El Hornero
Volumen 40 · Número 1 · Agosto 2025

Artículos

doi: 10.56178/eh.v40i1.1512

ESTABLISHING BIODIVERSITY BASELINES OF AVIAN COMMUNITIES IN TWO ARID ECOREGIONS OF NORTHERN PATAGONIA

Establecimiento de líneas base de biodiversidad en comunidades de aves en dos ecorregiones áridas del norte de la Patagonia

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ABSTRACT: Bird diversity and composition is key for environmental assessments and conservation planning. Bird diversity associated with arid ecosystems has received substantial research interest worldwide. However, bird communities in the arid areas of Patagonia have been scarcely examined. In this study, we analyze the richness, abundance, and composition of bird species along a transect from the Andes to the Atlantic coast in northern Patagonia associated with two arid ecoregions—the Monte and the Patagonian steppe. We established 14 sampling stations along Route 23. A total of 14 bird surveys were conducted at each station between 1998 and 2012. We examined variations in bird community composition across 14 stations using distance-based redundancy analysis (dbRDA) including the environmental variables of mean temperature, annual precipitation, the presence of trees (associated with ranch houses), and water availability (categorized as permanent, temporary, or absent). A total of 126 bird species belonging to 20 orders and 38 families were recorded at the sampling points. We found that mean temperature and water availability play a key role in structuring avian communities in arid ecosystems. Given the ongoing challenges posed by global warming in the region, including severe droughts, these findings highlight the importance of establishing a baseline for future studies. Such data are crucial for developing management plans aimed at preserving bird diversity in these vulnerable ecosystems.

KEYWORDS: *bird diversity, ecoregions, nomadic, Patagonia, ranch house, waterfowl, wetland*

RESUMEN: La diversidad y composición de aves son fundamentales para las evaluaciones ambientales y la planificación de la conservación. La diversidad de aves asociada a ecosistemas áridos ha recibido un notable interés científico a nivel mundial. Sin embargo, las comunidades de aves en las zonas áridas de la Patagonia han sido escasamente estudiadas. En este trabajo, analizamos la riqueza, abundancia y composición de especies de aves a lo largo de una transecta desde los Andes hasta la costa Atlántica en el norte de la Patagonia, abarcando dos ecorregiones áridas: el Monte y la estepa Patagónica. Establecimos 14 estaciones de muestreo a lo largo de la Ruta 23. En cada estación se realizaron 14 censos de aves entre 1998 y 2012. Examinamos las variaciones en la composición de las comunidades de aves entre las 14 estaciones mediante un análisis de redundancia basado en distancias (dbRDA), incluyendo como variables ambientales la temperatura media, la precipitación anual, la presencia de árboles (asociada a casas de estancia) y la disponibilidad de agua (clasificada como permanente, temporal o ausente). En total, se registraron 126 especies de aves pertenecientes a 20 órdenes y 38 familias en los puntos de muestreo. Encontramos que la temperatura media y la disponibilidad de agua desempeñan un papel clave en la estructuración de las comunidades de aves en ecosistemas áridos. Dado el desafío que implica el calentamiento global en la región, incluyendo sequías severas, estos resultados subrayan la importancia de establecer una línea de base para estudios futuros. Estos datos son cruciales para desarrollar planes de manejo orientados a preservar la diversidad de aves en estos ecosistemas vulnerables.

PALABRAS CLAVE: *aves acuáticas, casco de estancia, diversidad de aves, ecorregiones, humedal, nómadas, Patagonia*

Recibido: 5 de diciembre 2024 · Aceptado: 13 de junio 2025 · Editora Asociada: Susana Peluc

Arid and semi-arid regions cover approximately one-third of the Earth's terrestrial surface (Wickens 1998). Bird diversity associated with arid ecosystems has received substantial research interest worldwide due to the particularities of these communities (Cruz-McDonnell & Wolf 2016, Jordan et al. 2017, Iknayan & Beissinger 2020, Ma et al. 2023). Desert birds exhibit remarkable adaptive capacities to tolerate hydric and thermal stress, which closely links them to their harsh physical environments and makes them suitable indicators of climate and land use changes (Iknayan & Beissinger 2020). Thus, biodiversity assessments of dessert bird communities, particularly in understudied regions, are crucial to document the impacts of global change.

