Temporal Variation of Kelp Gull's (*Larus dominicanus*) Diet on a Coastal Island of the Rio de la Plata Estuary, Uruguay: Refuse as an Alternative Food Source

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Abstract.—Temporal variation in the diet of the Kelp Gull in relation to feeding on refuse was studied at a reproductive colony on Isla de las Gaviotas, Uruguay. Diet was assessed temporally within the reproductive season, and inter-annually for 2011 and 2012 reproductive seasons, and the 2013 non-reproductive season. Data analysis was focused on the proportion of the most important diet items recorded in regurgitated pellets: fish and organic refuse. Fish and organic refuse correlated negatively at an intra-monthly scale. Additionally, fish was more frequently recorded during the incubation period (68% of pellets) than during the chick-rearing period (42% of pellets). Conversely, proportion of organic refuse was larger during the chick-rearing period (18% of pellets) than during the incubation period (8% of pellets). During reproduction, fish proportion in diet was larger (2011 = 41% of pellets, 2012 = 32% of pellets) than refuse (2011 = 16% of pellets, 2012 = 15%) and the opposite situation occurred during the non-reproductive season (fish 2013 = 14% of pellets, refuse 2013 = 41% of pellets). *Received 6 March 2019, accepted 7 January 2020.*

Key words.—anthropogenic food, fish, foraging, garbage, gull diet, gull reproduction, incubation period, landfill, nestling period, seasonal diet.

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Gulls are a successful group of species because they use a variety of foraging tactics and exploit a wide range of food sources. Furthermore, gulls can adjust their diet to satisfy specific requirements, and because of this are extremely successful in human-modified habitats (Oro *et al.* 2013; Plaza and Lambertucci 2017). Human activities can provide alternative food sources such as refuse, which is temporally and spatially predictable (Newsome *et al.* 2015). For instance, several species of gulls such as Herring Gull (*Larus argentatus*), Great Black-backed Gulls (*L. marinus*) (Belant *et al.* 1993; Rome & Ellis 2004), Yellow-legged Gull (*L. michahellis*) (Duhem *et al.* 2005), Slaty-backed Gulls (*L. schistisagus*) (Watanuki 1992), California Gull (*L. californicus*) (Ackerman *et al.* 2018), and Kelp Gull (*L. dominicanus*) (Bertellotti *et al.* 2001) forage on landfills and refuse dumps where refuse is managed in such a way that part of it is available to be ingested (Auman *et al.* 2008). Thus, gulls could use human refuse as an alternative source when natural food is not available, or as a substitute of natural food sources (Pons 1992; Newsome *et al.* 2015; Plaza and Lambertucci 2017).

Changes in foraging strategies between critical life history phases might allow individuals to increase reproductive success and survivorship (Pons 1992; Suryan *et al.* 2000, 2002; Bukacińska *et al.* 1996). For example, a study found that Herring Gull and Great Black-backed Gull parents feed their chicks with a lower trophic level diet than adults feed themselves, possibly due to higher digestibility of prey from lower trophic levels (Steenweg *et al.* 2011). Another study has observed that during the pre-incubation period, adult breeding Herring Gull fed preferentially on mussels and refuse, and after hatching they changed their foraging preferences to small fish (Pierotti and Annett 1987). Fish are easier for nestlings to digest than refuse, and it is also composed of essential nutrients such as calcium, which is important for chick growth and development (Murphy *et al.* 1984; Annett and Pierotti 1999). Other studies revealed that the requirements of juveniles of Ring-billed Gull (*L. delawarensis*) could also be met by changes in adult feeding habits, from easily digestible insects and fish at the beginning of the rearing period to only fish at the end, when chicks are large enough to handle larger meals (Kirkham and Morris 1979). Certainly, changes in foraging strategies are variable between species and populations (Pierotti and Annett 2001; Montevecchi *et al.* 2009; Washburn *et al.* 2013). However, we still know little about the role that refuse plays in diet choice, how it relates to various components of a bird's life cycle, and how it varies at different temporal scales.

