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Original article

Filling gaps in the ornithological knowledge of the south of Serranía de los Yariguíes, Santander, Colombia

Nuevos aportes al conocimiento ornitológico del sur de la Serranía de los Yariguíes, Santander, Colombia

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Abstract

Montane forests in the northern section of Colombia's Eastern Cordillera harbor more than 360 bird species, but their knowledge is incomplete. During an expedition to the southern sector of Serran*ía* de los Yariguíes, in the municipality of El Guacamayo, Santander (1,985–2,596 MASL), we recorded 142 bird species using four complementary sampling methods. For 101 species, we obtained supporting audio recordings, and for 54, we secured voucher specimens deposited in the Ornithological Collection of the Natural History Museum at Universidad Industrial de Santander. Photographs and field observations, confirmed by at least two of the authors, added 25 species not recorded by the other two methods. We documented 17 species that represent noteworthy records for the region (e.g., *Ochthoeca cinnamomeiventris*, *Scytalopus rodriguezi*, and *Arremon assimilis*). We present data suggesting reproductive activity in April for at least eight species and describe a nest of *Psarocolius angustifrons* included in the collected series. The collection of museum voucher specimens and associated tissue samples allowed us to analyze the genetic diversity of *Eutoxeres aquila*, *Ocreatus underwoodii*, *Anabacerthia striaticollis*, and *Syndactyla subalaris*, which was low, and we found no differentiation among localities in Santander. Although most of the species recorded during this expedition are largely shared with other montane forests in the region, El Guacamayo in Santander offers an opportunity to observe montane avifauna along a broad altitudinal gradient and within relatively well-preserved ecosystems.

Keywords: Andes, biological collections, birds, montane forest, sound recordings.

Resumen

En los bosques montanos al norte de la cordillera Oriental colombiana viven más de 360 especies de aves, cuyo conocimiento todavía es incompleto. En una expedición al sur de la Serranía de los Yariguíes, en el municipio de El Guacamayo, Santander (1.985 – 2.596 m s.n.m.), registramos 142 especies de aves combinando cuatro métodos de muestreo. Registramos grabaciones de audio de 101 especies y de otras 54 obtuvimos especímenes depositados en la colección ornitológica del Museo de Historia Natural de la Universidad Industrial de Santander. Las fotografías y observaciones, confirmadas al menos por dos de los autores, correspondieron a 25 especies no registradas por los otros dos métodos. Obtuvimos registros de 17 especies notables de la región, entre ellas, *Ochthoeca cinnamomeiventris, Scytalopus rodriguezi* y *Arremon assimilis*. Presentamos datos de por lo menos ocho especies que sugieren actividad reproductiva en abril y describimos un nido de *Psarocolius angustifrons* incluido en la serie recolectada. La recolección de especímenes y las muestras de sus tejidos nos permitieron analizar la diversidad genética de *Eutoxeres aquila*, *Ocreatus underwoodii*, *Anabacerthia striaticollis* y *Syndactyla subalaris*, la cual fue baja; además, registramos diferenciación entre las localidades de Santander. Aunque las especies reportadas en esta expedición se han encontrado en otros bosques montanos de la región, El Guacamayo ofrece la oportunidad de observar la avifauna montana en un amplio gradiente altitudinal y en ecosistemas relativamente bien conservados.

Palabras clave: Andes, aves, bosques montanos, colecciones biológicas, grabaciones de audio.

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Introduction

Montane forests of the Tropical Andes harbor the highest levels of species richness worldwide for several avian taxa (**Fjeldsa *et al.***, 2020; **Sonne & Rahbek**, 2024). Particularly notable are the montane forests of Colombia's Eastern Cordillera, which support numerous range-restricted species (**Sánchez-González & Navarro-Sigüenza**, 2009; **Sonne & Rahbek**, 2024). These diversity and endemism patterns have been elucidated mainly through the study of museum voucher specimens collected over more than a century. In the department of Santander, northeastern Colombia (**Figure 1**), ornithological expeditions to montane forests, conducted since 1913, have documented at least 360 species, supported by more than 4,000 museum voucher specimens (**Donegan *et al.***, 2010; **Córdoba-Córdoba & Sierra**, 2018; **Arbeláez-Cortés *et al.***, 2020; **Arbeláez-Cortés *et al.***, 2023; **Barreto-Vargas**, 2024). This rigorous documentation of Santander's montane avifauna encompasses 121 localities across 31 municipalities within the department; however, several montane areas remain ornithologically unexplored (**Barreto-Vargas**, 2024).

