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Between the Land and Sea: How Yellow-Legged Gulls Have Changed Their Dependence on Marine Food in Relation to Landfill Management

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Abstract

The Basque region (Spain) is closing all its open-air landfills, which hence provides an excellent chance to account for the effects on the trophic and spatial ecology of the local yellow-legged gulls *Larus michahellis*, which highly depend on refuse tips to forage. The closure of several landfills across the region was mainly compensated by a higher intake of terrestrial food (mainly earthworms), though only in summer. The exploitation of terrestrial prey was marginal in winter, and seasonal trophic differences emerged, unlike findings when landfills were still open. With only one landfill now open in theory, movement and territory use analyses showed that two landfills were frequently visited. Positions at two of the target foraging habitats (landfills, pastures) summed ca. 10% of all stationary positions suggesting that, at least in these habitats, gulls seemed to invest a relatively small amount of time, which might support the idea that they were able to obtain food in a fast way and, probably, from resources that they know well and have a predictable temporal distribution.

Keywords: *Larus michahellis*, refuse tips, seabirds, spatial ecology, stable isotopes, trophic ecology

1. Introduction

Many species of gulls take great profit from exploiting feeding sources of human origin all around the world, such as fish discards or refuse tips [1–3]. When such resources are abundant and predictable over time, they can have a very deep impact into population parameters like survival [4], breeding performance [5, 6], or dispersal [7, 8].

The current European policy on refuse management previews to close all open-air landfills by 2020. This entails that many gull populations with high dependence on this resource will suffer severe declines in one of their main preys, with expected impacts on several life history aspects, from diet to spatial ecology or demography. At regional levels, the implementation of such policies provides us an excellent scenario to test for the effect of this change and evaluate the capacity of such species to rapidly adapt to the new environment.

The Basque region in northern Iberia is closing all its open-air landfills [8], which hence provides a good chance to account for the effects of this process on the diet and territory use of the local yellow-legged gulls *Larus michahellis*. The population of this species within the region reached a size of up to ca. 5600 adult breeding pairs during the decade of 2000, though, today, the population has probably less than 3000 pairs (J. Arizaga, unpubl. data), with moderate-[9] to-strong [10] decreases in most colonies.

When the use of landfills was generalized within the region, an important part of the diet was based on refuse food, and the rest was mainly fish or food of marine origin, while just ca. 10% of the diet comprised food of terrestrial origin, mainly earthworms [3]. During the decade of 2010, however, the number of active landfill sites has reduced quite consistently. Thus, in a winter coinciding with local landfill sites either closed or using falconry to deter gulls access to refuse tips, gulls were found to travel longer distances [7]. This suggests that they were forced to look for food in further distant places, which might also entail trophic changes.

The aim of the chapter is to determine how diet and territory use of a resident yellow-legged gull population has changed between two periods characterized by high and virtually low availability of food of landfill origin. For the second period, we also want to test if marine food has now more importance in the diet than before [11], that is, whether the marine environment is able to absorb a trophic demand that landfills virtually are not.

2. Material and methods

2.1. Sampling area

Results provided in this chapter were collected in the Gipuzkoa province, northern Iberia. Today, this region hosts a total of 5 colonies with a population size slightly inferior to 1000 adult breeding pairs overall. Of these, the sampling was carried out in three colonies which are the most important ones (from east to west): Ulia, Santa Clara and Getaria (**Figure 1**). All the colonies are situated in marine cliffs of similar characteristics. The population at Getaria and Santa Clara has an uncertain trend (possibly stable), while the one at Ulia is estimated to be in decline [12].