The Kelp Gull (*L. dominicanus*) is widely distributed in the southern hemisphere (Yorio *et al.* 2016). Its breeding distribution extends to South America, Australia, New Zealand, Southern Africa, Sub-Antarctic islands, and the Antarctic Peninsula (Burger and Gochfeld 1996; Yorio *et al.* 2016). The Kelp Gull's trophic ecology has been studied in many different habitats including freshwater, estuarine (Petracci *et al.* 2004; Silva-Costa and Bugoni 2013) and marine-coastal ecosystems (Bertellotti and Yorio 1999), inter-tidal environments, coastal cities (Giaccardi *et al.* 1997; Silva *et al.* 2000; Ludynia *et al.* 2005), islands (Coulson and Coulson 1993), and in Antarctica (Favero *et al.* 1997). Available evidence suggests that Kelp Gull foraging decisions could be influenced by spatial and temporal patterns in the availability and selection of food types, as well as by the stage of the life cycle of an individual (Bertellotti and Yorio 1999; Ludynia *et al.* 2005). Additionally, variability in the feeding behavior of this species might be influenced by accessibility to artificial food sources, such as refuse and fishing discards (Silva *et al.* 2000; Ludynia *et al.* 2005; Silva-Costa and Bugoni 2013).

In Uruguay, this species is one of the most abundant and widely distributed along the coast (Aldabe *et al.* 2006; Sarroca *et al.* 2006), breeding on at least eight coastal islands along the 680 km of Atlantic Ocean and the Rio de la Plata Estuary (Yorio *et al.* 2016). This estuary is one of the largest in the Americas (35,000 km^2) supporting the largest human settlements of Argentina and Uruguay, with a human population greater than 12 million people. It supports a variety of human activities, which could potentially generate a range of refuse sources, a possible anthropogenic food source for the Kelp Gull. Nonetheless, it is still poorly understood what the potential impacts of anthropogenic food are on the trophic ecology of this species.

The primary objective of this research is to investigate the role of refuse as an alternative food source and its potential impacts on the feeding ecology of the Kelp Gull. Particularly, we address the temporal variation in use of natural food and refuse by the Kelp Gull between incubation and chick-rearing periods (within the reproductive cycle), and between reproductive and non-reproductive seasons (inter-annually comparing different seasons of different years).

METHODS

Study Area

Isla de las Gaviotas (34° 54′ 10.41″ S, 56° 6′ 15.42″ W) is a small island of 2 ha situated 300 m off the coast of Montevideo, Uruguay, in the Rio de la Plata Estuary (Fig. 1; Guido *et al.* 2013). The Rio de la Plata Estuary is formed by the discharge of the Uruguay River into the

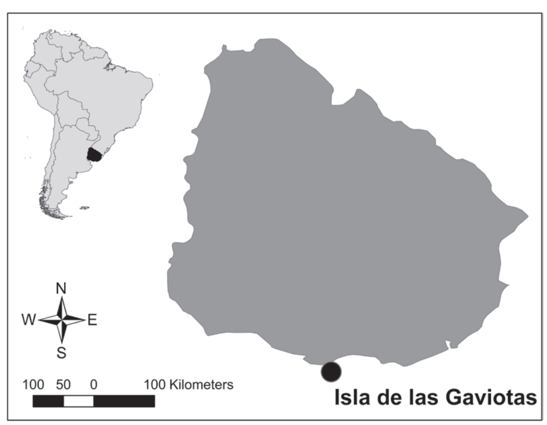

Figure 1. Geographic location of Isla de las Gaviotas on the Atlantic Coast of Uruguay.

Atlantic Ocean. This estuary is a highly productive area that maintains several industrial and artisanal fisheries in Argentina and Uruguay (Acha *et al.* 2008). Seabirds extensively use this estuary to forage and breed because of the important amount of natural food resources provided (Hureta *et al.* 2005; Bergamino *et al.* 2012). The Kelp Gull is the most abundant species on Isla de las Gaviotas and breeds between July and December in a small reproductive colony of approximately 115 breeding pairs (Yorio *et al.* 2016). Natural food sources can be found close to the island, while refuse sources are at least 18 km away.

