



The impact of anthropogenic food subsidies on a generalist seabird during nestling growth



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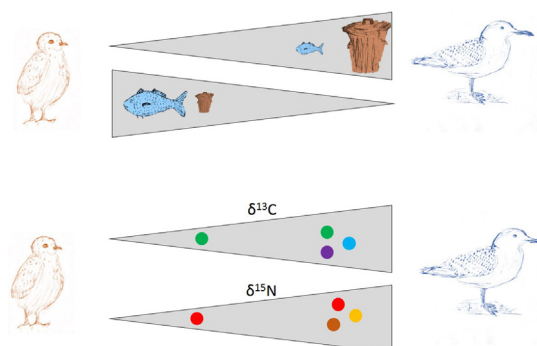
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HIGHLIGHTS

- Refuse impacted on Kelp Gull acquisition and allocation of resources.
- Kelp Gull nestlings assimilated refuse into their diets.
- Larger nestlings incorporated more refuse in their tissues than smaller ones.
- Isotopic variability increases during Kelp Gull nestlings' growth.

GRAPHICAL ABSTRACT



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ABSTRACT

Anthropogenic food subsidies, such as refuse, are an important driver of animal population changes and gulls heavily forage on this food source. Foraging on refuse during the rearing period could affect the acquisition of resources with potential demographic consequences. Using conventional diet analysis and stable isotopes of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of blood of Kelp Gull (*Larus dominicanus*) nestlings, we studied the variation of the chick growth in response to foraging on refuse on a reproductive colony in the Rio de la Plata Estuary in Uruguay. Using Bayesian mixing models on isotopic data, we estimated the proportion and variation of natural food and refuse in the diet of nestlings. Then, we modelled the variation between the mean posterior densities of the food sources and their standard deviation with the nestling morphometric measurements of different sizes. We found that refuse was gradually delivered to Kelp Gull nestlings during the chick rearing period. Additionally, variation of refuse incorporated into nestling tissues increased with nestlings' size. We propose that parents use more isotopically unique food sources during the nestling growth thereby increasing isotopic diversity. This study highlights the need to improve the current waste management system, which is being reviewed in Uruguay. We believe that decision makers should consider the results of this study, which show that refuse is directly impacting coastal ecosystems through mechanisms poorly explored by the environmental sciences.

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One of the least studied drivers of animal population change is anthropogenic food subsidies i.e., food sources derived from human activities that become available to animals (Leroux and Loreau, 2008; Polis et al., 1997). Anthropogenic food subsidies are exponentially growing (Hoorweg and Bhada-Tata, 2012) and are becoming available for coastal animals in the form of fishing discards and offal in marine ecosystems, and refuse in terrestrial and coastal ecosystems (Oro et al., 2013; Plaza and Lambertucci, 2017). While fishing discards are used by many birds, such as Charadriiformes, Procellariiformes, Sphenisciformes, and Pelecaniformes, refuse is exploited by fewer seabird taxa, where gulls emerge as the most significant group (Oro et al., 2013; Plaza and Lambertucci, 2017). Unlike other seabirds, gulls are usually generalist feeders, able to exploit a wide variety of food sources while employing a range of foraging strategies (Annett and Pierotti, 1999; Burger, 1988; Hand et al., 1987; Pierotti and Annett, 2001).

Considering the gull's plasticity in the use of food resources, the availability of anthropogenic food subsidies might have numerous socio-environmental implications. Some species have shown population size increases as a consequence of feeding on anthropogenic food subsidies, such as refuse (Belant et al., 1993; Coulson and Coulson, 1998; Duhem et al., 2005; Pons, 1992; Pons and Migot, 1995; Weiser and Powell, 2010). This phenomenon is of environmental concern because some gull species are predators of eggs and chicks of other bird species, some of them with declining population sizes and with considerable conservation challenges (e.g., Emslie et al., 1995; Martinez-Abraín et al., 2003; Voorbergen et al., 2012; Yorio et al., 1998). Moreover, several gull species expanded their breeding range and use the urban environment for nesting and feeding, causing a series of concerns about the condition of the properties and nuisance at public areas (Reynolds et al., 2019). Additionally, potential health and sanitary conflicts have been discovered because gulls are vectors of bacteria toxic for humans and cattle, with the potential to pollute freshwater sources (Anza et al., 2014; Moré et al., 2017). Gulls are the most common birds involved in aircraft strikes posing a safety hazard for air safety (Sodhi, 2002). Likewise, in South America, gulls feed on skin and blubber of southern right whales, particularly on mother-calf pairs, which reduce calf health and survivorship (Groch, 2001; Rowntree et al., 1998; Sironi et al., 2009). Hence, rising gull populations driven by increasing availability of refuse has numerous implications for socio-environmental systems.