Serranía de los Yariguíes, a ridge running parallel to the Eastern Cordillera (**Figure 1**) reaching 3,200 MASL., has been surveyed since the early 2000s to document its avifauna (**Donegan *et al.***, 2007; **Donegan *et al.***, 2010; **Arbeláez-Cortés *et al.***, 2020). Some phenotypically differentiated populations had been described as endemic to this ridge (**Donegan**, 2008; **Donegan & Avendaño**, 2010), but DNA information showed that several species lack genetic differentiation between montane forests on the Eastern Cordillera and Serranía de los Yariguíes (**Arbeláez-Cortés & Trujillo-Arias**, 2021). The ornithological expeditions cited above have been limited to the northern section of this ridge. Additional ornithological expeditions have been conducted in other mountainous areas of southern Santander, but outside Serranía de los Yariguíes (**Córdoba-Córdoba & Sierra**, 2018; **Arbeláez-Cortés *et al.***, 2023; **Gbif.org**, 2023b; **Stiles *et al.***, 2023; **Arbeláez-Cortés *et al.***, 2024). Thus, the montane forests in the southern extreme of Serranía de los Yariguíes represent a substantial gap in ornithological knowledge.

Our aim here was to present the results of an expedition designed to conduct a rigorous avian documentation, *sensu* **Lees *et al.*** (2014), of montane forests in El Guacamayo, a municipality in the southern Serranía de los Yariguíes. We planned to obtain records supported by tangible evidence (museum voucher specimens and audio recordings),

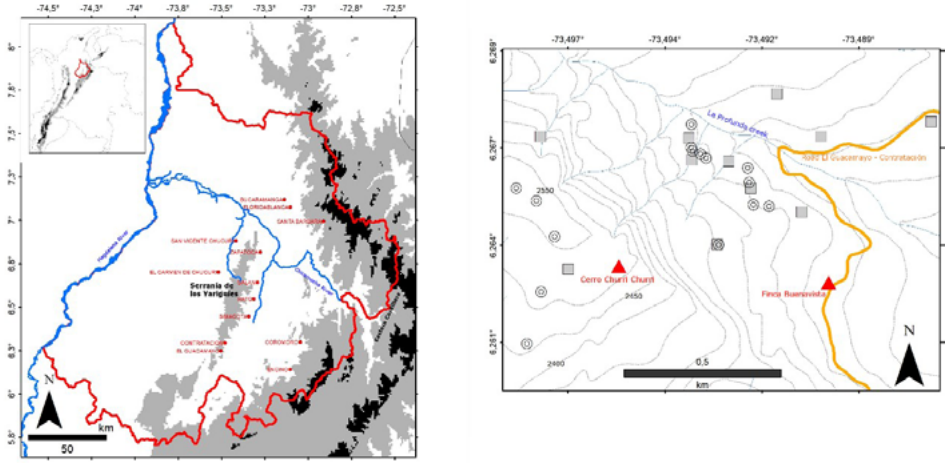

Figure 1. Left: Department of Santander, northeastern Colombia (inset). The Serranía de los Yariguíes, the Eastern Cordillera, and some municipalities are indicated. Grey areas are elevations between 2,000 and 3,500 MASL, and black ones are above 3,500 MASL. Right: Study zone of the expedition to El Guacamayo, Santander, Colombia. Red triangles: base camps. Grey squares: mist net stations. Concentric circles: standardized audio-recordings

complemented by field observations. Although a relatively well-preserved montane forest persists near inhabited areas of El Guacamayo, only a few observational records of its avifauna exist (**eBird**, 2025). The collection of biological material during the expedition also enabled the generation of DNA sequences for some species; accordingly, we present the genetic diversity of populations from Serranía de los Yariguíes and the Eastern Cordillera.

Methods

During the ornithological expedition to El Guacamayo, Santander, Colombia, we established a base camp at Finca Buenavista (6.2628°N -73.4898°W) (**Figure 1**) located along the road connecting the towns of Contratación and El Guacamayo, approximately five hours by vehicle from Bucaramanga. Finca Buenavista comprises secondary forest, apparently regenerating for at least 20 years on former cattle pastures, as well as remnant mature forest on steeper slopes at the base of Cerro Churri Churri (6.2670°N -73.4938°W) and along the banks of La Profunda creek (6.2671°N -73.4899°W) (**Figure 1**). Fieldwork was conducted at these sites from April 8 to May 6. 2024. We established a peripheral campsite at the summit of Cerro Churri Churri (6.2633°N -73.4958°W) (**Figure 1**), 1.5 hours on foot north of the urban center of El Guacamayo. This site is an azonal paramo that is altered in its lower section, but still has dense vegetation at higher elevations, connecting with extensive forests to the North. We surveyed Cerro Churri Churri on April 13–14, 19–20, and 23-24, 2024.