Pellet Sampling and Analysis

Kelp Gull diet composition was studied based on the analysis of regurgitated pellets containing hard parts of prey that cannot be digested (such as bones, otoliths, invertebrate exoskeletons) (Karnovsky *et al.* 2012). Pellets contain information about the recent diet of an individual, generally of the last food intake (Silva-Costa and Bugoni 2013). The analysis of these structures has many advantages, for example it is a non-invasive method because it does not require capture of individuals, which causes discomfort, stress, and occasional mortality, and it reduces disturbances to the colony, minimizing the probability of intra- and inter-specific predation of eggs and/or chicks. Additionally, this method is relatively easier than others, it is widely used in seabird diet studies, and an important amount of information can be quickly gathered (Duffy and Jackson 1986; Barrett *et al.* 2007). However, a drawback of this method is that it overestimates prey that contain indigestible hard parts and underestimates soft-bodied prey (Lindsay and Meathrel 2008). Thus, pellet analysis was considered a suitable methodology to achieve the goals of the present study, because refuse and natural food can be traced from hard parts (e.g., chicken bones, beef bones, plastic, fish bones, exoskeletons) and these prey types represent most of the diet of this species (Coulson and Coulson 1993; Bertellotti and Yorio 1999; Ludynia *et al.* 2005; Silva-Costa and Bugoni 2013).

A total of 21 surveys were conducted during 2011 (September 25th-November 23rd, $n = 10$) and 2012 (August 17th-December 1st $n = 11$) reproductive periods, and six during the 2013 (February 15th-June 5th) non-reproductive period. Individuals did not regurgitate pellets in their nests, which prevented the assessment of the diet of individual breeding pairs. Thus, we worked at the population level, sampling pellets in two fixed areas within the colony surrounded by nesting territories, to reconstruct the diet of the pool of reproductive individuals. During every survey, all the pellets within these areas were collected, stored in plastic bags and preserved at -20° C for further analysis.

With the aid of a binocular stereo microscope at 40X, pellet contents were analyzed and classified as follows. First, we determined whether each prey was of aquatic origin, refuse (i.e., terrestrial), or undetermined. Then aquatic prey were classified into their major taxonomic categories (class or order). Particularly, because wild-caught fish cannot be distinguished from fishing discards, this item was classified as "fish". Fish were identified in pellets from squamae, vertebrae, spines, otoliths, and bones. Otoliths are calcareous structures situated within the vestibular system of fish, which sense gravity and vibrations. Additionally, shape of otoliths is species-specific and can be used to determine the prey species in ecological studies. Additionally, refuse was classified as organic or inorganic. Organic refuse is any compound made from organic matter that degrades rapidly (e.g., food remains). Inorganic refuse was defined as those residuals in which decomposition is very slow because of their chemical characteristics (although some of them have an organic origin like plastic, these items were determined to be non-biodegradable).

Diet Composition

To characterize Kelp Gull diet composition, four indices commonly used in vertebrate diet studies were estimated: *a*) the "number of pellets" containing a prey item *b*) the "proportion of pellets" containing a prey item *c*) the "number of prey" occurrences per sample, and *d*) the "proportion of prey" items per sample. Each sample was composed by the set of pellets obtained in each survey.

Diet Variation between Incubation and Chick-rearing Periods

To study temporal variation in the Kelp Gull diet between surveys in relation to refuse feeding, we analyzed the co-variation of fish and organic refuse, which were the most important diet categories recorded (see Results). Organic refuse and fish reflect how gulls use terrestrial and aquatic sources, respectively (Duhem *et al.* 2003). Thus, to analyze the temporal variation in diet among the 27 surveys, we used Pearson correlation coefficient to determine the correlated proportion of pellets containing organic refuse and fish in the diet of the Kelp Gull.

Incubation period was defined as the period when most of the nests contained eggs to when the first chicks were observed in the colony. The chick-rearing period was defined as the period when the first chicks began to hatch until the first fledglings were observed in the colony. Because two consecutive cyclones hit the island on 18 September and 23 October 2012, only the 2011 data were analyzed in order to avoid potential errors in the comparison. The surveys of the 2011 incubation period were 24 and 29 September ($n = 44$ pellets). Data from surveys of 12, 19, and 28 October 2011 were analyzed for the chick-rearing period ($n = 164$ pellets).

