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Altitudinal patterns and seasonal stability in the avifauna of Cerro Chucantí, Panama

Patrones altitudinales y estabilidad estacional en la avifauna de Cerro Chucantí, Panamá

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Abstract

Darién combines humid lowland and montane forests with high endemism, but these ecosystems are increasingly threatened by deforestation, agriculture, cattle ranching, and logging. Because the birdlife of Cerro Chucantí remains poorly known, we assessed avian diversity across three elevational bands (500, 800, and 1200 m a.s.l.) in the Cerro Chucantí Private Nature Reserve, Panama, during the dry and rainy seasons of 2021, using mist nets, point counts, and incidental records. Over 36 sampling days, we recorded 2602 individuals representing 248 species. Passeriformes dominated both abundance and richness, whereas Trochilidae was the most abundant family and Tyrannidae the richest. Species composition differed significantly between the highest and lowest elevations, suggesting greater turnover and specialization at upper sites, while no significant seasonal differences were detected.

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These results provide a baseline for the avifauna of this isolated montane system and highlight the urgency of conserving Cerro Chucantí's cloud forests through expanded sampling and long-term monitoring.

Keywords: Bird diversity, conservation status, mist nets, montane forest, point counts, species turnover.

Resumen

Darién combina bosques húmedos de tierras bajas y montanos con alto endemismo, pero amenazados por la deforestación, la agricultura, la ganadería y la extracción de madera. Debido al escaso conocimiento sobre las aves de Cerro Chucantí, evaluamos la diversidad avifaunística en tres niveles altitudinales (500, 800 y 1200 m s.n.m.) de la Reserva Natural Privada Cerro Chucantí, Panamá, durante las temporadas seca y lluviosa de 2021, mediante redes de niebla, conteos por punto y registros incidentales. En 36 días de muestreo se registraron 2602 individuos de 248 especies. Passeriformes dominó en abundancia y riqueza, mientras que Trochilidae fue la familia más abundante y Tyrannidae la más rica. La composición de especies difirió significativamente entre los niveles altitudinales extremo alto y bajo, lo que sugiere mayor recambio y especialización en elevaciones superiores, mientras que no se detectaron diferencias estacionales significativas. Estos resultados aportan una línea base para la avifauna de este sistema montano aislado y destacan la urgencia de conservar los bosques nubosos de Cerro Chucantí mediante mayor muestreo y monitoreo a largo plazo.

Palabras clave: Diversidad de aves, estado de conservación, redes de niebla, bosque montano, conteo por puntos, recambio de especies.

INTRODUCTION

The Darién region comprises a humid lowland system interrupted by mountain massifs at the junction between Central and South America, along the border between Panama and Colombia (Renjifo et al., 2017). The peaks of eastern Panama and adjacent northwestern Colombia maintain an extensive belt of relatively well-preserved montane tropical forest (Wege, 1996). Within this complex, the Serranía de Majé stands out for its high richness and endemism, as evidenced by the recent discovery of new species of fungi, plants, insects, amphibians, and reptiles reported to date only from this area (Batista et al., 2020).

Despite its biological importance, the Cerro Chucantí Private Nature Reserve (RNPCC) lacks formal state protection and is increasingly pressured by slash-and-burn agriculture, extensive cattle ranching, and timber extraction in surrounding lower-elevation areas.

These threats heighten the risk of habitat loss and fragmentation, with potentially severe consequences for endemic species and those restricted to higher elevations; thus, effective protection of the reserve is a conservation priority (Batista et al., 2020).

Cerro Chucantí is considered a "sky island," a concept introduced by Heald (1967) to describe isolated mountains surrounded by lowlands. Although such environments were historically assumed to hold low diversity due to more restrictive conditions, they are now recognized as biodiversity refugia that concentrate highly specialized endemic species (Coyne & Orr, 2004; Cooke, 2005; Nogués-Bravo et al., 2008; Steinbauer et al., 2016). In this context, birds represent an especially informative focal group for evaluating the conservation status of the area because of their diversity, their value as a flagship taxon, their utility for inferring ecological integrity from community composition, and their sensitivity to land-use and climate change.

