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Population density of White-tailed deer in a protected area of the Ecuadorian Andes

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The white-tailed deer (*Odocoileus virginianus ustus*) is an ecologically important species as it is part of the diet of carnivores and scavengers. However, there is little research on its population density in the Ecuadorian Andes. We evaluated white-tailed deer population density during two consecutive years (i.e., 2023 and 2024) in three different cover types (i.e., shrubland, grassland, and sandy areas) in the Área de Conservación Hídrica (ACH) Antisana. Data were collected by direct observational counts of individuals in line transects of at least 1 km, between 8:00 and 17:00 h. The average population density was 12.61 ind km^{-2} in 2023 and 14.25 ind km^{-2} in 2024, although these differences were not significant. We also found no differences in deer densities across cover types, although this does not imply a homogeneous distribution of the species in the protected area. There is a clear need for long-term monitoring programs to understand the population dynamics of white-tailed deer and establish management strategies tailored to the unique conditions of each territory. We recommend implementing systematic protocols for estimating white-tailed deer population densities based on direct observation methods, as these provide reliable information on the number of individuals.

Keywords: Antisana, Cervidae, Paramo, Line transects, *Odocoileus virginianus ustus,* Population

El venado cola blanca (*Odocoileus virginianus ustus*) es una especie importante en los ecosistemas naturales, la cual hace parte de la dieta de carnívoros y carroñeros. Sin embargo, existen pocos estudios sobre su densidad poblacional en los Andes. Evaluamos la densidad poblacional del venado de cola blanca durante dos años consecutivos (i.e., 2023 y 2024) en 3 tipos de cobertura distintos (i.e., arbustal, herbazal y arenal) en el Área de Conservación Hídrica (ACH) Antisana. Los datos fueron obtenidos mediante conteo directo por observación de individuos en transectos lineales de al menos 1 km, entre las 08:00 y 17:00 h. La densidad poblacional promedio de venados fue 12.61 ind km^{-2} en 2023 y 14.25 ind km^{-2} en 2024, aunque dichas diferencias no fueron significativas. Tampoco encontramos diferencias en las densidades de venados en los distintos tipos de cobertura, aunque esto no implica una distribución homogénea de la especie en el área protegida. Es necesario realizar programas de seguimiento a largo plazo para conocer la dinámica poblacional del venado de cola blanca y establecer estrategias de manejo que se ajusten a las condiciones propias de cada territorio. Recomendamos implementar protocolos sistemáticos para la estimación de las densidades poblacionales del venado de cola blanca basados en métodos de observación directa, dado que estos proporcionan información confiable sobre el número de individuos.

Palabras clave: Antisana, Cervidae, *Odocoileus virginianus ustus,* Páramo, Población, Transectos lineales

The tropical Andes are a global biodiversity hotspot due to their high levels of endemism and ongoing habitat loss (Myers *et al.* 2000; Báez *et al.* 2016). High Andean ecosystems, particularly páramos, harbor remarkable plant diversity and play a key role in species evolution due to their unique biogeographical conditions (Arroyo and Cavieres 2013). In addition, these ecosystems provide essential services, including carbon storage, water regulation, and climate refugia for vulnerable species (Cincotta *et al.* 2000; Arroyo and Cavieres 2013). In Ecuador, páramo ecosystems are also fundamental for water supply, agriculture, and hydroelectric power generation, despite covering a small proportion of the national territory. However, they are increasingly threatened by anthropogenic pressures such as agricultural expansion, overexploitation, and population growth (Crespo *et al.* 2010; Etter *et al.* 2017; Sierra *et al.* 2021).

The ecological importance of white-tailed deer (*Odocoileus virginianus ustus*) is due at least in part to their role as a food source for other wild animals. Changes in deer abundance can cause variation in the diet of the cougar (*Puma concolor*), which can trigger predation of

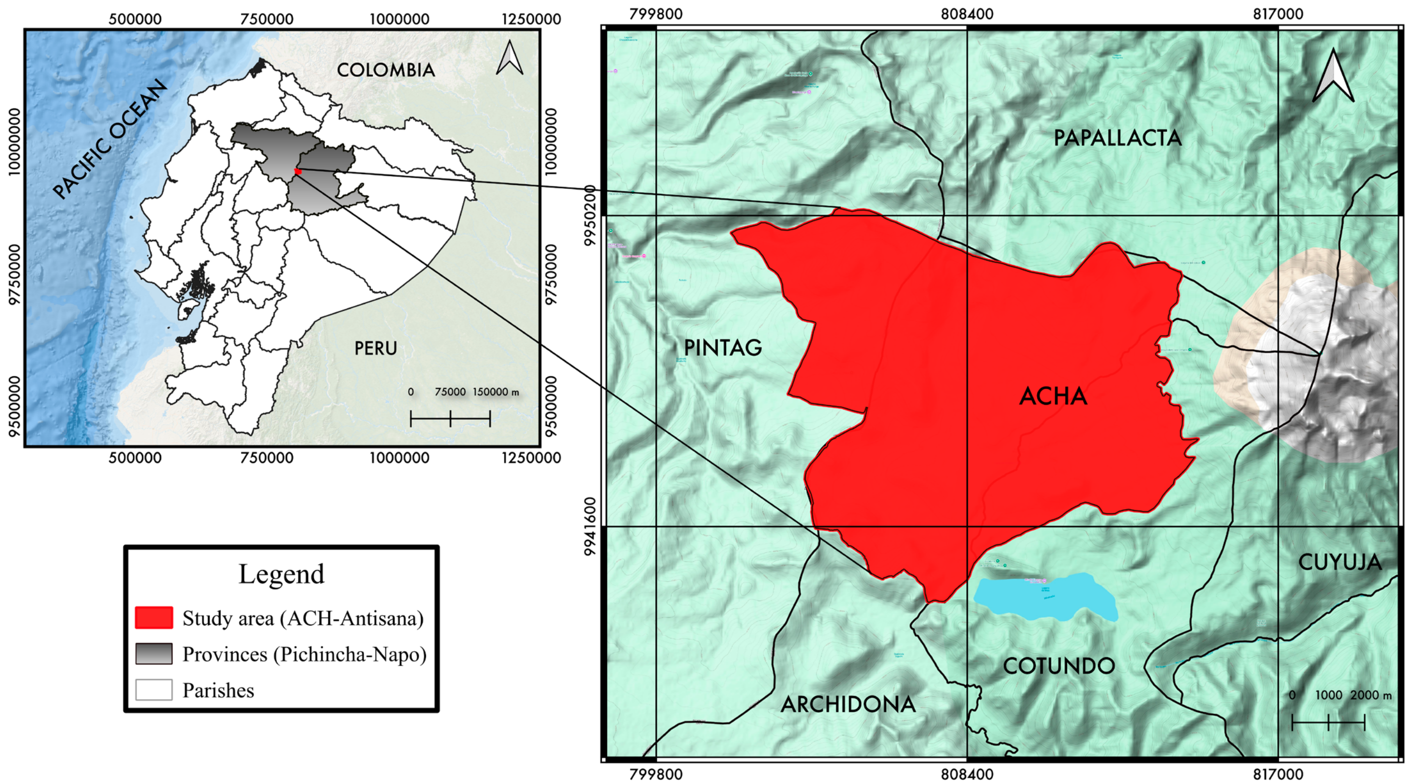

Figure 1. Geographic location of the ACH Antisana, Ecuador, where white-tailed deer data were collected during 2023 and 2024.

domestic animals, thus causing human-wildlife conflicts (Fulbright and Ortega 2007; Piña and Trejo 2014; Tellkamp *et al.* 2019). Likewise, artiodactyls are an important food source for obligate and facultative scavengers (Lambertucci *et al.* 2009; Perrig *et al.* 2017). However, its population status remains unknown, limiting the understanding of its potential effects on threatened species such as the condor, whose populations are declining due to human pressures (Restrepo-Cardona *et al.* 2022).