At Finca Buenavista, we established six mist-netting stations between 1,985 and 2,239 MASL., and an additional station at 2,565 MASL. on Cerro Churri Churri (**Figure 1**), as part of our standardized mist-netting protocol. We opened the mist-nets between 05:20 and 06:25 h and closed them between 15:20 and 17:00 h, complementing the standardized mist-netting with two targeting collection sessions using a compressed-air pistol (Crosman 2240; 5.5 mm caliber) in the vicinity of Finca Buenavista. We also included incidental captures in mist nets set for bats at nearby sites and conducted a one-hand capture. Mist-netting and air-gun collecting were conducted between April 9 and 21, 2024. Some captured birds were collected following standardized protocols (**Winker**, 2000; **Engilis *et al.***, 2018) and prepared in the field as museum voucher specimens, recording standard biological data (body mass with a digital scale, gonad size with a caliper, percentage of skull ossification, moult, brood patch, cloacal protuberance, presence of an eye-ring, and colour of the iris, bill, and tarsus). Tissue samples (muscle, heart, and liver) were preserved in 96% ethanol for all voucher specimens. Additionally, several spread wings and at least 30 carcasses were preserved likewise. All tissue samples were cryopreserved in the tissue collection of *Universidad Industrial de Santander* Natural History Museum in Bucaramanga (UIS-CT), after ethanol removal. Specimens were catalogued in the Museum's ornithology collection (UIS-AV) and taxonomically identified *sensu* **Gill *et al.*** (2023). Specimens were collected under the permit authorized by Resolution 994 of the National Environmental Licensing Authority (**ANLA**, 2020), with the approval of the UIS Scientific Research Ethics Committee (**CEINCI**, 2020), and the consent of local landowners. The information on all museum voucher specimens was reported to SIB-Colombia (https://ipt.biodiversidad.co/permisos/resource?r=proyecto_82682_uisav).

We also conducted standardized audio recordings between 05:16 and 06:10 h using a ZOOM H1 recorder mounted on a tripod at a height of 1–1.7 m, pointing toward the densest vegetation. The recordings were obtained at ten sampling points in Finca Buenavista (2,075 - 2,200 MASL.) (**Figure 1**), and lasted 20 minutes each. We also recorded at four other points (2,493 - 2,596 MASL.) on Cerro Churri Churri (**Figure 1**). Besides these standardized recordings, we obtained opportunistic audio recordings using a ZOOM H1 recorder and smartphones. We processed raw recordings with the Audacity software (**Audacity Team**, 2021) by applying a high-pass filter to remove low-frequency noise, peak normalization (set at −3.0 dB), and reducing manual noise through the selection of unwanted sound profiles. We analyzed these processed files using BirdNET-Analyzer v1.2.0 (**Kahl *et al.***, 2021) with the default species model, constraining it to the geographic

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coordinates and elevation range of the study area. Key parameter settings included: a confidence threshold = 0.1, sensitivity = 1.2, and evaluation frequency range = 0–15 kHz. We exported BirdNET output as a selection table compatible with Raven Pro 1.6.5 (**Yang**, 2025), providing species identifications, vocalization timestamps, and confidence scores. These selections were overlaid onto spectrograms in Raven for preliminary identifications. We verified the preliminary identifications by comparing them with reference recordings from the Macaulay Library (**Cornell University**, 2025) and Xeno-canto (**Xeno-canto Foundation**, 2021). Observations and photographs were obtained *ad libitum* using 10× 42 binoculars, a Nikon Coolpix P950 camera with integrated optical zoom lens (24–2,000 mm), and smartphones. The expedition species list included all taxa supported by physical or digital evidence (i.e., voucher specimens, audio recordings, or photographs), as well as taxa independently observed and confirmed by at least two of the authors.

Species richness was evaluated using the rarefaction and extrapolation framework of **Chao *et al.*** (2014) implemented in R (**R Core Team**, 2024) through the iNEXT package (**Hsieh *et al.***, 2016). Analyses were restricted to data from standardized mist-netting and audio recordings; *ad libitum* audio recordings and incidental captures in bat mist nets were excluded. We calculated total abundances per species for each method by summing detections across the entire sampling period, and these abundance vectors were used as input for subsequent analyses. Richness was estimated using the abundance-based approach (Hill number q = 0). Rarefaction and extrapolation curves were generated for both methods, with extrapolation extended to 800 individuals. Asymptotic species richness was estimated using the Chao1 estimator, which incorporates the frequency of rare species to infer undetected diversity. Confidence intervals were calculated using bootstrap resampling as implemented in iNEXT.