Although the Serranía de Majé is a recognized center of endemism, the avifauna of the RNPCC remains poorly documented. An early survey reported 49 species, including several associated with higher elevations but with broad distributions (Angehr & Christian, 2000). In addition, the historical isolation of montane populations by extensive lowlands has been proposed as a mechanism that could promote differentiated evolutionary lineages, underscoring the biogeographic relevance of the area (Miller et al., 2007; Renjifo et al., 2017). Characterizing bird richness and abundance along an altitudinal gradient is therefore necessary to identify factors shaping assemblage structure, quantify turnover and overlap among elevation bands, and inform conservation actions under changing environmental conditions (Rahbek, 1995; Grytnes, 2003; McCain & Grytnes, 2010).

MATERIALS AND METHODS

Study site

The Cerro Chucantí Private Nature Reserve (RNPCC) is located in the southeastern sector of the Serranía de Majé and forms part of the Eastern Panamanian Montane Forests ecoregion (World Wildlife Fund, 2014). The reserve covers more than 800 ha. The Serranía de Majé ranges from 800 to 1200 m a.s.l., but Cerro Chucantí rises above 1400 m a.s.l., making it the only area within the range that is predominantly covered by cloud forest (Samudio, 2001). Although no site-specific climatic record is available, annual precipitation in the ecoregion ranges from 3000 to 4000 mm and temperature ranges from 20 to 27 °C (World Wildlife Fund, 2014). Vegetation belts include lowland humid tropical forest between 0 and 600 m a.s.l. and a narrow belt of premontane humid forest above 1000 m a.s.l. (Ramírez, 2003) (Fig. 1).

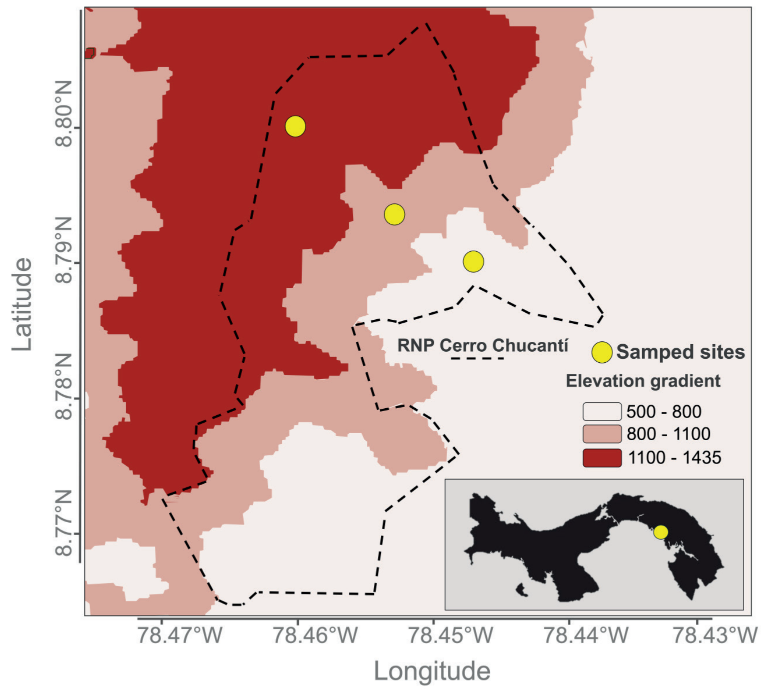

Figure 1. Map of the southeastern area of the Serranía del Majé, showing the polygon of the RNPCC, divided into the altitudinal levels used in the study, with the reference points where sampling was conducted.

Figura 1. Mapa de la zona sureste de la Serranía del Majé, que muestra el polígono de la RNPCC, dividido por niveles altitudinales utilizadas para el estudio con los puntos de referencia donde se realizaron los muestreos.