The methods used to estimate white-tailed deer population density include aerial surveys, mark-recapture techniques, the use of camera traps and remote thermal imaging, and fecal counts. Remote surveys are notable for their cost-effectiveness and efficiency (LaRue *et al.* 2007; Urbanek and Nielsen 2012). Counting individuals through direct observation is especially useful in areas with relatively high abundances and flat, open terrain that offers good visibility (Beltrán and Díaz 2010; Mandujano 2014). However, estimates of the species' abundance and population size are often made using indirect methods such as counting feces in fixed transects (Ortiz-Martinez *et al.* 2005; Piña and Trejo 2014; Mandujano 2016). Nevertheless, this method provides a relative density index due to variation in defecation and feces decomposition rates caused by intrinsic and extrinsic factors (Galindo-Leal 1992; Pérez-Mejía *et al.* 2004; Navarro 2005; Mandujano 2014). Lower defecation rates can cause individuals to be overestimated (Mandujano 2014). In addition, if the substrate and environmental conditions are not suitable, feces may not be preserved long enough to be recorded (Navarro 2005). Thus, estimates of deer density may vary depending on the sampling methods used (Hewitt 2011). Nevertheless, there is little knowledge about the ecology and threats facing the white-tailed deer in the Ecuadorian páramos. Domestic dogs represent a significant threat to the species (Zapata-Ríos and Branch 2018; Restrepo-Cardona *et al.* 2025). Similarly, hunting and wildlife trafficking are latent threats to the species (Sánchez 2009). Although the population density of a species is crucial for determining its conservation status and establishing effective management and conservation strategies (Mandujano *et al.* 2010), the information available on the population status of the white-tailed deer is scarce in Ecuador. Albuja (2007) studied the population density of this species in the Oyacachi-Papallacta and Antisana páramos, reporting a density of 1.6 ind km^{-2}. On the other hand, Tellkamp *et al.* (2019) evaluated the population density in the Área de Conservación Hídrica (ACH) Antisana and reported population densities of deer that ranged between 7.91 ind km^{-2} and 11.31 ind km^{-2} (Tellkamp *et al.* 2019).

Therefore, it is crucial to determine the population status of white-tailed deer in the Ecuadorian Andean páramos, given that changes in population density can affect the populations of native species that feed on these animals (e.g., puma, Andean condor) and thus also the ecosystem services that this biodiversity provides to people (Rojas 2010; Arenas 2011; Hansen *et al.* 2017; Chávez *et al.* 2022). Hence, the objective of this study was to evaluate the population density of white-tailed deer for two consecutive years (i.e., 2023 and 2024) and in three different cover types (i.e., shrubland, grassland, and sandy area) in the ACH Antisana.

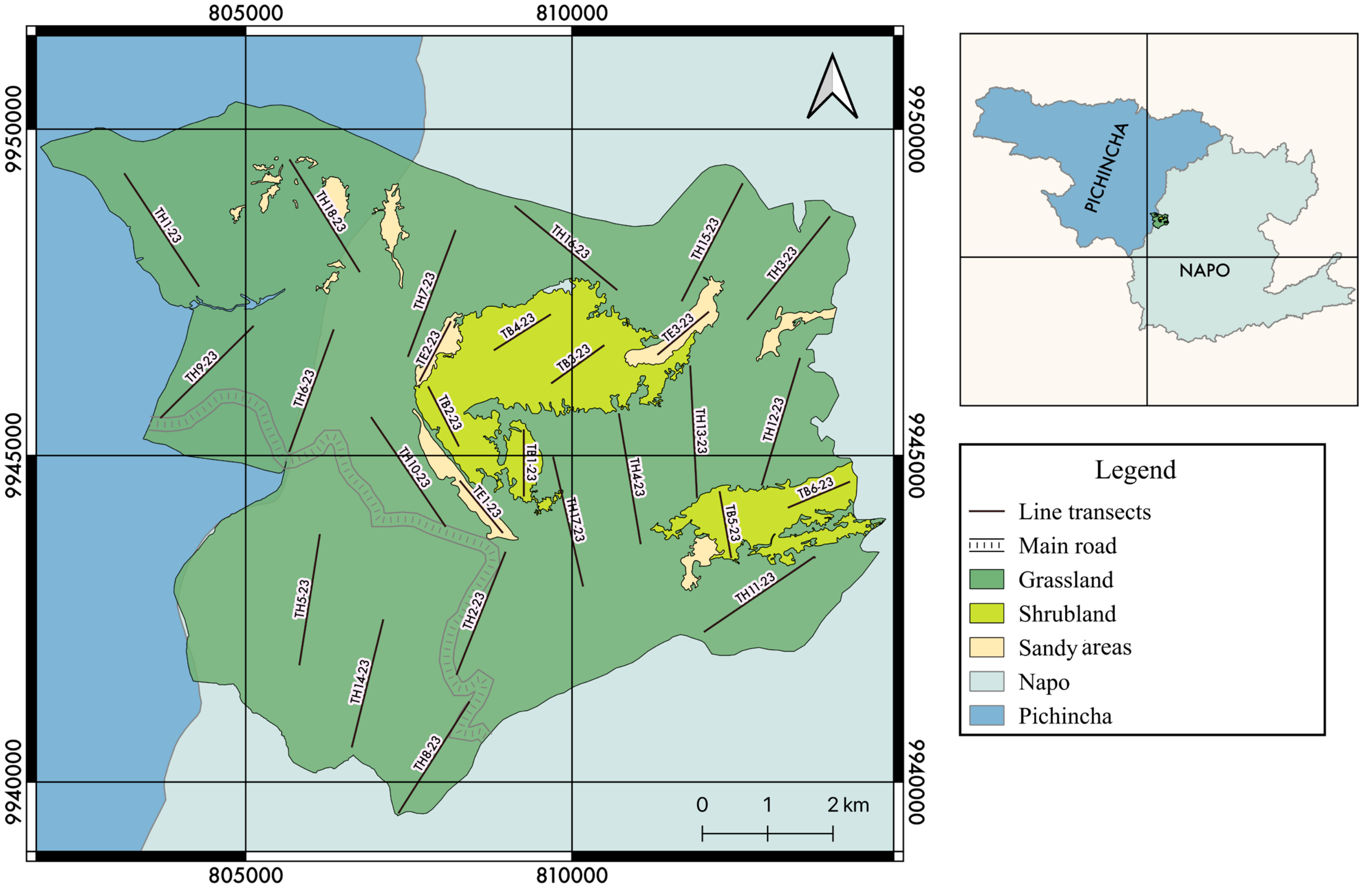

Figure 2. Cover types (grassland, shrubland, and sandy area) and location of 27 transects in grassland (18 transects), shrubland (6 transects), and sandy areas (3 transects) for the study of white-tailed deer in the ACH Antisana during 2023 and 2024.

Materials and methods

Study area. The study was conducted in the ACH Antisana located in the provinces of Napo and Pichincha (Figure 1), which covers an area of 8487 ha. The ACH Antisana is bordered to the north by the Chakana Reserve, to the west by private land, and to the south and east by Antisana National Park (FONAG 2019). Its altitude ranges from 3720 to 4640 meters above sea level, and it has an average annual rainfall of 1098 mm (Sklenář *et al.* 2015; Bécquer 2022). In the páramos of Ecuador, annual precipitation has a bimodal pattern with wet seasons from February to May and from October to December (Hofstede and Mujica 2002). In the study area, rainfall is concentrated between December and June, with a drier period from July to November (Pérez and Zapata 2025). The area provides water for consumption to 2,6 million inhabitants of the Metropolitan District of Quito (Crespo *et al.* 2010). Historically, land use in the site was dedicated to intensive livestock farming, with cattle, sheep, and horses. By 2012, there were an estimated 1500 sheep and 6000 cattle head in the area (FONAG 2024). However, in an effort to conserve its water sources and biodiversity, the area was declared an ACH in 2012, and management actions have subsequently focused on reducing livestock impacts and promoting ecological restoration (Crespo *et al.* 2010; Grubb *et al.* 2020).

The most representative ecosystems of the ACH Antisana are (1) the paramo grassland, characterized by its herbaceous appearance and evergreen phenology, and dominated by *Agrostis* sp., *Calamagrostis* sp., and *Cortaderia* sp. (MAE 2013; Bécquer 2022). And (2) the floodable paramo grassland is distinguished by its flooding regime, with the presence of *Lophozia laxifolia* and *Cortaderia sericantha* plants that form cushions and floating vegetation on compact, thick soil that retains moisture and produces conditions of impermeability and inefficient drainage, which favors the formation of peat bogs and swamps (MAE 2013).