In Patagonia, two vast arid ecoregions—the Patagonian steppe and the Monte desert—have been scarcely and unevenly surveyed in terms of their terrestrial bird communities (Llanos et al. 2011, Lambertucci & Ruggiero 2016). This dry, windy, and cold region, located between the Andes and the Atlantic Ocean, hosts relatively low bird diversity (Rabinovich & Rapoport 1975). However, Patagonian bird communities exhibit distinctive ecological and biogeographical characteristics that set them apart from those in other South American regions (Vuilleumier 1972, Rabinovich & Rapoport 1975, Ralph 1985). One notable feature is the strong seasonality in species composition, largely driven by migration. During the austral summer, numerous migratory species arrive from temperate South America, tropical latitudes, and even boreal regions of North America. In addition, the Monte Desert, which conforms the northeastern portion of Patagonia, is where most argentine endemic birds are found as is the only ecoregion unique to Argentina (Llanos et al. 2011, Pearman & Areta 2020).

The biodiversity and functioning of desert bird communities remain poorly understood and, under climate change, significant population declines could lead to local extinctions (Ma et al. 2023). In arid ecosystems, environmental filters such as water availability, temperature, and vegetation structure strongly shape bird communities, influencing both species richness and composition (Wiens & Rotenberry 1981, Wiens 1991, Srinivasan et al. 2018). Therefore, a thorough description of bird communities in the northern arid regions of Patagonia—incorporating long-term temporal variation—is essential to establish baselines for biogeographic knowledge and the conservation of these landscapes.

The objectives of this study are (1) to characterize avian species richness and composition in this understudied region, and (2) to assess the influence of key environmental variables—including temperature, precipitation, and water availability—on community structure. By filling these knowledge gaps in a largely unexplored area, this study contributes to a broader understanding of arid-zones ornithology and provides a baseline for future conservation planning.

METHODS

Study area

The study was carried out in northern Patagonia, along Route 23, which runs east-west from the Atlantic Ocean to Dina Huapi City, at the Andean foothills, encompassing two ecoregions, the Argentine Austral Monte (Monte) and the Patagonian steppe (Olson et al. 2001). In the Monte ecoregion, the vegetation is mainly

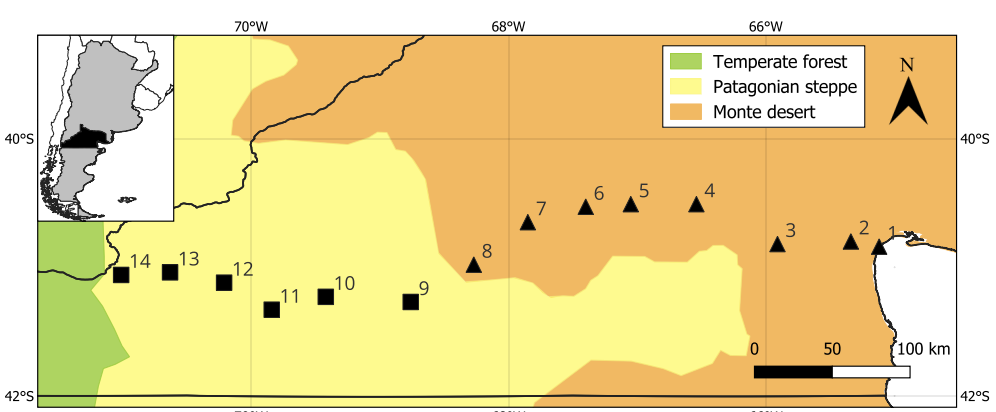

Figure 1. Location of sampling stations for bird surveys conducted between 1998 and 2012 in two ecoregions of northern Patagonia. Triangles represent the Monte ecoregion, while squares represent the Patagonian steppe ecoregion. The nearby ecoregion, the temperate forest, is also shown.

