we followed Frost [24] and Uetz *et al* [25] as classification systems for amphibians and reptiles, respectively.

Database searching

As a supplement to the species list obtained in the study area, we consulted the databases of the Biodiversity Information System of Colombia (SiB). We filtered records that came from preserved specimens, machine observations and observations. The latter were only taken from institutions with local environmental authority (Corporación Autónoma Regional de Cundinamarca - CAR) to avoid errors in species identification. We also reviewed historical data in biological collections at the Instituto de Ciencias Naturales (ICN) at Universidad Nacional de Colombia and the Amphibian and Reptiles collections of the Instituto de Investigación de Recursos Biológicos Alexander von Humboldt (IAvH) for the municipalities of Tibacuy, Nilo, Silvania and Viotá (Cundinamarca). These supplement species records were used to compile a complete list of amphibians and reptiles for the Sumapaz Province. However, they were not included in the assemblage analyses due to a lack of standardization and reliable information about their association with vegetation cover at the time of capture.

Data analysis

We used a species accumulation curve to determine the representativeness of the sampling following the guidelines of Villarreal *et al* [22]. For this, we used the Chao 1, ACE and Cole's Rarefaction estimators with abundance-based data, analyzing the herpetofaunal community as a whole and the amphibian and reptile communities separately. We calculated curves using EstimateS 9.1.0 software [26] for the 52 sampling units performed.

We assessed the diversity of reptiles and amphibians in the study area by calculating five diversity indices: species richness, Shannon-Wiener index, Simpson's index, Pielou's equitability, and Margalef's richness index. Such indices were chosen for their ability to reflect both species' richness and evenness in community structure. We used the *vegan* package in R to calculate these diversity indices, as it provides robust and widely accepted methods for ecological data analysis [27].

To evaluate species richness at varying sampling efforts and predict species richness beyond our observed sample size, we estimated the percentage of completeness achieved through sampling coverage curves, as well as the additional sampling necessary to reach the maximum number of species. This analysis estimates the proportion of the total number of individuals in a community that belong to a sampled species [28]. We used the *iNEXT* package [29] to create the 95% confidence intervals (IC) with a resampling of 1000 bootstraps. Furthermore, we plotted rank-abundance curves to compare the species abundance distributions among habitats.

To assess the dominance and community structure, we analyzed the species distribution across the three different habitat types: forest, crops, and open areas (see specific definition of habitat types in Ríos-Orjuela *et al* [19]). Using the *rankabuncomp* function from the *vegan* package [27], we generate rank-abundance curves for reptiles and amphibians which allows for the comparison of species' richness, evenness, and dominance patterns among habitats. We organized species abundance by habitat type, focusing on the three most abundant species per habitat. This subset provided insights into habitat-specific species dominance patterns. Rank-abundance plots were generated using *ggplot2* [30], complemented with *ggrepel* to annotate dominant species and ensure clear visualization of key species. We applied log-transformed abundance values to better illustrate the distribution across ranks. The rank-abundance plots provide detailed insights into how individual species contribute to the overall community structure, helping us evaluate biodiversity patterns beyond simple species counts. We also used stacked bar plots to explore species richness and individual abundance across the three previously mentioned habitats. All analyses were conducted in R version 4.1.0. [31].

Color schemes were standardized to maintain consistency between habitat types, with each habitat type assigned a distinct color palette. We used a color-blind friendly palette to ensure accessibility to all readers.

Results

Based on the information stored in databases, biological collections and literature regarding herpetofauna in the analyzed area of the Sumapaz River province we found records of 58 species (Table S1): 24 amphibians (21 anurans, 1 salamander and 2 caecilians) and 34 reptiles (11 lizards, 21 snakes, 1 tortoise and 1 crocodilian). As a result of our fieldwork, we recorded a total of 57 species (21 amphibians and 36 reptiles), 27 of these species are additional records for the region. Then, we were able to compile a more comprehensive state of knowledge to better understand the diversity of herpetofauna in this area.

