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ORNITHOLIMNOLOGICAL STUDY IN THE RELONCAVÍ SOUND, NORTHERN PATAGONIA, CHILE

Estudio ornitolimnológico en el Seno de Reloncaví, Patagonia Norte, Chile

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ABSTRACT: In this work, an ornitholimnological approach was used to determine the structure of bird assemblages in wetlands of Northern Chilean Patagonia. A greater richness of species was obtained for those wetlands with a greater perimeter (a proxy of the water mirror) and enhanced environmental conditions. Bird counts were made bimonthly, from May to November 2021 and in the winter of that year, nutrients (e.g., nitrogen and phosphorous) at the two largest wetlands as well as physicochemical parameters (e.g., dissolved oxygen) were determined. When compared with other studies carried out in Chile, a high bird species richness was observed (>70), especially during the counts carried out during high tide. The perimeter of the wetlands was positively related to the abundance of individuals. Wetlands located in the extremes of the study area, with smaller surfaces and irregular shapes exhibited lower abundances and species richness. The opposite occurred with the two largest wetlands, despite them having high loads of nitrogenous and phosphorous nutrients. Further research is needed to explain the importance of other covariables at the landscape level.

KEYWORDS: *bird species richness, nutrients, Patagonia, physicochemical parameters, shape index*

RESUMEN: En este trabajo se emplea una aproximación ornitolimnológica para determinar la estructura de los ensambles de aves en humedales de la Patagonia norte de Chile. Se encontró una mayor riqueza de especies para aquellos humedales de mayor perímetro (un “proxy” del espejo de agua) y mejor condición ambiental. Las contabilizaciones de aves se efectuaron bimensualmente desde mayo a noviembre de 2021 y en el invierno del mismo año se determinaron los nutrientes (e.g., nitrógeno, fósforo) y parámetros físico-químicos (e.g., oxígeno disuelto) de dos de los humedales más grandes. Se encontró una alta riqueza de especies de aves (>70), en comparación con otros estudios realizados en Chile, especialmente durante los conteos efectuados en pleamar. El perímetro de los humedales se relacionó positivamente con la abundancia de individuos. Los humedales situados en los extremos del área de estudio, de menor superficie y formas irregulares, presentaron una menor abundancia de individuos y riqueza de especies. Lo contrario ocurrió con los dos humedales más grandes, a pesar de presentar altas cargas de nutrientes nitrogenados y fosforados. Se necesita más investigación para explicar la importancia de otras variables a nivel de paisaje.

PALABRAS CLAVE: *índice de forma, nutrientes, parámetros físico-químicos, Patagonia, riqueza de especies de aves*

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The annual biological cycle of birds is linked mainly to periods of reproduction, molting and migration (Martínez 1993). Migratory shorebirds are important agents of coastal wetlands (Cursach et al. 2022). The coast of southern Chile, from Puerto Montt south (northern Patagonia) is characterized by an extensive geographical area of estuaries, channels, islands, and inland seas (Silva et al. 1997) along which coastal wetlands are major feature. Wetlands ecosystems are recognized internationally for their size, diversity, biogeographic importance, and the wide range of environmental goods and services that they provide (Hiraishi & Harada 2003; Dahdouh-Guebas et al. 2005). Waterfowl are one of the most charismatic components of the fauna that inhabits wetlands. These ecosystems provide important ecological functions including shelter, food, and nesting areas (Martínez 1993).

The richness and abundance of the waterfowl that inhabit a wetland depends on various factors such as the size and heterogeneity of the site, and the structure of the vegetation (Blanco & Canevari 1995). Waterfowl are rarely evenly distributed within the wetland, but species richness and abundance of individuals are associated with the local environmental characteristics. Such environmental characteristics depend on the productivity of the ecosystem, as well as the organic and inorganic nutrients transported by rivers. For example, an increase in anthropogenic activity triggers significant changes in landscape and water pollution, through the discharge of nutrients (Fuentes et al. 2021, 2023), particularly nitrogen and phosphorous which at higher concentrations cause eutrophication which may affect the presence or distributions of species (Seitzinger et al. 2002). Thus, the ecological and environmental characterization of the rivers that flow into these coastal areas becomes important, together with the maintenance of their environmental quality (Fuentes et al. 2023). This is relevant for the conservation of their biodiversity (Fuentes et al. 2015, 2016).

We hypothesize that the greatest bird species richness will be recorded in coastal wetlands that have largest perimeters (as a proxy of the water mirror), together with better environmental conditions. The present work combines ecological and limnological approaches (i.e., ornitolimnology, *sensu* Hulbert & Chang 1983, research at the population ecological level organization) to understand the structure of the avian assemblages of a wetland, along a gradient of nutrient concentrations and other physicochemical parameters. This is the first study in Chile that combines ecological and limnological approaches at the assemblage level organization.

METHODS

Study area

The study area is located in the Seno Reloncaví, northern Chilean Patagonia (see descriptions in Cursach and Delgado 2021, Cursach et al. 2021, 2022).