Sampling design and data collection

Four field trips of approximately 13 days each were conducted in 2021, two during the dry season (January and March) and two during the rainy season (August and October), to document both resident and migratory birds. During each trip, three altitudinal levels were sampled using two primary methods applied over three days per level: one day of point counts and two days of mist-netting. Species observed outside these standardized schemes were recorded as complementary observations.

Species identification followed Angehr & Dean (2010). Sampling procedures followed Ralph et al. (1996). Common names followed Ridgely and Gwynne (2005), and taxonomic updates were based on Audubon (2023).

For point counts, stations were established along the main trail at 100 m intervals. At each station, 10 minute counts were conducted within a 50 m radius. Point counts were conducted for one day per altitudinal level, with two daily surveys: a morning survey beginning at 06:00 h and an afternoon survey beginning at 15:00 h, adjusted as needed based on weather conditions and terrain difficulty. Observations were made visually and aurally using Bausch & Lomb Elite 8X40 mm binoculars; when necessary, audio recordings were taken for later confirmation.

At each point, start and end times, habitat category, detected species, number of records, and relevant field notes were recorded. Under this methodology, two people worked for a total of 120 person-hours.

For mist-netting, 12 m × 2.5 m mist nets (36 mm mesh, four shelves) were installed at 500, 800, and 1200 m a.s.l. in areas of high bird activity identified during preliminary searches. Nets operated for two days per altitudinal level (three per altitudinal level) from 06:00 to 16:00 h. Captured individuals were placed in paper bags inside cloth bags to reduce ectoparasite transfer and were processed at an intermediate station away from the nets. To identify recaptures, each bird was marked by clipping the tips of one left and one right rectrix following established codes and was subsequently released.

Data analysis

All analyses were performed in R. Alpha diversity was calculated using a species-by-sample abundance matrix, in which rows represented the sampling units classified according to altitudinal level and season, and columns represented the bird species recorded during standardized sampling. The matrix was constructed using the total number of individuals recorded per species from mist-netting and point counts. Incidental records were included only to complement the general species inventory and were excluded from diversity analyses because they were not obtained under a standardized sampling design. All species recorded during standardized sampling were included in the analyses.

The BiodiversityR package was used to calculate alpha diversity indices, including Shannon diversity (H'), Simpson diversity ($1 - D$), and Pielou's evenness (J). Shannon diversity was calculated using the natural logarithm base (ln). No logarithmic transformation or standardization was applied to the abundance data before calculating alpha diversity indices. These indices were selected because they provide complementary information on assemblage structure: Shannon diversity incorporates both species richness and relative abundance, Simpson diversity gives greater weight to dominant species, and Pielou's evenness describes the distribution of individuals among species.

Beta diversity was assessed using Bray–Curtis dissimilarities calculated with the vegan package from the abundance matrix. Bray–Curtis dissimilarity was selected because it is appropriate for abundance data, does not consider joint absences, and allows evaluation of variation in species composition among sampling units. No transformation was applied to the abundance data prior to the calculation of Bray–Curtis dissimilarities.

The function `betadisper` was used to evaluate the homogeneity of multivariate dispersions among altitudinal levels and between seasons. This analysis allowed us to determine whether groups differed in the variability of their species composition. Differences in multivariate dispersion were evaluated through permutation tests, and post hoc comparisons were conducted using TukeyHSD when significant differences were detected. Non-metric multidimensional scaling (NMDS), based on Bray–Curtis dissimilarities, was used to visualize patterns of similarity and dispersion among altitudinal levels and seasons.

RESULTS

Sampling effort, general composition, and dominant taxa

A total of 36 sampling days were completed, including 24 days of mist-netting and 12 days of point counts. Overall, 3600 net-hours were accumulated (10 hours × 24 days × 15 nets), and 120 person-hours were invested in point counts (5 hours × 12 days × 2 observers). A total of 2602 individuals belonging to 248 species, 44 families, and 19 orders were recorded (SM 1, 2). In terms of abundance by order, Passeriformes, with 1735 individuals (66.68%), Apodiformes with 418 individuals (16.06%), and Piciformes with 122 individuals (4.69%) were the most representative orders, whereas the remaining orders each accounted for less than 15% (Table 1).