As reported in **Figure 1**, the colonies are situated either close to fishing harbors or landfills. By far, the most important harbor within the region is situated in Getaria, while, in theory, all landfills have been closed and only one (Zaluaga), situated in a nearby region from France,

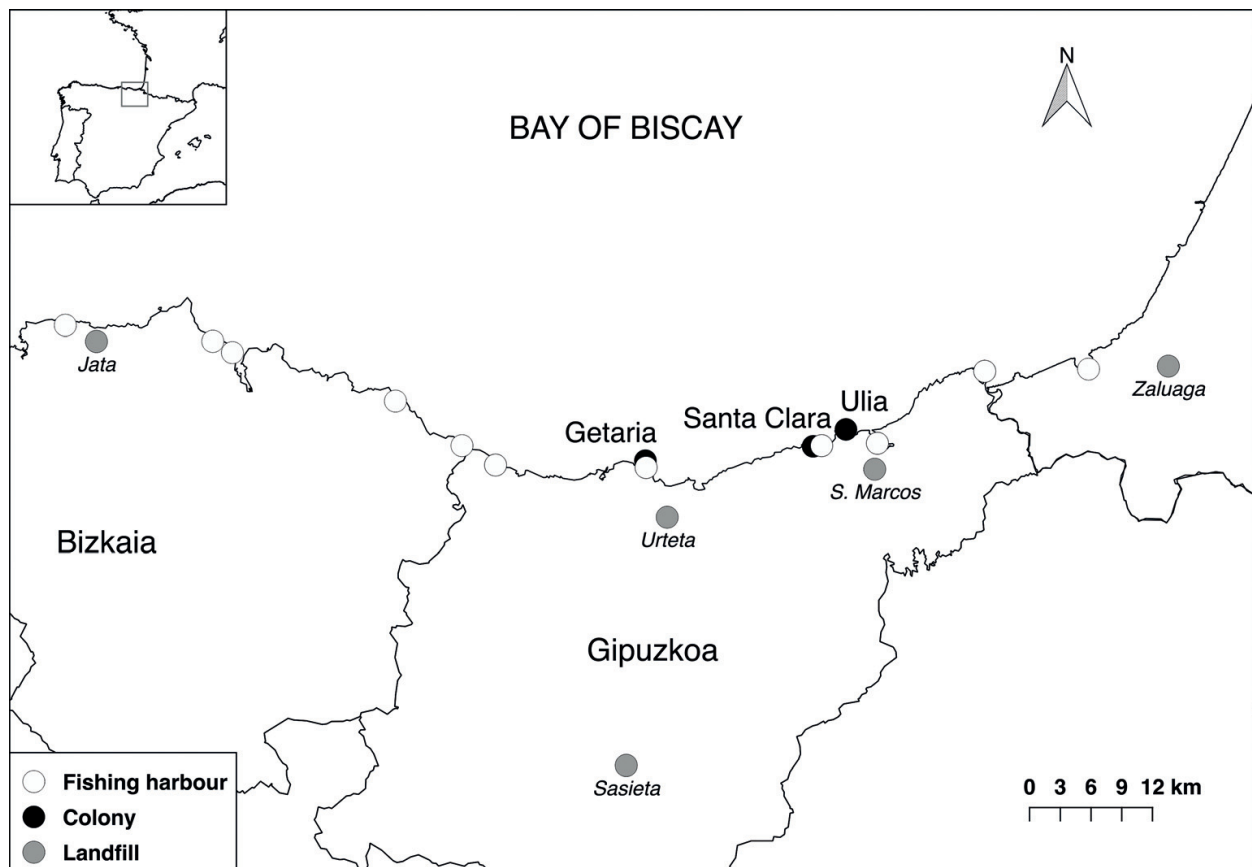


Figure 1. Geographical distribution of the colonies analyzed, and the main trophic sources (fishing harbors and landfills) existing within the region were the focus of the study and it was carried out from 2007 to 2016.

remains open (**Figure 1**). This last landfill site is known by attracting large numbers of several bird species, including gulls [13].

Regarding landfills, we considered in this study those situated within a radius of 75 km around our target colonies, since most local yellow-legged gulls do not move farther away during their whole life [7] and where marked gulls have been located. Included landfills were S. Marcos, Urteta, Zaluaga, Sasieta and Jata (**Figure 1**). Overall, these five dumps accumulated a mean annual amount of ca. 286,292 tons (**Table 1**). From a landfill management standpoint, two periods can be drawn: one with high food availability, when all these landfill sites within

Landfill	Period closed	Mean annual discharge (Tn)
S. Marcos	Since Oct. 2008	68,896
Urteta	Since Dec. 2014 (falcon: Dec. 2009–Dec. 2014)	91,079
Sasieta	Since Jan. 2015 (falcon: 2014)	71,086
Jata	Since Dec. 2013 (temporally re-open in Feb. 2016)	14,638
Zaluaga	Open (falcon: Oct. 2010–Jan. 2011) (deter works: since 2013)	40,593

Table 1. Characteristics of the five landfill sites existing within the region (around a 75 km radius from the colonies analyzed).

the region were open, and another one when most of the sites had been closed and only one/two remained open (but used falconry or other deterring tools).