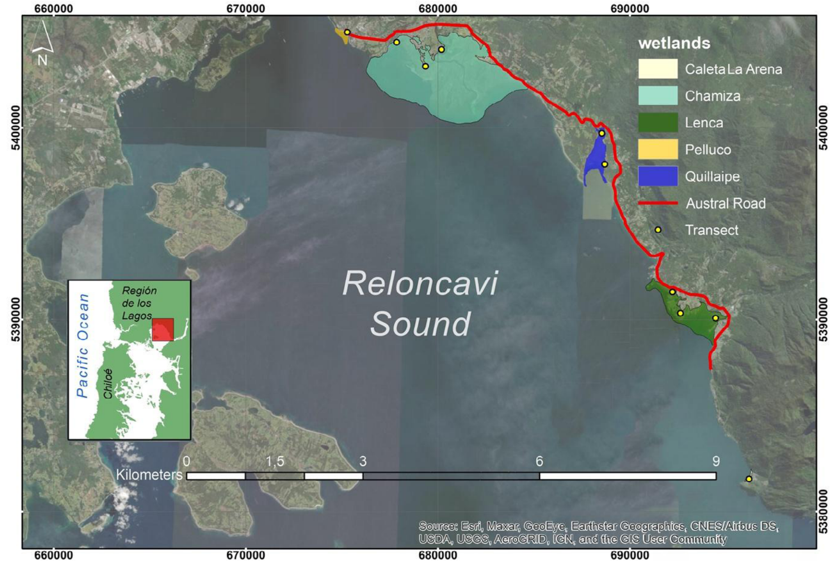

Figure 1. Location of the five wetlands in the first section of the Austral road, Reloncaví Sound, Northern Chilean Patagonia. Yellow circles show the transects used for bird records. Their number is proportional to the size of each wetland.

The coast of northern Chilean Patagonia is an extensive geographical area composed of estuaries, channels, islands, and inland seas (Silva et al. 1997). Along the northeastern coast of the Seno Reloncaví, a total of five basins and their corresponding wetlands were selected: Pelluco, Chamiza, Quillaipe, Lenca, and Caleta La Arena (Fig. 1). Given the temperate maritime climate of the region, all of these basins generate substantial flows of freshwater into the coastal environment. All the wetlands sampled are a mix of tidal estuarine and marine environments (González et al. 2003).

Pelluco (Fig. 2A), is a popular beach resort for the inhabitants of Puerto Montt, located on the eastern edge of the city; especially during the summer season. It features extensive real estate development, where much of the land cover is concrete infrastructure. Its freshwater supply comes from an estuary and storm drains that discharge onto the beach. Among the threats observed during the research period were unsupervised domestic dogs, in addition to noise pollution and other anthropogenic activities.

Chamiza (Fig. 2B), is located 10 km east of Puerto Montt, between the urban-rural sectors of Coihuín, Chamiza and Piedra Azul. It was approved by the Hemispheric Network of Shorebird Reserves "WHSRN" and the Hemispheric Council of WHSRN under the category of International Importance for hosting more than 10% of the biogeographic population of *Limosa haemastica*. Its freshwater supply comes from the Coihuín River. Among the threats observed during the research period were various types of debris, garbage derived from leisure activities during festive seasons, as well as the presence of sheep and cattle, unsupervised domestic dogs, and motor vehicles.

Quillaipe (Fig. 2C) is located 17 km east of Puerto Montt. It is influenced by a semidiurnal tide, with a range close to 4 m at spring high tide. In the intertidal zone there are two areas: a vegetated area (marsh), dominated by a hemicryptophytic perennial vascular flora (e.g., *Anagallis alternifolia* and *Puccinellia glaucescens*) (San Martín & Ramírez 2002) and an area lacking vegetation (tidal flat). The freshwater enters

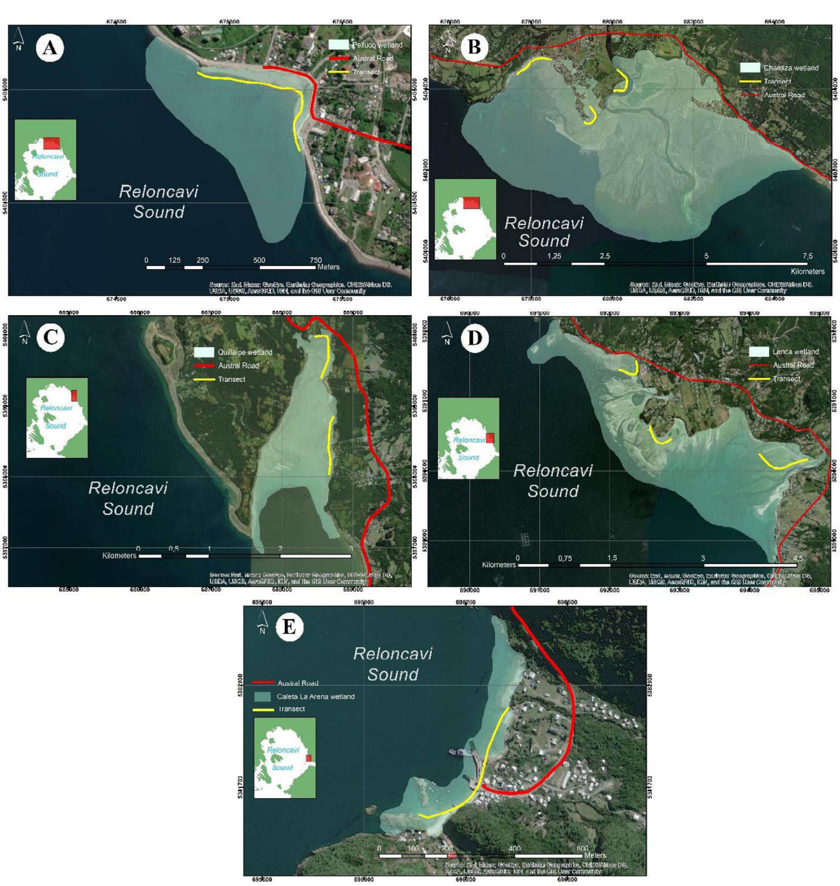

Figure 2. The five wetlands selected in this study: Pelluco (A), Chamiza (B), Lenca (C), Quillaipe (D), and Caleta La Arena (E). Yellow lines are the transects sampled.

the wetland from a number of small streams around its northern end. Among the threats observed during the research period were the presence of sheep, cattle, domestic dogs without supervision and mussel farming (M. Lee, pers. comm.).