A total of 85 species (35 amphibians and 50 reptiles) have been recorded in the municipalities in the study area (Table S1). For amphibians, most species belong to the order Anura, with Hylidae having the highest richness in the region (8 spp.), followed by Dendrobatidae and Strabomantidae (5 spp. each). Caecilians (Gymnophiona) were represented by *Caecilia thompsoni* (Caeciliidae) and *Microcaecilia* sp. (Siphonopidae) and salamanders (Caudata) by *Bolitoglossa muisca* (Plethodontidae). For reptiles, within the order Squamata, the family with the highest richness was Colubridae (23 spp.), followed by Anolidae (6 spp.). The orders Crocodylia and Testudines were represented by a single species each (*Caiman crocodilus* and *Kinosternon* sp.). There are records of two invasive species in the area, the North American Bullfrog *Aquarana catesbeiana* (Ranidae) and the South Asian House Gecko *Hemidactylus frenatus* (Gekkonidae).

Regarding the data from our fieldwork, both Hylidae (5 spp.) and Leptodactylidae (4 spp.) had the highest richness for amphibians, as for reptiles it was Colubridae (23 spp.) and Anolidae (4 spp.). In terms of abundance, we recorded 608 individuals: 391 amphibians and 217 reptiles (Table 1). The most abundant amphibian species were *Boana platanera* (62), *Engystomops pustulosus* (60) and *Pristimantis taeniatus* (55), while for reptiles *Gonatodes albogularis* (53), *Cnemidophorus lemniscatus* (33) and *Hemidactylus frenatus* (17) were the most abundant species in the sampled area (Table S1). Forest sustained the highest numbers of individuals for amphibians and the herpetofauna, but instead reptiles were slightly more abundant in open areas. We found consistently less individuals in crops.

Regarding diversity, the Shannon-Wiener index was highest for the entire herpetofauna community (3.237), followed by reptiles (2.793) and amphibians (2.469), indicating that the herpetofauna community exhibited a more even distribution of species compared to the reptile and amphibian groups individually. Simpson's index showed similarly high diversity across the groups, with values of 0.944 for herpetofauna, 0.894 for reptiles, and 0.896 for amphibians,

reflecting low dominance across species in the assemblages. In terms of species evenness, Pielou's equitability index was similar across groups, with reptiles at 0.779 and amphibians at 0.811. Margalef's index indicated that the reptile community (6.506) had greater species richness relative to sample size than the amphibian community (3.351), as shown in Table 1. In general terms, forests showed higher diversity scores for herpetofauna as a whole and for amphibians and reptiles separately (Figure 2). However, open areas showed a higher abundance of reptiles and evenness for amphibians, while evenness in the reptile community in coffee plantations was higher.

Table 1. Diversity indices for herpetofauna, reptiles, and amphibians. This table presents the calculated diversity indices, including species richness, Shannon, Simpson, Pielou's equitability, and Margalef's index for the herpetofauna community, as well as for the reptiles and amphibians separately. Richness represents the number of species, while the Shannon and Simpson indices measure diversity and dominance. Equitability reflects how evenly individuals are distributed among species, and Margalef's index provides a measure of species richness considering the number of individuals sampled.

	Herpetofauna			Reptiles			Amphibians		
	Forest	Crops	Open areas	Forest	Crops	Open areas	Forest	Crops	Open areas
Richness	45	14	34	24	8	23	21	6	11
Abundance	319	47	242	87	12	118	232	35	124
Simpson_1-D	0.929	0.758	0.922	0.919	0.894	0.841	0.877	0.571	0.848
Shannon_H	3.137	2.034	2.884	2.899	2.199	2.324	2.418	1.2	2.061
Margalef	7.632	3.376	6.012	5.15	2.817	4.611	3.672	1.406	2.075
Equitability_J	0.824	0.771	0.818	0.912	1.057	0.741	0.794	0.67	0.860