2.2. Data collection

The sampling protocol consisted of (1) collecting feathers from chicks and adults in order to estimate their diet with stable isotopic analyses and (2) attaching GPS devices in adults in order to analyze their spatial behavior and territory use.

Throughout the breeding season of 2007–2009 and 2014–2016, both chicks and adults were captured in the colonies for the collection of body (chicks) or wing (adults) feathers for the corresponding stable isotope analysis. Chicks were caught by hand at the age of ca. 20 days [14]. In total, 4–6 dorsal (mantle) feathers were taken and their body mass and tarsus length were also measured. In order to avoid possible pseudo-replications, we only considered one chick per nest. Adults were captured using spring traps while incubating. We took from them two wing feathers: the inner, first primary feather (P1) (it grows just after breeding and hence has isotopic values reflecting the diet during the preceding reproductive period) and the secondary S6 (grown in autumn-winter, thus reflecting the diet during the previous non-breeding period). In case they had already molted one of such feathers (usually P1), the next non-molted feather was taken. While chicks were sampled for the entire period (years 2007–2009 and 2014–2016), adults were only sampled in the years 2008–2010 and 2016. Feathers were stored in paper bags until they were analyzed in a laboratory (see below for details).

Regarding spatial ecology, overall, we captured using spring traps a total of 15 adult birds when they were incubating in 2017. Once captured, they were attached with a prototype GPS device provided by Wimbike, S.L. This device was linked to the bird with a hand-made Teflon harness. The weight of the GPS was always less than 5% of the bird's body mass. GPS was programmed in order to obtain a location every 30 min from 06:30 to 22:30 (GMT + 1), with two more positions at night (01:00 and 04:00).

2.3. Stable isotope analysis and mixing models

We used $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ signatures for the stable isotopic analyses. The methodology used for that goal was described in detail in Arizaga et al. [3] and was the same for the period 2007–2009 and 2014–2016 in order to obtain comparable results. Feathers were washed in a solution of 1 M NaOH, dried (60°C) to be homogenized into fine powder with an impactor mill (freezer/mill 6750-Spex Certiprep) operating at liquid nitrogen temperature. Weighed subsamples of such powdered feathers (ca. 0.3 mg) were put in tin capsules and isotopic analysis was carried out with an elemental analysis-isotope ratio mass spectrometry (EA-IRMS) using a Thermo Finnigan Flash 1112 coupled to a delta isotope ratio mass spectrometer via ConFlo III interface. Analyses were carried out at the Serveis Científics Tècnics [Technic Scientific Service], University of Barcelona.

To assess for the relative contribution of each resource category, we conducted a Bayesian multi-source mixing model (stable isotopic analyses in R: SIAR) [15]. Overall, we considered three prey types: landfill, marine, and terrestrial. Diet reconstruction in SIAR models was

Prey category	<i>n</i>	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$
Terrestrial ^a	5	-23.84 ± 2.90	$+8.86 \pm 2.82$
Landfill ^b	3	-21.12 ± 1.17	$+4.35 \pm 1.88$
Marine ^c	8	-18.04 ± 0.65	$+11.14 \pm 1.87$

Table taken from Arizaga et al. [3].

^aIncludes: annelids (earthworms), mollusks (family *Arionidae*).

^bPork, beef, and chicken.

^cFish prey of both benthic and pelagic origin.

Table 2. Isotopic signatures (mean \pm 95% confidence interval) of three prey types obtained from regurgitates of yellow-legged gull chicks in Gipuzkoa.

carried out considering the isotopic signatures of prey obtained from regurgitates (**Table 2**). SIAR results have been presented at 95, 75, and 50% credible intervals for the three types of feeding sources considered. Statistical analyses were done in R [16].

