J Ornithol (2012) 153:861–871
DOI 10.1007/s10336-012-0812-8

ORIGINAL ARTICLE

Spatial patterns in the use of foraging areas and its relationship with prey resources in the threatened Olrog's Gull (*Larus atlanticus*)

Nicolás Suárez · María Valeria Retana · Pablo Yorio

Received: 3 March 2011 / Revised: 11 December 2011 / Accepted: 3 January 2012 / Published online: 18 January 2012

Abstract Olrog's Gull *Larus atlanticus* is a threatened species which feeds during the breeding season almost exclusively on crabs. We studied the use of foraging areas and its relationship with prey resources in Olrog's Gulls breeding at Bahía San Blas, Argentina. Feeding areas were identified by radio-tracking 10 and 12 birds in 2006 and 2007, respectively (458 and 574 foraging trips, respectively) and monitoring 120 color-marked individuals during 2007 (3,447 locations). Feeding habitats were classified using dominant substrate and structural characteristics, and prey availability was assessed by sampling 2,220 1-m^2 quadrates distributed throughout gull potential feeding areas. Both telemetry and monitoring of marked individuals indicated that gulls used 20 km of coastline but foraged mainly in three sectors located between 1.5 and 7 km north of the colony. During both years, the use of feeding areas varied throughout the breeding cycle, with a higher use of areas closer to the colony during the chick stage. Results showed a differential distribution of crab species depending on habitat type, with a dominance of *Cyrtograpsus altimanus* in structured environments and *Neohelice granulata* in muddy substrates with vegetation. During incubation, gulls mostly used areas characterized by high densities of *N. granulata*, while during the early chick stage they mostly used sectors with high densities of *C. altimanus*. Prey size varied among crab species, *C. altimanus* being significantly smaller. Changes in Olrog's Gull use of coastal areas appear to be determined by the seasonal change in trophic requirements of adults and chicks, given the spatial segregation of their prey in relation to habitat characteristics.

Keywords Seabirds · Olrog's Gull · Foraging patterns · Intertidal prey

Zusammenfassung

Räumliche Muster in der Nutzung von Nahrungsgebieten und ihre Abhängigkeit vom Nahrungsangebot bei der gefährdeten Olrogmöve (*Larus atlanticus*)

Die Olrogmöwe *Larus atlanticus* ist eine gefährdete Art, die während der Brutzeit nahezu ausschließlich Krabben frisst. Wir untersuchten die Nutzung von Nahrungsgebieten und ihre Abhängigkeit vom Nahrungsangebot bei in Bahía San Blas, Argentinien, brütenden Olrogmöwen. Die Nahrungsgebiete wurden mittels Radiotelemetrie bei 10 (2006) bzw. 12 (2007) Vögeln mit insgesamt 458 bzw. 574 Nahrungsflügen ermittelt. Zudem wurden 2007 120 farbberingte Vögel mit insgesamt 3,447 Beobachtungen einbezogen. Die Nahrungshabitate wurden über das dominante Substart sowie strukturelle Eigenschaften klassifiziert. Die Verfügbarkeit von Nahrung wurde in 2,220 einen Quadratmeter großen Probeflächen, die über die potenziellen Nahrungsflächen verteilt waren, ermittelt. Telemetrie wie

Communicated by P. H. Becker.

N. Suárez · M. V. Retana · P. Yorio (✉)
Centro Nacional Patagónico (CONICET),
Blvd. Brown 2915, U9120ACD Puerto Madryn,
Chubut, Argentina
e-mail: yorio@cenpat.edu.ar

N. Suárez
e-mail: suarez@cenpat.edu.ar

M. V. Retana
e-mail: retana@cenpat.edu.ar

P. Yorio
Wildlife Conservation Society, Amenabar 1595, P 2, Of. 19,
C1426AKC Buenos Aires, Argentina

Sichtbeobachtungen zeigten, dass die Möwen 20 km Küstenlinie nutzten, aber im Wesentlichen nur in drei Gebieten, die zwischen 1,5 und 7 km nördlich der Kolonie lagen, Nahrung suchten. In beiden Jahren variierte die Nutzung der Jagdgebiete im Verlauf des Brutzyklus mit intensiverer Nutzung der näher gelegenen Gebiete während der Jungenaufzucht. Die Ergebnisse zeigten eine differentielle Nutzung der Krabben in Abhängigkeit vom Lebensraum mit einer Dominanz von *Cyrtograpsus altimanus* in strukturierten Gebieten und von *Neohelice granulata* in mehr schlickigen Gebieten mit Vegetation. Während der Bebrütungsphase nutzen die Möwen vor allem Gebiete, die durch ein dichtes Vorkommen von *N. granulata* bestimmt waren, wogegen sie zur Aufzuchtszeit vornehmlich Flächen mit hohen Dichten von *C. altimanus* nutzten. Die Größe der Nahrung variierte zwischen den Krabbenarten mit signifikant geringerer Größe von *C. altimanus*. Die Änderungen der Nutzung von Küstengebieten durch die Olrogmöwe scheint also vom saisonalen Nahrungsbedarf für die Altvögel und die Küken und der räumlichen Verteilung der Nahrung bestimmt zu sein.

Introduction

Development of coastal environments during recent decades has brought increasing pressure on coastal wildlife. Habitat modification and disturbance are important threats to many breeding and foraging bird populations, and this has led to growing concern due to rapid growth of wildlife-based tourism, recreation, and resource extraction activities (Whittacker and Knight 1998; Yorio et al. 2001). For example, several studies have shown the negative effects of human disturbance on the spatio-temporal distribution and foraging activity of waterbirds (Fitzpatrick and Bouchez 1998; Verhulst et al. 2001; Thomas et al. 2003), and consequences of human activities should be of particular concern in the case of species with specialized feeding habits or high conservation value.

Gulls are important components of waterbird assemblages using coastal environments, and many species in this group depend on intertidal resources at least during part of their annual cycle (Burger and Gochfeld 1996). Their dependence on intertidal environments makes them vulnerable to human activities, particularly in productive coastal areas (Burger and Galli 1987; Cornelius et al. 2001). Among gull species which are highly dependent on intertidal habitats is Olrog's Gull (*Larus atlanticus*), an endemic species of the Atlantic coast of Argentina, Uruguay and southern Brazil which has a small global breeding population (4,000–5,000 pairs; BirdLife International 2008). Its breeding range is restricted to just two relatively small areas in Argentina, southern Buenos Aires Province and southern Chubut Province, although over 90% reproduce in the former coastal area (Yorio et al. 1999). Because of its low population size, restricted distributional range, and conservation threats, Olrog's Gull has been internationally recognized as globally Vulnerable (BirdLife International 2008) and listed in Appendix I of the Convention on Migratory Species. Despite its relevance in terms of conservation, little is known about its spatial requirements during foraging. The use of natural and anthropogentic areas by Olrog's Gulls feeding during the winter has been assessed in Buenos Aires Province (Berón et al. 2007). However, Olrog's Gull use of foraging areas during the breeding season has been only described in one colony in southern Chubut Province (Yorio et al. 2004) and no information is available from its main breeding grounds in southern Buenos Aires Province.