shrubby, with a predominance of the genus *Larrea* (jarillas), associated with other shrubs such as *Neltuma* and *Schinus*. The climate is temperate-arid, with very marked thermal amplitudes. Rainfall is scarce (200-300 mm), and in the austral monte occurs year-round but mainly at the end of summer (Abraham et al. 2009). On the other hand, the vegetation in the Patagonian steppe primarily consists of grasslands. It is dominated by herbaceous plants, such as *Festuca* and *Papostipa*, as well as generally low, cushion-shaped shrubs like *Azorella*. The climate is temperate to cold and arid, with precipitations mainly in winter (250-500 mm) and with strong winds year-round. The topography of the Patagonian steppe region includes a diverse range of features such as plateaus, cliff outcrops, plains, hills, several small wetlands, and river valleys. In contrast, the Monte region is less complex, primarily consisting of plateaus and plains, with temporal streams and a coastline that borders the Atlantic Ocean.

Along Route 23, 14 sampling stations were set up, separated by approximately 50 km each (Fig. 1, Table 1). The sampling stations were arranged in two different ecoregions, Monte (n=8) and Patagonian steppe (n=6). The locations of the sampling stations were chosen to represent a variety of environments in northern Patagonia, including sites with characteristic vegetation, landscapes, and wetlands from both the Patagonian steppe and Monte ecoregions. The selection of sampling station aimed to capture a broad overview of the main environmental conditions rather than reflect the relative abundance of each environment type. Within the different ecoregions, we selected sites with varying water availability—permanent, temporary, or absent. Some stations, such as Maquinchao and Nahuel Niyeu, also include a mix of native and non-native vegetation associated with ranch houses (Table 1). Logistical considerations also played a role in site selection; given the long transect (approximately 650 km) and the distance between sampling sites. In Piedras Coloradas, which is on the border with the Atlantic Ocean, all species were recorded and analyzed, including marine birds.

Bird surveys

At each sampling station, all bird species heard or observed with 10X binoculars were recorded within an unlimited radius for a duration of 15 minutes by two observers (Ralph et al. 1993). The sampling area in each sampling station was similar and remained the same over time. Additionally, as a supplementary descriptive data, observations of species occurring outside the de-

Table 1. Description of sampling stations. Identification, location, altitude (masl), ecoregion, mean temperature (MT), annual precipitation (AP), observed richness, diversity (H) and main habitat type are indicated.

#	Name	Latitude	Longitude	Altitude	Ecoregion	MT	AP	Richness	H	Habitat
1	Piedras Coloradas	-40.84	-65.12	5	Monte	15.5	309	46	2.84	scrub, sea coast
2	El Gateado	-40.8	-65.34	155	Monte	14.9	316	30	2.44	scrub, temporal lake
3	Pajalta	-40.82	-65.91	167	Monte	15	275	29	2.78	scrub
4	Nahuel Niyeu	-40.51	-66.54	175	Monte	15.3	283	52	3.12	scrub, temporary stream, abandoned ranch house
5	Falkner	-40.51	-67.05	390	Monte	14	314	32	2.73	scrub
6	Talcahuala	-40.53	-67.4	525	Monte	13.3	303	26	2.47	scrub
7	Salina	-40.65	-67.85	703	Monte	13.1	311	41	2.47	scrub, permanent salt lake
8	Abanico	-40.98	-68.27	860	Monte	11.1	287	25	2.28	scrub
9	Maquinchao	-41.27	-68.76	885	Steppe	10.5	230	39	2.84	grassland, temporary stream, ranch house
10	Carrilaufquen Chica	-41.23	-69.42	827	Steppe	10.7	298	48	2.83	grassland, temporal lake
11	La Nada	-41.33	-69.84	952	Steppe	9.6	332	21	2.22	grassland
12	Bandurrial	-41.12	-70.21	686	Steppe	9.6	350	24	2.22	grassland, wetland
13	Pilcaniyeu	-41.04	-70.63	1005	Steppe	7.6	440	28	2.59	grassland, wetland
14	Los Juncos	-41.06	-71.01	915	Steppe	8.1	607	51	2.4	grassland, temporal lake

signated bird survey periods at each sampling station, as well as between stations, were documented. These records were not considered in the data analysis but were included to maintain a comprehensive list of bird species in northern Patagonia (Appendix 1).