	Herpetofauna	Reptiles	Amphibians
Richness	57	36	21
Abundance	608	217	391
Simpson_1-D	0.944	0.894	0.896
Shannon_H	3.237	2.793	2.469
Margalef	8.736	6.506	3.351
Equitability_J	0.801	0.779	0.811

The species accumulation and sample coverage curves (Figure 3A and 3B) demonstrate that the diversity of both reptiles and amphibians approached saturation with increased sampling. Amphibians reached the saturation point slightly earlier. Extrapolation analyses suggest that

additional sampling beyond 1000 individuals would not significantly increase species richness, particularly for amphibians. Both amphibian and reptile communities achieved near-complete sample coverage, with amphibians reaching this threshold faster (Figure 3B). The accumulation curves (Figures 3C and 3D) present results from different estimation methods (S(est), ACE, Chao, and Cole's rarefaction). Singleton and doubleton species—those recorded only once or twice—highlight the potential for undiscovered species, especially in reptiles.

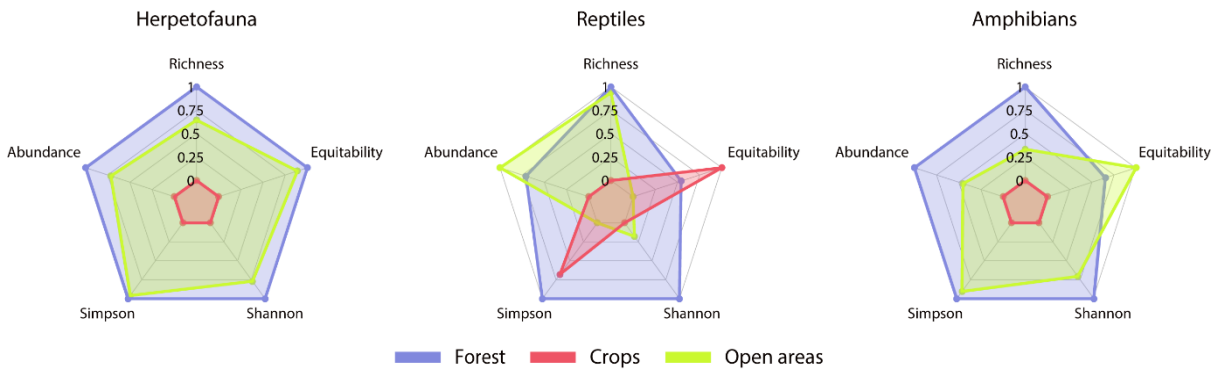

Figure 2. Biodiversity Metrics of Herpetofauna, Reptiles, and Amphibians Across Different Habitats. This figure presents radar charts comparing biodiversity metrics (Richness, Abundance, Equitability, Shannon Index, and Simpson Index) across different land use types (Forest, Crops, and Open areas) for the Herpetofauna, Reptiles, and Amphibians communities. Each plot illustrates the relative values of these metrics within each environment type, coded by color — Forest (blue), Crops (red), and Open areas (green). In herpetofauna, forested areas exhibit the highest scores across most biodiversity metrics, indicating greater biodiversity and ecosystem stability relative to other land use types. Open areas maintain intermediate values, whereas cropland shows the lowest biodiversity metrics across all indices. For reptiles**,** like herpetofauna, natural forested areas show higher values in richness, abundance, and diversity (Simpson and Shannon indices), suggesting forest habitats support more reptilian biodiversity. Cropland presents the lowest scores, with open areas falling in between. For amphibians**,** forests exhibit the highest biodiversity metric values, with richness and diversity indices significantly outperforming those in crops and open areas. Cropland remains the least supportive habitat for amphibians among the three types.