To compare mitochondrial DNA (mtDNA) sequences of individuals from the four focal species (see Appendix) collected in El Guacamayo with those from other populations in the montane forests of Serranía de los Yariguíes and the Eastern Cordillera of Santander (additional samples housed at UIS-CT), we extracted genomic DNA from muscle tissue using the EZ-10 Spin Column Genomic DNA Miniprep Kit (BIOBASIC). We amplified the ND2 locus using primers H1056U and L5215U under the following PCR conditions: 0.3 mM dNTPs, 1.5 mM $MgCl_2$, 0.4 mM of each primer, and 0.6 U of Taq polymerase. The thermal cycling protocol consisted of an initial denaturation at 94°C for 1 min, 10 cycles at 94°C for 15 s, 55°C for 30 s, and 72°C for 30 s, followed by 35 cycles at 94°C for 15 s, at 50°C for 30 s, and at 72°C for 30 s, and a final extension at 72°C for 7 min. PCR products were sequenced using the Sanger method. Sequences were aligned in BioEdit (**Hall**, 1999), the genetic diversity (π) was calculated in DnaSP 6 (**Rozas *et al.***, 2017), and the haplotype networks were constructed using the Network software (**Polzin & Daneshmand**, 2025).

Results

After a total sampling effort of 1,260 mist-net hours (1,180 h at Finca Buenavista and 80 h at Cerro Churri Churri), 4.7 hours of standardized audio recordings, two targeting collecting sessions using an air gun, and additional *ad libitum* recordings, observations, and photographs, we documented 142 species representing 34 families and 14 orders during our ornithological expedition to the South of Serranía de Los Yariguies at El Guacamayo, Santander (**Table 1S,** https://raccefyn.co/index.php/raccefyn/article/view/3395/5355). The various species were detected by different methods (**Table 1S,** https://raccefyn.co/index.php/raccefyn/article/view/3395/5355). We ordered the records according to the level of evidentiary support, beginning with those supported by museum voucher specimens. Standardized mist-netting resulted in the capture of 115 individuals, with a capture rate of 0.07 individuals per mist-net hour at Finca Buenavista and 0.36 individuals per mist-net hour at Cerro Churri Churri. We complemented standardized mist-netting with incidental captures in bat mist nets, air-gun sessions, and manual capture. We collected a total of 121 museum voucher specimens (UIS-AV 3210–3330) representing 54 species (**Table 1S,** https://

raccefyn.co/index.php/raccefyn/article/view/3395/5355), along with their corresponding tissue samples (UIS-CT 2820–2940). The most frequently represented species in the series were *Henicorhina leucophrys* (n = 11), *Myadestes ralloides* (n = 11), *Mionectes galbinus* (n = 8), *Chlorospingus flavopectus* (n = 7), and *Colibri cyanotus* (n = 5). However, half of the species were represented by a single specimen (**Table 1S**, **Figure 2**).

Out of the 121 voucher specimens, 48 were females and 63 males, while sex could not be determined in 10 specimens. Some specimens exhibited gonad sizes exceeding those recorded in the UIS-AV comparative series for the same taxa collected in other months, suggesting reproductive activity during April. These cases include *Aulacorhynchus albivitta* (UIS-AV-3325, left testis [LT]: 8.4 × 3.4 mm; comparative series mean LT = 6.5 × 2.7 mm in 5 males), *M. ralloides* (UIS-AV-3255, LT: 9.9 × 6.9 mm; series mean LT = 3.1 × 2.7 mm in 12 males), *H. leucophrys* (UIS-AV-3222, ovary [Ova]: 11 × 19 mm; series mean Ova = 4.6 × 2.6 mm in 4 females), and *C. flavopectus* (UIS-AV-3266, LT: 8.35 × 5 mm; series mean LT = 5.7 × 4.4 mm in 3 males). Additionally, individuals of *H. leucophrys* (UIS-AV-3324), *M. galbinus* (UIS-AV-3282), *Premnoplex brunnescens* (UIS-AV-3248), and *Anabacerthia striaticollis* (UIS-AV-3224) exhibited less than 20% skull ossification, indicating the presence of juveniles and suggesting that these taxa were in their breeding season in April. Regarding hummingbirds, which do not ossify their skulls with maturity, no individuals with enlarged gonads were recorded. Nevertheless, the endemic *Coeligena prunellei* was observed carrying nesting material, specifically lichen collected from a rocky wall.

Notably, we collected a female *Psarocolius angustifrons* and a nest (UIS-AV-3289) that were part of a colony (**Figure 3**). The specimen was an adult female (100% skull ossification) with undeveloped gonads (ovary 10 × 6 mm; ovule 2.4 mm) in relation to its body size (total length 40 cm, mass 560 g). The nest, constructed from various plant materials, measured 140 cm in length. The entrance, located at the top of the nest, approximately 38 cm from the attachment point, had a 17 cm perimeter, while the breeding chamber had a 74 cm perimeter. The dry mass of the nest was 530 g. The colony comprised eight nests suspended at approximately 2 m above La Profunda creek, with a spacing of at least 1 m between nests. Although the specimen and the nest were collected at the same site, there was no evidence that the individual was actively attending the nest, which contained no eggs.

