SPATIAL AND TEMPORAL VARIATION OF BEACHED BIRDS IN NORTHERN ARGENTINE PATAGONIA

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ABSTRACT

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Beached birds on marine coastal beaches, along with other megafauna, are a valuable source of biological information, offering insights into species occurrence and factors that negatively affect their populations. The main objective of this study was to evaluate the spatial and temporal variation, and species composition, of coastal and marine birds found on sandy beaches in the Bahía de San Antonio Protected Natural Area (Río Negro Province, Argentina), and to relate resulting species abundance and richness to oceanographic and environmental variables. A biweekly survey was carried out over two years (2020–2022), during which 672 beached birds were recorded. The overall encounter rate of beached birds was 1.35 birds/km. Most birds were identified to the species level, totaling 27 species belonging to 11 orders. The three most frequently encountered species were Magellanic Penguin *Spheniscus magellanicus* (49.38%), Kelp Gull *Larus dominicanus* (43.75%), and Neotropic Cormorant *Nannopterum brasilianum* (22.5%). The height of high tide and wind direction significantly affected beached bird abundance at various spatial and temporal scales. We conclude that the assemblage of beached birds is heterogeneous, mainly consisting of species that inhabit the Río Negro Province coast, rather than those from farther offshore. Future studies in the area should include drift experiments and cover a larger geographic scale.

Key words: Argentina, coastal and marine birds, Kelp Gull, Magellanic Penguin, Neotropic Cormorant, beached birds

INTRODUCTION

Coastal and marine birds are often considered reliable indicators of the health of marine ecosystems (Burger & Gochfeld, 2004; Mallory et al., 2010), and studies examining marine bird carcasses found on beaches—used as a proxy for the living community—have increased since the 1970s (e.g., Diamond et al., 2020; Powlesland, 1986; Veitch, 1978). Due to their particular life history traits, including high trophic position and longevity, birds accumulate exposure to anthropic stressors over large geographic areas. Thus, they are well-suited to serve as indicators of levels of chemical pollution, including oil spills (Camphuysen & Heubeck, 2001; Furness & Camphuysen, 1997), organic pollutants (Malcom et al., 2003; Sagerup et al., 2014), harmful algal blooms (Ben-Gigirey et al., 2021; Shumway et al., 2003), and marine debris, such as abandoned, lost, or discarded fishing gear (Kühn & Van Franeker, 2020; Phillips et al., 2010; Roman et al., 2019). Currently, a third of the 346 extant seabird species face some type of threat, and their global populations have significantly declined from 1950 to 2010 (Croxall et al., 2012; Grémillet et al., 2018; Paleczny et al., 2015). Therefore, monitoring bird populations—or even their proxies, such as beached birds—is paramount for developing effective biological management and conservation strategies (Mace & Baillie, 2007; Thomas, 1996).

Coastal and marine birds (along with other coastal wildlife) are considered beached when found dead, either on the beach or floating in the water, or when alive on the beach and unable to return to the water (Geraci & Lounsbury, 1993, 2005). Long-term systematic surveys of beached birds are an accessible, cost-effective, and easy-to-implement tool for obtaining information (i.e., species composition), and can also be used to determine the spatial and temporal patterns of species occurrence and their relative abundance in a certain area (Byrd et al., 2014; Hamel et al., 2009). These surveys can also provide insights into the interaction between birds and human activities (Nevins et al., 2011; Simeone et al., 2021; Zydelis et al., 2013). Surveys of beaches to detect beached birds have occurred since the middle of the 20th century along the coasts around the world (e.g., Camphuysen & Heubeck, 2001; Heubeck, 1995; Powlesland & Imber, 1988). The primary objective of this type of survey was (and remains) to establish patterns of beached bird occurrence and identify the factors contributing to their presence. The results can reveal long-term changes in the distribution and abundance of various species (and other megafauna), with a particular emphasis on oil-contaminated animals (e.g., Camphuysen & Vollaard, 2016; Larsen et al., 2007; Stowe & Underwood, 1984).

While beached bird surveys occur regularly around the globe (Bodkin & Jameson, 1991; Haman et al., 2013; Roletto et al., 2003), in the Southern Hemisphere there is a spatial bias towards coastal areas of Australia and New Zealand (Powlesland, 1986; Taylor, 2004), Chile (Simeone et al., 2021), and Perú (Garate, 2013; Ortiz-Alvarez et al., 2022). In the South Atlantic, studies have focused on South Africa (Avery, 1984; Batchelor, 1981) and Brazil (Mariani et al., 2019; Martuscelli et al., 1997). In Argentina, surveys have been centered in the Buenos Aires Province (Korschenewski, 1975; Narosky & Fiameni, 1986; Seco Pon & García, 2022), and to a lesser extent Tierra del Fuego, the Antarctic, and the South Atlantic Islands Province.

In northern Argentine Patagonia, the coastal biomes of the Río Negro Province are considered valuable breeding and feeding habitats for a great variety of birds, including coastal species (González, 2007; Llanos et al., 2011). In fact, several coastal areas are listed as Important Bird Areas (IBAs), including El Cóndor and San Antonio Oeste (Di Giacomo & Coconier, 2007). However, limited information is available along the Río Negro Province coasts despite the presence of valuable protected areas. For instance, the San Antonio Oeste IBA lies close to Bahía de San Antonio Protected Natural Area. Given this context, the main goal of this study was to evaluate the spatial and temporal variation of beached coastal and marine birds in the Bahía de San Antonio Protected Natural Area, and to relate findings (abundance and richness) with oceanographic and environmental variables.