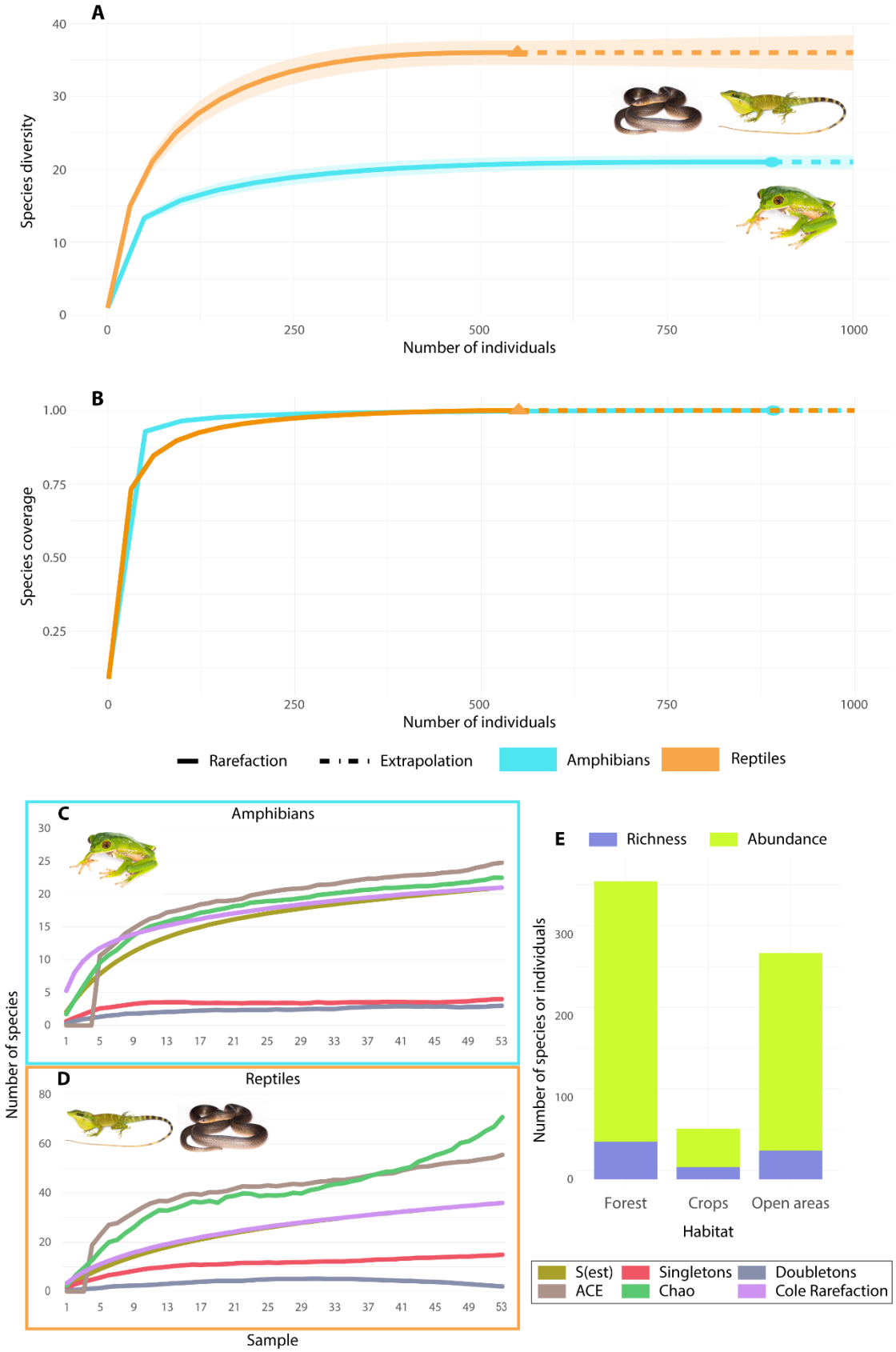

Figure 3. Interpolation and extrapolation of species richness and sample coverage for reptiles and amphibians. (A) Species diversity curves show the relationship between species