Olrog's Gull has a rather specialized feeding ecology during the breeding season, preying almost exclusively on crabs (Delhey et al. 2001; Herrera et al. 2005; Suárez et al. 2011). Food distribution and availability is one the main factors influencing spatial distribution of individuals. In intertidal environments, in particular, prey distribution and abundance vary with the physical characteristics of the environment (Puttick 1984; Yates et al. 1993; Danufsky and Colwell 2003), and many studies have reported that waterbird use of these habitats is positively correlated with the density of benthic invertebrates (Goss-Custard 1970; Colwell and Landrum 1993; Rose and Nol 2010). Therefore, Olrog's Gull foraging distribution during the breeding season should be related to the differential distribution and abundance of crabs in different coastal habitats. In addition, as individual food requirements may change throughout the breeding season in response to energetic requirements or restrictions imposed by reproductive factors (Pierotti and Annett 1991; Wilson et al. 2004), feeding habitat requirements of Olrog's Gulls should vary throughout the breeding cycle. The evaluation of the spatial use by foraging individuals in combination with the assessment of prey availability would greatly increase our knowledge on the relationship between foraging strategies and the characteristics of food resources in this threatened gull species.

Knowledge of the spatial and temporal foraging patterns and its relationship with resource use in intertidal feeding waterbirds is also essential for the development of adequate conservation and management guidelines of key coastal habitats. Bahía San Blas is one of the most important breeding grounds for Olrog's Gulls in southern Buenos Aires Province (Yorio et al. 2005), and, since 1987, has been included in a protected area under provincial jurisdiction. Several economic activities take place in this area, including sport fishing, recreation, and tourism (Zalba et al. 2008). The information on the location of foraging areas, including their spatial variability throughout the breeding cycle, is fundamental for coastal zoning and the assessment of potential conflicts between human activities and Olrog's Gull populations in this protected area. In this paper, we present information on the spatial distribution and use of feeding areas by Olrog's Gulls breeding at the Bahía San Blas protected area, Argentina. We identify main foraging areas, evaluate how spatial use varies throughout the breeding cycle, and analyse the relationship between the observed spatial patterns and the characteristics of potential food resources.

Methods

Study area and species

Olrog's Gull foraging patterns were studied at Islote Arroyo Jabalí Oeste (40°33′S, 62°16′W), located in south-western San Blas bay (Buenos Aires Province) and included within the Bahía San Blas protected area (Fig. 1). The coastal sector is characterized by extensive mudflats and marshes of *Spartina* spp. and *Salicornia ambigua*, with crab beds consisting of *Neohelice granulata*, *Cyrtograpsus altimanus*, and *C. angulatus* (Zalba et al. 2008). These are intertidal crabs common in South West Atlantic coastal and estuarine areas (Iribarne et al. 2003). In the study area, Olrog's Gulls feed almost exclusively on these three crab species, with the occasional occurrence of insects, molluscs, and fish (less than 1% of samples; Suárez et al. 2011). Gulls capture prey by walking along the exposed intertidal or in shallow water and by surface seizing or, occasionally, by surface plunging in shallow water (Copello and Favero 2001; Delhey et al. 2001; Gatto et al. 2008). In the study area, Olrog's Gulls start laying in late September, eggs start hatching in late October, and chicks start fledging in early December.

Foraging areas

The use of foraging areas by Olrog's Gull was studied by means of radio-telemetry between 25 October and 22 December 2006 and between 13 October and 23 December 2007. Gulls were captured using an incubation trap (Weaver and Kadlec 1970) during the late incubation period. A VHF radio-transmitter (Standard model; Advanced Telemetry Systems) was attached to 10 and 12 adult birds, one adult per pair, during the 2006 and 2007 breeding seasons, respectively. Transmitters weighed 9 g, which represents less than 2% of adult body mass (810 g; Yorio et al. 2004), and were fixed using waterproof tape to the two central tail feathers. Gulls were ringed with metal rings on the right leg and plastic color-rings on the left leg. The procedure was completed in less than 10 min and the released birds flew directly to the colony or nearby areas and returned to their nests in less than 10 min. All birds carrying devices continued breeding normally during the study period.

During 2006, instrumented gulls were monitored from two tracking stations 3.5 km apart and located 0.7 and 3.0 km from the colony (Fig. 1). The receiver equipment consisted of a single-channel receiver (R161A or R2000 models; Advanced Telemetry Systems) connected to a null peak directional antenna. The pulse rate of the signal was 45 pulses min^{-1}. To determine the feeding areas, records for each instrumented individual were obtained at 15-min intervals during periods of 8–16 h distributed throughout daylight hours. The location of each gull was estimated by biangulation from the direction of the signals obtained from the two receiver stations. The operators at the two tracking stations were in radio contact. During 2006, hand-held three-element Yagi aerial (Advanced Telemetry Systems) were used to track individuals which travelled beyond the limit of detection of the signal from the fixed tracking stations. In 2007, only hand-held three-element Yagi aerials were used to track instrumented gulls throughout the season, using line transects carried out along the coastline. Once an individual was detected, its location was defined by the intersection of the signal direction with the coastline, and then marked with a GPS.

To complement the assessment of foraging areas using instrumented gulls, 120 breeding individuals belonging to different nests (13% of the breeding population) were marked using a dye mixture (Belant and Seamans 1993) during the 2007 breeding season. The dye mixture consisted of 75 g of rhodamine dye with 100 ml of 70% isopropyl alcohol. This preparation was then mixed with an oil-based silica gel carrier, consisting of 120 g of silica gel (20–50 mm particle size) and 900 ml heavy mineral oil (SAE 90). The dye mixture was applied to domestic chicken eggs, and each dyed egg was placed in an Olrog's Gull nest that contained at least one egg. Dyed eggs were left in each nest for at least 10 min, a time sufficient to ensure that gulls returned to the nest to resume incubation and got the breast and/or abdominal feathers marked. After this time had elapsed, dyed eggs were retrieved to avoid the marking of the nest mate. The red mark remained visible for at least 50 days.