Lenca (Fig. 2D) is located 33 km east of Puerto Montt, this area comprises an estuarine system with salt marshes. There have been significant salt water incursions into the coastal areas at Lenca, due to the subsidence of land caused by the earthquake of May 1960 (San Martín & Ramírez 2002). Freshwater enters the wetland from the Lenca and Chaicas rivers. Among the threats observed during the research period were the presence of sheep, cattle, and domestic dogs without supervision, and motor vehicles.

Caleta La Arena (Fig. 2E) is a ferry port with regular sailings throughout the day across the Reloncaví fjord on the route connecting Puerto Montt and Hornopirén, with frequency increasing during the summer season. The freshwater enters the wetland from a small stream at the northern end. After Pelluco, it is one of the most anthropogenically impacted wetlands.

Wetland shape

In order to relate the shape of the five wetlands with individual abundances and species richness, their surface (km^2) and perimeter (km) were obtained through a satellite image from Google Earth Engine (September 19, 2021) and projected in WSG 84/ UTM 18S. The standard geometric calculations were obtained through a field calculator in QGIS (version 3.16.6). For the delimitation of the areas, the continental shelf, the tidal action zone, the flooded areas, and human buildings (houses and other constructions) were taken into account.

To quantify the shape of the wetlands, a simple perimeter index was used. Namely, the coefficient between the perimeter, km, and its area, km^2 (Heltzer & Jelinski 1999). This index provides high values for small wetlands, with elongated and irregular shapes. Likewise, low values for large wetlands, with compact and regular shapes (Rau & Gantz 2001). The relationship between the perimeter index and the individual abundances and species richness for each wetland was evaluated using simple parametric correlations. For this, the r´s Pearson product-moment correlation coefficient was used, using an online Statistical Computation Package (© Richard Lowry 1998-2023, http://www.vassarstats.net). A t-test for two independent samples was used with the same package to compare limnological data.

Composition, individual abundances, species richness, and diversity of bird species

Counting transects were established at the tide line of each of the wetlands described above. Zones were defined in order to not duplicate counts in the same geographic area; 3 transects were used at Lenca and Chamiza, the largest wetlands; 2 at Quillaipe; and 1 each at Pelluco and Caleta La Arena, the smallest wetlands (Fig. 2). Each count considered movement and active search for 40 to 45 min within a visual range of 180° without limit width (modified from Gantz & Rau 1999, Vergara & Schlatter 2006); recording all the birds that the equipment allowed, using binoculars (8X42), spotting scope (20-60X60 mm) and manual counters. Bird counts were carried out bimonthly (May 2021, July 2021, September 2021, and November 2021) in order to characterize the contrast between the austral winter and summer seasons. In the southern hemisphere the warm seasons are characterized by the beginning of reproduction and the presence of migratory birds. The counts were carried out by one experienced observer per transect, helped by standard Chilean ornithological guides (e.g., Couve et al. 2016), webpages (e.g., http://www.avesdechile.cl) and several technical articles of the outreach magazine "La Chiricoca" (http://www.lachiricoca.cl). The observations were also carried out in two synchronous batches, first the wetlands: Lenca, Quillaipe and Chamiza, and second: La Arena and Pelluco, without replicates (Gallardo & Rau 2019). Each counting day we consider one record at high tide (HT) and another at low tide (LT), using the same transect on both occasions. This allowed the influence of tidal cycles on the individual abundances and species richness to be evaluated, since increases at low tide are expected due to the entry of individuals and species from neighboring agroecosystems (Cursach et al. 2010).

Bird assemblage structure

The structure of the bird assemblages was assessed on the basis of the following ecological indices (Brower et al. 1990): species richness (S), Shannon´s diversity (H´), Simpson´s dominance (λ), and Pielou's evenness index (J'). Shannon's diversity index was calculated using natural logarithms (log_e). This is a measurement of the degree of uncertainty associated with the random selection of an individual in the assemblage (Pla 2006).

Ecological similarity-distance indices

To evaluate how similar the bird assemblages between the studied wetlands were, we used the qualitative coefficient (i.e., presence-absence of species) of Jaccard, Cj (Krebs 1989). This index is based on a scale that goes from 0 or 0% (total dissimilarity) to 1 or 100% (total similarity) and weights the differences between assemblages more than their similarities (Krebs 1989). Ecological similarity dendrograms were constructed with the quantitative Bray-Curtis index (Brower et al. 1990). Nonmetric multidimensional scaling analyzes (NMDS) were also performed to relate tidal cycles with the Jaccard similarity index and the Bray-Curtis indexes (Clarke 1993). The NMDS´s plots maximized the rank-order correlation between the distance measures and the distance in the ordination space. "Stress" of these plots was considered a measure of the mismatch between the two types of distances. Values <0.2 give a potentially useful two-dimensional image.