richness and the number of individuals sampled, with solid lines representing observed data and dashed lines indicating extrapolated estimates for reptiles (orange) and amphibians (blue). Shaded regions represent 95% confidence intervals derived from bootstrapped resampling (1000 iterations). (B) Sample coverage curves demonstrate the proportion of the total species captured as a function of the number of individuals sampled. The curves suggest the completeness of sampling for both groups, with the shaded regions showing 95% confidence intervals. (C & D) Accumulation curves display species richness estimation methods (S(est), ACE, Chao and Cole rarefaction) across different sample sizes for amphibians (C) and reptiles (D). Singleton and doubleton species (species recorded only once or twice) are highlighted to show their impact on richness estimations. (E) Bar plots compare species richness (purple) and individual abundance (green) across three habitat types: forest, crops, and open areas. The forest habitat supports higher species richness, while open areas show higher individual abundance.

Forest areas supported the highest species richness (Figure 4A), with amphibians such as *Engystomops pustulosus* and *Pristimantis gaigei* showing high abundance. Crops exhibited the lowest species richness, but still hosting certain species with few dominants like *P. taeniatus*. Open areas presented intermediate species richness but higher overall abundance, with key reptile species such as *Gonatodes albogularis* and *Cnemidophorus lemniscatus* dominating (Figure 4B). These findings reveal clear habitat preferences among species, with amphibians more common in forest habitats and reptiles more evenly distributed across the different environments.