The presence of color-marked individuals in foraging areas was evaluated using line transects carried out from a vehicle or boat along the potential foraging area, from Balneario Pocitos (see Fig. 1) up to 4.5 km south of the colony. The potential foraging area was defined through radio tracking of individuals from late incubation to the late chick rearing stage in 2006 (see above). In addition, transects were conducted along the west coast of Isla Gama and the channel between that island and Banco Nordeste

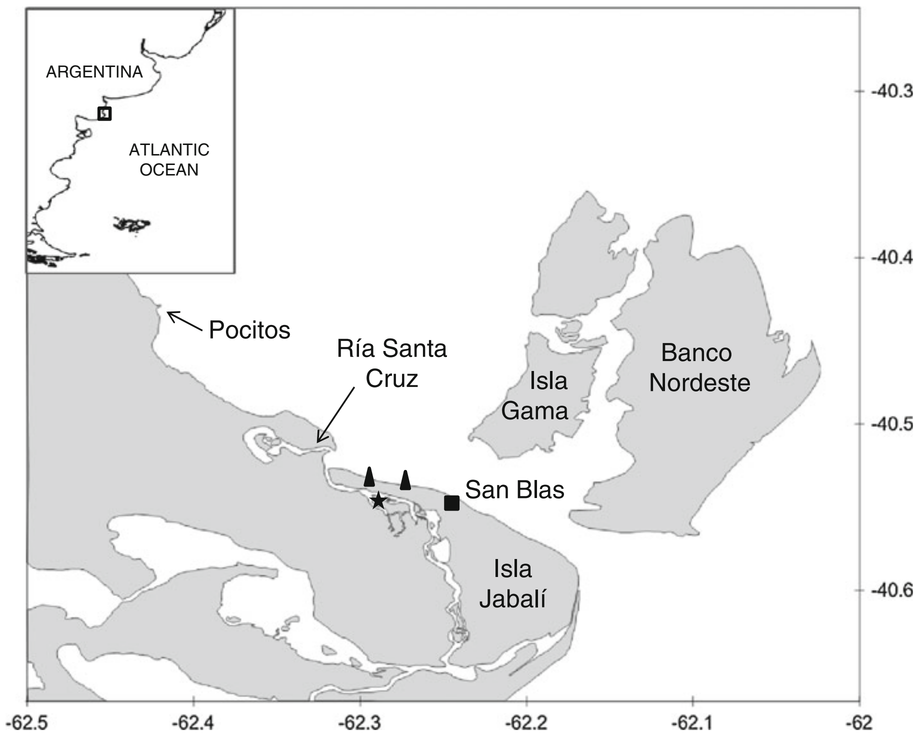

Fig. 1 The study area showing the location of the Olrog's Gull (*Larus atlanticus*) colony (*star*), tracking stations (*triangles*) and the town of San Blas (*square*)

(see Fig. 1). Sampling was conducted at intervals of 3 ± 1 days. In each transect, color-marked individuals were counted and located using a GPS. On nine occasions, additional surveys were conducted along the east coast of Isla Jabalí and up to 16 km south of the potential foraging area, so as to confirm that these sectors were not used by Olrog's Gulls as foraging grounds.

Feeding areas and prey characteristics

The distribution of breeding Olrog's Gulls in relation to the characteristics of the feeding habitat was assessed during 2007 using distributional data of color-marked individuals. Foraging areas were categorized into five habitat classes, based on dominant substrate and structural characteristics: (1) habitats dominated by hard substrates with presence of rocks and Pacific oysters *Crassostrea gigas* (RO), (2) habitats dominated by muddy substrates, without vegetation or surface structures (MM), (3) habitats characterized by muddy substrates, with the presence of *Spartina* spp. as dominant vegetation (MV), (4) habitats dominated by muddy substrates with presence of *Spartina* spp. and patches of Pacific oysters (MVO), and (5) habitats dominated by muddy substrates with presence of Pacific oysters and/or rocks (MRO). The distribution and characteristics of Olrog's Gull main prey resources (*N. granulata*, *C. altimanus*, and *C. angulatus*; Suárez et al. 2011) were assessed during 2007 in their potential foraging areas, excluding sandy and gravel shores. Sampling was conducted throughout the breeding cycle, by placing 1-m^2 quadrates in the upper, middle, and lower intertidal zones (Spivak et al. 1994). In each intertidal zone, 10 random replicates were obtained, totalling 30 samples in each of 74 stations separated by at least 0.12 km and distributed throughout the study area ($n = 2{,}220$ plots). In each sample, the number of burrows or crab individuals depending on species was counted, prey species were identified, and a subsample of crabs was collected to assess prey size, following Spivak and Sánchez (1992). The estimated number of burrows was assumed to be a reliable indicator of number of crabs.

Statistical analyses

Foraging distribution of instrumented gulls was estimated by the fixed kernel method (Wood et al. 2000), using ArcView 3.2 and the Animal Movement 2.0 extension (Hooge et al. 1999). Records made up by one or both directions with an error equal or larger than 4°, and those of instrumented gulls located less than 50 m from the colony (defined as the colony area) were rejected. Only one record per feeding area was used to develop maps. A bird was considered to be away on a feeding trip if it was absent from the colony area, and to be in a feeding area when it was located both outside the colony area and in approximately the same site for at least two sequential records (at least 20 min). For cases in which an individual moved to a different feeding area within the same foraging trip and remained in this second site for more than two sequential records, two different feeding areas were considered for the feeding trip.

Contingency tables and the χ^2 statistic were used to compare prey frequencies and numerical importance in foraging areas. Comparisons among prey variables were made using the Kruskal–Wallis and Dunn's Multiple Comparisons tests. Results are given as mean ± 1SD. The relationship between the spatial distribution of gulls and both habitat and prey characteristics was assessed using information obtained from color-marked individuals. Maps were generated dividing the sampled area in 0.022-km^2 cells (0.15 × 0.15 km) and pooling all 1-m^2 quadrates corresponding to the same cell. Cell size was defined considering that 0.15 km was the minimum distance at which a significant change in habitat characteristics along the coastline could be observed. Information on each habitat and prey variable, together with the information on the distribution of marked gulls, was organized using a geographic information system (Arc View 3.2; Environmental Systems Research Institute, 1992–1999).

A principal components analysis (PCA) was used to summarize the patterns of covariation present in habitat and prey variables corresponding to the 284 cells of 0.022 km^2 within the potential foraging area of Olrog's Gull. Cell scores were calculated on the resulting principal components (Chase 2002). This technique summarizes the measured dimensions of variation present, and then scores each site along those dimensions. To obtain the variables that best explained the distribution of Olrog's Gulls in the study area, regressions were made between color-marked gull densities and the scores of habitat and prey variables obtained in the Principal Component Analysis.

To analyse the variation in the variables along the breeding cycle, three stages were considered: incubation, early chick stage, and late chick stage. All records obtained before the mean hatching date were considered as incubation, those obtained during the 15 days after the mean hatching date as early chick stage, and those obtained afterwards as late chick stage.