Analyses of nutrients and physicochemical parameters

In order to determine the concentration of the contributions of nutrient inputs from coastal rivers to the studied wetlands during the winter of 2021 (July, September, and November), water samples were obtained from the Chamiza and Lenca wetlands and their respective Chamiza and Lenca rivers. Following Saldías et al. (2016) three equidistant monitoring points were established in the dispersion plume of the coastal river in the wetland zone and one monitoring point in the estuarine zone of the river. From each station, water samples were collected with a Niskin-type hydrographic bottle (2 L) to determine the concentration of nutrients (total nitrogen and total phosphorus, µg/L). The samples were kept cold using an ice pack until they arrived at the laboratory. Subsequently, these were sent to the Hidrolab Laboratory (https://www.hidrolab.com) in Santiago de Chile where the oxygen concentration (mg/L) and salinity (ppm) (three replicas per sample) was analyzed. A total of four sampling stations per wetland were used: three in continental waters, and one in estuarine waters.

The obtained data were analyzed using the parametric Student´s t test for two independent samples. Analyses were performed with an online Statistical Computational Package (© Richard Lowrie 1998-2023, http://www.vassarstats.net). In addition, we determined the trophic status of the Chamiza and Lenca wetlands. At this point, it was necessary to establish if they were wetlands with oligotrophic, mesotrophic, or eutrophic characteristics, comparing the total concentrations of nitrogen and phosphorous determined in the coastal wetlands with the threshold values proposed by Smith et al. (1999).

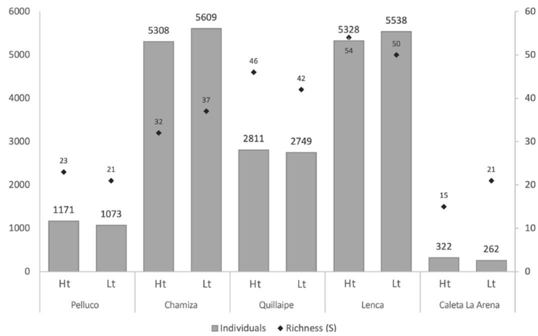

Figure 3. Number of individuals and species richness (S) by tides, high tide (HT) and low tide (LT) for 5 coastal wetlands of the first section of the southern highway (Pelluco, Chamiza, Quillaipe, Lenca, Caleta La Arena).

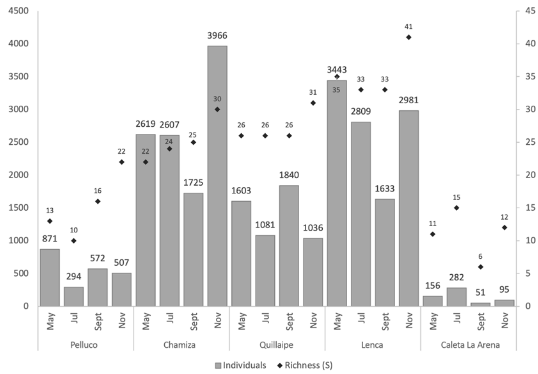

Figure 4. Number of individuals and species richness (S) by count for five coastal wetlands of the first section of the southern highway (Pelluco, Chamiza, Quillaipe, Lenca, Caleta La Arena). Months of May (May), July (Jul), September (Sept), November (Nov), of the year 2018.

RESULTS

Composition, abundance, richness, and diversity of bird species

The species richness found in the four counts was 73 bird species for the first section of the Austral road (Table 1). Wetlands with the highest number of species were Lenca and Quillaipe, with 57 and 50 species, respectively, followed by the wetlands of Chamiza, with 39 species, Pelluco with 28 and Caleta La Arena with 21 species. Regarding the tidal cycles, for the five wetlands at high tide, a total of 71 species were registered and 64 species at low tide. Pelluco and Caleta La Arena had the lowest number of species at high tide (Fig. 3), with 23 and 15, respectively. Pelluco, Lenca and Caleta La Arena had a greater species richness at low tide (Fig. 3). November was the month with the highest species richness, with 59 species registered. Finally, for all wetlands except Caleta La Arena, November was also the month with the highest species richness (Fig. 4). A total of 30 171 individuals were counted, fluctuating between 8692 in the month of May and 5821 in September; the highest count was recorded at Chamiza with 3966 individuals in November; at Lenca and Pelluco the highest counts were recorded in May, with 3443 and 871 individuals, respectively; followed by Quillaipe with 1840 individuals in September and Caleta La Arena with 281 individuals in July (Fig. 4).

Table 1. Families (in bold), species and total bird count for five wetlands in the first section of the Austral road, Reloncaví Sound, northern Chilean Patagonia. Pelluco, Chamiza, Quillaipe, Lenca, and Caleta La Arena.