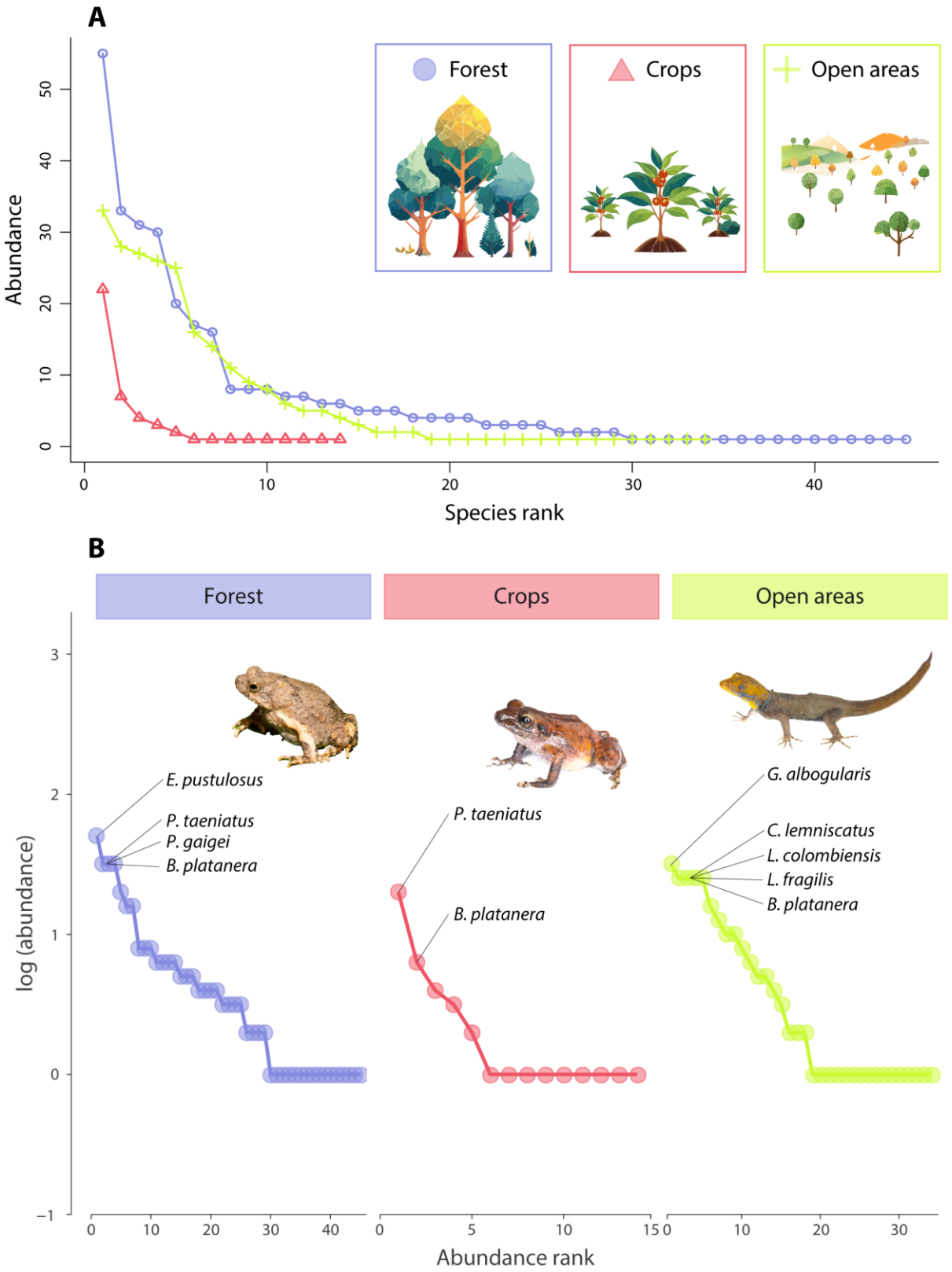

Figure 4. Species abundance and rank distributions across three habitat types. (A) Species abundance curves compare the distribution of species across the three habitat types. Forest habitats (blue circles) have higher abundance and evenness, while crop areas (red triangles)

show steep declines in abundance, indicating lower species diversity. Open areas (green crosses) display intermediate patterns of species distribution. (B) Rank-abundance plots display species-specific abundances (log-transformed) within each habitat type. Key amphibian and reptile species for each habitat are highlighted: *E. pustulosus* and *P. gaigei* dominate in forests; *P. taeniatus* is prevalent in crop areas; and *G. albogularis* and *C. lemniscatus* are common in open areas. These plots illustrate differences in community structure and dominance among the habitats.

Discussion

List of amphibians and reptiles and comments on records

This area of the Sumapaz River province holds 85 species of amphibians and reptiles. The environmental conditions of the Eastern Andes Cordillera ecoregion considerably influence the herpetofaunal assemblage [32], as well as the landscape dynamics that have determined habitat availability for these taxonomic groups. Previous records reviewed in this study from literature [33–37] and biodiversity databases accounted for around 68% of the diversity present in the area, therefore our results from this monitoring have increased the knowledge of the local diversity and allowed us to make different ecological inferences.

It is important to note that most of the "new" records provided by our sampling in the study area are from species whose distribution in the surrounding localities is well known or at least are expected to occur (i.e. *Leptodactylus fragilis*, *Rhinella humboldti*, *Cnemidophorus lemniscatus* or *Bothrops asper*), however, this review provides a more robust base line about the current knowledge of the biodiversity in the region, which can be helpful for future studies, local communities and, stakeholders for decision-making and territorial planning.

There are some records for both amphibians and reptiles worth discussing. We were unable to determine one species of *Anolis* based on the current knowledge of its diversity in the region. With a preliminary review on lepidosis and morphology we tentatively assigned it as close relative to *A. granuliceps*, but further work is required to define its identity. This also underscores the uncharacterized biodiversity of the region that only recently has been studied deeper. Moreno-Arias *et al* [38] recently described *Anolis tequendamae* whose distribution spans to this area, *Bolitoglossa muisca* was described with material from Silvania municipality by López-Perilla *et al* [34] and Acosta-Galvis *et al* [33] described *Hyloxalus arliensis* with

material from several localities in the Magdalena River valley including samples from Viotá. We now contribute new records of this species in the lowland humid forests of Tibacuy (vereda El Mango). Also recent papers about the taxonomy and systematics of *Scinax* [39,40] besides the molecular evidence provided by Guarnizo *et al* [41], opened the discussions to the fact that specimens usually identified in the local herpetology community as *Scinax ruber* and *S. x-signatus* in this region are more than likely undescribed lineages highlighting the need to develop integrative studies to clarify this taxonomical complex in Colombia.