Table 1. List of orders recorded across all methodologies, detailing the number of individuals and the number of species, along with their respective percentages of the overall total.

Tabla 1. Lista de órdenes reportados en todas las metodologías, detallando la cantidad de individuos y la cantidad de especies, con sus respectivos porcentajes del total general.

Order	Individuals	Percentage of individuals (%)	Species	Percentage of species (%)
TINAMIFORMES	5	0.19	2	0.81
GALLIFORMES	16	0.61	4	1.61
COLUMBIFORMES	52	2.00	8	3.23
CUCULIFORMES	16	0.61	4	1.61
CAPRIMULGIFORMES	1	0.04	1	0.40
NYCTIBIIFORMES	1	0.04	1	0.40
APODIFORMES	418	16.06	22	8.87
GRUIFORMES	2	0.08	1	0.40
CHARADRIIFORMES	2	0.08	2	0.81
PELECANIFORMES	2	0.08	1	0.40
CATHARTIFORMES	41	1.58	3	1.21
ACCIPITRIFORMES	34	1.31	15	6.05
STRIGIFORMES	19	0.73	6	2.42
TROGONIFORMES	37	1.42	5	2.02
CORACIIFORMES	17	0.65	2	0.81
PICIFORMES	122	4.69	18	7.26
FALCONIFORMES	17	0.65	8	3.23
PSITTACIFORMES	65	2.50	6	2.42
PASSERIFORMES	1 735	66.68	139	56.05
Total	**2 602**	**100.00**	**248**	**100.00**

At the family level, Trochilidae with 388 individuals (14.91%), Pipridae with 301 individuals (11.57%), and Turdidae with 264 individuals (10.15%) were the most abundant, while the remaining families each represented less than 10% (SM 3). In terms of taxonomic richness, Passeriformes, with 139 species (56.05%) and 20 families, was the best represented order, followed by Apodiformes with 22 species (8.87%) and Piciformes with 18 species (7.26%). Family-level richness was highest in Tyrannidae with 24 species (9.68%), followed by Trochilidae and Thraupidae with 20 species each (8.06%). Of the 248 species recorded, five exceeded 100 records: *Corapipo altera* with 230 individuals (Figure 2A), *Goldmania violiceps* with 174 individuals (Figure 2B), *Mionectes olivaceus* with 129 individuals (Figure 2C), *Catharus ustulatus* (Figure 2D), and *Chlorospingus tacarcunae* with 114 individuals (Figure 2E).

Altitudinal variation, seasonality, and alpha and beta diversity

With respect to sampling methodology, the species most frequently captured in mist nets was *Corapipo altera* (182 captures), the most frequently recorded species in point counts was *Chlorospingus tacarcunae* (89 observed individuals), and the most frequent incidental record during fieldwork at the reserve was *Brotogeris jugularis* (15 sightings). Along the altitudinal gradient, the high-elevation level was characterized by a greater representation of *Goldmania violiceps* (172 individuals), the mid-elevation level by *Corapipo altera* (132 individuals), and the low-elevation level by *Manacus vitellinus* (42 individuals) (Figure 2F). With respect to season, *Corapipo altera* predominated in both the dry season (97 individuals) and the rainy season (122 individuals). Multivariate dispersion of bird assemblages differed significantly among some of the sampled altitudinal levels (Figure 3). Post hoc comparisons indicated that the mid- and low-elevation levels did not differ significantly in multivariate dispersion ($p_{Mid\text{-}Low} = 0.9890910$), whereas the high-elevation level differed significantly from both the low-elevation level ($p_{Low\text{-}High} = 0.0047628$) and the mid-elevation level ($p_{Mid\text{-}High} = 0.0038946$). In terms of alpha diversity, diversity gradually decreased with increasing elevation according to the Shannon and Simpson indices (Table 2), and richness was higher at lower altitudinal levels (SM 2). By season, no significant differences in multivariate dispersion were detected between the dry and rainy seasons ($p_{dry\text{-}rainy} = 0.838$).