Family and species	Common Spanish name	Common English name	Pelluco	Chamiza	Quillaipe	Lenca	La Arena
Anatidae							
Cygnus melancoryphus	Cisne de Cuello Negro	Black-necked Swan	60	498	126	855	0
Tachyeres patachonicus	Quetro Volador	Flying Steamer Duck	0	0	16	16	0
Tachyeres pteneres	Quetro no Volador	Flightless Steamer-Duck	0	0	5	37	0
Coscoroba coscoroba	Coscoroba	Coscoroba Swan	0	0	0	6	0
Chloephaga poliocephala	Cauquén Real	Ashy-headed Goose	0	0	0	80	0
Mareca sibilatrix	Pato Overo	Chiloé Wigeon	0	218	96	331	0
Spatula cyanoptera	Pato Colorado	Cinnamon Teal	0	14	0	0	0
Anas georgica	Pato Maicero	Yellow-billed Pintail	0	141	33	73	0
Anas flavirostris	Pato Barcino	Yellow-billed Teal	0	200	68	71	0
Anser anser	Ganso Doméstico	Greylag Ggoose	0	0	0	4	0
Podicipedidae							
Podiceps occipitalis	Macacito Plateado	Silvery Grebe	2	0	0	0	0
Phoenicopteridae							
Phoenicopterus chilensis	Flamenco Austral	Chilean Flamingo	0	4	32	0	0
Sulidae							
Sula variegata	Piquero Peruano	Peruvian Booby	0	0	7	31	0
Phalacrocoracidae							
Nannopterum brasilianus	Biguá	Neotropic Cormorant	33	212	61	354	118
Leucocarbo atriceps	Cormorán Imperial	Imperial Shag	53	1	0	313	138
Pelecanidae							
Pelecanus thagus	Pelícano Peruano	Peruvian Pelican	5	44	13	183	10
Ardeidae							
Ardea alba	Garza Blanca	Great Egret	0	14	7	4	0
Egretta thula	Garcita Blanca	Snowy Egret	5	40	13	46	0
Threskiornithidae							
Theristicus melanopis	Bandurria Austral	Black-faced Ibis	8	15	39	28	1
Cathartidae							
Coragyps atratus	Jote de Cabeza Negra	Black Vulture	1	10	5	16	1
Cathartes aura	Jote de Cabeza Roja	Turkey Vulture	10	139	68	117	19
Accipitridae							
Circus cinereus	Gavilán Ceniciento	Cinereous Harrier	0	0	1	0	0

Family and species	Common Spanish name	Common English name	Pelluco	Chamiza	Quillaipe	Lenca	La Arena
Rallidae							
Fulica armillata	Gallareta Ligas Rojas	Red-gartered Coot	1	102	0	192	0
Recurvirostridae							
Himantopus mexicanus	Tero Real	Black-necked Stilt	0	12	0	0	0
Hematopodidae							
Heamatopus palliatus	Ostrero Común	American Oystercatcher	15	763	299	348	10
Haematopus leucopodus	Ostrero Austral	Magellanic Oystercatcher	4	216	0	0	0
Heamatopus ater	Ostrero Negro	Blackish Oystercatcher	0	0	4	28	4
Charadriidae							
Charadrius falklandinus	Chorlito de Doble Collar	Two-banded Plover	0	0	0	169	0
Vanellus chilensis	Tero Común	Southern Lapwing	73	304	250	113	0
Zonibyx modestus	Chorlo de Pecho Colorado	Rufous-chested Dotterel	76	0	176	182	0
Scolopacidae							
Tringa flavipes	Pitotoi Chico	Lesser Yellowlegs	0	40	33	0	0
Tringa melanoleuca	Pitotoi Grande	Greater Yellowlegs	0	50	38	0	0
Numenius phaeopus	Playero Trinador	Whimbrel	18	1051	111	484	3
Limosa haemastica	Bacasa de Mar	Hudsonian Godwit	0	523	531	5	0
Calidris bairdii	Playerito Unicolor	Baird's Sandpiper	0	20	9	53	0
Laridae							
Chroicocephalus maculipennis	Gaviota Capucho Café	Brown-hooded Gull	908	1686	990	2249	0
Leucophaeus pipixcan	Gaviota Chica	Franklin's Gull	125	1200	0	757	0
Larus dominicanus	Gaviota Cocinera	Kelp Gull	784	2893	2079	3010	177
Sterna hirundinacea	Gaviotín Sudamericano	South American Tern	0	0	0	42	0
Leucophaeus modestus	Gaviota Garuma	Grey Gull	0	0	0	53	0
Thalasseus elegans	Gaviotín Elegante	Elegant Tern	0	22	0	8	0
Rynchops niger	Rayador	Black Skimmer	0	3	226	113	0
Columbidae							
Columba livia	Paloma Doméstica	Rock Pigeon	6	0	0	0	0
Trochilidae							
Sephanoides sephaniodes	Picaflor Rubí	Green-backed Firecrown	0	0	13	2	1
Alcedinidae							
Megaceryle torquata	Martín Pescador Grande	Ringed Kingfisher	0	1	5	4	2
Picidae							
Colaptes pitius	Pitío	Chilean Flicker	0	0	1	0	0
Falconidae							
Caracara plancus	Carancho	Crested Caracara	0	0	3	3	4
Milvago chimango	Chimango	Chimango caracara	14	39	54	103	11