METHODS

Study area

The present study was carried out at the Bahía de San Antonio Protected Natural Area (hereinafter referred as to BSAPNA), Río Negro Province, northern Argentine Patagonia (40°47′00″S, 65°03′00″W). This area consists of both terrestrial (203 km^2) and marine domains (609 km^2). The terrestrial domain spans both governmental and private lands, encompassing the Port of San Antonio Este (381 inhabitants, 734 km^2), San Antonio Oeste (16,265 inhabitants, 9,900 km^2), and the village of Las Grutas (4,807 inhabitants, 8,151 km^2) (Instituto Nacional de Estadística y Censos [INDEC], 2010). The governmental areas are fully managed by the Río Negro Province, with moderate enforcement of management policies. The presence of a permanent human population within boundaries of the BSAPNA, along with the coexistence of conservation actions and economic activities—such as fisheries, agriculture, livestock, and industry—complicates the overall management of the BSAPNA (Morea, 2019).

The BSAPNA is located in the Monte Ecoregion, characterized by plains and plateaus (Cabrera, 1976), and the Argentine Province North Patagonian Gulfs Ecoregion (Balech & Ehrlich, 2008), an area which includes sand beaches, shells and sandbars, and extensive marsh, as well as sandy plains furrowed by drainage channels that are exposed at low tide. The prevailing climate is temperate semi-arid (Thornthwaite, 1948), shaped by local variations due to the proximity of the sea. Average surface water temperature in the region is around 15.1 °C (Saad et al., 2019). During March to November (austral autumn to spring), winds from the northwest predominate, while in the summer, the dominant winds are from the southeast (Genchi et al., 2010). Local tides are semidiurnal, ranging from 6–9 m in amplitude. The associated currents are in the order of 1–2 m/s (Mazio & Vara, 1983). The most intense waves generally come from the southeast, reaching periods of 7–10 s and heights of 0.5–1.5 m (exceeding 3 m in storm events; Scalise et al., 2009; Kokot et al., 2013).

Fish diversity is relatively high in the BSAPNA—including both benthonic and pelagic fishes—many of which are regularly targeted for sport and artisanal fishing activities (De la Barra et al., 2019; González et al., 2010; Narvarte et al., 2007; Narvarte et al., 2011). The area also supports several important resting, foraging, and breeding sites that are regularly used by several avian species (Blanco & Canevari, 1995; González, 2007; see Management Plan Bahía de San Antonio Protected Natural Area [Giaccardi & Reyes, 2012]).

Samplings

Within the BSAPNA, surveys were carried out in two sites known locally as (1) "Mar Grande" (40°45′22″S, 64°56′31″W) and (2) "Oasis" (40°46′19″S, 65°2′44″W), both sandy beaches located 8 km apart. The choice of the locations was based on their accessibility and/or by previous reports indicating the occurrence of beached marine vertebrates (Romero et al., 2021; Savigny & Carbajal, 2015; Fig. 1).

The data used in this study were collected through biweekly surveys at each sampling site. At each site, two adjacent transects, each approximately four kilometers long, were sampled. These transects ran parallel to the coastline, covering the entire beach. One transect encompassed the upper forebeach, and the other included the lower forebeach, with the location of the previous high tide serving as the reference point. For analysis, the upper and lower forebeaches were treated as separate levels. Each beach was surveyed independently and biweekly (two surveys per month) from June 2020 to June 2022 (24 months). Surveys were conducted on foot, as current legislation prohibits the use of engine-powered vehicles in this coastal area. For statistical analyses, the time periods from June 2020 to June 2021 and from June 2021 to June 2022 are referred to hereafter as the 2020/21 and 2021/22 periods, respectively.

Beached birds were registered in each transect. Each transect was covered once and all the sighted beached birds were pooled together. In this study, each transect represented a sampling unit, with a projected sample size of 192 transects for the beached bird transect survey. However, due to logistical challenges and COVID-19 restrictions, only 160 transects were completed. Beached birds encountered on each transect were photographed and identified to the lowest possible taxonomic level, either in situ or in the laboratory, using specialized guides (Narosky & Yzurieta, 2010; Povedano, 2016; Savigny, 2021). Depending on the degree of carcass preservation, each bird specimen was scored from 1 to 6 (minimum to maximum state of decay; adapted from Geraci & Lounsbury, 2005). The scores included the following values: "1" = live animal with external wounds, signs of malnutrition and/or dehydration; "2" = recently dead animal, fresh, odorless, *rigor mortis*; "3" = mild decomposition, internal organs intact, little odor, no eyes; "4" = advanced decomposition, detachment of feathers, skin and/or scales, swollen body due to the accumulation of gases, alteration of the color, texture and/or structure of the internal organs making their recognition difficult, strong odor; "5" = extremely advanced decomposition, dried body, presence of post-mortem wounds due to autolysis, parts of the skeleton visible, internal organs unrecognizable; and "6" = bones with or without remains of dry integument. Moreover, each seabird specimen was examined to determine the possible cause of death due to natural (physical condition, predation, parasite load) or anthropogenic (linear cuts, bullets wounds, entanglements in fishing gear, oil pollution, among others) causes. Carcasses were marked with colored wool and buried *in situ* to avoid double registration in successive outings.