We identified 101 species from the audio recordings, 28 of which were also documented by museum voucher specimens (**Table 1S,** https://raccefyn.co/index.php/raccefyn/article/view/3395/5355). Our photographic records comprised 34 species (**Table 1S**; **Figure 3**), eight of which were not recorded as specimens or audio. Additionally, at least two authors observed 63 species, 17 of which were recorded exclusively by this method. We documented 58% of species using a single method, 36% two or three methods, and only 6% using every type of recording. Notably, 21 species (15%) were recorded exclusively at Cerro Churri Churri despite the greater sampling effort conducted at Finca Buenavista.

We recorded 85 species using standardized audio records and 42 through standardized mist-netting. However, asymptotic richness estimated using the Chao1 estimator indicated substantially higher values for both methods (**Figure 4**). For audio-recording, the estimated richness was 186 species (95% CI: 122 –249), indicating low sampling completeness and a high proportion of rare species. In contrast, mist-netting showed a smaller difference between observed and estimated richness, with a Chao1 estimate of 52 species (95%CI: 35–69), suggesting comparatively higher inventory completeness.

For the four species analyzed for mtDNA (each represented by voucher specimens from El Guacamayo and other localities in Serranía de los Yariguíes and the Eastern Cordillera in Santander), we obtained ND2 alignments ranging from 458 to 707 bp (**Table 1**) (**Appendix,** https://raccefyn.co/index.php/raccefyn/article/view/3395/5355). Genetic diversity was low across all four species (PI < 0.003, H < 5) (**Table 1**) and approximately

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Figure 2. Photographs of some individuals captured and collected in El Guacamayo, Santander, Colombia, during the April–May 2024 expedition to the South of Serranía de los Yariguíes. **A)** *Colibri cyanotus*, **B)** *Boissonneaua flavescens*, **C)** *Malacoptila mystacalis*, **D)** *Hemitriccus granadensis,* **E)** *Thamnophilus unicolor,* **F)** *Premnoplex brunnescens,* **G)** *Synallaxis unirufa*, **H)** *Scytalopus latrans*, **I)** *Henicorhina leucophrys*, **J)** *Myadestes ralloides*, **K)** *Arremon brunneinucha*, **L)** *Diglossa caerulescens*

an order of magnitude lower in the Serranía de los Yariguíes than in the Eastern Cordillera (**Table 1**). Given this limited variation, we were able to construct haplotype networks only for two species (**Figure 5**). In both cases, these networks revealed a common haplotype shared by individuals from multiple localities, along with two to four rare haplotypes restricted to individuals from a single locality.