One critical phase of the life cycle through which refuse can affect the ecology of gulls is nestling growth (Davoren and Burger, 1999). It is worth mentioning that for the purpose of this research, refuse refers to edible refuse with nutritional content, excluding plastics, glass, metal, etc. Thus, during the growth period parent's resource acquisition might be influenced by chick's body size, because larger chicks are capable of foraging on larger prey (Hone and Benton, 2005). We hypothesize that larger nestlings could be able to incorporate refuse (which is generally larger than natural food) into their diets because they are able to handle larger meals than smaller nestlings that are able to only ingest smaller, natural prey. Hence, we predict a positive relationship between refuse consumption with nestling size. We also test the hypothesis that refuse increases the variability of resource acquisition of the nestlings, and this positively correlates with nestling size. Accordingly, we predict a positive relationship between variability of refuse in the diet of individual nestlings and body size.

The overarching goal of this investigation is to study the impact of refuse on nestling growth. A powerful approach to study patterns of resource acquisition of animals and how they are impacted by ingestion of refuse is isotopic ecology through Stable Isotope Analysis (SIA). SIA is based on the assumption that stable isotopes in the proteins of the consumers reflect those of their prey in a predictable way (Peterson and Fry, 1987; Thompson et al., 1999). In recent decades it became an effective instrument to investigate the foraging ecology of animals (Wolf et al., 2009).

The most frequently employed stable isotope ratios in trophic ecology are nitrogen ($^{15}\text{N}/^{14}\text{N}$) and carbon ($^{13}\text{C}/^{12}\text{C}$). Nitrogen isotopic

signature ($\delta^{15}\text{N}$) of the proteins of consumers is enriched in 0.4–4.3‰ relative to their dietary source, and is a good indicator of trophic level of the species (Hobson et al., 1994; Kurle et al., 2014; Newsome et al., 2007). On the other hand, the carbon isotopic signature ($\delta^{13}\text{C}$) is fractionated from prey to consumer tissues at a rate from 0.1 to 4.1‰, but generally they are between 0 and 1‰ (Hertz et al., 2016; Kurle et al., 2014). Those species with small discrimination factors in $\delta^{13}\text{C}$ have small differences between basal energy sources and individual consumers. Hence, in this situation small values of discrimination factors make carbon ideal to assess the principal basal food sources of a trophic network (Hertz et al., 2016). Additionally, based on the distribution of $\delta^{13}\text{C}$ in marine ecosystems, we can also determine latitudinal variation in diets, as well as pelagic or benthic sources of $\delta^{13}\text{C}$ (Hobson et al., 1994). Moreover, using stable isotopes we can infer marine or terrestrial food diets because marine ecosystems are more enriched in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in relation to terrestrial ecosystems (Peterson and Fry, 1987).

The application of SIA has been applied to a variety of seabird species and research topics. Three principal areas have been identified by Hobson (2011): the analysis of trophic relations, and the identification of biomass sources; mapping endogenous and exogenous nutrient inputs of breeding individuals; and the study of migratory individuals or populations to their breeding grounds. In addition, niche segregation between age classes and different time scales has also been assessed (Campioni et al., 2015; Ceia et al., 2012; Votier et al., 2011; Weimerskirch et al., 2014). However, there is very limited evidence addressing the isotopic ecology of generalist and opportunistic seabirds and its variation when foraging on anthropogenic food sources such as refuse (Ceia et al., 2014).

One species with opportunistic and generalist trophic behavior is the Kelp Gull (*Larus dominicanus*) (Yorio et al., 2016). In Uruguay, it breeds on eight colonies along the coast, and almost half of its breeding population is located on the Río de la Plata Estuary (Yorio et al., 2016). This estuary is formed by the discharge of the Paraná and Uruguay rivers into the Atlantic Ocean in South America between Argentina and Uruguay. Diverse economic activities are developed in this estuary where 12 million people live. Household and recreational activities, as well as industries (fisheries, slaughterhouses, tanneries, crop mills, among others), generate a great amount of refuse available for the Kelp Gull to forage. Previous evidence based on pellet analysis has shown that refuse is present in the diet of this species in this estuary (Burgues, 2015; Lenzi et al., 2016; Petracci et al., 2004; Silva et al., 2000). Nonetheless, conventional dietary analyses have limitations, like bias towards hard parts when pellet samples are used, which provides short term information on individual diets (Barrett et al., 2007; Karnovsky et al., 2012). SIA overcomes these limitations offering a larger window of information on feeding habits, and an estimation of assimilated nutrients, not only the ingested ones, allowing us to reconstruct the chemical structure of the trophic network (Fry, 1991; Minagawa and Wada, 1984). An important disadvantage of SIA is the inability to resolve prey taxonomy, however when combined with conventional dietary methodologies, it becomes a powerful integrative approach to study the trophic ecology of organisms (Bearhop et al., 2004).