Oceanographic and environmental data

Four days prior to each survey, data on oceanographic and environmental variables for the study area were collected; the

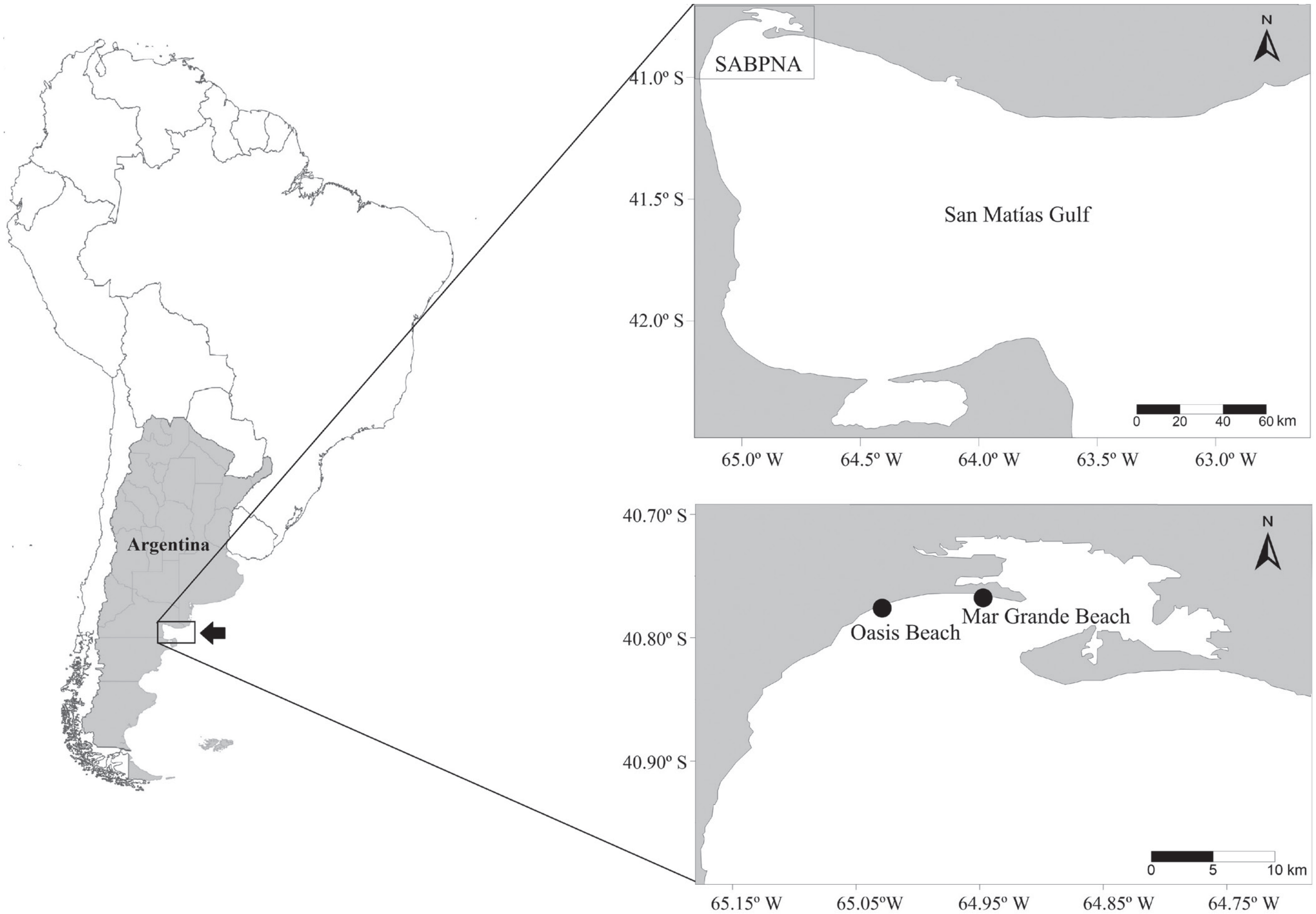

Fig. 1. Location of the study area in relation to Bahía de San Antonio Protected Natural Area, San Matías Gulf, Río Negro Province, Argentina.

variables that were chosen have been recorded in other beach surveys (Haman et al., 2013; Wiese & Elmslie, 2006). The height of high tides (m), and the intensity (knots) and direction (in degrees) of the tidal currents, were retrieved from the Naval Hydrography Service (Naval Hydrography Service, n.d.). Wave height (m), wind intensity (knots) and direction (degrees), and sea surface temperature (in ºC) were retrieved from Windguru (Windguru, n.d.). A daily average value for each variable was calculated (without transformation). This approach—which considered variability in oceanographic and environmental conditions for the four days prior to the survey—assumed that if a coastal or marine bird died in the open sea, its carcass could be transported to the beach within that time frame (Brusius et al., 2020; Brusius et al., 2021; Vassallo, 2021).

Data analysis

The beached birds for each transect were characterized by abundance (number of specimens), occurrence (presence/absence), and species richness (S, number of species). The frequency of occurrence was defined as the percentage of transects in which each species or order was registered per survey, expressed as absolute (number of events) and relative (percentage) frequency of occurrence. Bird abundance was defined as the total number of each species or order found on the beach tallied during each transect. This metric was similar between sampling sites (Mar Grande: n = 320; Oasis: n = 352). Thus, no significant differences were found in the number of beached birds across sampling sites (Kruskal-Wallis $H_{1;160}$ = 0.49, P = .48). Therefore, the decision was made to combine both sampling sites for further analysis.