Field data collection. To estimate the population density of white-tailed deer, the direct counting method was used by observing individuals in linear transects. Sampling was carried out between October and November 2023 and between October and December 2024, in accordance with the schedule and logistical framework of the monitoring project under which this study was conducted. The sampling was carried out in three types of cover types: grassland, shrubland, and sandy areas, which cover an area within the ACH Antisana of 72.92 km^2, 8.89 km^2, and 2.43 km^2, respectively (Figure 2). The three cover types are spatially distinguishable within the study area but are not completely isolated, allowing movement of white-tailed deer among them. Therefore, cover types were considered as sampling categories to evaluate relative differences in

Figure 3. Selected cover types in the Área de Conservación Hídrica Antisana in 2023 and 2024: A) grassland, B) grassland transect, C) sandy areas, D) sandy areas transect, E) shrubland, F) shrubland transect.

density rather than independent population units. A total of 27 linear transects were established based on spatial coverage, representation of the different cover types and field accessibility within the study area, ensuring an adequate sampling effort while maintaining logistical feasibility and consistency between surveys. The transects had variable widths and lengths of 2 km for grassland cover types and 1 km for shrubland and sandy area. To avoid sampling bias, a stratified random sampling design was used, where transects were randomly located within each cover type using previously defined polygons (Terán-Valdez *et al.* 2018). Random points were generated in QGIS and used as starting locations, with the number of transects proportional to cover type area. Transect orientation was randomly assigned among cardinal directions (Mandujano 2014). A minimum distance of 1 km between transects was maintained to avoid overlap, and any transect not meeting spatial criteria was re-randomized. The width of the transects was determined by the position of the deer observed. In addition, to reduce possible overlaps in observations, a minimum distance of 1 km between transects in the same cover type was considered to reduce

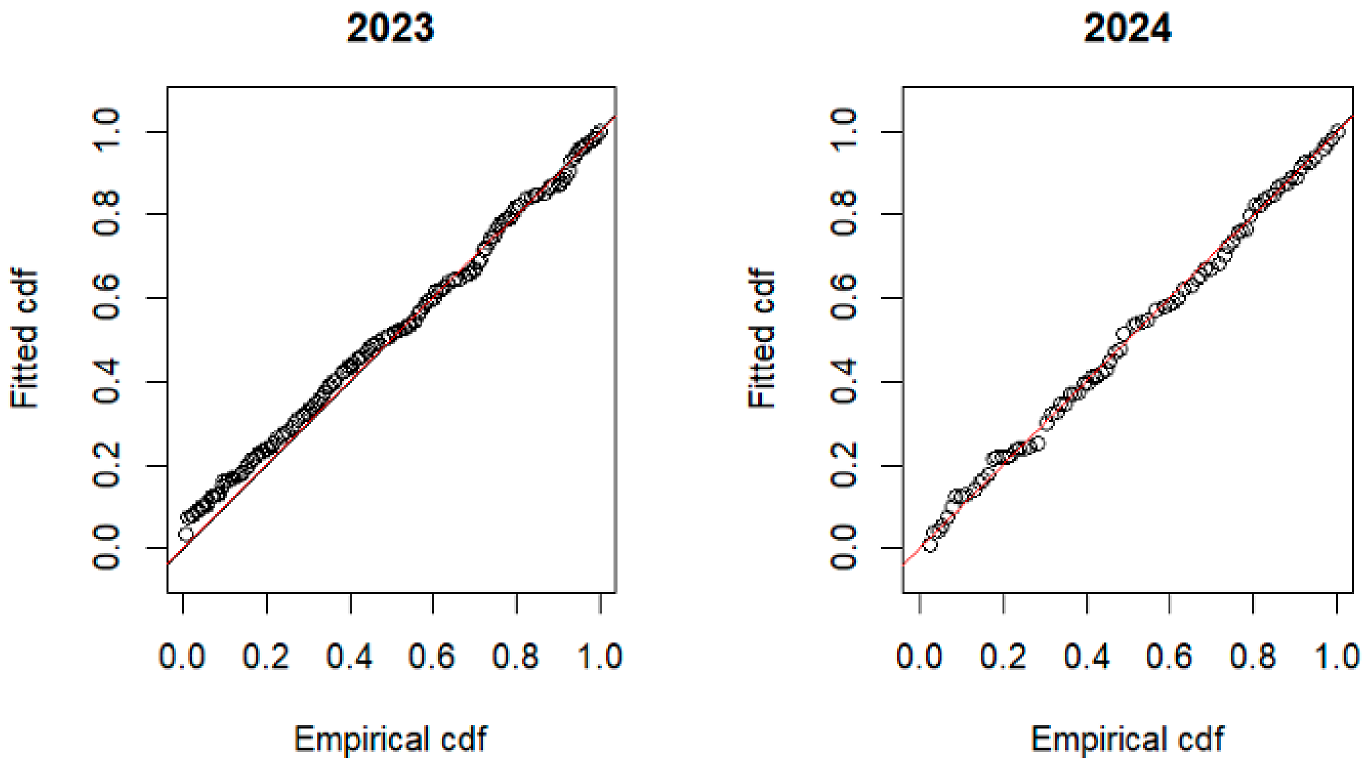

Figure 4. Quantile-quantile plots (Q-Q plots) indicating the fit of the detection function to the data for the years 2023 and 2024.

the likelihood of repeated detections. While specific home range estimates for this species in páramo ecosystems are unavailable, studies in tropical environments have reported home ranges ranging from 0.12 to 0.9 km^2 (Contreras-Moreno *et al.* 2021).

Each transect was surveyed once a year, between 8:00 a.m. and 5:00 p.m., as outside this time frame deer tend to gather to feed and rest. Each transect was surveyed on foot by two researchers, ensuring that a set direction was followed at a constant speed of 2 km/h and without backtracking (Figure 3). All deer on both sides of the transect were recorded (Mandujano 2014; Narváez and Zapata-Ríos 2020). When an individual was detected, the perpendicular distance of the animal from the transect was recorded using a LEUPOLD-RX-1000i/TBR rangefinder, and in the case of grouped deer, the perpendicular distance from the transect to the center of the group was measured (Gallina *et al.* 2014; Adams *et al.* 2020). No sampling was carried out on days with high rainfall because rain reduces the ability to detect animals, while on days with light or passing rain, the surveys were carried out as normal (Adams *et al.* 2020; Narváez and Zapata-Ríos 2020).

Statistical analysis. Deer density was estimated using alternative models, which were chosen based on a detection function adjusted to the data from perpendicular distance measurements to individuals or groups of individuals in each transect (Thomas *et al.* 2010). The R package "Distance" (Buckland *et al.* 2015) was used, which provides four models [unif (unif), half-normal (hn), hazard-rate (hr), and negative exponential] for the detection function, and also allows the addition of series adjustment terms [(cosine (cos), hermite polynomial (herm), simple polynomial (poly), and null adjustments] to the model when the simple model ("key function") alone does not provide an adequate fit. The key function 'unif' was used. It can be used to perform strip transect analysis, but it is also useful for analyzing linear transect data if series adjustment terms are added (Buckland *et al.* 2015). Likewise, the ‹hazard rate› function was used because it has a 'shoulder' (Buckland *et al.* 2015). However, the key function 'negative exponential' was not used because it does not have a 'shoulder' (Buckland *et al.* 2015). Next, a comparative analysis was performed between different selected models with their respective series adjustments: unif (cos, poly), half-normal (cos, herm, poly), and hazard-rate (cos, herm, poly), to find the appropriate detection function.

A plausible and parsimonious model was selected based on the Akaike›s information criterion (AIC), goodness of fit (Cramér-von Mises test and the Quantile-Quantile plot) and the shape criterion of the detection function (presents a 'shoulder'). The model was chosen according to the criterion of parsimony, i.e., the one with the lowest AIC (Martínez *et al.* 2009). The Cramér-von Mises test was used to evaluate the difference between the empirical and theoretical distributions, rejecting the null hypothesis (< 0.05) (Buckland *et al.* 2015). The Q-Q plot compared the empirical distribution function (EDF) with the theoretical cumulative distribution function (CDF), considering the model to be inadequate if the points deviated from the reference line (Miller *et al.* 2019). Finally, the density per m^2 was calculated and transformed to ind km^{-2} for the three cover types in 2023 and 2024.