Another significant and concerning record was from the invasive species *Aquarana catesbeiana.* After its introduction in Colombia around 1986, this frog was initially reported in Fusagasugá and Silvania (Cundinamarca) in 1993, where was later observed in nearby municipalities such as Pandi, Nilo and Arbeláez [42]. This means that the species has been in this area for at least 30 years, but still with limited knowledge of its actual distribution and population status. Recently CAR [43] have gathered records in Tibacuy and nearby municipalities in the process of formulating a management plan to control and monitor the species. Our fieldwork provided one additional record in Tibacuy in 2019, but we did not observe it in Nilo or Viotá. Besides active sampling, to increase the understanding about *A. catesbeiana* in Cundinamarca we suggest that future work could benefit from advances in passive acoustic monitoring and citizen science initiatives.

There are also several relevant historical records in the municipalities studied, especially toward higher altitudes. Species such as *Atelopus subornatus* and *Hyloxalus ruizi* were observed in the area surrounding El Alto de San Miguel (within the limit of Sibaté and Silvania municipalities) by Lynch [35]. Both species are critically endangered [44], and besides southern records of *A. subornatus* in Tolima [45], there are no recent records in these municipalities, and we did not register them in this study. Other species currently threatened in the area worth mentioning are *H. vergeli, P. uisae* and *P. renjiforum* (Table S1).

Overall, our results demonstrate a well-structured herpetofaunal community in this region, with reptiles exhibiting greater species richness than amphibians. These findings align with previous studies conducted in similar transitional ecosystems in Cundinamarca, where reptiles are often more species-rich than amphibians due to their broader adaptability to varied ecological conditions [46]. The diversity in the study area, as indicated by the Shannon and Simpson indices, suggests a healthy ecosystem with a balanced distribution of individuals among species.

Habitat assemblages

Different biodiversity metrics evidenced consistently that forests in this Andean region are key for both amphibians and reptiles. This is expected as natural areas keep higher structural complexity, stable microclimates, several microhabitats and resources availability that suite habitat requirements for species with different life history traits and with less anthropic pressures in general [47,48]. 17 species were only observed in forested areas (7 amphibians and 10 reptiles), although it cannot be assumed that those are forest specialists, some species present traits that make them more specialized in this habitat. For example, riparian forests are essential for species with reproductive modes linked to lotic environments as it is the case for Centrolenidae [49], or they allow for specialized escape behavior as in *B. galeritus* to cross water bodies [50].

The relatively high Margalef's index for reptiles (6.506) compared to amphibians (3.351) reflects the greater species richness within the reptilian community, which may be attributed to the variety of microhabitats available in the transitional forest ecosystem, a trend previously reported by Cervantes-López and Morante-Filho [8]. This region, located between tropical and montane forest zones, provides ideal conditions for reptiles, which are often more tolerant of drier conditions and variable temperatures compared to amphibians, which are more dependent on moisture and stable environmental conditions, making them more susceptible to changes in land use [8,51,52].

Our findings suggest that intermediate habitats, such as croplands, play an important role in the conservation of biodiversity. The presence of species such as *Pristimantis taeniatus* in these environments serves to illustrate the significance of agricultural landscapes in complementing conservation efforts by acting as secondary habitats. These findings lend support to the notion that heterogeneous land-use matrices can serve to enhance biodiversity, as evidenced by recent studies on coffee agroecosystems in the Colombian Andes [19].