Differences in avian assemblages tallied between the lower and upper levels of each beach, and between seasons (intra- and inter-annual) of the sampled period, were analyzed separately using multivariate analysis techniques via the software package "PRIMER," version 6.1 (Clarke & Gorley 2006). For this analysis, we applied hierarchical and multidimensional clustering of raw data (without transformation) using the Bray-Curtis similarity index. Analysis of similarities (ANOSIM) uses the Bray–Curtis similarity matrix to compute the R statistic, which varies between −1 and 1, reaching its maximum value when all between-group dissimilarities are greater than all within-group dissimilarities. Statistical significance was determined by comparing the sample R with those produced by randomly assigning samples to groups (Clarke & Warwick, 2001). The P value of the test was calculated using the proportion of random arrangements with R values greater than the sample value. To test whether avian assemblages' composition differed between levels of the beach within each sampled season (controlling for sampling period), we performed a two-way nested ANOSIM. Similarity percentages (SIMPER) were employed to determine the species that contributed the most to the dissimilarities between groups (Clarke, 1993; Clarke & Warwick, 2001). Only those species that contributed at least 10% of the similarity (see Results) were considered in the analysis.

To determine possible spatial or temporal variations in the number of individuals of the most abundant beached species, non-parametric analysis was conducted, since lack of normality in the data prevented us from conducting parametric analysis. When significant differences were detected, post hoc comparisons were carried out by pairwise comparisons. Pairwise comparisons were tested using a Wilcoxon rank-sum test (Wilcoxon, 1945).

The effect of oceanographic, environmental, spatial, and temporal variables on the overall abundance of beached birds was evaluated using generalized linear models (GLMs), with a negative binomial distribution. For species richness, the same GLM approach was used, employing a Poisson distribution (Crawley, 2007; Zuur et al., 2009). Potential correlations among oceanographic (height of high tide, intensity and direction of tidal current, wave height, and sea surface temperature) and environmental (intensity and wind direction) variables were identified *a priori* by estimating all pairwise Spearman rank correlation coefficients. Following this analysis, the oceanographic variables retained for the GLM model were height of high tide and wave height, while the environmental variable was wind direction (categorical variable: north, south, east, and west quadrant). Spatial and temporal variables were level of the beach (categorical variable: lower and upper) and season of sampled period (categorical variable per period: autumn, winter, spring, and summer), respectively. The fitness of the models was checked in DHARMa diagnostic plots using the "DHARMa" package (Hartig, 2022).

Total encounter rate was calculated by combining all species (including those unidentified) and relating the total number of beached birds to the beach linear distance covered during the survey. The same method was applied to the most abundant species. All analyses, except multivariate, were performed using R, version 4.1.2 (R Core Team, 2021). In all cases, differences were considered significant when $P < .05$. All reported values are the means (± 2 standard deviations [SD]).

RESULTS

Composition of beached bird assemblages

A total of 672 beached birds were recorded, with a maximum of 30 individuals per transect (Table 1). All birds were found dead. A high percentage of the birds (98%, $n = 657$) were identified to species, representing 27 species across 11 orders. A small fraction (2%, $n = 15$) could not be identified. Birds associated with coastal habitats (87%, $n = 569$) were more abundant than those associated with pelagic habitats (13%, $n = 88$; Table 1).

The most abundant and frequent beached species were Magellanic Penguin *Spheniscus magellanicus* (49.38%, $n = 250$), followed by Kelp Gull *Larus dominicanus* (43.75%, $n = 123$) and Neotropic Cormorant *Nannopterum brasilianum* (22.5%, $n = 59$; Table 1). An average total encounter rate of 1.35 ± 1.59 birds was estimated per linear kilometer (birds/km). Among these three species, the Magellanic Penguin encounter rate was 0.50 ± 0.84 birds/km, and the encounter rate for Kelp Gulls and Neotropic Cormorants was 0.25 ± 0.39 and 0.11 ± 0.28 birds/km, respectively.

Beached bird assemblages across temporal and spatial scales

Regardless of the temporal scale, the overall percentage of similarity among beached bird assemblages was comparable between beach levels (lower forebeach = 12%, upper forebeach = 25%). In the lower forebeach, Magellanic Penguins accounted for 53.2% of the average similarity, followed by Kelp Gulls (28.8%). In the upper forebeach, these species made comparable contributions to the overall similarity (Magellanic Penguins 46.8%, Kelp Gulls 29.5%), with Neotropic Cormorants contributing 10.2% (Table A1 in Appendix, available on the website). The composition of species assemblages varied significantly between levels of the beach (two-way ANOSIM, $P = .002$; Fig. A1 in Appendix). Differences were mainly driven by the relative contribution of Magellanic Penguins (30%), Kelp Gulls (20.4%), and Neotropic Cormorants (11.3%) (Table A2 in Appendix). Other species contributed < 10% of the total species composition. Beached bird richness was significantly higher in the upper forebeach (Kruskal-Wallis $H_{1;160} = 44.11$, $P < .001$), with 33 species recorded, compared to only 23 species recorded in the lower forebeach (Table A3 in Appendix).

Irrespective of the spatial scale, the overall percentage of similarity among beached bird assemblages was relatively analogous among seasons (autumn: average similarity value$_{\text{periods 2020/21 and 2021/22}}$ = 16.6%, winter: average similarity value$_{\text{periods 2020/21 and 2021/22}}$ = 10.7%, spring: average similarity value$_{\text{periods 2020/21 and 2021/22}}$ = 15.6%, summer: average similarity value$_{\text{periods 2020/21 and 2021/22}}$ = 26.8%). In autumn (both sampled periods combined), Magellanic Penguins contributed 34.5% of the average similarity, followed by Kelp Gulls (19.2%). In winter, Magellanic Penguins contributed 31.1% of the average similarity, followed by unidentified gulls (14.5%), Kelp Gulls (13.6%), and the Great Grebe *Podiceps major* (10.2%). In spring, Kelp Gulls contributed 28.2% of the average similarity, followed by Magellanic Penguins (23.6%) and Neotropic Cormorants (22.9%). Finally, in summer, Magellanic Penguins contributed 39.5% of the average similarity, followed by Kelp Gulls (11.9%), Manx Shearwaters *Puffinus puffinus* (10.3%), and unidentified gulls *Larus* spp.. (10.2%) (Table A4 in Appendix). The composition of beached bird assemblages varied significantly between seasons (two-way ANOSIM $P = .015$; Fig. A2 in Appendix).