Family and species	Common Spanish name	Common English name	Pelluco	Chamiza	Quillaipe	Lenca	La Arena
Psittacidae							
Enicognathus ferrugineus	Cachaña	Austral Parakeet	0	0	0	70	0
Enicognathus leptorhynchus	Choroy	Slender-billed Parakeet	0	0	4	0	0
Rhinocryptidae							
Scytalopus magellanicus	Churrín Andino	Magellanic Tapaculo	0	0	2	0	0
Furnariidae							
Cinclodes patagonicus	Remolinera Araucana	Dark-bellied Cinclodes	9	6	34	11	21
Cinclodes oustaleti	Remolinera Chica	Gray-flanked Cinclodes	19	0	1	3	7
Aphrastura spinicauda	Rayadito	Thorn-tailed Rayadito	0	0	2	0	4
Tyrannidae							
Eleania albiceps	Fiofío Silbón	White-crested Elaenia	0	0	3	3	0
Lessonia rufa	Sobrepuesto Común	Austral Negrito	0	2	4	19	0
Hymenops perspicillatus	Pico de Plata	Spectacled Tyrant	0	0	2	1	0
Muscisaxicola maclovianus	Dormilona Cara Negra	Dark-faced Ground-Tyrant	0	12	2	15	0
Pyrope pyrope	Diucón		2	0	5	3	1
Colorhamphus parvirostris	Peutrén	Patagonian Tyrant	0	0	1	0	0
Cotingidae							
Phytotoma rara	Rara	Rufous-tailed Plantcutter	0	0	0	1	0
Hirundinidae							
Tachycineta leucopyga	Golondrina Patagónica	Chilean Swallow	3	396	79	182	33
Pygochelidon cyanoleuca	Golondrina Barranquera	Blue-and-white Swallow	0	14	0	4	0
Troglodytidae							
Troglodytes aedon	Ratona Común	House Wren	0	0	0	5	0
Turdidae							
Turdus falcklandii	Zorzal Patagónico	Austral Thrush	2	0	1	3	0
Motalicidae							
Anthus correndera	Cachirla Común	Correndera Pipit	0	2	1	0	0
Thraupidae							
Sicalis luteola	Misto	Grassland yellow Finch	3	0	0	46	0
Emberizidae							
Zonotrichia capensis	Chingolo	Rufous-collared Sparrow	2	0	3	3	0
Icteridae							
Leistes loyca	Loica Común	Long-tailed Meadowlark	0	5	2	5	0
Curaeus curaeus	Tordo Patagónico	Austral Blackbird	0	0	0	2	4
Molothrus bonariensis	Tordo Renegrido	Shiny Cowbird	0	0	0	5	0
Fringillidae							
Spinus barbatus	Cabecita Negra Austral	Black-chinned Siskin	0	5	2	2	0
Passeridae							
Passer domesticus	Gorrión Común	House Sparrow	3	0	0	0	15

Considering the total counts, the species with the highest abundances during the period of observations were: Kelp Gull (*Larus dominicanus*) with 8943 individuals, Brown Hooded Gull (*Chroicocephalus maculipennis*) with 5833 individuals, and Franklin's Gull (*Leucophaeus pipixcan*) with 2082 individuals. The maximum monthly counts corresponded to Kelp Gull with 3206 individuals in May and the Brown-hooded Gull with 2186 individuals in July, both species were present in all counts; 2082 individuals of Franklin's Gull were observed in November, which was also the only month in which it was recorded (see Table 2 for other species).

With respect to species that were observed at only one wetland, at Pelluco they were: Silvery Grebe (*Podiceps occipitalis*) and Rock Pigeon (*Columba livia*); at Chamiza: Black-necked Stilt (*Himantopus mexicanus*) and Cinnamon Teal (*Spatula cyanoptera*); at Quillaipe: Chilean Flicker (*Colaptes pitius*), Cinereous Harrier (*Circus cinereus*), Patagonian Tyrant (*Colorhamphus parvirostris*), Magellanic Tapaculo (*Scytalopus magellanicus*) and Slender-billed Parakeet (*Enicognathus leptorhynchus*); and at Lenca: Rufous-tailed Plantcutter (*Phytotoma rara*), South American Tern (*Sterna hirundinacea*), Greylag Goose (*Anser anser*), House Wren (*Troglodytes aedon*), Shiny Cowbird (*Molothrus bonariensis*), Coscoroba Swan (*Coscoroba coscoroba*), Grey Gull (*Leucophaeus modestus*), Austral Parakeet (*Enicognathus ferrugineus*) and Ashy-headed Goose (*Chloephaga poliocephala*). The greatest species richness during the observation period was recorded at Lenca. Only at Caleta La Arena were no unique species observed.

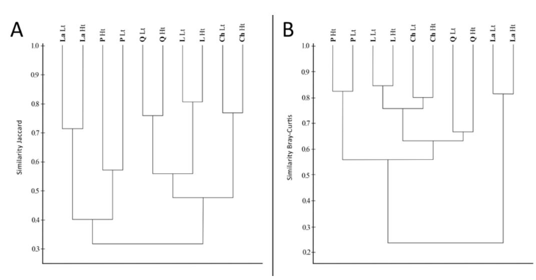

Figure 5. Dendrogram constructed with the Jaccard ecological similarity index (A) and Bray-Curtis index (B) for bird assemblages in the studied five wetlands and two tides. Wetlands of Pelluco (P), Lenca (L), Chamiza (Ch), Quillaipe (Q), Caleta La Arena (La), high tide (Ht), low tide (LT).

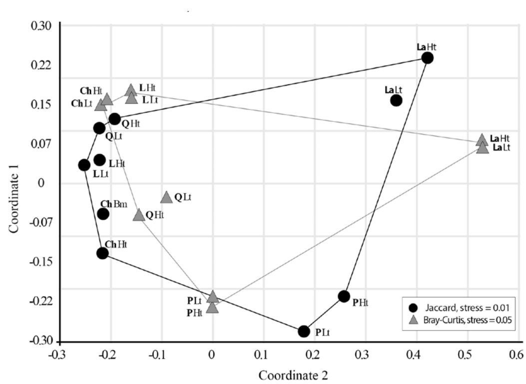

Figure 6. NMDS analysis (ecological similarity index) for assemblages by studied wetlands and tides. Wetlands of Pelluco (P), Lenca (L), Chamiza (Ch), Quillaipe (Q), Caleta La Arena (La), high tide (HT), low tide (LT).

Wetland shape

Chamiza had the largest surface and perimeter, and Caleta La Arena had the smallest surface and perimeter (Table 3). Chamiza presented the lowest perimeter index, whereas Caleta La Arena presented the highest value (Table 3). The area of the wetland was not correlated with the abundance of individuals ($r = 0.776$, $df = 3$, $P = 0.123$), though it was correlated with their perimeter ($r = 0.918$, $df = 3$, $P = 0.028$). The correlation of the abundance of individuals with the perimeter index was high and negative, though without statistical significance ($r = -0.85$, $df = 3$, $P = 0.068$). On the other hand, the area of the wetlands was not correlated with the wetland's species richness ($r = 0.154$, $df = 3$, $P = 0.805$), nor with their perimeter ($r = 0.436$, $df = 3$, $P = 0.463$). The correlation of the species richness with the perimeter index was relatively high and negative but not statistically significant ($r = -0.742$, $df = 3$, $P = 0.151$).