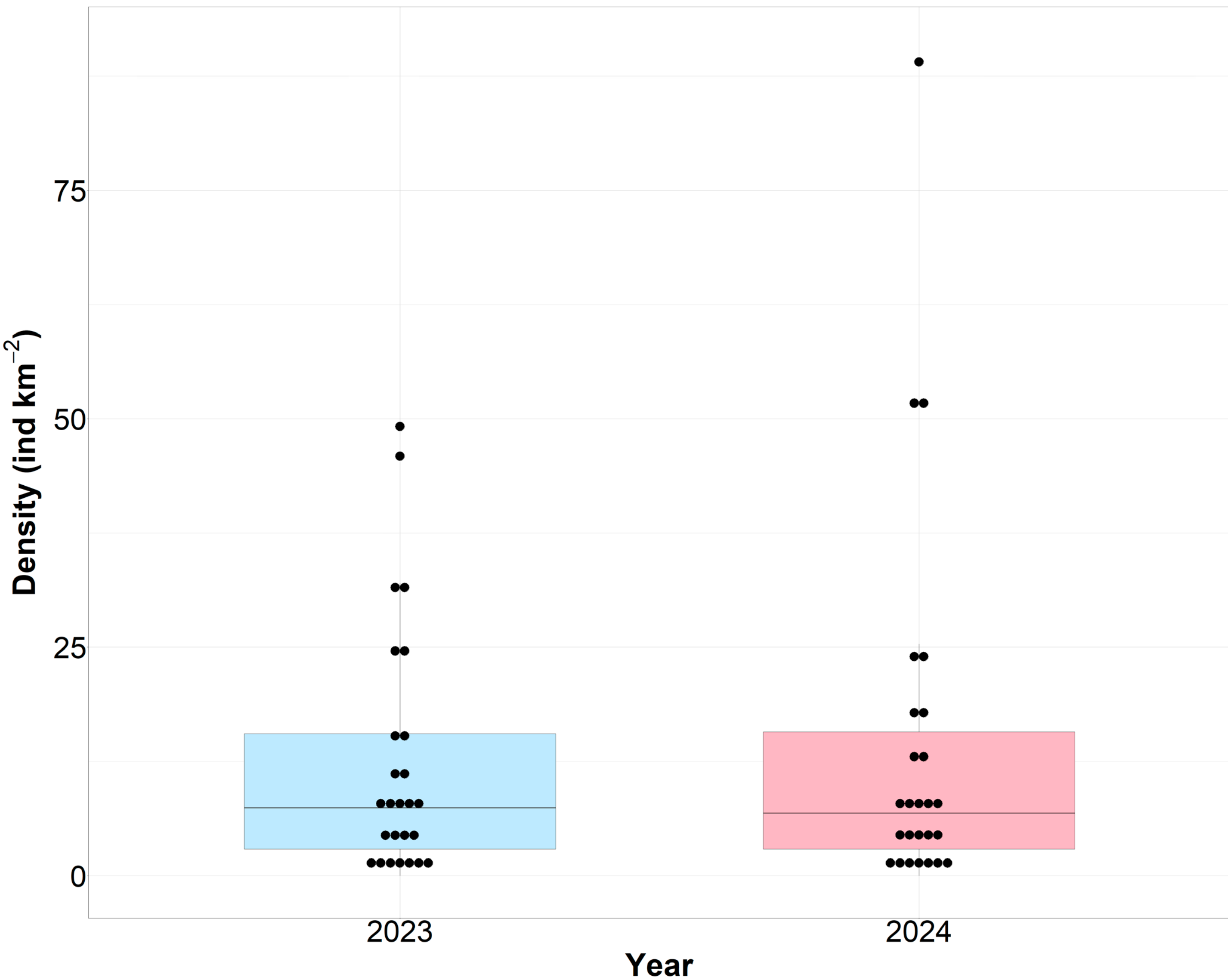

Figure 5. Box plot of white-tailed deer population density in the ACH Antisana transects for the years 2023 and 2024. Wilcoxon test for paired data, $p > 0.05$.

Prior to comparing the annual population density and density per cover type, the Shapiro-Wilk normality test was applied, which indicated that the data did not follow a normal distribution. The Wilcoxon test was used for both cases. To compare the population density between cover types in 2023 and 2024, the Kruskal-Wallis test was used separately for each year. All analyses were performed using statistical software R version 4.3.0 (R CoreTeam 2021).

Additionally, a heat map was generated in QGIS 3.10 (QGIS Development Team 2019). For this, the vector layers of transects by cover type were processed, incorporating density data and transect codes. These layers were then combined into a single file (.shp) and midpoints were generated along each transect. Next, the kernel density estimation algorithm was applied, using the midpoint layer as input, a kernel bandwidth of 2.4 km, and a pixel size of 30 m, and the entities were weighted according to density. Finally, a grayscale raster was obtained, the map was cropped to the study area, and the thermal intensity values were reclassified (QGIS Project 2020).

Results

A total of 45 km was covered in 27 transects in 2023 and 43 km in 26 transects in 2024. One transect could not be covered in 2024 due to logistical difficulties. During the surveys, 617 deer were recorded in 2023 and 470 deer in 2024. Group density decreased between 2023 and 2024, while individual density and expected group size increased. Similarly, estimated abundance was higher in 2024. Overall, the coefficients of variation were not high in both years, although slightly higher in 2024 (see Table 1). Model 4 (Hazard-rate + cos, see Supplementary 2) was selected as the most robust for both years, according to the AIC, Goodness of Fit, and Q-Q plot (Figure 4). Based on this model, average annual population densities were estimated, yielding values of 12.61 ind km^{-2} for 2023 and 14.25 ind km^{-2} for 2024, representing a population increase of 13.01% between the two years.

Population densities were calculated by cover type for each year (see Table 2). In both years, grassland concentrated the highest abundance and density of individuals, whereas

Table 1. White-Tailed Deer Population Density for 2023 and 2024 in the ACH Antisana

Parameters	Year 2023	Year 2024
Sampling Effort (km)	45	43
Number of Deer Groups Observed	161	92
Groups Density (groups km^{-2})	3.19 ± 0.26 (CV= 8.01%)	2.98 ± 0.35 (CV= 11.83 %)
Individuals Density (ind km^{-2})	12.61 ± 0.8 (CV= 6.03%)	14.25 ± 1.5 (CV= 10.41%)
Expected Group Size (ind group^{-1})	3.95 ± 0.27 (CV= 6.82%)	4.79 ± 0.33 (CV= 6.94%)
Estimated Abundance/Population (N)	1061.92 ± 64.08 (CV= 6.03 %)	1200.66 ± 125.05 (CV= 10.41%)

N: Estimated deer population over 84.24 km2 (individual density times total area)
CV: Coefficient of variation

shrubland and sandy areasshowed lower values. From 2023 to 2024, density increased in grassland and shrubland but decreased in sandy area. Coefficients of variation were higher in shrubland and sandy area, reflecting greater variability in these environments. In 2023, the shrubland recorded the highest density of deer (14.07 ind km^{-2}), while the sandy areas had the lowest density. In 2024, the highest density was recorded in grassland cover type and the lowest density in sandy areas. At the transect level, in 2023, transect TB1-23 had the highest density with 49.15 ind km^{-2}, whereas no individuals were recorded in transects TB5-23 and TE3-23. In 2024, transect TH14-24 showed the highest density with 89.05 ind km^{-2}, and no deer were recorded in transects TB3-24, TH1-24, and TH9-24.