During 2020/21, the lowest number of beached species was recorded in spring (S = 12), while the highest occurred in winter (S = 21). In 2021/22, the minimum number of beached species was again observed in spring (S = 9), but the maximum occurred in autumn (S = 15; Table A5 in Appendix). Two species (Magellanic Penguin, Kelp Gull) were found in all seasons, but other species were found only occasionally (Tables A6, A7 in Appendix). The number of beached birds did not vary significantly with respect to season during 2020/21 (Kruskal-Wallis $H_{3;82} = 4.76$, $P = .19$), nor during 2021/22 (Kruskal-Wallis $H_{3;78} = 7.06$, $P = .06$). This was also true during the entire study period (Kruskal-Wallis $H_{7;160} = 14.02$, $P = .05$). The two-way nested ANOSIM analysis indicated statistically significant differences in beached bird assemblages between levels of the beach when controlling for the sampled period (two-way ANOSIM, $P = .014$). Differences were mainly driven by the relative contribution of Magellanic Penguins (30.1%), Kelp Gulls (20.4%), and Neotropic Cormorants (11.3%) (Table A8 in Appendix).

When considering the most abundant beached species, both Magellanic Penguins (Kruskal-Wallis $H_{7;160} = 24.57$, $P = .0009$) and Neotropic Cormorants (Kruskal-Wallis $H_{7;160} = 19.23$, $P = .007$) showed significant differences in the quantities of beached individuals between seasons (Tables A9, A10 in Appendix).

TABLE 1
Bird species found beached throughout the study period (*n* = 160 transects)[a]

Scientific and common names	*n*	% *n*	Mean ± standard deviation	Max	%AF	%RF	National status (ARG)	Status (IUCN)
Sphenisciformes	250	37.20	1.56 ± 2.61	18	79	49.38		
Magellanic Penguin *Spheniscus magellanicus*[b,c]	250	37.20	1.56 ± 2.61	18	79	49.38	VU	LC
Charadriiformes	206	30.65	1.29 ± 1.63	8	92	57.5		
Kelp Gull Larus *dominicanus*[b,c]	123	18.30	0.77 ± 1.19	6	70	43.75	NA	LC
Larus spp.	52	7.74	0.33 ± 0.71	4	37	23.13		
Brown-hooded Gull *Chroicocephalus maculipennis*[b,c]	3	0.45	0.02 ± 0.14	1	3	1.88	NA	LC
South American Tern *Sterna hirundinacea*[b,c]	5	0.74	0.03 ± 0.17	1	5	3.13	NA	LC
Sterna spp.	14	2.08	0.09 ± 0.30	2	13	8.13		
Sandwich Tern *Thalasseus sandvicensis*[b]	1	0.15	0.01 ± 0.08	1	1	0.63	NA	LC
Stercorarius spp.	1	0.15	0.01 ± 0.08	1	1	0.63		
American Oystercatcher *Haematopus palliatus*[b,c]	3	0.45	0.02 ± 0.14	1	3	1.88	NA	LC
Magellanic Oystercatcher *Haematopus leucopodus*[b]	1	0.15	0.01 ± 0.08	1	1	0.63	NA	LC
Two-banded Plover *Anarhynchus falklandicus*[b,c]	2	0.30	0.01 ± 0.11	1	2	1.25	NA	LC
White-rumped Sandpiper *Calidris fuscicollis*	1	0.15	0.01 ± 0.08	1	1	0.63	NA	LC
Procellariiformes	87	12.95	0.54 ± 1.53	13	38	23.75		
Southern Fulmar *Fulmarus glacialoides*	8	1.19	0.05 ± 0.33	3	4	2.50	NA	LC
Manx Shearwater *Puffinus puffinus*	27	4.02	0.17 ± 0.84	8	13	8.13	NA	LC
Puffinus spp.	9	1.34	0.06 ± 0.26	2	8	5.00		
Great Shearwater *Ardenna gravis*	16	2.38	0.10 ± 0.42	3	11	6.88	NA	LC
Ardenna spp.	11	1.64	0.07 ± 0.28	2	10	6.25		
White-chinned Petrel *Procellaria aequinoctialis*	1	0.15	0.01 ± 0.08	1	1	0.63	A	VU
Southern Giant Petrel *Macronectes giganteus*	1	0.15	0.01 ± 0.08	1	1	0.63	VU	LC
Macronectes spp.	2	0.30	0.01 ± 0.11	1	2	1.25		
Thalassarche spp.	12	1.79	0.08 ± 0.36	3	8	5.00		
Suliformes	76	11.31	0.48 ± 0.96	7	48	30.00		
Neotropic Cormorant *Nannopterum brasilianum*[b]	59	8.78	0.37 ± 0.92	7	36	22.50	NA	LC
Imperial Shag *Leucocarbo atriceps*	12	1.79	0.08 ± 0.29	2	11	6.88	NA	LC
Phalacrocorax spp.	5	0.74	0.03 ± 0.21	2	4	2.50		
Podicipediformes	21	3.13	0.13 ± 0.45	3	15	9.38		
Great Grebe *Podiceps major*[b]	18	2.68	0.11 ± 0.39	2	14	8.75	NA	LC
Silvery Grebe *Podiceps occipitalis*[b]	2	0.30	0.01 ± 0.11	1	2	1.25	NA	LC
White-tufted Grebe *Rollandia rolland*[b]	1	0.15	0.01 ± 0.08	1	1	0.63	NA	LC
Anseriformes	6	0.89	0.04 ± 0.22	2	5	3.13		
Coscoroba Swan *Coscoroba coscoroba*[b]	2	0.30	0.01 ± 0.16	2	1	0.63	NA	LC
Black-necked Swan *Cygnus melancoryphus*[b]	2	0.30	0.01 ± 0.11	1	2	1.25	NA	LC
Red Shoveler *Spatula platalea*[b]	1	0.15	0.01 ± 0.08	1	1	0.63	NA	LC
Anas spp.	1	0.15	0.01 ± 0.08	1	1	0.63		
Phoenicopteriformes	4	0.60	0.03 ± 0.16	1	4	2.50		
Chilean Flamingo *Phoenicopterus chilensis*	4	0.60	0.03 ± 0.16	1	4	2.50	VU	NT
Pelecaniformes	2	0.30	0.01 ± 0.11	1	2	1.25		
Black-crowned Night Heron *Nycticorax nycticorax*[b,c]	1	0.15	0.01 ± 0.08	1	1	0.63	NA	LC
Heron, No ID (unidentified)	1	0.15	0.01 ± 0.08	1	1	0.63		
Gruiformes	1	0.15	0.01 ± 0.08	1	1	0.63		
Fulica spp.	1	0.15	0.01 ± 0.08	1	1	0.63		
Falconiformes	3	0.45	0.02 ± 0.14	1	4	2.50		
Peregrine Falcon *Falco peregrinus*[b,c]	1	0.15	0.01 ± 0.08	1	1	0.63	NA	LC
Chimango Caracara *Milvago chimango*[b,c]	2	0.30	0.01 ± 0.11	1	2	1.25	NA	LC
Strigiformes	1	0.15	0.01 ± 0.08	1	1	0.63		
Burrowing Owl *Athene cunicularia*[b,c]	1	0.15	0.01 ± 0.08	1	1	0.63	NA	LC
No ID (unidentified)	15	2.23	0.09 ± 0.29	1	14	8.75		
Total beached birds	672	100.00						