A total of 14 bird surveys were conducted at each sampling station between 1998 and 2012 (excepting the initial survey, when we did not sample stations 1 to 5). Bird surveys occurred once a year, except in 2001 when two surveys were carried out (summer and spring), and in 2004 and 2007 when no surveys took place. The surveys were primarily conducted during the spring (November) or summer (February) seasons (Appendix 2). Due to their logistical complexity (long distances between sampling stations and route conditions), bird surveys were spread over two consecutive days within each period. We alternated the start times of bird surveys (morning, midday, and afternoon) at different sampling stations, attempting to register during different times of the day. Bird surveys were not conducted on days with strong winds, rain, or extremely high or low temperatures.

Environmental variables

From each sampling station, we obtained climatic data (temperature and precipitation) from the CHELSA database (Karger et al. 2017). This dataset includes mean temperature and precipitation values, averaged from monthly records over a 10- to 30-year period. Water availability at each site was also recorded and categorized as permanent, temporary, or absent. Additionally, the presence of non-native trees—associated with ranch houses—was noted along the sampling stations.

Data analysis

Species richness and diversity using the Shannon index was calculated for each site. We examined variation in bird community composition across 14 sampling station using distance-based redundancy analysis (dbRDA). Species abundance data were Hellinger-transformed to reduce the disproportionate influence of highly abundant species, and community dissimilarities were calculated using Bray-Curtis distances (Legendre & Gallagher 2001). Environmental predictors included climatic (mean temperature and annual precipitation), presence of non-native trees (associated to ranch houses) and water availability (permanent, temporary, or absent). Other geographical variables, such as longitude and altitude, were not included in the data analysis due to high collinearity. For instance, longitude were strongly correlated with precipitation (r = 0.97), and temperature (r = - 0.92). The analysis was performed in R version 4.3.1 (R Core Team 2019), using the vegan package version 2.6-4 (Oksanen et al. 2022).

RESULTS

A total of 126 bird species belonging to 20 orders and 38 families were recorded at the sampling points from 1998 to 2012 (Appendix 3). The orders with the highest number of species were Passeriformes (n=62), Charadriiformes (n=17), and Anseriformes (n=12), while the families with the highest number of species were Tyrannidae (n=22), Furnariidae (n=13), and Anatidae (n=12). Two non-native species were detected, the House Sparrow (*Passer domesticus*) and the California Quail (*Callipepla californica*). Accumulated observed species richness varied from 21 species at La Nada to 52 at Nahuel Niyeu across the sampling stations (Table 1). For most sampling stations, the accumulated number of species reached an asymptote with the bird surveys conducted, suggesting that the majority of species present were detected in this study (Appendix 4). The stations with the highest observed richness were Piedras Coloradas (46) and Nahuel Niyeu (52) in the Monte ecoregion, and Carrilaufquen Chica (48) and Los Juncos (51) in the Patagonian steppe ecoregion. Sampling stations with the highest diversity (H) were Nahuel Niyeu and Piedras Coloradas in the Monte ecoregion, and Maquinchao and Carrilaufquen Chica in the Patagonian steppe. The abundance was highest in Los Juncos and Carrilaufquen Chica, both of Patagonian steppe ecoregion.

Species richness and abundance showed high variation among sampling stations across the 14 bird surveys (Fig. 2). For instance, Los Juncos, Carrilaufquen Chica, and Nahuel Niyeu exhibited variations of three to five times in the number of species recorded during the surveys (Fig. 2a). Likewise, abundance varied significantly within some stations across surveys, with Los Juncos and Carrilaufquen Chica showing differences of nearly two orders of magnitude in the number of individuals recorded on different survey dates (Fig. 2b).