The deer population density data for 2023 and 2024 did not follow a normal distribution ($p < 0.05$). The results of the Wilcoxon test (V = 170, $p = 0.901$) indicated that there were no significant differences between the deer densities recorded in 2023 and 2024 (Figure 5). No significant differences were detected in the densities recorded in both years in grassland (V = 76, $p = 1$), sandy (V = 4, $p = 0.75$), and shrubland (V = 6, $p = 0.438$) cover types (Figure 6). Kruskal Wallis tests ($\chi^2 = 0.684$, d.f. = 2, $p = 0.710$) indicated that there were no significant differences between the densities recorded in the three cover types in 2023 (Figure 7) or in 2024 ($\chi^2 = 0.166$, d.f. = 2, $p = 0.920$) (Figure 8).

Table 2. White-Tailed Deer Population Density by cover types for 2023 and 2024 in the ACH Antisana

Cover types	2023			2024		
	Observed Abundance	Estimated Abundance (N)	Density (ind km^{-2})	Observed Abundance	Estimated Abundance (N)	Density (ind km^{-2})
shrubland	91	125.09 ± 71.2 (CV= 56.92%)	8.04 ± 4.35 (CV= 54.1 %)	58	120.90 ± 71.03 (CV= 58.75%)	13.59± 7.99 (CV= 58.75%)
sandy areas	26	19.54 ± 10.57 (CV= 54.10%)	8.04 ± 4.35 (CV= 54.10 %)	13	14.82 ± 4.37 (CV= 29.49%)	6.09 ± 1.80 (CV= 29.49%)
grassland	500	939.2 ± 219.16 (CV= 23.33%)	12.88 ± 3.01 (CV= 23.33%)	399	1203.33 ± 435.57 (CV= 36.20%)	16.50 ± 5.97 (CV= 16.20%)

N: Number of deer in each cover type per year, calculated from the density and the corresponding area (grassland: 72.92 km^2, shrubland: 8.89 km^2, sandy areas: 2.43 km^2).
CV: Coefficient of variation

The shrubland had deer densities ranging from 0 to 49 ind km^{-2} in 2023 and from 0 to 50 ind km^{-2} in 2024. The sandy areas recorded values between 0 and 14 ind km^{-2} in 2023 and between 2 and 8 ind km^{-2} in 2024. The grassland recorded values between 0 and 45 ind km^{-2} in 2023 and between 0 and 89 ind km^{-2} in 2024. In 2023, the highest densities (up to 49 ind km^{-2}) were concentrated in the central region of the study area, decreasing progressively towards the west and north, where no individuals were recorded (Figure 9). The southwest zone had areas with densities of up to 45 ind km^{-2}, while in the southeast, a small area with densities of up to 24 ind km^{-2} was identified. In 2024, the general pattern remained the same, with the highest densities (up to 89 ind km^{-2}) located in the southwest region of the study area, followed by the central region. In the southeast, an area with densities of up to 52 ind km^{-2} was recorded, while the north and northwest continued to show low or zero densities.

Discussion

Our findings differ slightly from those reported for 2018 and 2019 in the ACH Antisana, where using direct methodologies (counts at observation points) and indirect methodologies (fecal accumulation rate, standing fecal culture, and remote fecal sampling), deer population densities ranging from 7.91 ind km^{-2} to 11.31 ind km^{-2} were reported (Tellkamp *et al.* 2019). The differences in results could be due to the sampling times used. White-tailed deer are considered a facultatively or semi-gregarious species, forming small and variable groups depending on season, sex, and behavioral context (Saalfeld *et al.* 2008). Because variation in group size can influence the precision of density estimates obtained through distance sampling, surveys conducted when deer are less aggregated may facilitate the detection of a greater number of groups and reduce variability in group size (Galindo-Leal and Weber 1998; Thomas *et al.* 2010; Buckland *et al.* 2015). The sampling

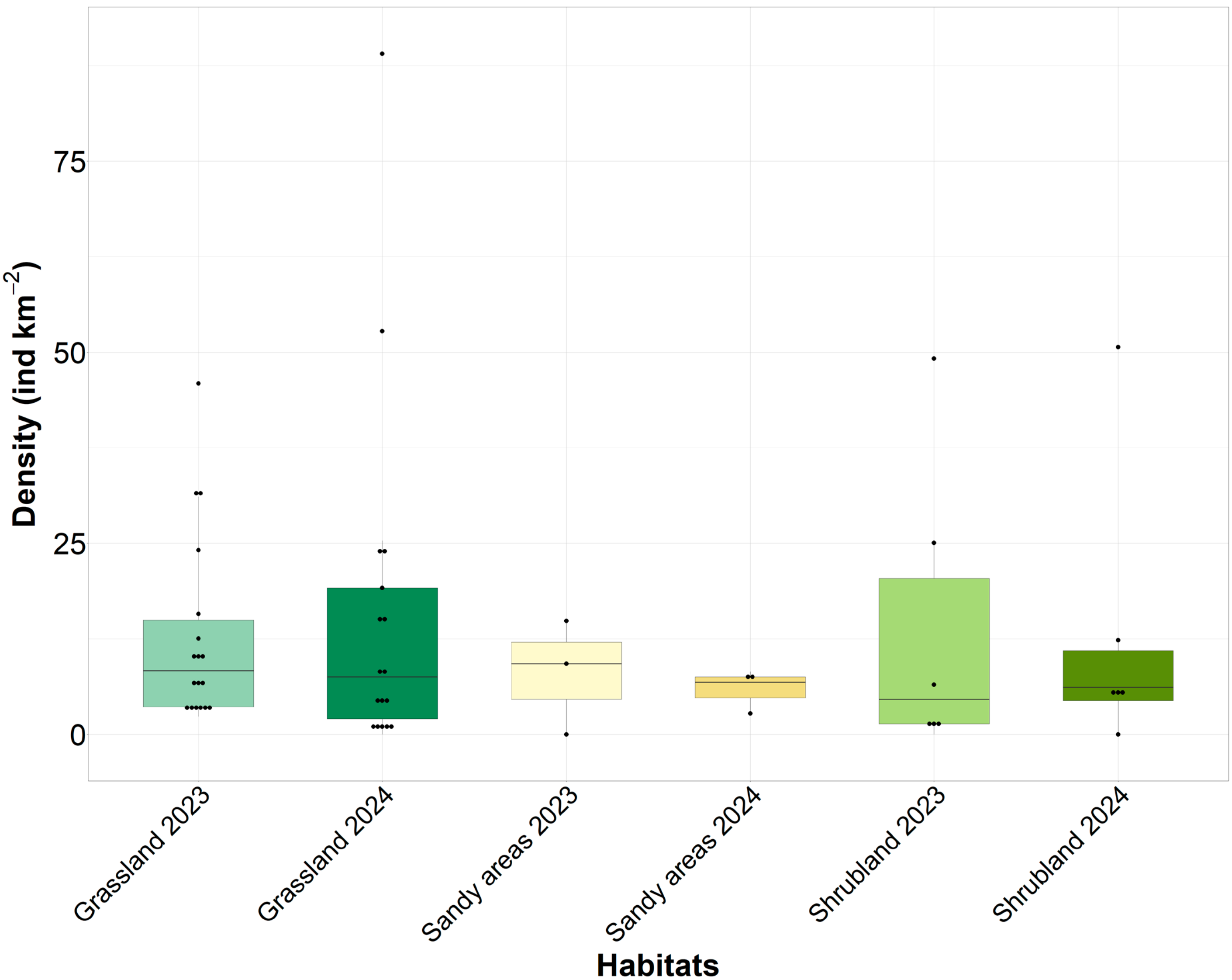

Figure 6. Population density of white-tailed deer in grassland, shrubland, and sandy areas in 2023 and 2024 in the ACH Antisana. Wilcoxon paired test $p > 0.05$ for shrubland, sandy areas, and grassland cover types.

carried out by Tellkamp *et al.* (2019) took place between 06:00 and 09:00 hrs and between 15:00 and 18:00 hrs. In contrast, our observations were made between 08:00 and 17:00 hrs, thus avoiding the species' peak grouping times, as population density estimates can be affected by variability in the size of the groups observed. This strategy may have facilitated the detection of more groups of smaller sizes, potentially improving to more accurate estimates.