[a] AF = frequency of occurrence as presence/absence per transect; RF = percentage of occurrence where each order and species was present per transect throughout the study period; National Status Conservation of Argentina (ARG) = Categorization of the Ministerio de Ambiente y Desarrollo Sustentable & Aves Argentinas 2017 (VU = vulnerable, NA = not threatened, A = threatened); Conservation status according to the International Union for Conservation of Nature (LC = least concern, VU = vulnerable, NT = almost threatened). For all species, the minimum number of individuals recorded was 0.

[b] Species that nests in the province of Río Negro.

[c] Species that nests in the Bahía de San Antonio Protected Natural Area (BSAPNA). No ID = unidentified.

Preservation status of the bird carcasses

Most birds were found in a state of extremely advanced decomposition (code "5", 42%, n = 283), followed by carcasses composed of body parts, bones with or without remains of dry integument (code "6", 33%, n = 221), and birds found in an advanced decomposition state (code "4", 15%, n = 98). To a lesser extent, recently dead birds (code "2", 6%, n = 40), or birds in slight decomposition, were found, with intact internal organs, little odor, and absence of eyes (code "3", 4%, n = 30) (Fig. 2).

Oceanographic, environmental, temporal, and beach-scale analysis

The global GLM model was used to determine the effect of oceanographic and environmental variability, along temporal and beach scales, on the overall abundance of beached birds. The model showed a good fit, with residuals following a normal distribution and non-significant dispersion (P = .99). Modelling showed a significant effect of the height of the high tide and the direction of the wind, along with the temporal and spatial scales on the abundance of beached birds (GLM P < .05, explained deviance = 46%). This metric was significantly higher as the height of the high tides increased (GLM $F_{1;160}$ = 2.4, P = .01) along with westerly winds (GLM $F_{1;78}$ = 2.21, P = .02). At the spatial scale, this metric was significantly higher in the upper forebeach (GLM $F_{1;160}$ = 7.92, P < .001), but it was lower during the spring of 2021/22 at the temporal scale (GLM $F_{7;160}$ = -2.49, P = .01) (Table 2).

The global model assessing the effect of the same set of predictor variables on overall beached bird richness showed a good fit, with residuals following a normal distribution and non-significant dispersion (P = .18). The model indicated a significant effect of temporal and spatial scales on species richness (GLM P < .05, explained deviance = 42%). Specifically, species richness was lower during the spring of 2021/22 (GLM $F_{7;160}$ = -3.09, P = .001) and higher in the upper forebeach (GLM $F_{1;160}$ = 7.00, P < .001) (Table 2).

DISCUSSION

To our knowledge, this is the first study with a broad temporal scope to investigate beached birds in the northern sector of the San Matías Gulf, or elsewhere along the northern Argentine Patagonian coast. Our findings indicate that the Magellanic Penguin, Kelp Gull, and Neotropic Cormorant were the most abundant and frequently encountered species. This is likely related to the proximity of the study area to nesting grounds of these species: Novaro Island and the islets of Canal Escondido in the BSAPNA, and several islets within Lobos Islet National Park and at Punta Pozos. The population size of these species in these areas is likely important. For example, at a national level, the San Matías Gulf hosts < 1% of the Magellanic Penguin population (in terms of breeding pairs), 5.3% of the Kelp Gull population, and 29.3% of the Neotropic Cormorant population (see Frere et al., 2005; García Borboroglu et al., 2022 and references cited therein; González et al., 1998; Lisnizer et al., 2014; Pozzi et al., 2015). Other potential factors contributing to the dominance of just three species include their starvation-survival state and the presence of parasites (Ewbank et al., 2020; García et al., 2020, among others), which may increase vulnerability to anthropogenic disturbance, particularly the presence of feral and non-feral dogs on the coast (V. Pizá, personal observation, November 06, 2020).