Few bird species (*Chloephaga picta*, *Podiceps major, Nannopterum brasilianum*, *Zenaida auriculata*, *Daptrius chimango, Falco sparverius, Mimus patagonicus, Zonotrichia capensis* and *Leistes loyca*) were observed in all 14 bird surveys. Only *Z. auriculata* was recorded at all 14 sampling stations, and *Cathartes aura, Tachycineta leucopyga, Z. capensis, L. loyca* in 13 of the 14 sampling sta-

tions. The most abundant species, comprising 50% of all recorded individuals, were species associated with wetland habitat (*Spatula platalea, Fulica armillata*, *Phoenicopterus chilensis*, *Anas georgica*, *C. picta*, *Anas flavirostris*, *Larus dominicanus*, *Calidris bairdii*, *Mareca sibilatrix*).

Community analysis

The distance-based redundancy analysis (dbRDA) revealed significant variation in bird community composition across the 14 sites in northern Patagonia (global model: F = 3.56, p = 0.001) (Fig. 3). The model explained approximately 69% of the total variation in species composition (R^2 = 0.69), based on Hellinger-transformed species data and Bray–Curtis dissimilarity. The first two dbRDA axes were significant and accounted for the majority of the explained variation: CAP1 explained 34.2% and CAP2 explained 15.3% of the total variance in community composition. The positioning of site centroids suggests that sites with similar environmental conditions support bird communities with comparable species composition. Forward selection of environmental variables showed that mean temperature (F = 4.19, p = 0.001) and water availability (F = 3.70, p = 0.001) were the main drivers of community structure (Fig. 3). Annual precipitation (F = 1.36, p = 0.227) and the presence of trees were not statistically significant (F= 1.34p = 0.189). Finally, the dbRDA ordination revealed differences in bird community composition associated with environmental variables. Most of the sampling stations (2, 3, 4, 5, 6, and 8) located in the Monte ecoregion, which were in areas with temporary or no water availability, clustered more tightly in the ordination space. In contrast, the sampling stations from the Patagonian steppe were more widely dispersed. This pattern suggests lower within-region variability in species composition in the Monte compared to the Patagonian steppe.

DISCUSSION

This study represents the largest and longest-running transect-based monitoring effort of bird diversity