Results

Distribution of feeding areas

The use of foraging areas described by means of radiotelemetry was similar between 2006 (6,824 bird locations, 458 foraging trips) and 2007 (7,543 locations, 574 foraging trips) (Fig. 2). When working from the fixed tracking stations, signals from instrumented birds while absent from the colony were received in 99.1% of cases. Foraging trips in both years were mostly to the north of the colony (67 and 73% in 2006 and 2007, respectively), reaching almost to Balneario Pocitos, a distance of 17 km, although some individuals travelled 13 km east to the south-western sector of Banco Nordeste (7 and 8% of trips in 2006 and 2007, respectively) (Fig. 2). Three main feeding areas were identified based on 50% Kernel contours: (1) the mudflats adjacent to the colony (up to 1.5 km southwards), (2) the mouth of Ría Santa Cruz and north-eastern Isla Jabalí (3.3–3.5 km from the colony), and (3) an area located 7 km south of Balneario Pocitos (this last area was used only in 2006) (Fig. 2). The area encompassing the mouth of Ría Santa Cruz and the north-eastern sector of Isla Jabalí was the most visited by instrumented gulls throughout the season, with 34 and 46% of recorded trips in 2006 and 2007, respectively. Instrumented gulls were never recorded further than 4.5 km to the south of the colony nor along the east coast of Isla Jabalí. In all cases ($n = 6{,}824$ and 7,543 in 2006 and 2007, respectively), gulls were located within the limits of the protected area. Color-marked individuals during 2007 (3,447 locations, 124 transects) used approximately the same foraging areas identified using radiotelemetry in both seasons. Color-marked gulls foraged mostly to the north (82% of observations), they visited mostly the mouth of Ría Santa Cruz (54% observations), and some individuals also travelled to Banco Nordeste (7% of observations).

During both breeding seasons, the use of feeding areas varied throughout the breeding cycle, with a more restricted spatial distribution and a higher use of areas closer to the colony during both chick stages (Fig. 3). During incubation, gulls used most of the coastal sector to the north of the colony, and the maximum recorded distance was 16.3 km. During the early chick stage, the size of the area used decreased, with a more intense use of the mouth of Ría Santa Cruz and the north-eastern sector of Isla Jabalí (Fig. 3).

Gull distribution in relation to prey characteristics

No significant differences were found between the three stages of the breeding cycle with respect to the frequency of occurrence and numerical importance ($\chi^2_2 = 16.3$, NS), density (Kruskal–Wallis test: $H_2 = 71.42$; $P < 0.05$) or size (Kruskal–Wallis test: $H_2 = 61.23$; $P < 0.05$) of crabs in Olrog's Gull potential feeding areas, and thus data from the different stages were pooled. Within the foraging range of Olrog's Gulls, the three main prey species differed in both distribution and relative abundance. The most widely distributed prey was *C. altimanus*, which was present in 74% of cells, followed by *C. angulatus* (61% of cells), and *N. granulata* (44% of cells) ($n = 284$). The mean number of prey individuals recorded per quadrate (the three species pooled) was 31 ± 27 crabs/m^2 (range 3–145) ($n = 284$ cells). The crabs *C. altimanus* and *N. granulata* showed significantly higher densities than *C. angulatus* (Table 1). *C. altimanus* showed the highest frequency of occurrence and numerical importance, followed by *N. granulata* and

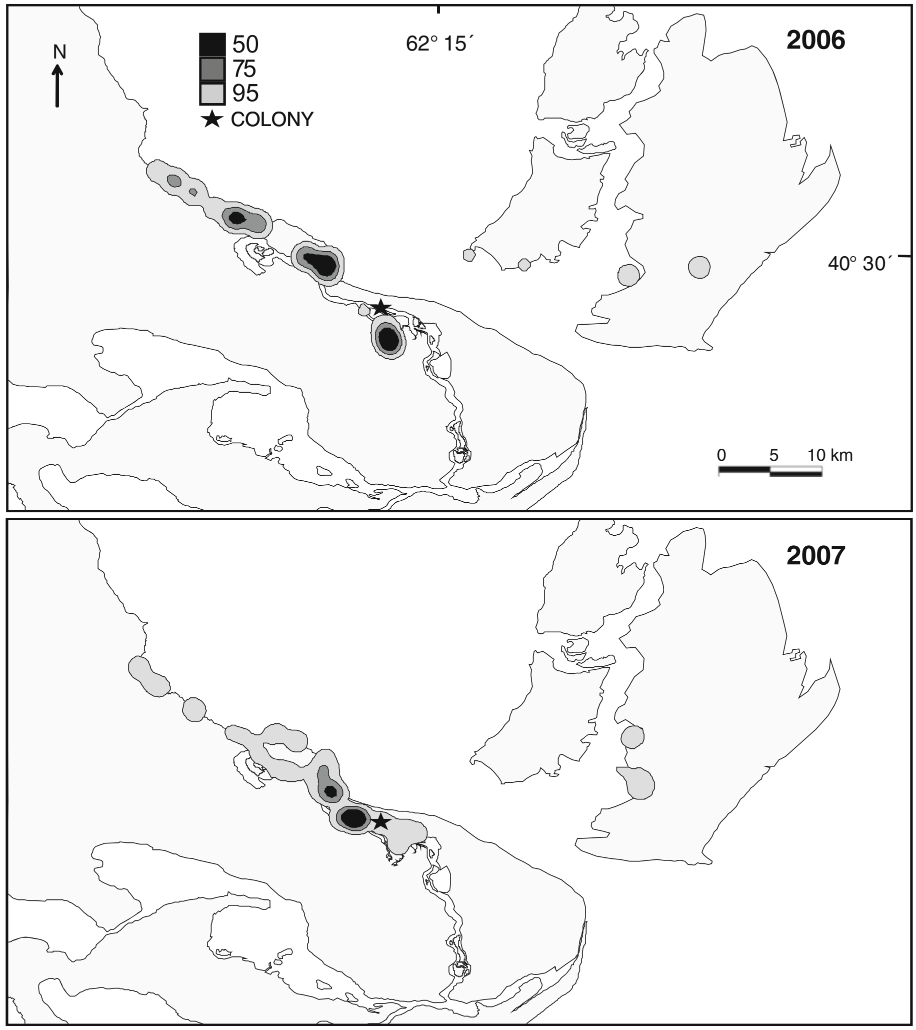

Fig. 2 Feeding areas of Olrog's Gulls breeding at Islote Arroyo Jabalí Oeste, southern Buenos Aires Province, Argentina, during 2006 and 2007. Data obtained through radiotelemetry. The colored areas represent the density of locations obtained by kernel analysis. Kernel contours shown as 50, 75 and 95% of locations. *Star* study area detailing the location of the colony of Olrog's Gulls

C. angulatus (Table 1). Body size also varied significantly among crab species, being *C. angulatus* and *N. granulata* significantly larger than *C. altimanus* (Table 1).

Structured habitats (MRO and RO) were best represented in the study area (50.6% of the sampled environment), followed by vegetated habitats (MV and MVO; 37.9%), and muddy habitats (MM; 11.5%). The Principal Component Analysis of the 10 variables measured in the 284 cells distributed throughout the potential foraging areas of Olrog's Gulls generated two components that explained 74.7% of the total variance (Table 1). The first principal component explained 42.2% of the variance and represented the densities of *C. altimanus* and *N. granulata*, contributing the two species with factor loadings of opposite sign (Table 2). Prey body size and MV habitat also contributed to the variance of this first component, with the same sign observed for the density of *N. granulata*, while RO habitat contributed to the variance with the same sign as *C. altimanus*. The second principal component, which explained 32.5% of the total variance, represented the density of *C. angulatus* and the MM habitat, both with positive values, and the prey sex ratio (M:F) with a negative value (Table 2). In general, the variance in both components was represented by the three main prey species, showing the densities of *C. altimanus* and *N. granulata* as contributing with an opposite sign to the variance in the first principal component, and with the variance of the second component positively represented by the densities of *C. angulatus*.