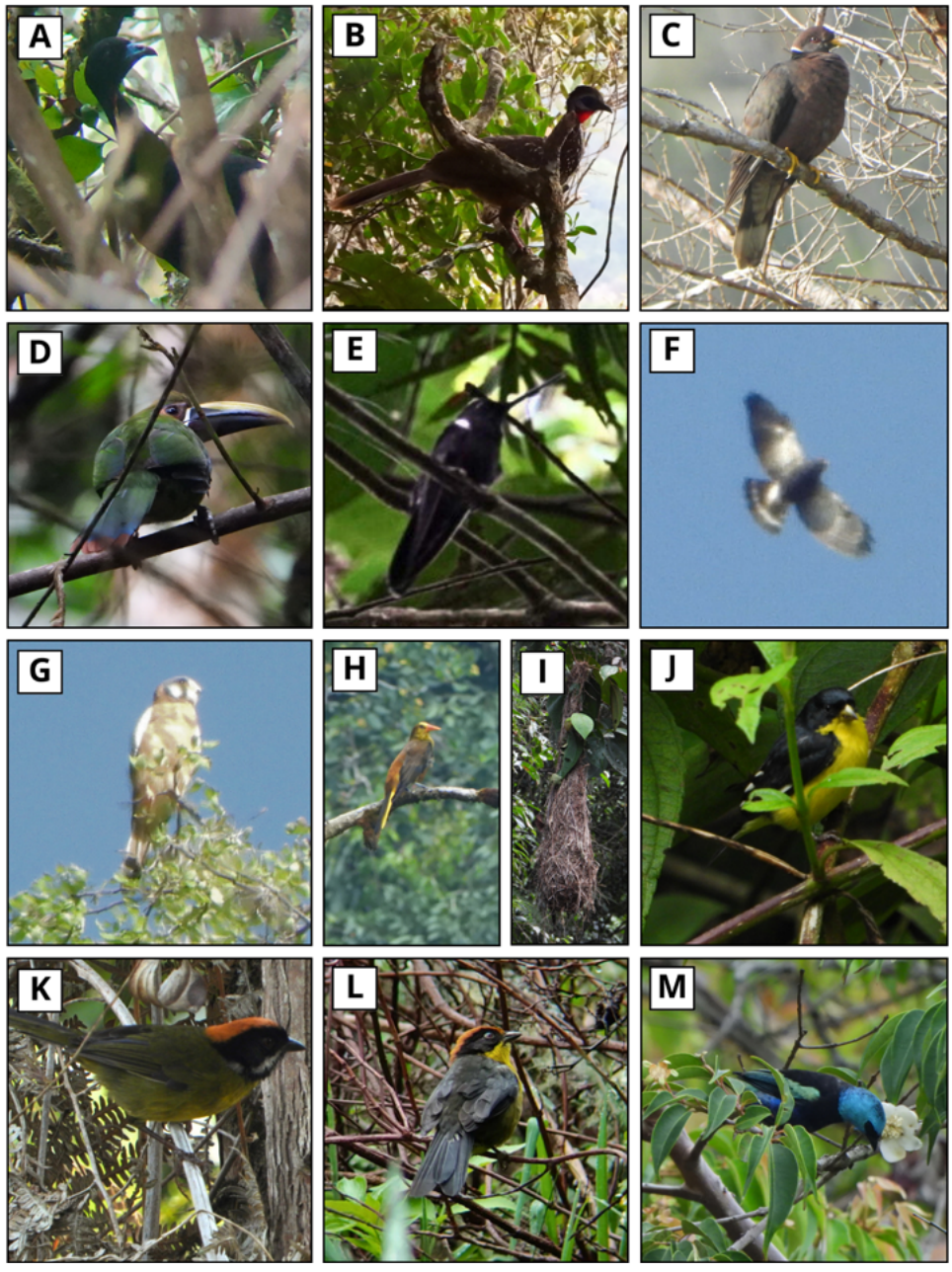

Figure 3. Photographs of some individuals not captured in El Guacamayo, Santander, Colombia, during our April–May 2024 expedition to the South of Serranía de los Yariguies corresponding to some species in the region. **A)** *Aburria aburri*, **B)** *Penelope argyrotis*, **C)** *Patagioenas fasciata*, **D)** *Aulacorhynchus albivitta*, **E)** *Coeligena prunellei*, **F)** *Parabuteo leucorrhous*, **G)** *Falco femoralis*, **H)** *Psarocolius angustifrons*, **I)** *Psarocolius angustifrons* (nest), **J)** *Spinus psaltria*, **K)** *Atlapetes albofrenatus*, **L)** *Atlapetes latinuchus*, **M)** *Stilpnia cyanicollis*

Discussion

In the montane forests of Serranía de los Yariguíes, between the 1,900 and 2,600 m a.s.l. surveyed by our expedition, 222 species had previously been reported (**Donegan *et al.***, 2010; **Gbif.org**, 2023a), 56% of which we also recorded in this study. Based on the Chao1 estimate of 186 species derived from standardized audio records, our combination

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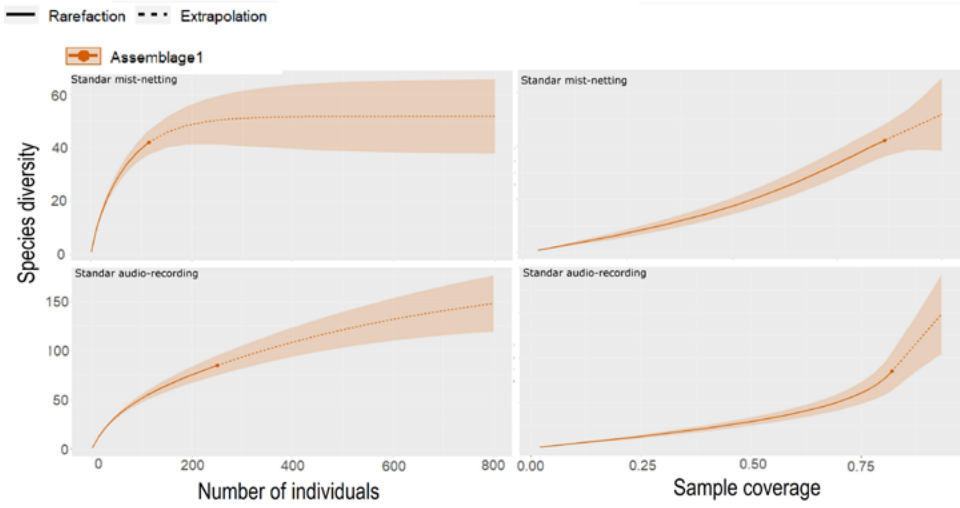

Figure 4. Species richness assessed by rarefaction and extrapolation of individuals (left) and for coverage (right) using the two standardized methods to document bird species at El Guacamayo, Santander, Colombia, during the April–May 2024 expedition to the South of Serranía de los Yariguíes

Table 1. Genetic diversity (π) of four bird species from montane forests in Santander, Colombia