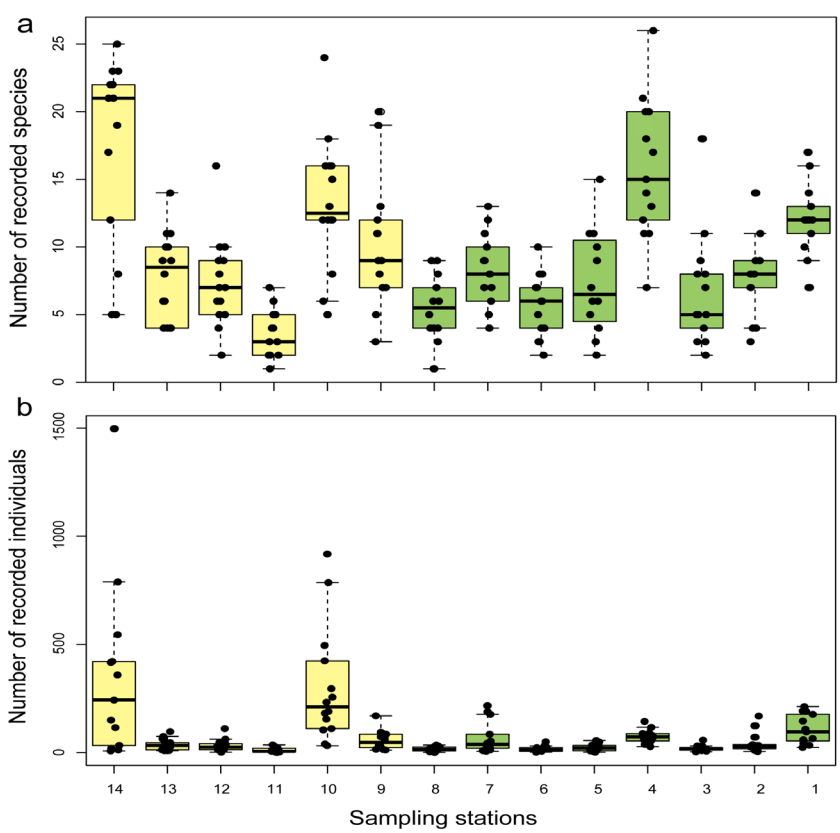

Figura 2. Number of recorded species (a) and number of recorded individuals (b) at 14 sampling stations arranged from east (1) to west (14) during bird surveys conducted from 1998 to 2012. The boxes represent the interquartile range (Q1–Q3), the black line inside each box indicates the median, and the whiskers extend to the minimum and maximum values or to outliers. Green boxes correspond to the Monte ecoregion, while yellow boxes represent the Patagonian steppe ecoregion. Each black dot represents a single bird survey.

in northern Patagonia, providing valuable insights into the avifauna of these arid regions in southern South America. Results from the distance-based redundancy analysis (dbRDA) indicate that bird community composition in these arid Patagonian ecosystems is significantly influenced by environmental variables, such as mean temperature and water availability. These findings are consistent with ecological expectations for arid landscapes, where abiotic factors such as climate and water availability play a central role in shaping species distributions and structuring community assembly (Smith 2015, Pascoe et al. 2021, Oñate et al. 2023).

Among the analyzed variables, mean temperature and water availability were the most important. Temperature suggests that thermal gradients act as environmental filters, influencing species distributions both directly, through physiological tolerances, and indirectly, via habitat structure and resource availability. Similar patterns have been documented in arid Australia, where bird assemblages show high temporal variability in response to rainfall variability and resource pulses (Pascoe et al. 2021). In North American deserts, such as the Mojave, bird community composition has been shown to respond to temperature variation, with warming and drying trends leading to significant declines in bird populations (Iknayan & Beissinger 2020). In northern Patagonia, temperature closely follows the decreasing west-to-east elevation gradient. Thus, most stations in the steppe are at higher elevation and have lower mean temperatures than those in the Monte, which have direct effects on bird diversity and composition.

Water availability emerged as another key factor structuring communities in northern Patagonia. The presence of permanent or seasonal water sources likely provides critical resources in these dry environments, influencing local species richness and abundance. This aligns with studies in arid zones from Africa and Australia, where bird diversity is often higher near water points, even under otherwise homogeneous conditions. In Australia, temporal water bodies can support pulse-driven increases in bird activity and richness, reinforcing the ecological importance of water in structuring faunal communities in deserts (Pascoe et al. 2021). Wetlands located in the arid zones of Patagonia serve as oases, sustaining significantly higher productivity than the surrounding habitats, and serving as havens for fauna (Epele et al. 2021). In Patagonia, as in other arid ecosystems, wetlands support high bird species richness and play a crucial role in biological conservation (Weller 1999, Caziani et al. 2001, Roshier et al. 2002, Maleki et al. 2016). However, wetlands are highly vulnerable to human activities and climate change. In fact, climate change is causing deserts, already defined by climate extremes, to heat up and dry out more quickly than other ecoregions (Wolf 2000, Iknayan & Beissinger 2020, Ma et al. 2023). More frequent and severe droughts, linked to climate change, have led to a dramatic decrease in the amount of water present in Patagonia in recent years (i.e. after 2007; Hurtado et al. 2023). Ad-