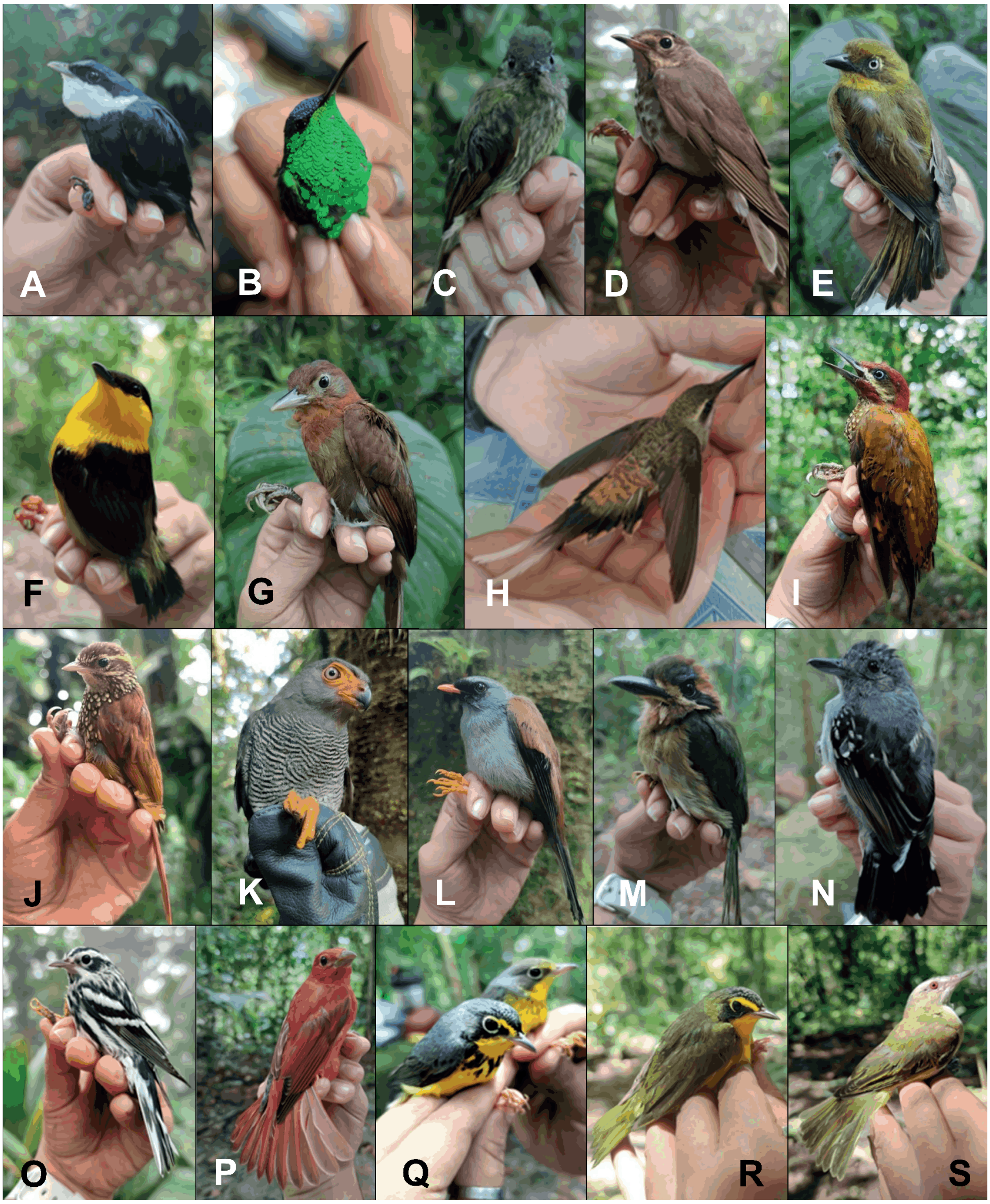

Figure 2. Birds recorded in the study. A. *Corapipo altera*, B. *Golmania violiceps*, C. *Mionectes olivaceus*, D. *Catharus ustulatus*, E. *Chlorospingus tacarcunae*, F. *Manacus vitellinus*, G. *Automolus rubiginosus*, H. *Phaethornis longirostris*, I. *Piculus callopterus*, J. *Margarornis bellulus*, K. *Micrastur ruficollis*, L. *Myadestes coloratus*, M. *Hylomanes momotula*, N. *Thamnophilus atrinucha,* O. *Mniotilta varia*, P. *Piranga rubra*, Q. *Cardellina canadensis*, R. *Geothlypis formosa*, S. *Vireo flavoridis*.

Figura 2. Aves reportadas en el estudio. A. *Corapipo altera*, B. *Golmania violiceps*, C. *Mionectes olivaceus*, D. *Catharus ustulatus*, E. *Chlorospingus