Mean density of *C. altimanus* showed a significant and positive correlation with structured habitats (RO and MRO), and a negative correlation with *N. granulata*, mean prey size and MM and MV habitats (Table 3). Mean abundance of *N. granulata* was positively associated with mean prey sex ratio and with MV and MVO habitats, and a showed a negative correlation with the other two crab species and RO habitat (Table 3). *C. angulatus* was negatively correlated with mean density of *N. granulata* and with RO habitat, while it showed a positive association with mean prey size and MM habitat (Table 3).

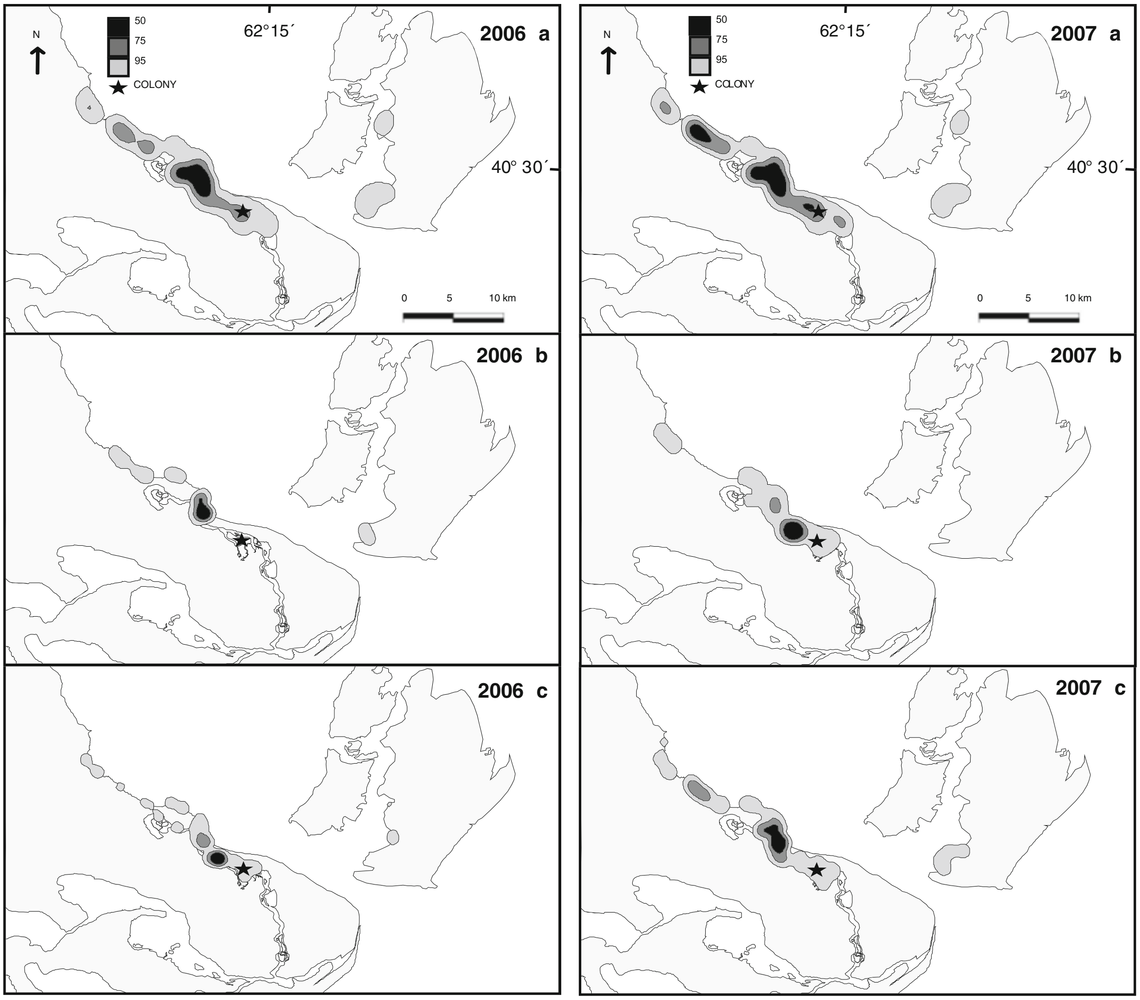

Fig. 3 Feeding areas of Olrog's Gulls breeding at Islote Arroyo Jabalí Oeste, southern Buenos Aires Province, Argentina, in different stages of the breeding cycle during 2006 and 2007. Data obtained through radiotelemetry. The colored areas represent the density of locations obtained by kernel analysis. Kernel contours shown as 50, 75 and 95% of locations. *Star* study area detailing the location of the colony of Olrog's Gulls. Incubation (**a**), early chick stage (**b**), and late chick stage (**c**)

Table 1 Characteristics of Olrog's Gull (*Larus atlanticus*) main prey species in potential feeding areas of gulls breeding at Islote Arroyo Jabalí Oeste, southern Buenos Aires Province, Argentina, during 2007 ($n = 2{,}220$ plots)

Prey characteristics	*C. altimanus*	*C. angulatus*	*N. granulata*	χ^2 test	
				χ^2	*P*
Frequency of occurrence (%)	47% a	32% c	41% b	12.1	<0.05
Numerical importance (%)	42% a	19% b	39% a	18.3	<0.05
Prey characteristics	*C. altimanus*	*C. angulatus*	*N. granulata*	Kruskal–Wallis test	
				H	*P*
Mean density ± SD (range)	19 ± 37 (0–78) a	11 ± 47 (0–83) b	20 ± 41 (0–92) a	13.31	<0.05
Size (mm)	10.2 ± 8.3 c	28.3 ± 10.1 a	22.8 ± 11.6 b	8.41	<0.05

Different letters indicate significant differences among different prey

In each of the stages of the breeding cycle, there was a linear relationship between color-marked gull abundance and the scores of one of the principal components (Table 4). During incubation, there was a significant negative linear relationship between gull abundance and the first principal component, indicating that gull abundance

Table 2 Factor loadings and total and cumulative percent variance explained for principal components analysis of habitat and prey variables measured in 284 0.022-km^2 cells distributed along potential feeding areas of Olrog's gulls breeding at Islote Arroyo Jabalí Oeste, southern Buenos Aires Province, Argentina