We combined conventional dietary analysis with measurements of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of gull tissues (blood) and those of their prey, to study the variation of refuse consumption on Kelp Gull nestlings during their growth. Using Bayesian mixing models (Moore and Semmens, 2008; Newsome et al., 2012), we modelled the contribution of natural and refuse sources to the nestlings' cohort in general and for each nestling in particular. Additionally, we evaluated the variation of refuse consumption among nestlings of different ages comparing the mean posterior densities and standard deviation of refuse with nestling's morphometric measurements.

1. Materials and methods

1.1. Study area

Diet and stable isotope samples for this study were obtained on a Kelp Gull colony on Isla de Flores (34°56'30"S–55°55'29"W), a coastal

island in the Río de la Plata Estuary in Uruguay during the 2017 reproductive season. This island has a surface of 29.6 ha; it is located 12 km from the coastal border of Montevideo and Canelones Departments along the Río de la Plata Estuary (Fig. 1). This island supports more than 30 species of birds where the Kelp Gull is the most abundant, especially during the reproductive season (Lenzi, unpubl. Data). The Kelp Gull colony of Isla de Flores has been estimated in approximately 5000 breeding pairs (Yorio et al., 2016).

1.2. Nestling's morphometric measurements, diet sampling, and stable isotope analysis

In order to gather morphometric measurements, diet, and blood samples of chicks, Isla de Flores was visited during the chick rearing period between 23 and 27 September 2017. Sampling during this time period reduced the likelihood that changes in food availability within the reproductive season could alter isotopic signatures. A total of 21 chicks of different body size were captured individually by hand or with the aid of a fishing landing net. Each chick was placed in a fabric bag within a box for further processing. Later on, culmen and tarsus length of chicks were measured using a digital caliper (Carrera Precision CP8806-T) to the nearest 0.1 mm. Wing length was also measured with a ruler to the nearest 1 mm. Then, nestlings were weighed with a scale to ± 0.1 g (Ohaus CL201). To obtain diet samples, we employed a stomach pump following Wilson (1984), briefly described as follows. With the aid of a syringe and a catheter, we propelled water into the stomach of the nestling. Then, the gastric system was emptied applying pressure gently on the abdomen with the bird inverted over a bucket (Wilson, 1984). After the lavage, we weighed each sample using a scale to the nearest 0.1 g, and stored it at -20 °C for SIA. Then, we cut one growing dorsal body feather and stored it in a plastic bag for further processing. Additionally, we collected 0.1 ml of blood from the brachial vein. Each blood sample was scattered on a glass microscope slide and stored for laboratory processing, following Bugoni et al. (2008). Nestlings were released in the same spot they were captured. Post-release behavior was

monitored for 3 min (every chick showed normal escape behavior, and no injury was recorded during fieldwork activities).

In the laboratory, blood and diet samples were oven dried at 60 °C for 48 h. Then, dried blood samples were scraped over clean sheets of aluminum foil. A sub-sample of 0.5–1.5 mg of each tissue (diet samples and blood) was encapsulated for further SIA. Nitrogen and carbon isotope ratios were measured by Elemental Analyzer Continuous Flow Isotope Ratio Mass Spectrometry at the Center for Stable Isotopes, University of New Mexico (<http://csi.unm.edu>) using a Costech ECS 4010 Elemental Analyzer coupled to a ThermoFisher Scientific Delta V Advantage Plus mass spectrometer via a CONFLO IV interface. Average analytical precision based on routine analysis of laboratory standards was better than 0.1‰. Lipids generally are depleted in ^{13}C relative to proteins and carbohydrates which introduces potential biases to the results. Thus, isotopic signatures of consumers and prey with a C:N ratio greater than 3.5 were mathematically lipid-corrected using Eq. (3) of Post et al. (2007).

Stable isotope ratios were expressed in conventional notation as parts per thousand according to the following equation:

$$\delta X = \left[\left(\frac{R_{\text{sample}}}{R_{\text{standard}}} \right) - 1 \right] * 1000$$

where δX is $\delta^{15}\text{N}$ or $\delta^{13}\text{C}$ and R_{sample} is the corresponding ratio $^{15}\text{N}/^{14}\text{N}$ and $^{13}\text{C}/^{12}\text{C}$. R_{standard} is based on the $^{15}\text{N}/^{14}\text{N}$ or $^{13}\text{C}/^{12}\text{C}$ ratio of a given standard. In the case of $\delta^{13}\text{C}$ the standard is the isotopic signature of Vienna Pee Dee Belemnite (V-PDB). The standard for $\delta^{15}\text{N}$ is the $^{15}\text{N}/^{14}\text{N}$ ratio of air nitrogen.