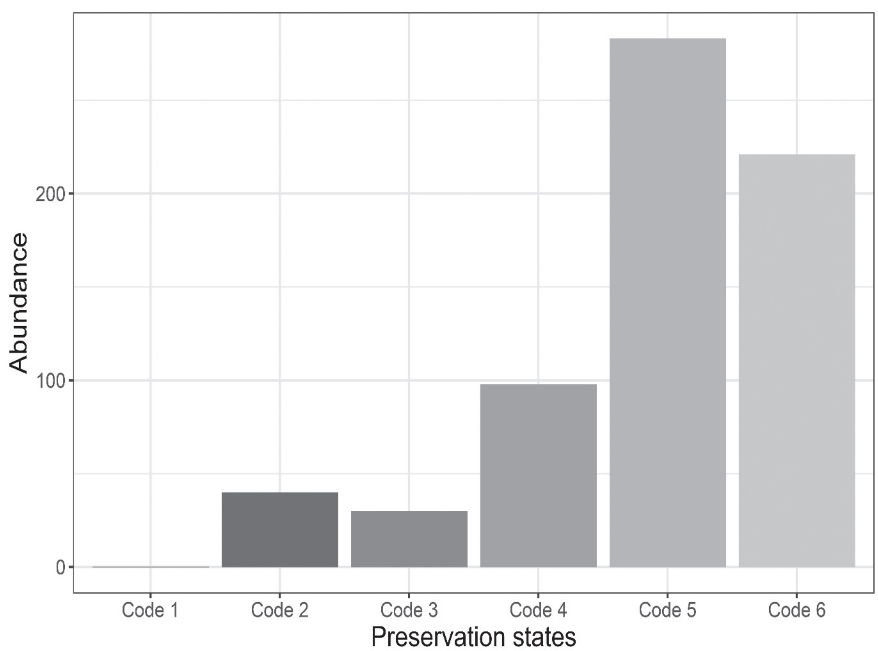

Fig. 2. Abundance (number of carcasses) of the specimens found beached according to their preservation status (scores). Scores were as follows: code 1, live animal with external wounds, signs of malnutrition and/or dehydration; code 2, recently dead birds, fresh odorless; code 3, mild decomposition, internal organs intact, little odor, no eyes; code 4, advanced decomposition, detachment of feathers, skin and/or scales, swollen body due to the accumulation of gases, alteration of the color, texture, and/or structure of the internal organs making their recognition difficult, strong odor; code 5, extremely advanced decomposition, dried body, presence of post-mortem wounds due to autolysis, parts of the skeleton visible, internal organs unrecognizable; code 6, carcasses composed of bones with or without remains of dry integument.

TABLE 2
Generalized linear model (GLM) results describing the relationship between abundance of beached birds and species richness, and the different explanatory variables (*n* = 160 transects)[a]

		Abundance				Richness			
Factors	**Factor levels**	**Estimate**	**SE[b]**	***Z* value**	***P* value**	**Estimate**	**SE[b]**	***Z* value**	***P* value**
Levels of the beach									
	Upper forebeach	1.069	0.134	7.928	**< .001***	0.817	0.116	7.007	**< .001***
Season									
	Winter 2	-0.342	0.308	-1.110	.266	-0.488	0.254	-1.915	.055
	Autumn 1	0.118	0.273	0.431	.666	-0.154	0.212	-0.727	.467
	Autumn 2	-0.222	0.269	-0.826	.408	-0.332	0.210	-1.579	.114
	Spring 1	-0.177	0.303	-0.584	.559	-0.312	0.240	-1.299	.193
	Spring 2	-0.745	0.299	-2.493	**.012***	-0.775	0.250	-3.098	**.001***
	Summer 1	0.563	0.311	1.806	.07	0.335	0.233	1.434	.151
	Summer 2	0.298	0.300	0.992	.992	-0.152	0.244	-0.622	.534
Height of the high tide		0.523	0.218	2.401	**.001***	0.325	0.179	1.821	.060
Tidal current intensity		-0.311	0.409	-0.761	.446	-0.214	0.330	-0.649	.516
Wave height		0.821	0.439	1.870	.061	0.228	0.341	0.670	.503
Direction of the wind									
	North	0.044	0.377	0.117	.906	-0.252	0.293	-0.861	.389
	West	0.757	0.417	1.815	.069	0.397	0.314	1.264	.206
	South	0.230	0.370	0.621	.534	-0.192	0.284	-0.677	.498

[a] The levels taken as reference for the explanatory variables for beach level, season, and wind direction were 'lower level', 'winter1' and 'wind blowing from the east quadrant,' respectively. Seasons denoted by the number 1 are those included in the period 2020/21, whereas those depicted by the number 2 included the period 2021/22. *P* values in bold and with and asterisk shows statistical significance.

[b] SE = standard error

Bycatch in commercial fisheries could also play a role (González Zevallos & Yorio, 2006; Yorio & Caille, 1999, among others).