Habitat and prey variables	Principal component	
	1	2
Size	**−0.74**	0.39
C. altimanus density	**0.86**	−0.20
C. angulatus density	−0.12	**0.81**
N. granulata density	**−0.66**	−0.32
Sex ratio	−0.37	**−0.42**
MRO	0.11	0.03
MM	−0.04	**0.58**
MV	**−0.45**	−0.14
MVO	−0.09	−0.03
RO	**0.40**	−0.12
Percentage total variance	42.19	32.46
Cumulative variance	42.19	74.65

Factor loadings with absolute values >0.4 are shown in bold

MRO habitats dominated by muddy substrates with presence of Pacific oysters and/or rocks, *MM* habitats dominated by muddy substrates without vegetation or surface structures, *MV* habitats characterized by muddy substrates with the presence of *Spartina* spp. as dominant vegetation, *MVO* habitats dominated by muddy substrates with presence of *Spartina* spp. and patches of Pacific oysters, *RO* habitats dominated by hard substrates with presence of rocks and Pacific oysters *Crassostrea gigas*

Table 3 Pearson correlation coefficients between 10 variables included in the principal component analysis

	Size	*C. altimanus* density	*C. angulatus* density	*N. granulata* density	Sex ratio
Size	1.00				
C. altimanus density	**−0.61**	1.00			
C. angulatus density	**0.51**	**−0.28**	1.00		
N. granulata density	**0.48**	**−0.44**	**−0.34**	1.00	
Sex ratio	0.07	−0.02	−0.21	**0.45**	1.00
MRO	−0.19	**0.35**	0.24	−0.25	0.02
MM	0.28	**−0.30**	**0.48**	−0.21	−0.22
MV	**0.33**	**−0.46**	−0.13	**0.64**	0.28
MVO	0.29	0.12	−0.20	**0.38**	0.02
RO	**−0.54**	**−0.62**	**−0.32**	**−0.39**	−0.09

Significance level of $P < 0.01$ is indicated in bold

Habitat abbreviations as in Table 2

was explained by sites with high densities of *N. granulata,* habitats characterized by MV or MVO, and large prey. During the early chick stage, there was a significant positive regression with the first principal component, indicating that gull abundance was explained by the presence of structured environments RO and MRO, the main habitats for *C. altimanus*. Finally, during the late chick stage, the regression was significant and negative with the second principal component, showing that gull abundance in this stage was explained by the presence of *N. granulata* and *C. altimanus*, with MV, RO and MVO habitats important predictive variables of gull abundance.

Discussion

This study provides the first information on the spatial foraging patterns of breeding Olrog's Gull in southern Buenos Aires, the coastal sector which holds most of the species' breeding population (Yorio et al. 2005; Petracci et al. 2008). In general, the coastline used by Olrog's Gulls encompassed approximately 20 km, although the areas actually used for foraging were mostly located less than 4 km north from the colony. Foraging range was thus relatively small, in agreement with what was observed for the same species breeding at Islas Vernaci, southern

Table 4 Pearson correlation coefficients between the scores of each principal component and the density of colored individuals for each stage of the breeding cycle

		Component 1	Component 2
Incubation ($n = 126$)	Correlation coefficient	**−0.46**	−0.04
	Significance (bilateral)	0.001	0.57
Young chicks ($n = 78$)	Correlation coefficient	**0.39**	−0.03
	Significance (bilateral)	0.001	0.73
Old chicks ($n = 103$)	Correlation coefficient	−0.09	**−0.31**
	Significance (bilateral)	0.51	0.001

Significance level of $P < 0.01$ is indicated in bold

Chubut Province, where most foraging individuals fed within 3 km of the colony (Yorio et al. 2004). At Bahía San Blas, gulls concentrated their feeding activity at just a few coastal sites, using these same core areas during the different stages of the breeding cycle and in both study years. The small foraging range and frequent use of particular foraging areas are probably related to the abundance of crabs close to the colony, and to the high spatial and temporal predictability of this food resource.

The southern limit of the foraging distribution of gulls breeding at Islote Arroyo Jabalí Oeste appears to be determined by a change in the dominant intertidal habitat, from a substrate which is almost exclusively mud to a muddy substrate with abundant gravel characterized by a surface layer of anoxic sediments (N. Suárez, personal observation). This habitat is inadequate as crab habitat, and therefore unattractive for gulls as a foraging area. Although in low numbers, individuals breeding at Islote Arroyo Jabalí Oeste also foraged along intertidal environments relatively close to another Olrog's Gull colony located nearby at Banco Nordeste. Foraging seabirds should rarely feed in areas closer to other colonies than their own (Cairns 1989), and studies in other seabirds have shown that birds from neighboring colonies feed in mutually exclusive foraging areas (Wanless and Harris 1993; Sapoznikow and Quintana 2003). Future studies should evaluate the foraging patterns of Olrog's Gulls breeding at Banco Nordeste and the degree of spatial overlap with gulls breeding at Islote Arroyo Jabalí Oeste, so as to obtain a more adequate view of their spatial requirements and the relevance of Bahía San Blas for the Olrog's Gull.

The relative use by Olrog's Gulls of areas located at different distances from the colony and characterized by different structural characteristics varied throughout the breeding season. Seasonal changes in the use of foraging areas have been documented in other seabird species (Huin 2002; Skórka and Wójcik 2008; Boersma and Rebstock 2009), and it has been argued that this is likely in response to prey depletion in the vicinity of the colony or to differences in the quality of foraging habitats in relation to seasonal requirements of individuals (Gorke and Brandl 1986; Lewis et al. 2001; Boersma and Rebstock 2009). In Bahía San Blas, variability in Olrog's Gull use of coastal areas appears to be determined by their prey preferences and the seasonal change in trophic requirements, given the spatial segregation of their prey in relation to habitat characteristics. Results showed a differential distribution of crab species depending on habitat type, with a dominance of *C. altimanus* in structured environments, *N. granulata* in marshes characterized by muddy substrates with *Spartina* spp., and *C. angulatus* in sectors dominated by muddy substrates, as has already been reported for this and other coastal sectors by Iribarne et al. (2003) and Isacch et al. (2006). During the incubation stage, Olrog's Gulls mostly used foraging areas characterized by high densities of *N. granulata*, consistent with the predominance of this crab species in their diet during that stage of the breeding cycle (Suárez et al. 2011). During incubation, birds took advantage of the relatively more abundant and larger prey, possibly maximizing their energy gain. The selection of patches with higher prey densities and sizes has been reported in several waterbirds, including other gull species (Colwell and Landrum 1993; Leopold et al. 1989; Silva et al. 1999; Bertellotti et al. 2003). During the small chick stage, in contrast, the coastal sectors most frequently used were those characterized by a high density of *C. altimanus*, the dominant prey in the diet of young chicks (Suárez et al. 2011). This change in spatial use of feeding areas may be in response to the need to provision young with smaller prey, as reported in other seabird species (Pedrocchi et al. 1996; Shealer 1998; Ramos et al. 2009). Foraging trips during the chick stages were more frequent, of shorter duration, and to areas closer to the colony than those performed during the incubation stage, probably due to the parents' need to feed their offspring more often (Suárez 2010). It is interesting to note that adults expanded their foraging range later in the season, again including areas dominated by *C. altimanus* or *N. granulata*, and made longer foraging trips than those made when chicks were younger. This change in their foraging pattern may have been related to the decrease in food size restrictions as a result of chick growth.