Species	N	ND2 aligment	Haplotypes total	π total	π Serranía de los Yariguíes	π Eastern Cordillera
Eutoxeres aquila	6	638bp	1	0	0	0
Ocreatus underwoodii	5	573bp	2	0,0007	0	0,00175
Anabacerthia striaticollis	9	707 bp	5	0,00126	0,00081	0,00284
Syndactyla subalaris	12	458 bp	3	0,00126	0,00097	0,00146

of methodological approaches would account for 76% of the species expected to occur within the study area. We also obtained 17 new records for this elevation band (**Table 1S,** https://raccefyn.co/index.php/raccefyn/article/view/3395/5355), of which only one, that of *Ochthoeca cinnamomeiventris*, is supported by a museum voucher specimen (AV-3214/ CT-2824), whereas *Spinus psaltria* (**Figure 3J**) is supported by photographic evidence. Most of the new records are supported by audio recordings (see the Xeno-canto catalogue in Appendix 1), including *Scytalopus rodriguezi* (XC1036744), which represents the southernmost record for this Colombian endemic species in Santander. *Phaethornis longirostris* (XC1036740) and *Arremon assimilis* (XC1036728) recordings constitute the first published audio records of these species in Santander. Four other new records are based exclusively on observations, but they correspond to species that are common in the region, such as *Myiozetetes similis*, *Pheugopedius spadix*, *Cinclus leucocephalus*, and *Spinus spinescens*. The scarcity of museum voucher specimens from Serranía de los Yariguíes is underscored by the fact that out of the 51 species collected during our expedition, 29 represent their first material evidence (**Gbif.org**, 2023b) on this ridge (**Table 1**). For the species collected, the nearest previously documented specimen museum vouchers (**Gbif.org,** 2023b) were located between 9 and 137 km from our study site (mean = 46 km), and 76% of the species were recorded within 50 km of their closest known

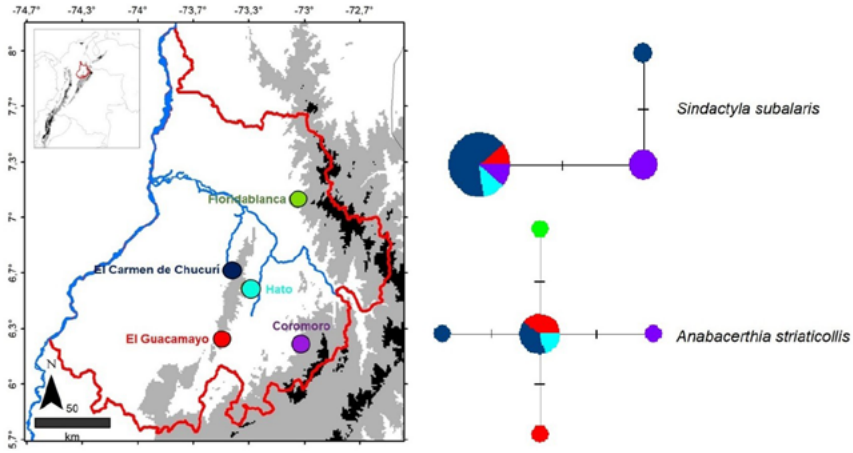

Figure 5. Left: Montane forest localities included in mtDNA analyses for four bird species from Santander, Colombia. Grey areas correspond to elevations between 2.00 and 3,500 MASL, and black ones to more than 3,500 MASL. Right: Haplotype networks of the ND2 mtDNA sequences for two bird species collected at El Guacamayo, Santander. Circles: haplotypes and their size correspond to the sampling number. Colors in the networks correspond to the colors for localities in the map.

specimens. Based on eBird (**eBird,** 2021), 13 of the species we recorded had few records in Santander (< 1%) compared to their observations in Colombia, including *Phaethornis syrmatophorus*, *Pharomachrus auriceps*, *Thripadectes virgaticeps*, *Scytalopus latrans*, *Cyclarhis nigrirostris,* and *A. assimilis*. In contrast, more than half of the eBird records of *S. rodriguezi* for Colombia have been obtained in Santander. This information suggests that El Guacamayo may be of particular interest to birdwatchers, both for species that are rarely recorded in Santander or for endemic taxa that occur within this department.

Our results confirmed that multiple survey methods are necessary to adequately document avian diversity in the Neotropics, as these approaches are complementary and no single method detects all species (**Stiles & Roselli**, 1998; **Polanco *et al.***, 2015; **Suárez-García *et al.***, 2017; **Deus *et al.***, 2023). In our study, audio-recordings accounted for the highest proportion of documented species (70%), which is consistent with the range reported in other Neotropical avian surveys (56–72%) (**Arbeláez-Cortés *et al.***, 2023; **Deus *et al.***, 2023). However, the nature of the evidence generated by each method differs, contributing in distinct ways to addressing gaps in ornithological knowledge (**Lees *et al.***, 2020). In this regard, museum voucher specimens constitute the most rigorous and informative form of documentation, as they provide permanent, verifiable records that can directly address multiple knowledge gaps, especially since tissues and carcasses have been preserved in addition to skins.