To compare the diet between these two periods of the breeding cycle, a one-way analysis of similarity (one-way ANOSIM; Clarke 1993) was performed. Separating both periods, a contingency table with diet categories as columns, pellets as rows, and number of prey was used as input. Bray-Curtis was used as the similarity index to calculate the similarity matrix. Subsequently a SIMPER analysis was performed as a *post-hoc* test to estimate the contribution of each diet category to both periods.

Diet Variation between Reproductive and Non-Reproductive Seasons

To analyze variation in diet between years and between reproductive and non-reproductive periods, we compared 2011 and 2012 reproductive seasons, and both reproductive seasons to the 2013 non-reproductive season. To perform this comparison, we used those surveys from 2011 between 24 September and 28 October (six surveys, *n* = 138 pellets). We analyzed samples collected before the end of the fledgling period to avoid those from non-breeders that were using abandoned breeding territories and to improve the comparison with the 2012 reproductive season. Because of the cyclone during the 2012 incubation period, we used the pre-cyclone surveys as the reproductive sample in the comparison: 17 August and 12 September 2012 (three surveys, *n* =113 pellets). All the surveys from 2013 were used as non-reproductive (15 February, 13 March, 18 and 24 April, 9 May, 5 June; *n* =187 pellets).

To compare the diet among the reproductive and non-reproductive periods, we used one-way analysis of similarity (Clarke 1993) from the contingency table used in the previous analysis but separating reproductive and non-reproductive periods. Bray-Curtis similarity index was used to estimate the similarity matrix. Additionally, we used a SIMPER analysis to examine which diet categories contributed more to the differences between seasons. To perform data analysis, we used PAST software v. 3 (Hammer *et al.* 2001) and R v. 3.4.3 (R Development Core Team 2018).

RESULTS

Diet Composition

A total of 801 pellets were analyzed: 237 in the 2011 reproductive season, 377 in the 2012 reproductive season, and 187 in the 2013 non-reproductive season. The Kelp Gull diet on Isla de las Gaviotas was classified into 12 major prey types (Table 1). Fish was the most frequent prey type (56% of pellets) identified in pellets from squamae, vertebrae, spines, otoliths, and bones. Organic refuse (36% of pellets) was also recorded from chicken eggshells and skin, fat and bones from homemade meals (chicken, beef, and pork). Glass, rubber, plastic film, plastic remains (bottle caps, containers, undetermined plastic fragments), styrofoam, aluminum foil, threads, ropes, metal (caps, nails, wire), and paper (containers, cardboard) were found in pellets and classified as inorganic refuse (25% of pellets; Table 1). Bivalves, crustaceans, insects, other invertebrates, and mammals were recorded as well, but represented less than 5% of pellets (Table 1).

Regarding the number and proportion of prey occurrences, a total of 2,968 individual prey were classified as natural origin (bivalves, insects, crustaceans, other invertebrates, fish, and mammals), and of those, 2,354 were fish remains with overall proportion of 65% of prey occurrences (Table 1). Organic and inorganic refuse each contributed 9% of prey occurrences (Table 1). Additionally, we found 2,454 remains of non-natural prey types such as stones, feathers, and inorganic and organic refuse. A total of 4,110 otoliths was recorded;

Table 1. Prey types of the Kelp Gull (*Larus dominicanus*) on Isla de las Gaviotas, Uruguay.

Prey type	Number of pellets	Proportion of pellets (%)	Avg. number of prey	Proportion of prey (%)
Aquatic origin				
Fish	450	56	2.94	65
Crustaceans	19	2	0.03	<1
Bivalves	22	3	0.03	<1
Terrestrial origin				
Organic refuse	293	36	0.39	9
Inorganic refuse	200	25	0.39	9
Vegetables	137	17	0.23	5
Mammals	15	2	0.02	<1
Insects	40	5	0.05	1
Other invertebrates	2	<1	0.01	<1
Feathers	186	23	0.24	5
Stones	121	15	0.17	4
Undetermined	39	5	0.05	1

32% were found in the 2011 and 65% in the 2012 reproductive seasons, and 3% in the 2013 non-reproductive season. The majority of the otoliths came from three species: whitemouth croaker (*Micropogonias furnieri*), stripped weakfish (*Cynoscion guatucupa*), and toadfish (*Thalassophryne montevidensis*).