Olrog's Gulls foraged in habitats with the presence of Pacific oysters, particularly during the chick stage when the diet includes *C. altimanus* (Suárez et al. 2011), which is mostly found in structured habitats (Iribarne et al. 2003).

Pacific oysters were introduced in the area in the 1980s with the purpose of implementing an aquaculture production, and subsequently an abandoned stock became established in the field (Orensanz et al. 2002). In the study area, crabs and other epifaunal organisms showed higher densities inside oyster beds compared with outside, probably as a result of increasing habitat structure (Escapa et al. 2004). As a result, densities of several bird species, including Kelp Gulls (*Larus dominicanus*) and shorebirds, were higher inside oyster beds compared with similar zones without oysters (Escapa et al. 2004). Unfortunately, no information is presented in that study on the differential use of oyster beds by Olrog's Gulls, so future studies should assess if this species also benefits from these newly generated environments.

The information on the Olrog's Gull spatial requirements has great value for the conservation and management of its foraging habitats. As a result of their dependence on intertidal habitats, gulls may be directly affected by human interference through the interruption of their normal activities or indirectly through habitat modification. The town of Bahia San Blas, of about 600 inhabitants, is located 1 km from the study colony, and the main economic activities taking place in the area include coastal sport and artisanal fishing and the harvesting of the Pacific oyster (Zalba et al. 2008). These activities temporally overlap with the Olrog's Gull breeding season, as they are mostly concentrated in the spring and summer. The current management plan proposal does not consider any recommendation regarding spatial protection of Olrog's gull breeding or foraging habitats nor specific regulations aimed at minimizing the impact of human activities on its population. Information on the use of foraging areas by the Olrog's Gull should contribute greatly to the development of spatial and temporal zoning schemes to minimize both human disturbance of feeding birds and the degradation of foraging habitats. For example, regulation efforts should be focused on the core gull foraging areas identified in this study, particularly as some of these are relatively close to the town of Bahía San Blas (Zalba et al. 2008). However, it should be considered that human use patterns may change depending on economic incentives and social needs. For example, protected area authorities seek to promote various tourism and recreational activities (Zalba et al. 2008), which will surely result in an increase in the influx of visitors in coming years. In addition, the extent of coastal areas used for oyster harvesting is expanding throughout the northern coasts of Bahía San Blas, both in hard and soft sediments (P. Barón, personal communication). This study has identified some of the most relevant feeding areas for breeding Olrog's Gulls, but future studies should also assess the temporal and spatial patterns of human activities, so as to improve the information needed to develop recommendations for spatial planning to minimize the conflict between this threatened gull and humans.

Acknowledgments We thank the Wildlife Conservation Society for financial support, Centro Nacional Patagónico (CONICET) for institutional support, and Dirección de Administración de Áreas Protegidas (Ministerio de Asuntos Agrarios Provincia de Buenos Aires) for the permits to work at Bahía San Blas Reserve. Thanks to P. Dell'Arciprete for her help in spatial analysis and mapping.

References

Belant JL, Seamans TW (1993) Evaluation of dyes and techniques to color-mark incubating herring gulls. J Field Ornithol 64:440–451

Berón MP, Favero M, Gómez Laich A (2007) Use of natural and anthropogenic resources by the Olrog's Gull *Larus atlanticus*: implications for the conservation of the species in non-breeding habitats. Bird Conserv Int 17:351–357

Bertellotti M, Pagnoni G, Yorio P (2003) Comportamiento de alimentación de la Gaviota Cocinera durante la temporada no reproductiva en playas arenosas de Península Valdés, Argentina. Hornero 18:37–42

BirdLife International (2008) Species fact sheet: *Larus atlanticus* [Internet]. Birdlife International, Cambridge. http://www.birdlife.org. Accessed 20 Feb 2011

Boersma PD, Rebstock GA (2009) Foraging distance affects reproductive success in Magellanic penguins. Mar Ecol Prog Ser 375: 263–275

Burger J, Galli A (1987) Factors affecting distribution of gulls (*Larus* spp.) on two New Jersey coastal bays. Environ Conserv 14:59–65

Burger J, Gochfeld M (1996) Family Laridae (Gulls). In: del Hoyo J, Elliot A, Sargatal J (eds) Handbook of the birds of the world, vol 3 (Hoatzin to Auks). Lynx, Barcelona, pp 572–623

Cairns DK (1989) The regulation of seabird colony size: a hinterland model. Am Nat 134:141–146

Chase MK (2002) Nest site selection and nest success in a song sparrow population: the significance of spatial variation. Condor 104:103–116

Colwell MA, Landrum SL (1993) Nonrandom shorebird distribution and fine-scale variation in prey abundance. Condor 95:94–103

Copello S, Favero M (2001) Foraging ecology of Olrog's Gull *Larus atlanticus* in Mar Chiquita Lagoon (Buenos Aires, Argentina): are there age-related differences? Bird Conserv Int 11:175–188

Cornelius C, Navarrete SA, Marquet PA (2001) Effects of human activity on the structure of coastal bird assemblages in Central Chile. Conserv Biol 15:1396–1404

Danufsky T, Colwell MA (2003) Winter communities and tidal flat characteristics at Humboldt Bay, California. Condor 105: 117–129

Delhey JKV, Carrete M, Martínez M (2001) Diet and feeding behaviour of Olrog's gull *Larus atlanticus* in Bahía Blanca, Argentina. Ardea 89:319–329

Escapa M, Isacch JP, Daleo P, Alberti J, Iribarne O, Borges M, Dos Santos EP, Gagliardini DA, Lasta M (2004) The distribution and ecological effects of the introduced Pacific oyster *Crassostrea gigas* (Thunberg, 1793) in northern Patagonia. J Shellfish Res 23:765–772

Fitzpatrick S, Bouchez B (1998) Effects of recreational disturbance on the foraging behaviours of waders on a rocky beach. Bird Study 45:157–171

Gatto A, Quintana F, Yorio P (2008) Feeding behavior and habitat use in a waterbird assemblage at a marine wetland in coastal Patagonia, Argentina. Waterbirds 31:463–471

Gorke M, Brandl R (1986) How to live in colonies: spatial foraging strategies of the black-headed gull. Oecologia 70:288–290

Goss-Custard D (1970) The responses of Redshank (*Tringa totanus* (L.)) to spatial variations in the density of their prey. J Anim Ecol 39:91–113

Herrera G, Punta G, Yorio P (2005) Diet specialization of the threatened Olrog's gull *Larus atlanticus* during the breeding season at Golfo San Jorge, Argentina. Bird Conserv Int 15:89–97