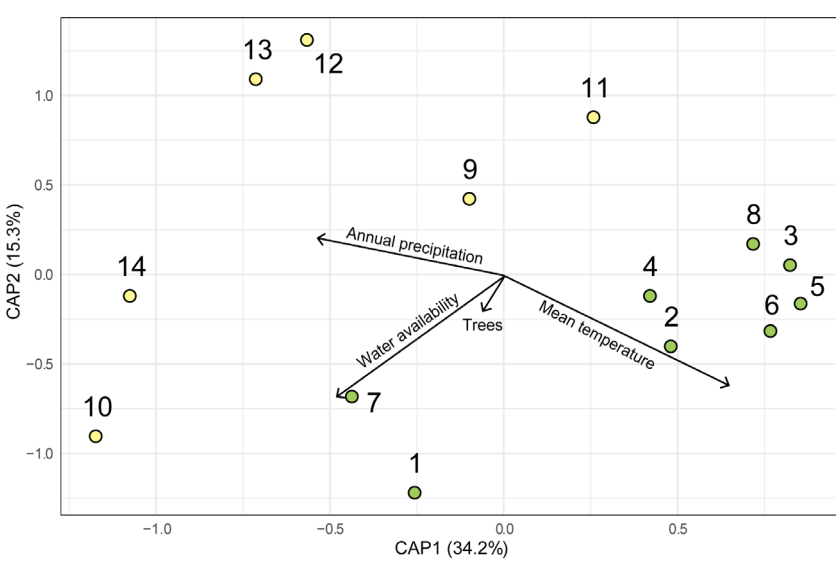

Figura 3. Distance-based redundancy analysis (dbRDA) of bird communities in relation to environmental variables: mean temperature, annual precipitation, presence of trees (associated with ranch houses), and water availability. Sampling stations from the Monte ecoregion (green dots) and Patagonian steppe (yellow dots).

ditionally, Patagonian wetlands have been intensively grazed by livestock (sheep) over the past century (Gonzalez & Ghermandi 2021). This decrease in wetlands' water and vegetation will certainly continue to impact both the richness and abundance of birds in northern Patagonia within the next decades.

Although both ecoregions contain wetland environments, their bird communities are not similar. The wetlands associated with temporary lakes in the Monte (e.g., El Gateado and La Salina sampling stations) exhibit lower bird richness and abundance compared to those in the Patagonian steppe (e.g., Los Juncos and Carrilaufquen Chica sampling stations). While flamingos are present in lakes across both ecoregions, waterfowl species are predominantly concentrated in the wetlands of the Patagonian steppe. These differences in species composition may be linked to the availability of water and resources throughout the year, as well as to the physicochemical properties of the lakes. In the Monte, most temporary water bodies hold water for only a few weeks annually due to irregular summer rainstorms associated with the Atlantic anticyclone (Paruelo et al. 1998, Abraham et al. 2009). In contrast, in the Patagonian steppe, winter rains brought by the Pacific anticyclone contribute to temporary lakes that take several months to fill and retain water for weeks or even months (Paruelo et al. 1998). This prolonged water availability in the Patagonian steppe provides a more stable and abundant food supply for aquatic herbivores. Additionally, the physicochemical properties and ostracod compositions of lakes in the Monte and the Patagonian steppe differ (Cusminsky et al. 2020). Although the availability of algae is not well documented, it is plausible that, like ostracods, it varies between ecoregions. Such differences could further influence the distribution and abundance of wetlands´ bird species. Notably, Piedras Coloradas, located at the Atlantic coast, present a similarities with La Salina, a site associated with a permanent saline lake. Despite different macrohabitats, these two sites shared similar avian community compositions, potentially due to the presence of marine-associated birds at Piedras Coloradas and aquatic species adapted to saline environments at La Salina.