1.3. Stable isotope Bayesian mixing models

Prior to the analysis of the mixing models we tested the assumptions that every source in a mixing model contributes to the diet of the consumer, and that the model correctly explained the isotopic signature of the consumers (Smith et al., 2013). Additionally, the assumption



Fig. 1. Geographical location of the study area.

that trophic enrichment factors, isotopic turnover rates, and variance in source signatures were assumed to be correct. These assumptions were tested using a sensitivity analysis following the procedure of Smith et al. (2013). We used the four most representative sources in our sample (fish, chicken, insects and fat) not considering any aggregation of food items (see below). Results of this analysis showed that assumptions were met (consumer isotopic signature falls within a polygon formed by the sources signatures), and are presented as Supplementary Material in Fig. S.1.

Because the use of multiple basal resources can favor the underdetermination of contributions of each resource in mixing models (Fry, 2013), the isotopic signatures of the most important resources were selected when they represented more than 25% of the diet. Based on this criteria we defined “natural diet” as those remains composed of fish (Scaenidae), and “refuse diet” to those composed of chicken remains (see Results). According to Burgues (2015) and J. Lenzi unpublished data, fish and chicken are by far the most frequent prey items of the Kelp Gull in the Rio de la Plata Estuary. It is important to note that refuse consumed by nestlings was not composed of plastics or other non-digestible items.

The modelling approach considered the entire set of blood samples representing the colony level and the individual level. The contribution of natural and refuse diets was estimated from chicks' regurgitation samples, because selecting only the well-known diet items is essential for model accuracy (Parnell et al., 2010). Priors for the Bayesian mixing models were set as uninformative, following a Dirichlet distribution.

The models also require the trophic discrimination values for $\delta^{15}\text{N}$ of blood, i.e., the difference of the isotopic signature between predators and prey. Because there are no published discrimination factors of Kelp Gull blood, we used discrimination factors from published controlled experiments of other gull species. Discrimination factors used were $3.1 \pm 0.2\text{‰}$ for nitrogen and $-0.3 \pm 0.8\text{‰}$ for carbon, from the studies on Ring-billed Gull (*Larus delawarensis*) (Hobson and Clark, 1992). To perform the Bayesian mixing models, we used MixSIAR models contained in the MixSIAR package (Stock and Semmens, 2016) of R v. 3.4.3 (R Development Core Team, 2018).

1.4. Variation of diet sources with nestling size

To analyze the variation between diet sources (natural food and refuse) and nestling size, we correlated the mean posterior density of refuse, estimated by Bayesian mixing models of individual chicks, with wing length, culmen length, tarsus length, and weight of chicks using Spearman correlation. For those significant correlations, we fitted linear and non-linear models with the morphometric measurements as dependent variables and the posterior density of refuse as independent variables. This allowed us to examine the shape of the relationship between refuse assimilation and nestling growth measurements. The models employed were the Linear, vonBertalanffy, Logistic, and Gompertz equations. To discern which model best fitted the data we used Akaike Information Criterion (AIC) (Akaike, 1973). The model with the lowest AIC value was selected as the candidate to best explain the data. If the difference in AIC values between the model with the lowest AIC and the following competing model were less than or equal to 2 units, both models were selected as candidate models (Johnson and Omland, 2004).

Table 1
Diet based on stomach lavage of Kelp Gull chicks ($n = 23$) hatched on Isla de Flores during the 2017 reproductive season.

Item	Occurrence in chick's stomach	Percentage of occurrence	Weight (Mean \pm SD)	Weight %
Fish (Scaenidae)	9	39.1	33.99 \pm 24.1	26.0
Chicken	7	30.4	18.11 \pm 12.8	13.8
Insects	1	4.3	2.20 \pm 0.0	1.7
Animal fat	3	13.0	15.17 \pm 8.4	11.6
Animal guts	2	8.7	41.75 \pm 2.1	31.9
Shrimp	1	4.3	19.60 \pm 0.00	15.0

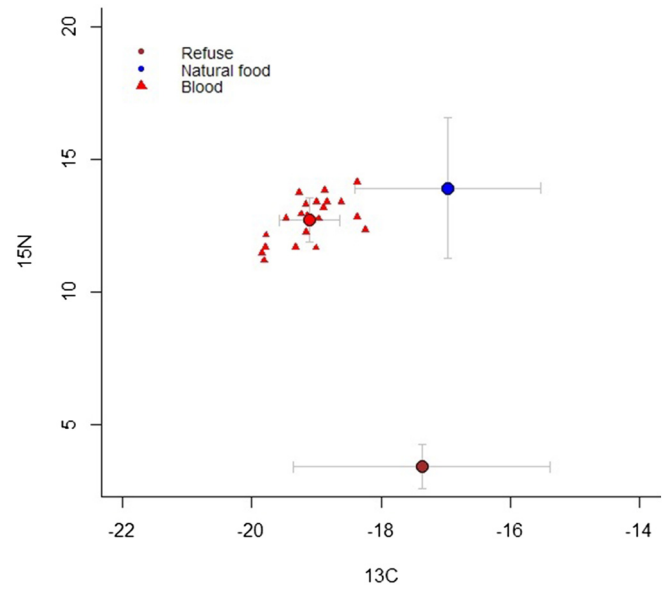


Fig. 2. Biplot of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ signatures of food sources (natural and refuse), and blood of Kelp Gull nestlings from Isla de Flores. Lipid content was corrected in both consumers and prey following Eq. (3) of Post et al. (2007).