Nevertheless, the density values obtained differ significantly from the findings of Albuja (2007) between 1996 and 1997, who, through counts of individuals in transects and observation points, reported a population density of 1.6 ind km^{-2} in the Oyacachi-Papallacta and Antisana moorlands, a figure well below that reported in this study. These differences in deer density after almost two decades could be attributed to various factors. During the 1990s, deer poaching was a relatively common practice in Antisana National Park and its buffer zone, as was intensive livestock management (Albuja 2007). However, control and patrolling by park rangers have been progressively strengthened over the years (Terán-Valdez *et al.* 2018; Grubb *et al.* 2020).

The ACH Antisana has shown a favorable recovery process, which would explain the high number of deer in the area. During the last decade, the reduction of grazing pressure through livestock removal (Crespo *et al.* 2010; Grubb *et al.* 2020) and, in 2017, ecological restoration of sandy areas in this protected area began with the planting of native plants, including the species chocho silvestre (*Lupinus pubescens*), chilca (*Baccharis caespitosa*), achupalla (*Puya clava-herculis*), and chuquiragua (*Chuquiraga jussieui)* which are part of the deer's diet (FONAG 2017). Also, since 2019, hunting control and the removal of introduced species, particularly livestock, camelids and horses have led to an increase in white-tailed deer populations (Crespo *et al.* 2010; Grubb *et al.* 2020). Also, the hunting control and the removal of introduced species, particularly livestock, camelids and horses have led to an increase in white-tailed deer populations (Grubb *et al.* 2020; Crespo *et al.* 2010). Additionally, 2021 human access to the protected area

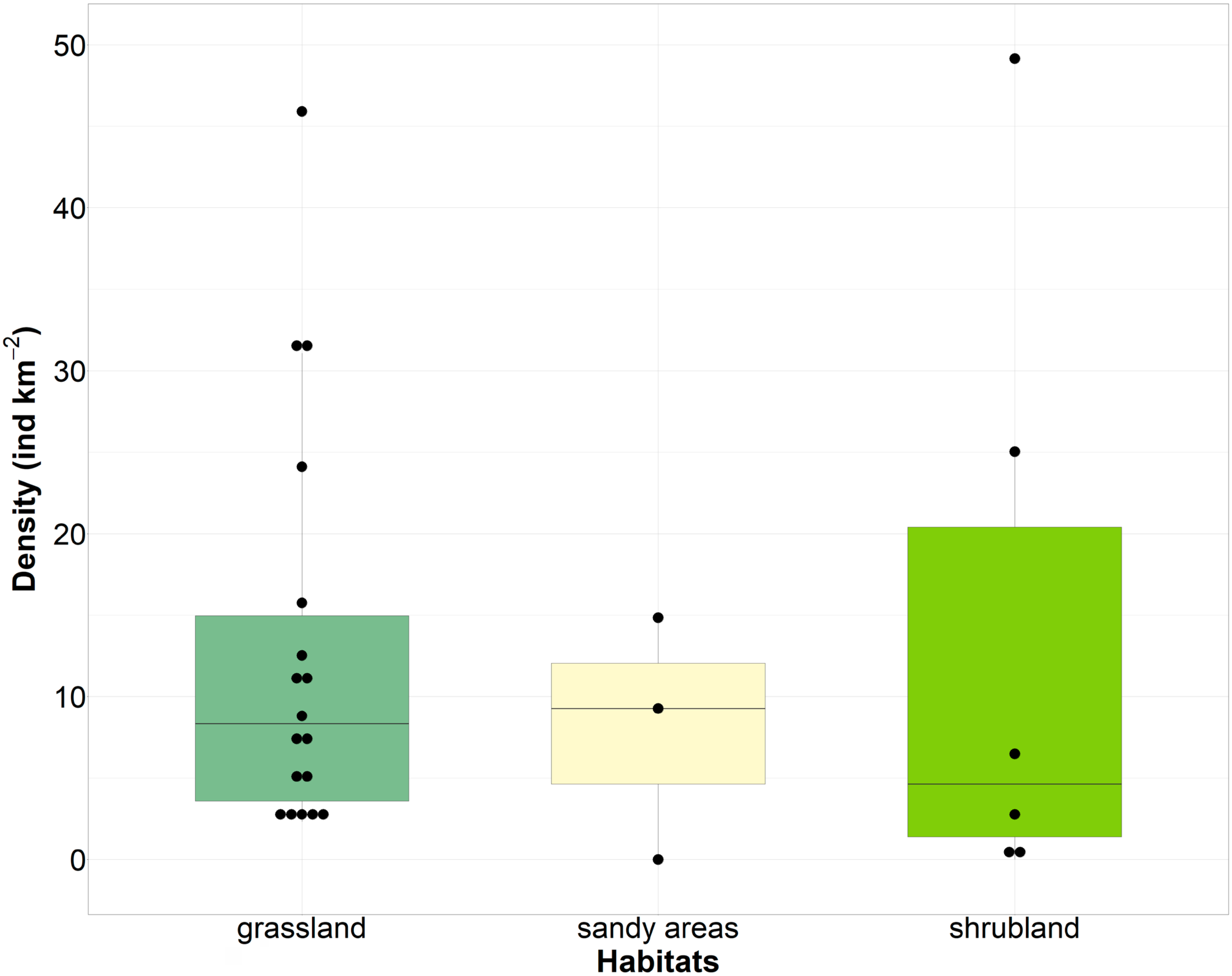

Figure 7. Population density of white-tailed deer in grassland, shrubland, and sandy areas of the ACH Antisana in 2023. Kruskal Wallis test $p > 0.05$.

was restricted, which favored the recovery of vegetation cover (FONAG 2021). This entire process could explain the increase in the deer population and the ability of a recovered ecosystem to sustain these populations. This suggests that the recovery of ecosystem structure and function likely plays a key role in maintaining current deer population levels.

Our density findings are consistent with those reported for other northern Andean páramo ecosystems. In Chingaza National Natural Park, Colombia, and Sierra Nevada de Mérida National Park, Venezuela, white-tailed deer densities ranging from 11.55 to 43 ind km^{-2} and groups of up to 50 individuals have previously been reported (Correa-Viana 1994; Mateus-Gutiérrez 2014). Similarly, in the ACH Antisana, groups of up to 49 white-tailed deer were recorded. However, more recent studies conducted in Chingaza National Natural Park revealed substantially lower densities, ranging from 0.16 to 2.09 ind km^{-2} depending on the study sector and estimation method (Carrillo-Villamizar and López-Arévalo 2024). These authors also reported that deer abundance has declined compared to previous estimates from the same park, where the highest abundances were recorded in 2004, suggesting important temporal and spatial variation in population density within páramo ecosystems. Despite these lower current densities, previous studies in Chingaza documented the formation of large groups of white-tailed deer, which is consistent with the large aggregations observed in the ACH Antisana (Mateus-Gutiérrez 2014; Carrillo-Villamizar and López-Arévalo 2024).

At the local scale, however, no significant differences in deer densities were detected between different cover types (grassland, shrubland, and sandy area) within each year, nor when comparing the same cover type between 2023 and 2024 suggesting that cover type alone does not strongly influence their distribution and abundance in the study area (Pérez-Moreno *et al.* 2020). Nevertheless, this does not imply a homogeneous spatial distribution. White-tailed deer are often associated with heterogeneous environments, where different vegetation types may provide complementary resources, including forage and