2.4. Movement and territory use analyses

We used for such analyses data on 8 out of the 15 gulls marked. This was due to the fact that some devices did not provide enough data for the analyses or due to the abandonment of the colony before the end of the breeding season. Selected individuals, therefore, were those shown to remain in the colony for the entire breeding season and with a high amount of data for the analyses (**Table 3**).

Our GPS devices did not provide information on whether the bird was flying or was in a stationary position (feeding, resting, ...). Thus, in order to know whether the bird was in the air or whether it had landed, we considered locations in which the bird was found in less than 500 m from the previous location as stationary. The remaining locations were considered as flying.

Bird ID	Colony	Sex	Capt. date	Last date with data	No. positions	Max. distance (km)
ID 02	Ulia	M	17/05/17	15/07/17	777	41.2
ID 05	Ulia	M	23/05/17	03/06/17	204	32.5
ID 09	Ulia	F	23/05/17	15/07/17	2345	47.2
ID 11	Santa Clara	M	13/06/17	15/07/17	1059	36.0
ID 12	Getaria	F	02/06/17	22/06/17	578	35.0
ID 13	Getaria	M	03/06/17	15/07/17	1818	55.0
ID 14	Getaria	F	02/06/17	15/07/17	1511	33.3
ID 15	Getaria	M	02/06/17	15/07/17	1906	68.6

Analyses were constrained to data obtained up to 15 July (here assumed to be the end of the breeding season).

Table 3. Data provided by the selected adult yellow-legged gulls marked with GPS.

Every stationary position was attached to a single habitat using CORINE land cover. Thereafter, original habitats were lumped into 11 categories: marine (positions over the sea), landfill, pastures, colony, forest, bare soil, harbor, beach, marsh, river and urban.

Finally, we also determined the distance to all positions (either in flight or stationary) to the colony.

3. Results

3.1. Trophic ecology

Mixing models on C and N signatures of chicks revealed a slight- (marine prey, from >40 to <40%) to-moderate (landfill prey; from 40 to ca. 20%) decrease in the proportion of prey of marine or refuse origin between the periods 2007–2009 and 2014–2016 (**Figure 2**). In parallel, we also detected a remarkable increase (from <20 to ca. 40%) of prey of terrestrial origin (**Figure 2**).