Diet Variability

A negative relationship between the proportion of fish consumption and organic refuse was observed in weekly variations in diet composition (r = -0.92, n = 27, P < 0.001; Fig. 2). Difference in the overall diet (including all prey types) between incubation and chick-rearing periods was not statistically significant (ANOSIM: R = -0.02, P > 0.05). The proportion of organic refuse was lower during the incubation period (8% of pellets) than during the chick-rearing period (18% of pellets). Conversely, the proportion of fish was higher during the incubation period (68% of pellets) than during the chick-rearing period (42% of pellets; Fig. 3). In addition, the proportion of fish was larger than organic refuse in both periods (Fig. 3).

There were overall differences between all reproductive and non-reproductive seasons in the diet of the Kelp Gull (ANOSIM: R = 0.13, P < 0.01) (Fig. 4). Diet was different between the 2011 and 2012 reproductive seasons, although these differences might not be important based on the low R-value (ANOSIM: R = 0.03, P < 0.01). In addition, more important differences were detected between the 2011 reproductive season and the 2013 non-reproductive season (ANOSIM: R = 0.12, P < 0.001), as well as between the 2012 reproductive season and the 2013 non-reproductive season (ANOSIM: R = 0.14, P < 0.01). Finally, SIMPER analysis indicated that fish and organic refuse were the most important prey types that influenced differences in reproductive and non-reproductive seasons (Table 2). The largest proportion of

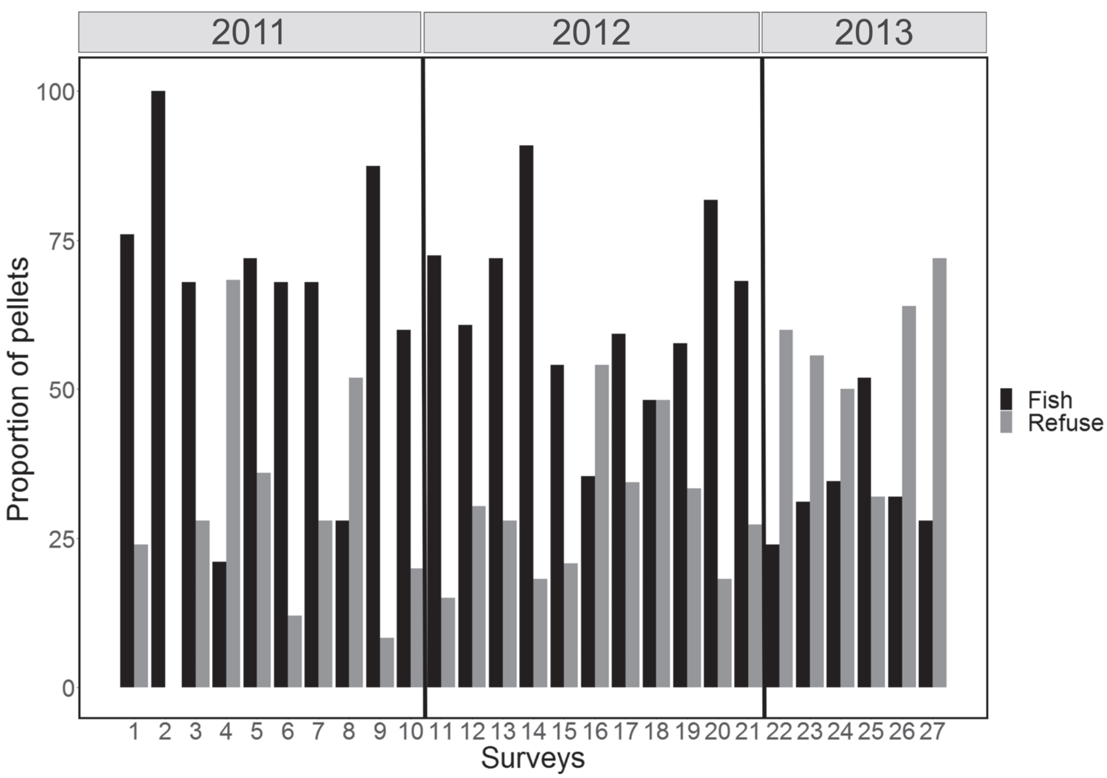

Figure 2. Variation of fish and organic refuse in the diet of Kelp Gull (*Larus dominicanus*) assessed from 27 surveys carried out on Isla de las Gaviotas, Uruguay. Vertical black lines represent the transition between 2011 and 2012 reproductive periods, and 2013 non-reproductive period.