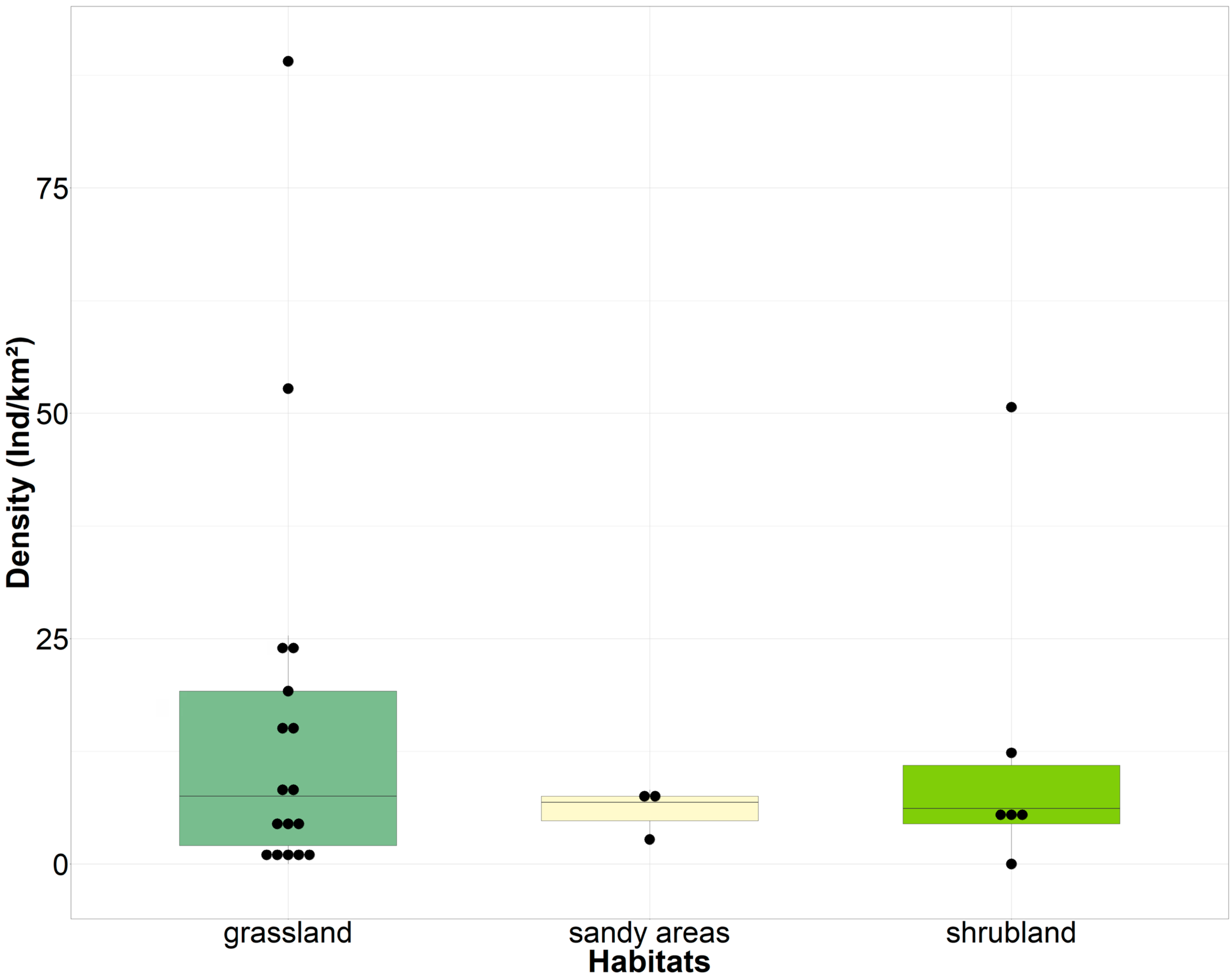

Figure 8. Population density of white-tailed deer in grassland, shrubland, and sandy areas in the Antisana Water Conservation Area in 2024. Kruskal-Wallis test $p > 0.05$.

cover (Fulbright and Ortega 2007; Gastelum-Mendoza *et al.* 2023). In this context, suggesting that patterns of deer density are driven more by the integration of resources of the landscape than by individual cover types. In Mexico, López-Téllez *et al.* (2007) reported variations in deer density in four locations: Mitepec and El Salado exhibited high densities (3.2–3.4 ind km^{-2}), while Huachinantla and Jolalpan exhibited low densities (0.1–0.5 ind km^{-2}). This may be due to spatial and temporal components (availability of vegetation cover, food, and water), which affect the deer distribution patterns (Garavito 2004; Chávez *et al.* 2022).

In this context, variations in cover types of use may also be influenced by population density and perceived predation risk. Under high-density conditions, females with young and other individuals may prefer areas with dense vegetation that provide greater protection (Garavito 2004). Although differences were not statistically significant, higher density values were observed in shrubland and grassland cover types.

Shrublands likely provide both shelter and high-quality forage resources, as white-tailed deer are selective feeders that preferentially consume young leaves and stems of shrubs, which are rich in protein and low in fiber and lignin (Fulbright and Ortega 2006; Pérez-Moreno *et al.* 2020). In addition, woody vegetation often constitutes a major component of their diet, and increases in shrub availability have been linked to population growth in some regions (Taylor and Hahn 1947; Ramírez *et al.* 1996; Arceo *et al.* 2005). Also, their dense structure may reduce detectability and increase protection from predators (Christopher *et al.* 2002; Vargas and Pedraza 2004; Ortiz-Martínez *et al.* 2005).

Grasslands are dominated by grasses and herbaceous plants that serve as key complementary food resources, particularly under conditions of increased competition or seasonal variation in forage availability (Brokx and Andressen 1970; Gallina 1990; Gallina and Bello 2010; Plata *et al.* 2009, 2011). Previous studies have also reported that white-tailed deer use shrublands primarily for cover and

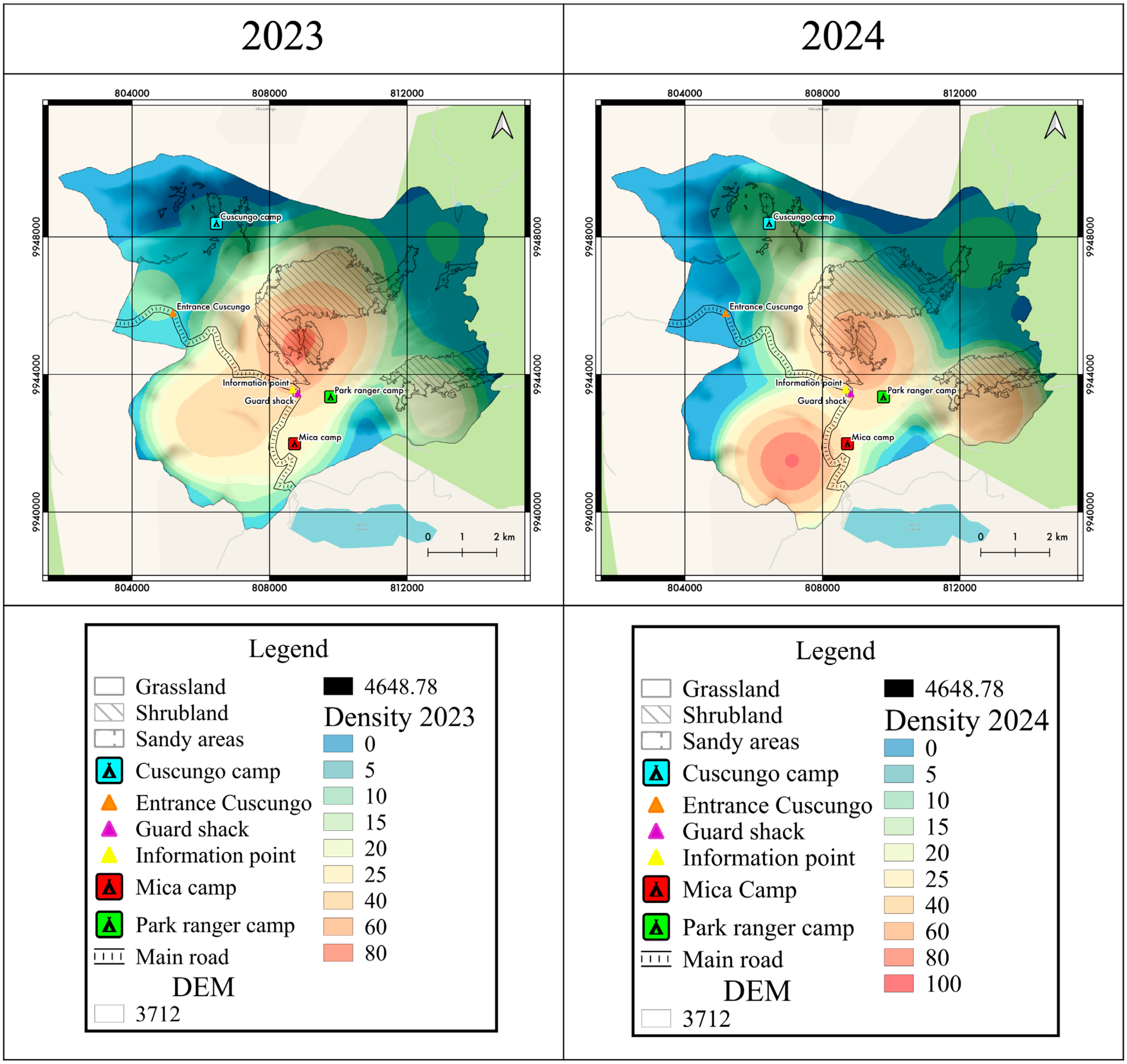

Figure 9. Heat maps of white-tailed deer population density in the grassland, shrubland, and sandy areas of the Antisana Water Conservation Area in 2023 and 2024. Warm colors indicate areas of higher population density, while cool colors represent areas of lower density. Density measured in ind km^{-2}

grasslands for feeding and resting (Correa-Viana 1994). Together, these findings suggest that observed density patterns are better explained by the combined availability of resources across vegetation types than by any single cover type component.