Some bird species exhibit nomadic behavior, moving with little or no seasonal regularity to track resources that fluctuate over space and time (Dean 2004, Gibson et al. 2022). This behavior is common not only in desert areas but also among waterbirds. Waterbirds, such as flamingos and waterfowl, exhibit nomadism to adapt to the unpredictable availability of water resources (Pedler et al. 2014). These species respond quickly to changes in wetland distribution caused by flooding and drying of temporary lakes (Brandolin & Blendinger 2016). Furthermore, several nomadic and migrating species also exhibit flocking behaviors and tend to form large groups related to foraging and/or reproductive conducts (Teitelbaum & Mueller 2019). The large inter-annual fluctuation in richness and abundance of waterbirds in the wetlands of the Patagonian steppe was likely due to nomadic and migrating movements of species. Although the movements of nomadic birds have been well studied in other parts of the world, especially in Australia (Jordan et al. 2017), information for Patagonian birds is not yet available. Despite our monitoring provides little specific information on nomadic bird behavior; it suggests that this is a likely phenomenon in waterbirds communities in northern Patagonia, which deserves further research to better understand bird diversity across space and time.

We found that ranch houses increase bird diversity by acting as oases in northern Patagonia. The mixture of planted native and non-native vegetation along with water availability associated with basic human landscaping around ranch houses provides enhanced resources (water, food, refuge and nesting places) for a variety of bird species, mainly insectivores. This is the case with the Nahuel Niyeu station, where we recorded the greatest diversity among stations in the Monte ecoregion. Nahuel Niyeu is an abandoned ranch house with non-native tree species (e.g. *Pinus* sp., *Eucalyptus* sp., *Tamarix* sp.) and a temporary stream that have created a favorable environment for birds, especially insectivorous species. Maquinchao, also has a ranch house and a temporary stream, showing high bird diversity in the Patagonian steppe. Despite we clearly do not have enough replicates for supporting a strong pattern regarding increased bird diversity in human-modified landscapes in northern Patagonia, several studies found similar associations elsewhere (Maestas et al. 2003; Bock et al. 2008).

Finally, we believe that the austral portion of the Monte ecoregion is fairly well represented in this study for describing the bird community, while the Patagonian steppe is not. More sampling stations (replicates) of representative environments in the Patagonian steppe are necessary to include a comprehensive description of the bird community of this ecoregion. Our sampling in the Patagonian steppe is somewhat biased towards an over representation of wetlands. Thus, terrestrial passerine birds in the Patagonian steppe could be underrepresented in our community

characterization. Sampling in more homogeneous sites is necessary to obtain an adequate representation of birds in the Patagonian steppe.

Conservation

Although no large number of endemic or endangered species were found at the sample sites, at least according to the International Union for Conservation of Nature (IUCN), it is notable that the arid environments in Northern Patagonia have almost no protected areas. Less than 5% of these ecoregions is under protection and most of these reserves are only nominally protected, offering little real safeguarding to biodiversity (Chehébar et al. 2013). The greatest threats in the Monte desert are wildfires and overgrazing while in the Patagonian steppe are extreme droughts (Llanos et al. 2011, Hurtado et al. 2023). Using climate change projections and species distributions on desert birds globally, Ma et al. (2023) found that the austral Neotropical desert areas will be highly impacted. In the face of global climate change, the study area will be strongly impacted, affecting bird populations. Long-term studies, such as ours, incorporate natural fluctuations in richness and abundance and yield abundant information on communities' composition, which serve as baselines for future studies and as a reference for management plans.

ACKNOWLEDGEMENTS

We are grateful for the collaboration of Alfonso Paravano, Carolina Quintero, Cecilia Ezcurra, Eduardo Shaw, Erick Ambat, Federico Beaudoin, Graciela Sosa, Gonzalo Ignazi, Karin Heinemann, Leonardo Fernández, Liz Gallegos, Mariano Gelain, Mauricio Rumboll, Mercedes Sahores, Romina Vidal Russell, Shannette Rillorta and Verónica Nelson, who joined us during our fieldwork throughout Patagonia. We also extend our thanks to Estancia Maquinchao for providing us with accommodation at the ranch house. The authors also thank Ariadna Tripaldi for her helpful comments on the manuscript and figure 1 edition. Comments of two reviewers helped us to improve the manuscript This study was financed with authors' own funds.

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