tacarcunae*, F. *Manacus vitellinus*, G. *Automolus rubiginosus*, H. *Phaethornis longirostris*, I. *Piculus callopterus*, J. *Margarornis bellulus*, K. *Micrastur ruficollis*, L. *Myadestes coloratus*, M. *Hylomanes momotula*, N. *Thamnophilus atrinucha,* O. *Mniotilta varia*, P. *Piranga rubra*, Q. *Cardellina canadensis*, R. *Geothlypis formosa*, S. *Vireo flavoridis*.

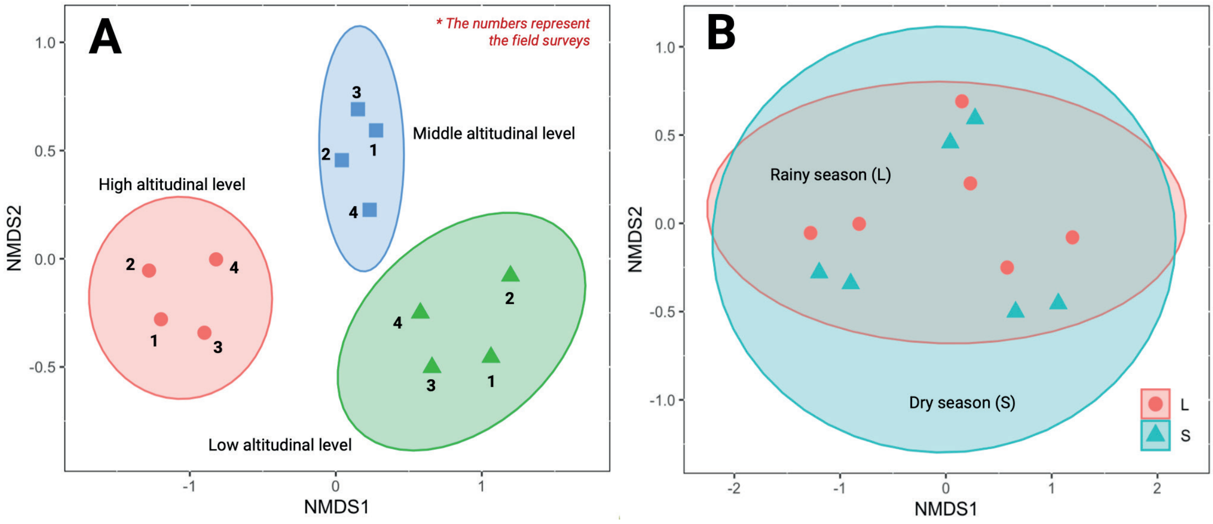

Figure 3. A. Non-metric multidimensional scaling (NMDS) comparing dissimilarities among the three altitudinal levels, with an overall similarity of p = 0.002, where pLow–High = 0.005, pMiddle–High = 0.004, and pMiddle–Low = 0.989; B. NMDS comparing dissimilarities between the dry and rainy seasons, where pDry–Rainy = 0.838.