Bird assemblage structure

From a temporal scale, Shannon diversity remained stable between 2.18 and 2.51, as well as the dominance, with values between 0.13 and 0.21. The evenness was between 0.57 and 0.62. For the bird assemblages of each of the studied wetlands, the highest dominance occurred in Pelluco ($\lambda = 0.29$), whereas the lowest dominance was observed in Chamiza ($\lambda = 0.13$). The lowest evenness was found in Pelluco ($J' = 0.51$), whereas the highest occurred in Caleta La Arena ($J' = 0.66$). Shannon diversity remained between 2.01 and 2.59, except for Pelluco which presented the lowest value (1.69).

Similarity-distance ecological indices

The Jaccard similarity indices (Fig. 5A) showed two main divisions, from the lowest to the highest similarity. The first, at approximately 30%, separate Caleta La Arena and Pelluco, Quillaipe, Lenca and Chamiza. At about 50% Chamiza was separated and Lenca and Quillaipe were grouped together. An NMDS analysis (Jaccard similarity analysis index, Stress 0.01) (Fig. 6) yielded basically the same spatial arrangement: grouping of the Quillaipe, Chamiza and Lenca, and the separation of Pelluco and Caleta La Arena.

Table 2. The 15 most abundant species for the monthly counts of birds carried out in 2021 in the Reloncaví Sound, Chilean northern Patagonia. The counts were performed in May, austral autumn (May); July, austral winter (Jul); September, austral winter (Sept); November, austral spring (Nov). Total, number of individuals counted by species.

Species	Spanish common name	English common name	May	Jul	Sept	Nov	Total
Larus dominicanus	Gaviota Cocinera	Kelp Gull	3206	2263	1960	1514	8943
Chroicocephalus maculipennis	Gaviota Capucha Café	Brown-hooded Gull	1434	2186	1284	929	5833
Leucophaeus pipixcan	Gaviota Chica	Franklin's Gull	0	0	0	2082	2082
Numenius phaeopus	Playero Trinador	Whimbrel	200	89	241	1137	1667
Cygnus melancoryphus	Cisne de Cuello Negro	Black-necked Swan	254	472	324	489	1539
Heamatopus palliatus	Ostrero Común	American Oystercatcher	719	232	297	187	1435
Limosa haemastica	Becasa de Mar	Hudsonian Godwit	531	5	22	501	1059
Nannopterum brasilianus	Biguá	Neotropic Cormorant	194	117	182	285	778
Vanellus chilensis	Tero Común	Southern Lapwing	129	162	203	246	740
Tachycineta leucopyga	Golondrina Patagónica	Chilean Swallow	0	0	584	109	693
Mareca sibilatrix	Pato Overo	Chiloé Wigeon	306	27	114	198	645
Leucocarbo atriceps	Cormorán Imperial	Imperial Shag	183	188	78	56	505
Zonibyx modestus	Chorlo de Pecho Colorado	Rufous-chested Dotterel	254	170	10	0	434
Coragyps aura	Jote de Cabeza Negra	Turkey Vulture	201	82	40	30	353
Rynchops niger	Rayador	Black Skimmer	323	0	3	16	342

Table 3. Association between the perimeter index (p/A) versus abundance and richness of species found in the five wetlands studied in the Reloncaví Sound, northern Chilean Patagonia.

Wetland	Area (km^2)	Perimeter (km)	Perimeter index	Abundance of individuals	Species richness
Pelluco	0.3	2.8	8.4	871	28
Chamiza	23.2	32.8	1.4	3,966	39
Quillaipe	1.8	10.5	5.8	1,84	50
Lenca	4.2	15.5	3.7	3,443	57
Caleta La Arena	0.1	2.1	21.0	282	21

The analyses carried out with the Bray-Curtis index (Fig. 5B) showed four main divisions, from least to the most similarity between the wetlands: The first, at approximately 25%, separating Caleta La Arena from the other wetlands. The second at approximately 55%, separating Pelluco from the others. The third division separated Quillaipe at 65%. Finally, Chamiza and Lenca were grouped together with an approximate similarity of 75% for both tides (counts at high tide and low tide). The NMDS analysis (Bray-Curtis index, Stress 0.05) (Fig. 6) basically yielded the same spatial arrangement: greater distances between Caleta La Arena and Pelluco, and comparatively minor differences for Quillaipe. Finally, Lenca and Chamiza were grouped together.

Analyses of nutrients and physicochemical parameters

In the case of the nutrients analyses, the sample size was n = 14 and in the case of the analyses of physicochemical parameters the sample size was n = 21. The wetlands studied (Chamiza and Lenca) did not present statistically significant differences (df = 6, $P > 0.05$), neither in nutrients nor physicochemical parameters. Additionally, the concentration of total nitrogen (1156.86 ± 391.47 µg/L) and total phosphorous (42.14 ± 26.70 µg/L) at Chamiza and total nitrogen (1063.36 ± 329.45 µg/L) and total phosphorous (39.07 ± 25.87 µg/L) at Lenca were high. According to the thresholds indicated in Smith et al. (1999) both wetlands exhibit a degraded environmental condition. Specifically, Lenca was classed as eutrophic and Chamiza as hypertrophic. However, both wetlands had high concentrations of dissolved oxygen, the highest at Lenca (10.91 ± 1.31 mg/L), where the environmental conditions are slightly better than those at Chamiza.