Additionally, other cover types may fulfill complementary functions. Harley (2019) mentions that deer species such as red deer (*Cervus elaphus*) take dust baths using their antlers to dig into the ground. Although this behavior has not yet been documented in white-tailed deer, sandy areas may provide opportunities for similar behavioral activities, as patches of sand with multiple tracks were observed during fieldwork, as if the deer had rolled around there. These observations highlight the need for further studies to confirm the potential role of sandy areas in the species' ecology.

The spatial distribution pattern observed in the ACH Antisana indicates a non-random aggregation of white-tailed deer within specific zones of the landscape. Higher densities concentrated in central and southwestern areas suggest the presence of core use areas within the protected landscape, while lower densities in peripheral zones may reflect reduced cover type suitability or higher levels of disturbance. Ungulate populations in heterogeneous and protected landscapes commonly exhibit core–periphery spatial structures, where individuals concentrate their activity in core areas that maximize access to resources while minimizing exposure to disturbance and perceived risk (Boyce *et al.* 2016). This pattern coincides with the spatial distribution of anthropogenic pressures in many protected area systems, which are often not uniformly distributed but tend to be concentrated near the edges, while central areas can function as relative refuges with lower levels of disturbance (Dillon *et al.* 2025). In this context, the spatial aggregation of deer over the two years may reveal a non-uniform distribution in the study area, with higher values concentrated in central zones and lower densities toward the periphery. This indicates that broader spatial processes, such as landscape structure and the distribution of resources or disturbances, may play a more important role than cover type per se in shaping deer distribution patterns.

One limitation of this study is that sampling was conducted only during the last half of 2023 and 2024, which restricts a more complete understanding of the species' population dynamics throughout the year. According to López-Téllez *et al.* (2007), deer density estimates can vary between locations and transects depending on the sampling time. In this regard, it is worth noting that sampling took place during the transition between the dry and rainy seasons (October–December), a period in which changes in resource availability and individual activity may occur. Despite this temporal restriction, the study involved an extensive field phase, with a greater sampling effort than that carried out by Albuja (2007) and Tellkamp *et al.* (2019). To the best of our knowledge, there are no specific studies on the reproductive seasonality of the white-tailed deer in the ACH Antisana. Furthermore, the species' reproduction in temperate and cold zones begins in late November, peaking in December (Albuja 2007; Ugarte 2011; Chávez *et al.* 2022). During this period, males and females increase their activity in searching for mates, which can increase their detectability (Hölzenbein and Marchinton 1992; Galindo-Leal and Weber 1998). In 2024, sampling was extended until December 11, partially coinciding with the reproductive season and the beginning of the rainy season, which could partially explain the increase in deer density recorded that year, although the differences were not statistically significant. In contrast, most of the 2023 sampling was conducted in October, during the dry season and outside the breeding season.

Although despite the annual estimates showed good accuracy, evidenced by their low coefficients of variation, which reflect less variability in the data and therefore greater sampling reliability (Shechtman 2013), the smaller number of observations in some cover types may have influenced the ability to detect differences. In distance sampling, small sample sizes can affect the accuracy of the detection function and increase the variability of density estimates (Buckland *et al.* 2015). Therefore, although no significant differences were identified, the presence of subtle variations between cover types cannot be ruled out.

Long-term monitoring programs are essential to better understand the population dynamics of white-tailed deer and establish management strategies tailored to the conditions of each territory (Sánchez-Rojas 2009; Abrante-Hernández *et al.* 2013). These studies should include not only information on the population density of the species but also on its age structure, growth rate, and sex ratio, as this information is key to understanding the dynamics of any animal population (Ezcurra and Gallina 1981; Mandujano and Aranda 1993; Ojasti and Dallmeier 2000). We recommend implementing systematic protocols for estimating white-tailed deer population densities based on direct observation methods, as these provide reliable information on the number of individuals and are a useful tool for establishing long-term monitoring programs.

Conclusions

This study provides updated evidence of relatively high densities of white-tailed deer in the ACH Antisana compared to historical records of the zone, suggesting a positive population trend that is likely associated with ongoing ecological recovery processes, including vegetation restoration, reduction of anthropogenic pressure, and improved cover type conditions.

No significant differences in deer densities were detected among cover types or between sampling years, indicating that cover type alone does not strongly determine deer density. Instead, the species appears to respond to a heterogeneous landscape where cover type elements provide complementary resources that jointly support population maintenance.

Overall, these results highlight that white-tailed deer density is closely linked to ecosystem recovery processes and site heterogeneity. Our findings highlight the importance of continuing restoration and management actions within the ACH Antisana, especially in areas that have been historically degraded by anthropogenic activities. The conservation of this high Andean ecosystem not only guarantees the survival of the white-tailed deer but also contributes to the preservation of other species that depend directly or indirectly on it and to maintaining ecosystem services. Thus, promoting comprehensive conservation strategies in the paramo are essential to ensure the long-term dynamics of the ecosystem.

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Declaration of Artificial Intelligence Use

We declared that we used DeepL Translate for a preliminary translation. Also, we used ChatGPT for brainstorming and outlining purposes.

Author contributions

Michelle Alexandra Rodríguez-Noroña: Conceptualization, fieldwork, data curation, formal analysis, fund acquisition, research, methodology, project administration, resources, software, visualization, original draft writing, writing-reviewing and editing; David Andrés Herrera-Orellana: Fieldwork, data curation, writing-reviewing and editing; Paúl Monar-Barragán: Conceptualization, writing-reviewing and editing, fund acquisition, research, project management, resources, validation, writing-reviewing and editing; Juan Sebastián Restrepo-Cardona: Validation, writing, revision, and editing; Evelyn Edith Araujo: Conceptualization, acquisition of funds, research; Iván Vinicio Jácome-Negrete: Conceptualization, fieldwork, supervision, research, resources, validation, writing-reviewing and editing.

Supplementary data

SD1. Direct observation of white-tailed deer in cover types transects in the Antisana Water Conservation Area in 2023 and 2024: A) Observation with rangefinder, B) male white-tailed deer, C) Observation with rangefinder, D) Group of white-tailed deer, E) Data entry on field form, F) female white-tailed deer

SD2. Summary of detection function models fitted to Deer data. "CvM" stands for Cramér-von Mises, $\hat{P}_a$ is average detectability, se($\hat{P}_a$) is standard error. Models are sorted in ascending order according to their AIC.

SD3. Adjustments to the detection function (Hazard-rate + cos) to the perpendicular distance distribution data for the years 2023 and 2024.

SD4. Database collected in 2023 used to estimate the density of white-tailed deer (*O. virginianus ustus*) using the R-Distance package.

SD5. Database collected in 2023 used to estimate the density of white-tailed deer (*O. virginianus ustus)* in cover types (TH: grassland, TB: shrubland, TE: sandy areas) using the R-Distance package.

SD6. Database collected in 2024 used to estimate the density of white-tailed deer (*O. virginianus ustus*) using the R-Distance package.

SD7. Database collected in 2024 used to estimate the density of white-tailed deer (*O. virginianus ustus*) in cover types (TH: grassland, TB: shrubland, TE: sandy areas) using the R-Distance package.

SD8. R scripts used for density estimates and construction of white-tailed deer figures.

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