Figura 3. A. Escalamiento multidimensional no métrico (NDMS) que compara las desimilaridades entre los tres niveles altitudinales con similitudes de p=0.002, donde pBajo-Alto= 0.005, pMedio-Alto= 0.004, pMedio-Bajo= 0.989; B, NDMS que compara las desimilaridades entre la estación seca y estación lluviosa, donde PSeca-lluviosa= 0.838.

Table 2. Alpha diversity indices: species richness, Shannon diversity (H), Simpson diversity (1 − D), and evenness (J), by season, survey, and altitudinal level.

Tabla 2. Índices de diversidad alfa: riqueza de especies, diversidad de Shannon (H), diversidad de Simpson (1 − D) y equitatividad (J), por temporada, gira y nivel altitudinal.

Season	Survey	Altitudinal level	Richness	Shannon (H)	Simpson (I-D)	Evenness (J)
Dry	1st	High	35	2.85	0.90	0.80
Dry	1st	Middle	44	3.37	0.94	0.89
Dry	1st	Low	52	3.56	0.95	0.90
Dry	2nd	High	32	2.93	0.92	0.84
Dry	2nd	Middle	59	3.42	0.93	0.84
Dry	2nd	Low	71	3.86	0.96	0.90
Rainy	3rd	High	36	2.73	0.88	0.76
Rainy	3rd	Middle	65	3.70	0.95	0.88
Rainy	3rd	Low	46	3.46	0.95	0.90
Rainy	4th	High	39	2.86	0.90	0.78
Rainy	4th	Middle	74	3.55	0.93	0.82
Rainy	4th	Low	67	3.82	0.96	0.91

Noteworthy records, migratory status, and conservation status

During this study, the Ruddy Foliage-gleaner *Automolus rubiginosus* (Figure 2G) was captured, a species not previously reported for Cerro Chucantí. According to Angehr & Dean (2010), this species has been recorded from the highlands of Chiriquí, Cerro Azul, and, in eastern Panama, from Cerro Tacarcuna and Darién National Park. In this study, it was captured at the highest station in the reserve, at approximately 1300 m.a.s.l., in April 2021. According to the IUCN, of the 248 recorded species, 237 are classified as Least Concern (LC), 10 as Near Threatened (NT), and one as Vulnerable (VU). At the national level, 68 species fell within some threat category under the national status of the Ministry of Environment: 57 Vulnerable (VU), such as *Phaethornis longirostris* (Figure 2H); 10 Endangered (EN), such as *Piculus callopterus* (Figure 2I); and one Critically Endangered (CR), *Margarornis bellulus* (Figure 2J). In addition, 22 species are included in CITES, 19 in Appendix II (e.g., *Micrastur ruficollis*, Figure 2K) and three in Appendix III. Of the total species recorded, 222 corresponded to resident birds (e.g., *Myadestes coloratus*, Figure 2L; *Hylomanes momotula*, Figure 2M; *Thamnophilus atrinucha*, Figure 2N), 24 were migratory (e.g., *Mniotilta varia*, Figure 2O; *Piranga rubra*, Figure 2P; *Cardellina canadensis*, Figure 2Q; *Geothlypis formosa*, Figure 2R), and two were migratory species with local populations (Mig/local), including *Vireo flavoviridis* (Figure 2S) (SM 2).

DISCUSSION

Recorded diversity and ecological relevance of RNPCC

The record of 248 species and 2602 individuals in the Cerro Chucantí Private Nature Reserve confirms the high value of this area as a biodiversity refuge within the Serranía de Majé. The predominance of Passeriformes in both richness and abundance, together with the high representation of families such as Trochilidae and Tyrannidae, is consistent with patterns reported for bird assemblages in humid tropical forests.