To evaluate the variation between diet variability of individual chicks and their body size, we calculated the standard deviation (SD) of refuse from the Bayesian mixing models to obtain a measure at the individual level of the variability of the isotopic signatures (Newsome et al., 2007). Thus, we followed the procedure as with the mean posterior density, using the same model selection approach. To perform model fitting and selection, we used PAST software v 3.14 (Hammer et al., 2001).

2. Results

Six food categories were found in 23 nestling stomachs (two extra diet samples were collected from two of the 21 nestlings) represented mostly by fish and chicken that accounted for 70% of the diet. Additionally, insects, animal fat, animal guts, and shrimp were observed as well but in much lower proportion (Table 1). Although we only found two samples of animal fat, this was the heaviest item with a mean of $41.75 \text{ g} \pm 2.1$ followed by shrimp, which was collected once (19.60 g).

The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ isotopic signatures in nestlings' blood were $-19.11\text{‰} \pm 0.47$ and $12.72\text{‰} \pm 0.84$, respectively (Fig. 2). Additionally, signatures for natural food were $-16.98\text{‰} \pm 1.44$ for $\delta^{13}\text{C}$ and $13.91\text{‰} \pm 2.65$ for $\delta^{15}\text{N}$, and for refuse was $-17.37\text{‰} \pm 1.98$ for $\delta^{13}\text{C}$ and $3.44\text{‰} \pm 0.84$ for $\delta^{15}\text{N}$ (Fig. 2).

Posterior densities estimated from Bayesian mixing models at the colony level, indicated that nestlings assimilated more natural food than refuse. Mean posterior densities for blood were for natural food 0.55 ± 0.04 , Bayesian credible intervals - BCI [0.47–0.65], and for refuse 0.45 ± 0.05 - BCI [0.32–0.53]. Refuse assimilation predicted from Bayesian mixing models positively correlated with wing and culmen lengths (Table 2). The model selection approach showed that the Logistic

Table 2

Spearman correlation between chick morphometric measurements and mean refuse and standard deviation (SD) predicted by Bayesian stable isotope mixing models for blood of Kelp Gull chicks ($n = 21$) on Isla de Flores during the 2017 reproductive season.

	Chick measurement	Spearman ρ	P-value
Blood			
Mean/SD refuse	Wing	0.49/0.45	0.03/0.06*
	Culmen	0.55/0.44	0.01/0.06*
	Tarsus	0.33/0.34	0.15/0.12
	Weight	0.32/0.33	0.16/0.15

Results in bold indicate significant P-values.

* Indicate marginally significant P-values used in the model selection analysis.

Equation was the model that best explained the co-variation between refuse and wing length (Table 3). Alternatively, Logistic, vonBertalanffy and Gompertz equations were the models that best described the variation between culmen length and refuse (Table 3, Fig. 3).

Model parameters of the logistic equation for wing length indicate that parents feed their nestlings with refuse exponentially, up to 69 mm (i.e., inflection point of the logistic curve) wing length (Goshu and Koya, 2013). Nestlings larger than this figure were fed by refuse up to an asymptotic wing length of 138 mm (Table 3, Fig. 3). A similar pattern occurs with nestling's culmen growth. Logistic, vonBertalanffy and Gompertz models indicate that parents fed their nestlings with refuse from their hatching (inflection points between 13 and 21 mm. of culmen size) up to their maximum asymptotic culmen length of 42–43 mm. (Table 3, Fig. 3).

As nestlings grow, the standard deviation, estimated from Bayesian mixing models for refuse positively correlated with wing and culmen lengths, although this was not statistically significant ($P = 0.06$; Table 2). The best model that described the relationship between SD of refuse with wing length and culmen length, was the Logistic Equation (Table 4, Fig. 4).

3. Discussion

Fish and chicken were the most frequent diet items recorded in the stomachs of Kelp Gull chicks on Isla de Flores. By frequency and weight, fish was the most important food item recorded in the diet of Kelp Gull nestlings. Unfortunately, we cannot establish if fish originated from fishing discards or from natural foraging. Interestingly, we did not record beef in chick diet samples, which is another frequent food source for adult Kelp Gulls in the Rio de la Plata Estuary of Uruguay (Burgues, 2015; unpubl. data). Larger nestlings tended to be fed with a higher proportion of refuse than smaller nestlings probably because refuse (mostly chicken wings in our study) have larger bones and are more difficult to manipulate and ingest than small fish (Annett and Pierotti,

1989; Steenweg et al., 2011). In addition, availability of fish (i.e., Sciaenidae) could increase during the chick rearing period due to dispersion and/or reproductive movements, allowing Kelp Gull parents to feed their chicks with this natural source. We tried to avoid this potential confounding factor by sampling the chicks of different sizes within a short period of the breeding season. However, we acknowledge that physiological condition might vary with chick size and potentially affect isotopic signatures. Considering this, we find support to the hypothesis that changes in body size of chicks could affect resource acquisition, because larger individuals may be capable of ingesting larger prey items provisioned by parents (Hone and Benton, 2005). Evidence to support this hypothesis has been found elsewhere (e.g., Brousseau et al., 1996; Pedrocchi et al., 1996; Ramos et al., 2009) and for the Kelp Gull in particular, although at the population level (Bertellotti and Yorio, 1999; Favero and Silva, 1998; Ludynia et al., 2005).