Hooge PN, Eichenlaub W, Solomon E (1999) The animal movement program. US geological survey. Alaska Biological Science Center, Anchorage, AK

Huin N (2002) Foraging distribution of the black-browed albatross, *Thalassarche melanophris*, breeding in the Falkland Islands. Aquat Conserv 12:89–99

Iribarne O, Martinetto P, Schwindt E, Botto F, Bortolus A, Garcia Borboroglu P (2003) Evidences of habitat displacement between two common soft-bottom SW Atlantic intertidal crabs. J Exp Mar Biol Ecol 296:167–182

Isacch JP, Pérez CF, Iribarne O (2006) Bird species composition and diversity at middle Argentinean coast of La Plata river. Ornitol Neotrop 17:419–432

Leopold MF, Swennen C, Bruijn LLM (1989) Experiments of selection of feeding site and food size in oystercatchers, *Haematopus ostralegus*, of different social status. Neth J Sea Res 23:333–346

Lewis S, Sherratt TN, Hamer KC, Wanless S (2001) Evidence of intraspecific competition for food in a pelagic seabird. Nature 412:816–819

Orensanz JM, Schwindt E, Pastorino G, Bortolus A, Casas G, Darrigran G, Elías R, López Gappa JJ, Obenat S, Pascual M, Penchaszadeh P, Piriz ML, Scarabino F, Spivak ED, Vallarino EA (2002) No longer a pristine confine of the world ocean: a survey of exotic marine species in the Southwestern Atlantic. Biol Invasions 4:115–143

Pedrocchi V, Oro D, González-Solís J (1996) Differences between diet of adult and chick Audouin's gulls *Larus audouinii* at the Chafarinas Islands, SW Mediterranean. Ornis Fenn 73:124–130

Petracci PF, Sotelo MR, Díaz LI (2008) A new colony of Olrog's Gull (*Larus atlanticus*) in the Bahía Blanca, Bahía Falsa and Bahía Verde Natural Reserve, Buenos Aires, Argentina. Hornero 23:37–40

Pierotti R, Annett CA (1991) Diet choice in the herring gull: constraints imposed by reproductive and ecological factors. Ecology 72:319–328

Puttick GM (1984) Foraging and activity patterns in wintering shorebirds. In: Burger J, Olla BL (eds) Behavior of marine animals: shorebird migration and foraging behavior. Plenum, New York, pp 203–231

Ramos R, Ramírez F, Santera C, Jover L, Ruiz X (2009) Diet of yellow-legged Gull (*Larus michahellis*) chicks along the Spanish Western Mediterranean coast: the relevance of refuse dumps. J Ornithol 150:265–272

Rose M, Nol E (2010) Foraging behavior of non-breeding semipalmated plovers. Waterbirds 33:59–69

Sapoznikow A, Quintana F (2003) Foraging behavior and feeding locations of imperial cormorants and rock shags breeding in sympatry in Patagonia, Argentina. Waterbirds 26:184–191

Shealer D (1998) Size-selective predation by a specialist forager, the roseate tern. Auk 115:519–525

Silva MP, Favero M, Martínez M (1999) Prey size selectivity by kelp gulls on Antarctic limpets at King George Island, Antarctica. Polar Biol 21:397–400

Skórka P, Wójcik JD (2008) Habitat utilization, feeding tactics and age related feeding efficiency in the Caspian gull *Larus cachinnans*. J Ornithol 149:31–39

Spivak ED, Sánchez N (1992) Prey selection by *Larus belcheri atlanticus* in Mar Chiquita lagoon, Buenos Aires, Argentina: a possible explanation for its discontinuous distribution. Rev Chil Hist Nat 65:209–220

Spivak E, Anger K, Luppi T, Bas C, Ismael D (1994) Distribution and habitat preferences of two grapsid crabs in Mar Chiquita Lagoon (Buenos Aires Province, Argentina). Helgolander Meeresun 48:59–78

Suárez N (2010) Estrategias de alimentación de la Gaviota de Olrog (*Larus atlanticus*) y su relación con las fuentes de alimento. Doctoral thesis, Universidad Nacional del Comahue, Argentina

Suárez N, Retana V, Yorio P (2011) Seasonal changes in diet and prey selection in the threatened Olrog's gull *Larus atlanticus* breeding in Patagonia, Argentina. Ardeola 58:35–47

Thomas K, Kvitek RG, Bretz C (2003) Effects of human activity on the foraging behaviour of sanderlings *Calidris alba*. Biol Conserv 109:67–71

Verhulst S, Oosterbeek K, Ens BJ (2001) Experimental evidence for effects of human disturbance on foraging and parental care in oystercatchers. Biol Conserv 101:375–380

Wanless S, Harris MP (1993) Use of mutually exclusive foraging areas by adjacent colonies of blue-eyed dhags (*Phalacrocorax atriceps*) at South Georgia. Colon Waterbirds 16:176–182

Weaver DK, Kadlec JA (1970) A method for trapping adult gull. Bird-Banding 41:28–31

Whittacker D, Knight RL (1998) Understanding wildlife responses to humans. Wildl Soc Bull 26:312–317

Wilson LJ, Daunt F, Wanless S (2004) Self-feeding and chick provisioning diet differ in the common guillemot *Uria aalge*. Ardea 92:197–208

Wood AG, Naef-Daenzer P, Prince PA, Croxall JP (2000) Quantifying habitat use in satellite-tracked pelagic seabirds: application of kernel estimation to albatross locations. J Avian Biol 31: 278–286

Yates MG, Jones AR, Goss-Custard JD, Mc-Grorty S (1993) Satellite imagery to monitor ecological change in estuarine systems: example of the Wash, England. In: Moser MRC, Prentice RC, van Vessem J (eds) Waterfowl and wetland conservation in the 1990s-A global perspective (Proceedings of the international waterbird and wetlands research Bureau symposium, St. Petersburg Beach, Florida, USA). IWRB Spec. Publ. 26, Slimbridge, pp 56–60

Yorio P, Frere E, Gandini P, Conway W (1999) Status and conservation of seabirds breeding in Argentina. Bird Conserv Int 9:299–314

Yorio P, Frere E, Gandini P, Schiavini A (2001) Tourism and recreation at seabird breeding sites in Patagonia, Argentina: current concerns and future prospects. Bird Conserv Int 11: 231–245

Yorio P, Quintana F, Gatto A, Lisnizer N, Suárez N (2004) Foraging patterns of breeding Olrog's gull at Golfo San Jorge, Argentina. Waterbirds 27:193–199

Yorio P, Bertellotti M, García Borboroglu P (2005) Estado poblacional y de conservación de gaviotas que reproducen en el litoral Argentino. Hornero 20:53–74

Zalba SM, Nebbia AJ, Fiori SM (2008) Propuesta de Plan de Manejo de la Reserva Natural de Uso Múltiple Bahía San Blas. Universidad Nacional del Sur, Bahía Blanca