Altitudinal gradient: declining diversity and compositional turnover

The gradual decline in diversity with increasing elevation, as evidenced by the Shannon and Simpson indices (Table 2) and by the greater richness at lower elevations (SM 2), agrees with patterns described for altitudinal gradients in mountainous regions of Central and South America, where species richness tends to be concentrated in lowlands (Terborgh, 1971, 1977; Patterson et al., 1998; Blake & Loiselle, 2000; García-Trejo &

Navarro-Sigüenza, 2004; Martinez & Rechberger, 2007; Santana Castellón et al., 2017; Gastezzi Arias et al., 2021). Within this framework, greater resource availability and higher habitat structural complexity at lower elevations may contribute to sustaining higher diversity (Gastezzi Arias et al., 2021; Loera-Casillas et al., 2022). However, beta diversity analyses revealed an additional important pattern: the high-elevation level showed a significantly different species composition from the mid- and low-elevation levels (Fig. 3), whereas the latter two were highly similar, suggesting a distinctive assemblage in the upper elevations. This result agrees with previous observations indicating that, as altitude increases, similarity among communities decreases and endemism increases (González-García & Gómez de Silva, 2002; García-Trejo & Navarro-Sigüenza, 2004; Martinez & Rechberger, 2007). The differential dominance of species across altitudinal levels, with *Goldmania violiceps* at the high-elevation level, *Corapipo altera* at the mid-elevation level, and *Manacus vitellinus* at the low-elevation level (Figure 2F), supports this segregation along the gradient and is consistent with changes in habitat structure and resource availability across elevation.

Seasonality, noteworthy records, and conservation implications

The absence of significant differences between the dry and rainy seasons ($p_{dry\text{-}rainy} = 0.838$) indicates high temporal stability of the assemblage, even though climatic conditions during the rainy season may constrain mist-net sampling. This pattern is consistent with the idea that climate may influence community structure at a macrogeographic scale (Būhning-Gaese, 1997; Cueto & Casenave, 1999), but that in cloud forests and sites with relatively stable hydrological conditions, bird composition may remain stable without marked seasonal changes. The record of *Automolus rubiginosus* at the high-elevation station (~1300 m a.s.l.) represents an important contribution to knowledge of the local avifauna, since this species had not previously been reported for Cerro Chucantí in Angehr & Dean (2010), thereby reinforcing the need for continued sampling efforts. Finally, the presence of species under national threat categories and the inclusion of species in CITES underscore the value of the reserve as a priority site for conservation. In particular, the differentiated composition of the high-elevation level suggests that upper areas may be especially sensitive to disturbance, as they harbor a more distinctive and potentially more vulnerable assemblage.

CONCLUSIONS

The Cerro Chucantí Private Nature Reserve harbors a highly diverse avifauna, confirming its importance as a key biodiversity refuge within the Serranía de Majé. The patterns documented in this study show that bird diversity and richness decline with increasing elevation, while species composition changes markedly in the upper part of the gradient, where a more distinctive assemblage occurs. At the same time, the absence of significant seasonal differences suggests that the bird community remains relatively stable throughout the year, likely supported by the environmental continuity of this montane system. The record of *Automolus rubiginosus* further demonstrates that Cerro Chucantí still holds valuable biological information that remains to be documented. Taken together, these findings highlight the ecological importance of conserving the full altitudinal gradient of the reserve, particularly the upper elevations, where bird assemblages appear to be more specialized and potentially more vulnerable to habitat loss and other environmental disturbances.

AUTHOR CONTRIBUTIONS

JA: field collection, sample processing, species identification, data recording, and writing of the first draft; **JJ:** field collection, sample processing, species identification, data recording, and writing of the first draft; **RP:** species identification, formal analysis, and writing of the first draft; **YA:** software and statistical analyses; **GB:** conceptualization and review of the first draft; **AMJ:** species identification, data recording, and writing of the first draft. All authors reviewed the final version of the manuscript.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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