The incorporation of refuse into a nestling's diet might have implications for nestling survival and recruitment. Refuse could provide more energy to individual nestlings than natural food (Hunt, 1972) and also could increase the frequency of feeding bouts because it is highly spatially predictable. This might increase recruitment for the breeding population, which has direct implications to population dynamics. In Argentina, 29% of the Argentinean Kelp Gull colonies are annually increasing by 10–20% (Lisnizer et al., 2015). These authors found that individuals forage on anthropogenic food subsidies in those regions where recruitment and intrinsic population growth are very large. On the other hand, foraging on refuse may have negative implications for chick survival, indicating that energy provided by refuse might not be enough for chick growth and development (Pierotti and Annett, 1987). Instead, nutritional quality could better explain the lower fitness observed in those individuals that forage on refuse, than those that forage on natural food (Pierotti and Annett, 2001).

Considering that there is an industrial trawling fleet that operates in the Rio de la Plata Estuary that produces 2800–6700 tons of discards annually (Kelleher, 2005; Rey et al., 2000), and that adult Kelp Gulls forage on this type of resource in the estuary (Yorio et al., 2016), the question is why Kelp Gull breeding on Isla de Flores do not feed their chicks exclusively with fishing discards, and feed their chicks with refuse instead. According to Pierotti and Annett (2001), fish are an important source of nutrients that chicks will not find in the refuse, so this should be the principal food source for these chicks. Possibly, the availability of fishing discards might not be as predictable as refuse is, and when mixed with other foods, can support the nutritional needs of the nestlings. Pierotti and Annett (2001) performed an experiment where they fed a group of Western Gull nestlings with chicken and another group with fish, and the first group experienced severe developmental problems, unlike the second group. However, in a natural situation like this study, individuals feed on a variety of natural food sources that might complement a refuse-based diet, for instance marine and terrestrial invertebrates, besides fish.

Kelp Gull nestlings fed on a range of food sources, possibly with a mixture of nutritional content, which could buffer potential negative impacts of foraging solely on refuse. This idea is supported by the evidence we found for the hypothesis that larger nestlings showed more variability in resource acquisition, shown by a positive relationship between the standard deviation of refuse and body size. This suggests that diet variability increases with body size, and diet variability (feeding on refuse) results in an expansion of nestling isotopic composition. According to Yeakel et al. (2016), this could be possible because parents use more isotopically unique food sources during nestling growth, like refuse from terrestrial ecosystems, which is depleted in ^{15}N composition in comparison with marine food sources. Thus, if isotopic variability increases during nestling growth, we might propose that older nestlings become more isotopic generalists as they grow (Yeakel et al., 2016).

We should also consider the possibility that the increase of a generalist behavior with nestlings' age might not be related with an expansion of the isotopic variability by feeding on refuse, but with

Table 3

Linear and non-linear models describing the variation between wing length (WL) and culmen length (CL) with the mean posterior density of refuse (R) predicted by the Bayesian mixing models in blood samples of Kelp Gull nestlings ($n = 21$) from Isla de Flores during the 2017 reproductive season. AIC values that designate the selected models are shown in bold.

	Wing (WL)	Culmen (CL)
Blood		
Linear model	WL = 480.4 * R - 63.9	CL = 42.2 * R - 18.3
AIC	80,727	743
Logistic	WL = 137.8/1.5E09 * exp. (-34.6 * R)	CL = 41.5/(1.87.5 * exp. (-10.1 * R))
AIC	72,821	729
vonBertalanffy	WL = 193.5 * (1 - 15.7 * exp.(-10.1 * R))	CL = 42.8 * (1 - 2.4 * exp. (-6.7 * R))
AIC	75,810	731
Gompertz	WL = 178.8 * exp.(-1010.8 * exp. (-21.3 * R))	CL = 42.1 * exp.(-4.6 * exp. (-8.4 * R))
AIC	74,075	729