DISCUSSION

We were able to evaluate both ecological and limnological approaches to study the structure of bird assemblages present in five wetlands of southern Chile. In two wetlands with the largest area and perimeter (Chamiza and Lenca) we also measured their nutrients (nitrogen and phosphorous) and physicochemical parameters (dissolved oxygen and salinity), thus limiting the scope of our study. The area of wetlands in relation to their diversity of species has been shown at a global level (Cerda-Peña & Rau 2023). We found a positive association between area and total abundance of individuals per wetland, though only marginally significant. On the other hand, the abundance of individuals was positively and significantly related to the perimeter of wetlands, suggesting that also the shape of the wetlands is a variable that explains the abundance of individuals of the bird species present. Among several potential explanations, this may probably be because its perimeter is exposed and vulnerable to urbanization and exotic forest plantations (Hidalgo-Corrotea et al. 2023). A similar pattern was also described by Heltzer & Jelinski (1999), for bird assemblages associated to grasslands in North America. The associations of the abundance of individuals and species richness species with the perimeter indices were negative but not significant. Another possible reason that the perimeter was more important may be that the bird congregate at low tide along the water edge to forage and at high tide at the back of the marsh to roost. So the open spaces between the tides are less frequently used by the birds (M. Lee, pers. comm.).

When considering the five studied wetlands, a total of 73 bird species were found, with 57 (>78%) of them present at Lenca. Thirty-five species were observed at Lenca during the winter of 2007 (Cursach et al. 2010). As a comparison, Gallardo & Rau (2019) found 32 species for two continental islands inside the Reloncaví Sound. For southern Chile, the maximum number of species recorded so far is 65, recorded at the Nature Sanctuary of the Maullín River (Delgado et al. 2022), ca. 65 km west of the Reloncaví Sound.

Regarding the tidal cycles, larger wetlands presented a greater number of species at high tide, a pattern similar to that previously described by Cursach et al. (2010). Here, the increase in species from the agroecosystems that usually surround the wetlands in the study area could be influencing the pattern. Among the 15 most abundant species recorded, three species of gulls dominated. Such species are abundant in the northern Chilean Patagonia (Cursach et al. 2022). Among them the Seagull, *Larus dominicanus*, is the main predator of eggs and chicks of the tern species *Sterna hirundinacea* present in the study area (Cursach et al. 2021). Seagulls can be considered synantropic species that use anthropogenic food sources in human modified landscapes. The available information suggests that predictable and abundant anthropogenic food subsidies, such as fishery discards, salmon feed pellets (M. Lee, pers. comm.) and urban waste, are key factors contributing to the population growth in some coastal sectors (see Yorio et al. 2016, Frixione et al. 2023). No unique bird species were found at the smallest wetland. On the other hand, Lenca presented nine unique species, which represented more than 15% of its total species richness. This is an estuarine wetland with halophytic vegetation (San Martín & Ramírez 2002), which presents high fluctuations in its tidal cycles.

By using various complementary approaches, large and intermediate wetlands generally presented the greatest similarity and least ecological distance between them. These were relatively close to each other, with distances that varied approximately between 10 and 30 km. Conversely, the smallest wetlands located at the extreme points of the study area were the most differentiated and were distant from each other, at distances that varied approximately between 5 and 50 km. In a previous work carried out in the study area, Cursach & Rau (2008) found that human disturbances caused a decline in the diversity of bird species; likewise, an increase in the abundance of generalist omnivorous birds was observed.

Eutrophication indicators (Smith et al. 1999) suggest that both types of wetlands presented disturbed environmental conditions. This is linked to anthropogenic activities that are carried out *in situ* at the wetlands (Hidalgo-Corrotea et al. 2023), as well as the pollutants that are transported from the rivers that flow into them (Fuentes et al. 2023). However, the higher concentration of oxygen favored the presence of a greater species richness in Lenca wetland. This situation has been also found in lacustrine aquatic systems (Basaula et al. 2021). Chamiza and Lenca have an important conservation value for migratory shorebirds (Cursach et al. 2021), but currently the urbanization of their rivers favors the contamination of their waters by solid and liquid household waste. The Lenca basin is much less developed compared to Chamiza. The Chamiza valley is full of parcels with imperfect ditches and dairy farms, while the two rivers that discharge into Lenca come from the National Park Alerce Andino (M. Lee, pers. comm.).

In conclusion, our data show that the perimeter of the wetlands (a substitute of the water mirror) tend to be positively associated to a greater abundance of birds. Likewise, the environmental condition of one of the wetlands (higher concentration of dissolved oxygen) also resulted in greater species richness. Although, two of the wetlands also presented eutrophy (Lenca) and hypertrophy (Chamiza) in relation to the load of nitrogenous and phosphorous nutrients. Floristic composition could be another factor; Ramírez et al. (2023) have shown that floristic similarity is very low in southern Chile's wetlands. For example, only in Quillaipe were halophyte marshes and camephytes (whose replacement buds are found on stems at ground level) abundant. Also, it must be considered the impact of aquaculture on coastal waters adjacent to flatlands and wetlands. The cultivation of mussels that occurs between Quillaipe and Lenca can generate alterations in the quality of water and sediments in the intertidal zone. Which in turn changes the food supply for the birds (M. Lee, pers. comm.). Further research is needed to explain the importance of other covariables at the landscape level.

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