Although museum voucher specimens represented fewer species than observational and acoustic records, their contribution is unique because of the type of biological information they provide. Under the extended specimen framework in ornithological collections, each specimen is understood as a multidimensional unit of information that can support diverse ecological and evolutionary analyses, including morphological, genomic, and ectoparasite studies, as well as phenological inference (**Webster**, 2017; **Oniki-Willis *et al.***, 2020; **Kapun *et al.***, 2025). In our study, measurements associated with reproductive activity (i.e., gonad size and percentage of skull ossification) during April provided direct biological evidence that is rarely obtained through inventories using only observational or acoustic methods. A national synthesis of avian breeding phenology in Colombia relying on secondary data sources indicated that bird assemblages from mid-elevation regions exhibited a breeding peak in March, while the breeding activity in the Andes was reported to extend from March to June, with an apparent interruption

during April (**Moreno-Palacios *et al.***, 2025). Our results provide primary, specimen-based evidence from particular Andean species in Santander, enabling direct inference of reproductive timing at both population and regional scales, and complement previous breeding information from other montane forest species in this region that has likewise been derived from analyses of museum voucher specimens (**Arbeláez-Cortés *et al.***, 2023). These results highlight the continuing importance of collecting specimens for biological collections as sources of verifiable, high-resolution biological data across spatial and temporal scales.

The material we collected also contributes to addressing the so-called "Darwinian shortfall" (**Lees *et al.***, 2020). Previously published DNA information for eight species from Serranía de los Yariguíes indicated that only *Adelomyia melanogenys* and *Atlapetes albinucha* (**Rocha-Méndez *et al.***, 2018; **Arbeláez-Cortés & Trujillo-Arias**, 2021) show genetic differentiation relative to populations inhabiting other montane forests in the Eastern Cordillera. The data for four additional species presented here further support the general pattern of low genetic differentiation between the montane forests of Serranía de los Yariguíes and those of the Eastern Cordillera, at least south of the Chicamocha River Canyon (**Arbeláez-Cortés & Trujillo-Arias**, 2021). To expand sampling to include additional material of the four focal species from montane forests north of the Chicamocha River Canyon, especially in the municipality of San Andrés, encompassing some of the montane forests closest to the canyon, would be critical to rigorously test for phylogeographic structure across this landscape feature.

Four recent ornithological expeditions to montane forests in Santander (**Córdoba-Córdoba & Sierra**, 2018; **Arbeláez-Cortés *et al.***, 2020; **Arbeláez-Cortés *et al.***, 2023) provide a useful basis for comparison with the avifaunal composition documented at El Guacamayo. Each expedition included more than one week of fieldwork, with a mist-netting effort of over 374 mist-net hours per site, and incorporated at least one additional method also employed in our study (observations or audio recordings). Of the 142 species documented at El Guacamayo (1,985–2,596 m a.s.l.), 55 are also present in Coromoro (2,014–3,121 m a.s.l.), whereas 48 or fewer have been registered in higher elevations at Peñón montane forests (2,390–2,856 m a.s.l.) and Santa Bárbara (2,850 m a.s.l.), or in lower elevation forests within the Serranía de los Yariguies (El Carmen de Chucurí, 1,400–1,850 m a.s.l.). These results suggest that similarity in species composition is more strongly associated with elevational overlap than geographic proximity *per se*.

Conclusions

In our expedition, the integration of multiple bird-survey methods enabled us to determine that the montane forests south of the Serranía de los Yariguíes, at El Guacamayo, continue to harbour substantial avian diversity. However, the low mist-netting capture rates suggest that the population densities of many species may be relatively low. Nonetheless, the avifauna of this area is comparable, both in species composition and in the genetic diversity of four of the species analyzed, to that of montane forests at similar elevations in the Eastern Cordillera. Our findings help to close a geographic gap in the ornithological knowledge of Santander and broaden our understanding of Serranía de los Yariguíes by providing new material evidence (museum voucher specimens, tissues, and audio-recordings) to support future research. They may also contribute to the promotion of nature-based tourism initiatives in the area. Indeed, our expedition generated audiovisual material to produce a documentary (**Regueros *et al.***, 2024) that will allow a broader audience to become familiar with the region, its biodiversity, and the methods employed to document it.

Supplementary information

See the supplementary information in https://raccefyn.co/index.php/raccefyn/article/view/3395/5355

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Conflicts of interest

The authors declare that there is no conflict of interest of any kind regarding the publication of the results of our work.

Author contributions

EAC conceived the research idea, designed the study, performed data collection, data analysis, and interpretation, and led manuscript writing. FRG conceived the research idea, designed the study, performed data collection, data analysis and interpretation, and supported manuscript writing. SABV, LLL, DRMC, and CAPQ performed data collection and analysis and supported manuscript writing.

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