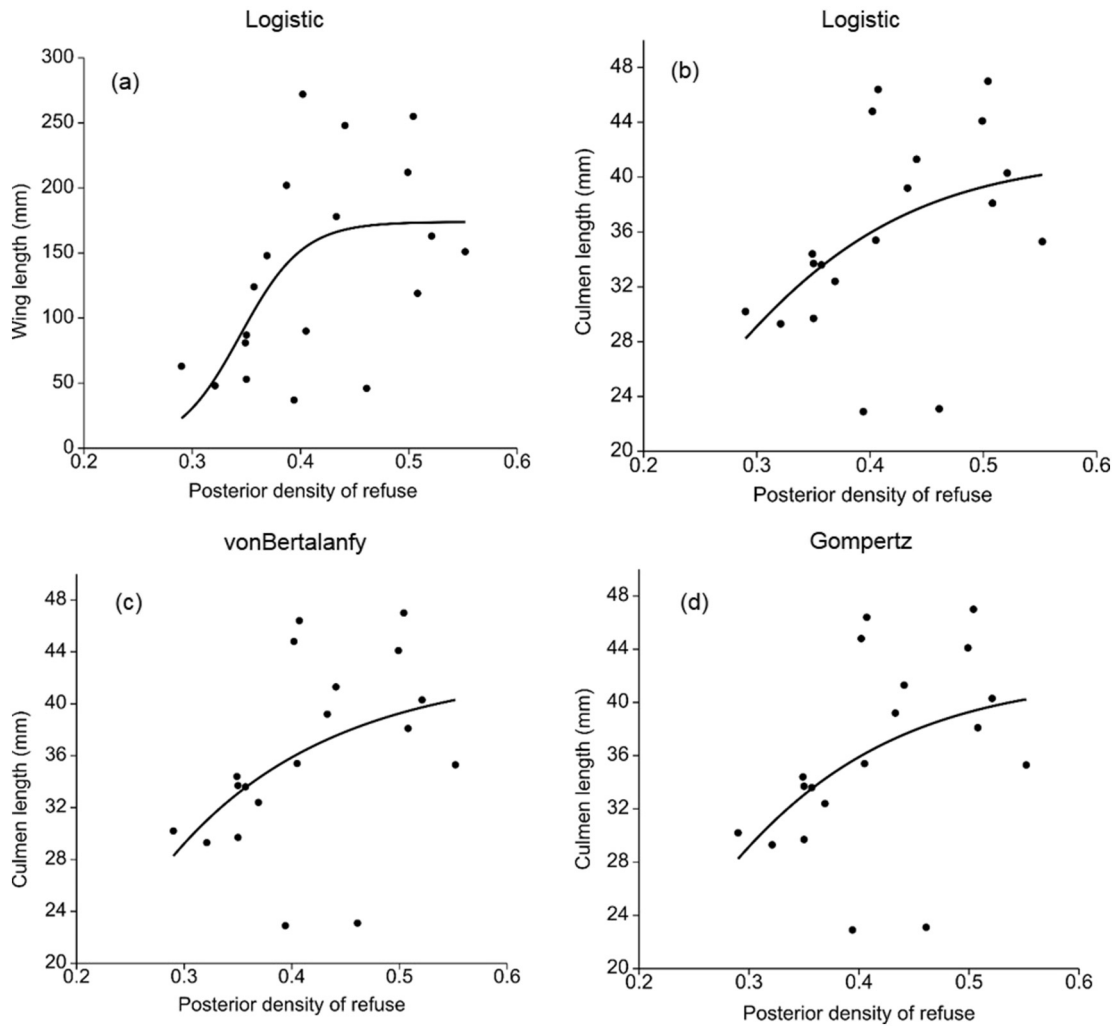


Fig. 3. Non-linear equations selected from the model selection analysis describing wing (a) and culmen (b, c, d) lengths of chicks with the mean posterior density of refuse estimated by the Bayesian mixing models of chick’s blood from the colony on Isla de Flores.

specialists foraging in a variety of habitats, including refuse (Flaherty and Ben-David, 2010). In our study system, however, nitrogen isotopic signature clearly separated the terrestrial and aquatic foraging habitats, with refuse (chicken) and fish representing each habitat, respectively. Alternatively, it is possible that diet items foraged by parents in different habitats might not have been recorded during the collection of nestling diet samples. Consequently, it is possible that foraging parents increase the isotopic diversity of the sample through the addition of unexpected specialist individual nestlings.

As an anthropogenic food subsidy, refuse has the potential to alter not only many aspects of the life cycle of seabirds, but also the insular

ecosystems where they reproduce. Because adult Kelp Gulls acquire resources for their nestlings in terrestrial ecosystems, they are able to translocate energy and nutrients to insular ecosystems (González-Bergonzoni et al., 2017). Refuse may not only be subsidizing the Kelp Gull, but also the rest of the insular terrestrial communities. In the Rio de la Plata Estuary, some coastal islands are inhabited with exotic vegetation (Guido et al., 2013), which could receive an extra supply of nutrients from human refuse, digested and excreted by nestlings and adults. In this context, a positive feedback within the community is expected, as Kelp Gull reproductive success improves with an increase in vegetative cover available for nesting (Yorio et al., 1995). If vegetation cover

Table 4

Linear and non-linear models describing the variation between wing length (WL) and culmen length (CL) with the standard deviation of the estimation of refuse (SD_R) from the Bayesian mixing models in blood samples of the Kelp Gull chicks from Isla de Flores during the 2017 reproductive season. AIC values that designate the selected models are shown in bold.