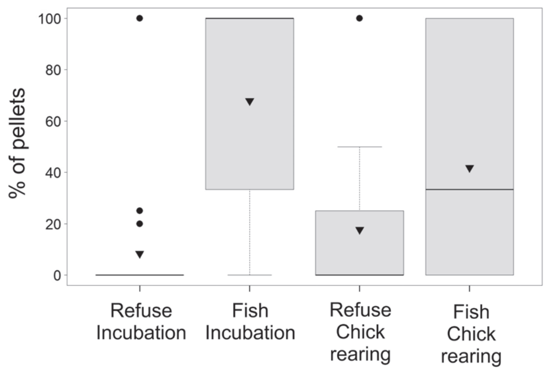

Figure 3. Median (horizontal bars) and mean (black triangles) proportion of pellets (%) of organic refuse and fish between incubation and chick-rearing periods of the Kelp Gull (*Larus dominicanus*) on Isla de las Gaviotas, Uruguay, during the 2011 reproductive season.

fish was recorded in 2011 reproductive season (41% of pellets) followed by 2012 reproductive season (32% of pellets) and was lower in 2013 non-reproductive season (14% of pellets) (Fig. 4). Conversely, organic refuse was largest during 2013 non-reproductive season (41% of pellets), and lower in 2011 (16% of pellets) and 2012 (15% of pellets) reproductive seasons (Fig. 4).

Discussion

As was shown by other studies that analyzed gull foraging ecology through pellet analysis, our results suggest that Kelp Gull feeding habits on Isla de las Gaviotas followed a generalist and opportunistic diet evidenced by the diversity of food items (Bertellotti and Yorio 1999; Silva *et al*. 2000; Petracci *et al*. 2004; Ludynia *et al*. 2005). Organic refuse and fish were the main food items in our analysis and possibly the most abundant, available and predictable food sources around the colony. Additionally, natural food and organic refuse were reflected in the diet of the Kelp Gull and used differently through the study period. Our results suggest that during short and long term periods, individuals might change foraging decisions between fish and organic refuse possibly in response to food availability and/or physiological constraints.

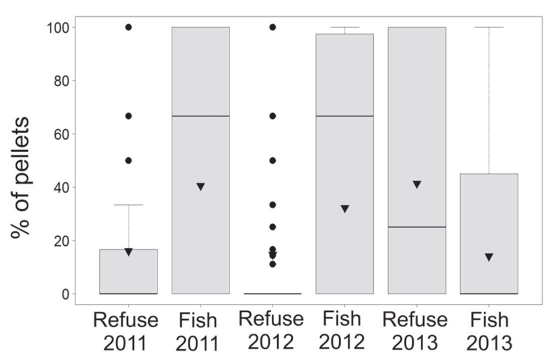

Figure 4. Median (horizontal bars) and mean (black triangles) of proportion of pellets of organic refuse and fish between 2011 and 2012 reproductive seasons and 2013 non-reproductive season of the Kelp Gull (*Larus dominicanus*) on Isla de las Gaviotas, Uruguay.

Short term changes in natural food availability might explain the variation in the use of fish and organic refuse during the reproductive period. We observed that those fish species that were most often preyed on by Kelp Gull, the whitemouth croaker and stripped weakfish, are also the targets of the coastal trawling fishing industry (Gutiérrez and Defeo 2012), which activity is variable in space and time (Norbis *et al.* 2006). When total length of these fish species is lower than allowed (32 cm for whitemouth croaker and 27 cm for stripped weakfish; Article 49, Decree 149/997), individuals are discarded and scavenged by the Kelp Gull (Segura *et al.* 2008; Yorio *et al.* 2016). In addition, natural fish availability in the Rio de la Plata Estuary seems to be positively influenced by vertical mixing of organic matter (and fish prey) due to the changing wind conditions during the day or week (Quirós and Baigún 1985; Schreiber 2002; Acha *et al.* 2008; Simionato *et al.* 2008). This phenomenon might generate increments of fish in the short term that Kelp Gull could take advantage of. Hence, short term variability of fish biomass in the Rio de la Plata Estuary could consequently trigger the consumption of refuse in the terrestrial environment that is more predictable.