Other species among the beached assemblage belonged to the Order Procellariiformes, such as Manx Shearwater and Great Shearwater *Ardenna gravis*. These two shearwater species are largely long-distance migrants: the Manx Shearwater migrates transequatorially, with ranges spanning Canada, the USA, the Faroe Islands, Ireland, Norway, and Spain (Blake, 1977; Cramp & Simmons, 1977), while the Great Shearwater's range encompasses the Tristan da Cunha, Nightingale, Inaccessible, and Gough islands (Carboneras, 1992; Ryan, 2007). Beached shearwaters are particularly abundant along the southern coasts of Buenos Aires Province, further north in Argentina, compared to albatrosses and petrels (Tamini & Dellacasa, 2009). Our results align with this pattern. Pelagic seabirds likely become beached primarily due to starvation and fatigue associated with migration (Mariani et al., 2019; Taylor, 1999, among others).

Few studies have reported beached bird encounter rates for the western South Atlantic coast (but see Estévez et al., 2002). The average encounter rate observed in this study (1.35 birds/km) falls within the range of encounter rates reported in other South American studies. At a regional level, encounter rates may vary from 0.12 birds/km in southeastern Buenos Aires Province, northern Patagonia (Jorge, 2016), to 2.3 birds/km on the northern coast of Chile (Portflitt Toro et al., 2018), and 2.56 birds/km along the coast of Rio Grande do Sul, Brazil (Petry & Fonseca, 2002). The encounter rate for Magellanic Penguins (0.50 penguins/km) was one order of magnitude lower when compared with that reported by Vanstreels et al. (2013) (1.32 penguins/km) for a period of seven years on the coast of Rio Grande do Sul. This could be related to the fact that the southern coast of Brazil receives a larger proportion of individuals during their post-reproductive migrations from Patagonia. To date, encounter rates of Kelp Gulls and Neotropic Cormorants have not been reported for the coast of the western South Atlantic, making regional comparisons impossible.

Nearly half of the carcasses we found were in a state of extremely advanced decomposition. This may be related to drift time in the sea, prolonged exposure to scavengers like the Kelp Gull, Chimango Caracara *Milvago chimango*, Crested Caracara *Caracara plancus*, Black Vulture *Coragyps atratus*, and Turkey Vulture *Cathartes aura* (V. Pizá, personal observation, March 26, 2021) both while in the water or after being deposited on the coast. Additional factors may include scavenging by terrestrial carnivores, feral dogs, and various arthropods (V. Pizá, personal observation, October 23, 2020).

A variety of factors, both natural and/or anthropogenic, may contribute to the wrecking of birds. These include (1) changes in the distribution and abundance of prey (Cairns, 1987; Diamond & Devlin, 2003), (2) factors intrinsic to the individual (such as sex, age class, and physical condition; Hindwood & McGill, 1955; Holmes, 1981; Mariani et al., 2019; Seco Pon & García, 2022), (3) maritime traffic (García Borboroglu et al., 2010; Perkins, 1983), (4) ingestion of and entanglement in marine debris (Jiménez et al., 2015; Kühn & van Franeker, 2020), and (5) injury due to interaction with fishing operations (González Zevallos & Yorio, 2006; Oro et al., 2013). Climatic anomalies (Montevecchi & Myers, 1997; Trathan et al., 2015) and changes in environmental and oceanographic conditions (e.g., sea surface temperature and salinity, winds, wave height, currents, and tides) are considered the main natural stressors for facilitating the transfer of seabird carcasses to the coast (Haman et al., 2013; Wiese & Elmslie, 2006). Thus, studying beached birds requires approaches that consider both the oceanographic dynamics of the coastal area and the various causes of mortality, in order to gain a better understanding of their spatio-temporal patterns (Hart et al., 2006; Tavares et al., 2016).

Our analysis revealed a significant increase in beached bird abundance with higher high tides and specific wind directions. These findings align with previous studies (Bugoni et al., 2007; Tavares et al., 2020; Wiese & Jones 2001), although they are in contrast to others (Van Pelt & Piatt, 1995). These results reinforce the importance of conducting experiments to better understand the process of sinking, refloating, and the eventual arrival of dead bird carcasses on the coast. Additionally, particle transport simulation models, coupled with a baroclinic numerical model, could provide further insights (Saraceno et al., 2020; Tonini et al., 2013). Such studies should be accompanied by an assessment of the relationship between these processes and environmental data gathered *in situ*, including ocean circulation systems and local wind patterns (Bodkin & Jameson, 1991; Flint & Fowler, 1998; Hart et al., 2006).

This study confirmed that spatial scale influences both the abundance and richness of beached birds, with both metrics being higher in the upper forebeach. This spatial segregation may be a sampling artifact, as the beaches had a gentle slope toward the sea, while their backshore was protected from the strong winds by 10-m-high cliffs (Fucks et al., 2012; Isla et al., 2023). Thus, successive tidal cycles could accumulate carcasses at each high tide line, potentially affecting our records. Future studies are needed to assess the broader spatial extent of this pattern, taking tidal cycles (syzygy and quadrature tides) into account. Nevertheless, beached birds were consistently found during all seasons of the year, particularly those species that occur near the coast. This suggests that the wrecking of birds occurs regularly on the beaches of the Río Negro Province coast, indicating extensive avian use of the San Matías Gulf throughout the year, in accord with marine surveys (Curcio et al., 2017). Although the present study was conducted in a small coastal sector of the San Matías Gulf, it largely reflects the diversity of coastal and marine birds present in the region.

CONCLUSIONS

The data collected during beached bird surveys in northeastern San Matías Gulf were valuable for identifying trends in beached birds, as well as the environmental and oceanographic conditions that may explain some of the observed variation in the wrecking. To determine whether the data reported here are representative of the entire San Matías Gulf coastline or the broader maritime coasts of the Río Negro Province, it is crucial to expand the geographic scope of future beached bird surveys.

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