	Wing (WL)	Culmen (CL)
Blood		
Linear model	WL = 6263.4 * SD _R -716.1	CL = 516.6 * SD _R 34.7
AIC	79,153	768
Logistic	WL = 178.2/1 1.4E20 * exp.(-303.8 * SD _R)	CL = 41.7/(1 2.8E09 * exp.(-106.3 * SD _R))
AIC	72,756	729
vonBertalanffy	WL = 193.4 * (1-4.5E10 * exp.(-124.0 * SD _R))	CL = 43.5 * (1-1489.6 * exp.(-66.7 * SD _R))
AIC	75,370	764
Gompertz	WL = 180.5 * exp.(-8.8E16 * exp.(-232.2 * SD _R))	CL = 42.4 * exp.(-20121 * exp.(-86.3 * SD _R))
AIC	73,762	763

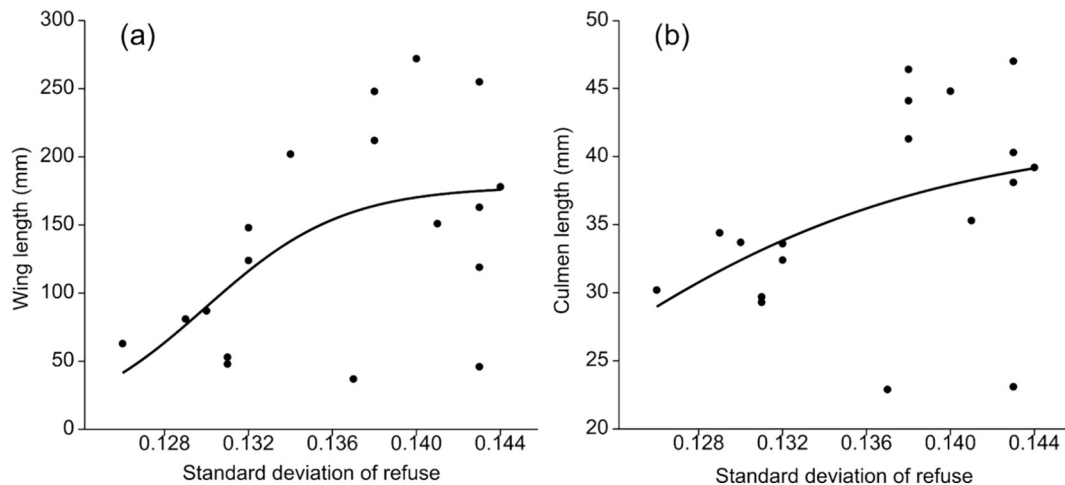


Fig. 4. Equations selected from the model selection analysis describing wing (a) and culmen lengths (b) of Kelp Gull chicks with the standard deviation of refuse estimated by the Bayesian mixing models of chick's blood from the reproductive colony on Isla de Flores.

increases as a product of nutrient translocation, we could expect an improvement in reproductive success of the Kelp Gull, as well. Hence, anthropogenic food subsidies and insular ecological systems, which might apparently be unrelated, could be connected by animal diet and movements, and might have unknown impacts that require study.

4. Conclusions

This study supports the idea that one of the consequences of an inadequate waste management system is that it makes available energetic and nutritional subsidies to generalist seabirds like gulls, with potential individual- to ecosystem-level effects. Refuse was ingested and assimilated by Kelp Gull nestlings during the rearing period. The amount of refuse incorporated to nestling's tissues increased with age supporting the hypothesis that larger nestlings could be able to incorporate refuse to their diets because they are able to handle larger meals than smaller nestlings. Additionally, the variability of incorporation of refuse nestlings' tissues was broader as they aged, supporting the hypothesis that refuse increase the variability of parent's resource acquisition as nestlings could incorporate bigger meals during growth.

This study incorporates a new dimension to waste management practices, which could be useful for managers and stakeholders. The government of Uruguay and private organizations are elaborating a law to regulate waste production and management, which intends to promote the circular economy to optimize the use of materials along their life cycle, encourage new business opportunities from waste, promote employment generation, and ultimately achieve environmental and economic sustainability. This study shows that environmental implications of refuse are not only associated to follow parameters and practices related to waste generation, collection, and final deposition; it is also related with the ecological functioning of socio-ecological systems, which are connected through animal foraging as well. Considering this dimension of waste management, we could prevent future environmental problems including biodiversity loss, coastal pollution, strikes with aircrafts, water quality, and health problems, among others.

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.scitotenv.2019.05.485>.

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