Additionally, Kelp Gull parents might have changed their foraging strategies to feed their nestlings on Isla de las Gaviotas. The lower proportion of fish during the chick-rearing period than the incubation period and the higher proportion of refuse during the chick-rearing period than incubation period contrasts with other studies

Table 2. SIMPER analysis for the proportion of pellets in Kelp Gull (*Larus dominicanus*) on Isla de las Gaviotas, Uruguay, comparing reproductive (2011 and 2012) and non-reproductive (2013) seasons.

	Proportion of Pellets (% Contribution)		
Prey Type	2011/2012	2011/2013	2012/2013
Fish	19	28	26
Organic refuse	16	25	23
Feathers	14	12	10
Vegetable	10	7	10
Inorganic refuse	10	8	7
Stones	9	4	6
Undetermined	6	2	6
Crustaceans	5	5	1
Bivalves	4	3	2
Insects	3	6	7
Mammals	3	<1	3
Other invertebrates	<1	0	<1

of this species. For instance, Ludynia *et al.* (2005) found that fish were increasingly important as the reproductive season progressed through pre-incubation, incubation, and chick-rearing periods in an urban Kelp Gull colony in Chile. A similar pattern was also observed in South Africa, where adults incorporated more natural food in their diet during the incubation period, and chicks incorporated more marine prey (although chick diet was assessed from regurgitations; Steele 1992; Witteveen 2015). However, a study conducted by Lenzi *et al.* (2019) using stable isotopes and chick regurgitations in a colony close to Isla de las Gaviotas, found that larger nestlings might gradually be fed with more organic refuse than fish as they grow. Thus, considering the different methodologies of some above-mentioned studies, our results highlight the generalist and opportunistic feeding behavior of the Kelp Gull on Isla de las Gaviotas, and probably the necessity to change foraging strategies in this changing environment highly impacted by human activities.

In the long term (interanual scale), Jaureguizar *et al.* (2004) found that in the area where Isla de las Gaviotas is situated, whitemouth croaker and stripped weakfish densities were largest during the Kelp Gull reproductive and post-reproductive periods (summer and autumn, respectively). Fish availability during the reproductive period is important when chicks demand high quality food to grow and are not able to manipulate and ingest larger refuse meals (Annett and Pierotti 1989; Davoren and Burger 1999; Steenweg *et al.* 2011; Lenzi *et al.* 2019). Conversely, during the post-reproductive period, individual Kelp Gulls foraged more on refuse, despite the higher amount of natural fish and probably fishing discards available according to Jaureguizar *et al.* (2004). Possibly, female post-reproductive recovery of nutrients and energy could be achieved faster by incorporating refuse. Instead, Jaureguizar's *et al.* (2004) study might not accurately reflect the fish availability during our study period, several years later. Thus, spatial and temporal fish population dynamics might also need to be addressed in the present times to have better clues of their influence on Kelp Gull trophic ecology in the Rio de la Plata Estuary.

Long term differences in diet might also have occurred in response to a possible restriction of the feeding range due to the attachment to the reproductive colony (natural food sources can be found close to the island, while refuse sources are at least 18 Km away), and/or energetic requirements of adults and chicks (Navarro and González-Solís 2007; Steenweg *et al.* 2011). Kelp Gulls are central-place foragers, which prevent individual pairs from making long foraging trips because they have to incubate eggs or rear their nestlings. Thus, foraging on fish closer to the reproductive colony could reduce the time of foraging trips, increasing food profitability. Additionally, reproduction imposes a large physiological cost for breeding females because they invest much energy in the maturation of their reproductive system and egg production (Whittow 2002). Thus, food with high nutrient content, like fish, might be important for females to recover their reserves (e.g., calcium and proteins) after egg laying, allowing them to be more efficient during the parental care period that lasts for several weeks (Pierotti and Annett 1990; Williams 2005). During the non-reproductive season chicks have already grown and might be able to incorporate more organic refuse in their diet. In fact, other studies have recorded Kelp Gull juveniles foraging in dumps throughout the year (Yorio and Giaccardi 2002; Giaccardi and Yorio 2004).

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