The completeness of sample coverage (Figure 3B) highlights the adequacy of our sampling strategy, especially for amphibians, which reached saturation faster than reptiles. This result underscores the need for ongoing monitoring of the group, particularly given the vulnerability of amphibian populations to environmental changes such as habitat loss, climate change and exotic species [23]. The rarefaction and extrapolation curves confirm that our sampling efforts captured most of the species present in the study area. However, the presence of singleton and doubleton species—recorded only once or twice—indicates the potential for undiscovered

species, particularly among reptiles (Figures 3C and 3D). Continued surveys targeting less-explored microhabitats (e.g., riparian zones or localities at higher altitudes) could reveal additional species, such as those previously reported from databases or museum specimens, and which were not observed in our surveys (Table S1).

The differences in richness and abundance between amphibians and reptiles (Fig. 3) show the expected differential response of both groups to the environmental conditions and perturbation level present in the study area [9,10]. Amphibian communities presented a lower number of species, but a higher abundance than reptiles, not only due to the effect of differences in the ecology or reproductive biology of each group, but also as a consequence of the presence of species with generalist habits (such as *E. pustulosus*, *P. taeniatus* and *G. albogularis*) that colonize semi-natural or disturbed environments with relative ease, from which specialist species move after disturbance [53], modifying the ecosystem dynamics as a consequence of changes in dominance at the community level [54].

Although species richness is the most used measure of biodiversity, other measures (such as functional diversity) are relevant in disturbed environments, where the history of disturbances in the study ecosystem influences the ecological dynamics within it, reducing functional diversity and, potentially, the provision of ecosystem services [9,54–57]. Although the evaluation of functional diversity of amphibian and reptile communities in environmental gradients for the Colombian Andes is limited, environmental heterogeneity plays an important role in the degree of association of communities with disturbed environments [58].

Beyond the high richness of amphibians and reptiles observed, the Andean region in Colombia has undergone a considerable change in the vegetation cover available for the local fauna. As a result of the intensification of agriculture, cattle ranching and infrastructure development in the region, the area of forest has decreased considerably [59]. In the Colombian Andes, there is a differential velocity in land use change along the altitudinal gradient [60] with secondary forests and grasslands being the most dynamic vegetation units in terms of area gain and loss [61]. Frequently, such deforested areas go through an intermediate state as crops, which becomes a constant challenge for the consolidation of amphibian and reptile communities, favoring ecologically generalist species (such as *E. pustulosus* and *G. albogularis*), which dominate the transitional environments and relegate species with specific ecological requirements (such as glass frogs or snakes), resulting in low diversity, homogenization of

ecological functions and a decrease in the ecosystem services provided by amphibians and reptiles within the ecosystem [9,62].

Given the scenario of intensive change in the availability of forested environments in the Andean region and the negative effects of climate change on the populations of amphibians and reptiles that inhabit mountainous areas at intermediate elevations [47,63,64], it is of vital importance to develop long-term monitoring programs to evaluate changes in the distribution of species and ensure the conservation of vulnerable species, mitigating the loss of forest habitats and preserving corridors that promote ecological connectivity [9].

Finally, our study provides evidence about the differential impact of agroforestry systems in transformed landscapes on amphibian and reptile assemblages. In the context of increasing deforestation and expansion of the agricultural frontier, it is of particular interest to identify the characteristics that allow maintaining environments with the ecological quality necessary to sustain stable amphibian and reptile communities, favoring the conservation of forested areas and designing mixed environmental matrices that favor species diversity, and, by extension, the environmental services provided by them.

Supplementary materials

ST1: Species recorded in the municipalities of the study area (Cundinamarca, Colombia).

Document D1: Spanish translation of the present manuscript.

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Data Availability Statement

Data will be available by request to the authors.

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Conflict of interest

The authors declare no conflict of interest.

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