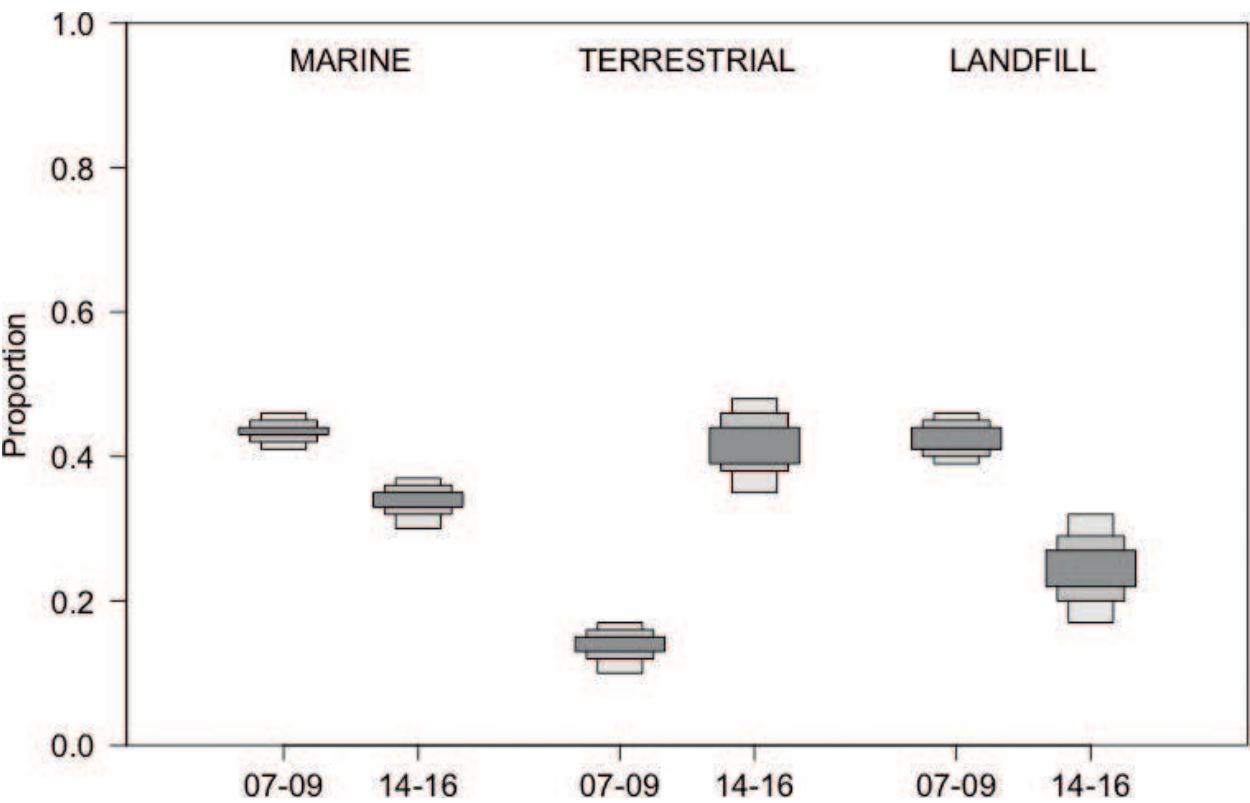


Figure 2. Mean (± 95 , 75, and 50% credibility intervals) proportion of prey type contribution to chicks' diet between two periods of high (2007–2009; $n = 172$) and low (2014–2016; $n = 80$) availability of prey of landfill origin.

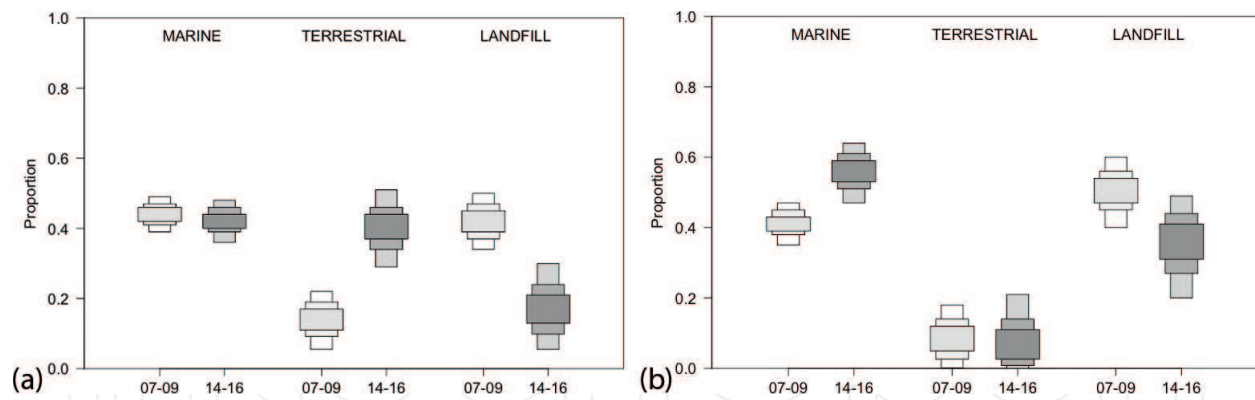


Figure 3. A. Mean (± 95 , 75 and 50% credibility intervals) proportion of prey type contribution to adults' diet between two periods of high (2007–2009; $n = 36$) and low (2014–2016; $n = 33$) availability of prey of landfill origin in summer time. B. Mean (± 95 , 75 and 50% credibility intervals) proportion of prey type contribution to adults' diet between two periods of high (2007–2009; $n = 36$) and low (2014–2016; $n = 33$) availability of prey of landfill origin in winter time.

Regarding adults, a pattern like that was found in their offsprings, which was detected for the summer period (**Figure 3**), highlighting the importance of prey of terrestrial origin during the 2014–2016 period. The estimation of the diet in winter, however, fitted to another pattern (**Figure 3**). In this period, the diet was enriched in prey of marine origin during the period 2014–2016 as compared to 2007–2009 (up to ca. 60%) and became poorer in prey of landfill origin (up to ca. 40%). The amount of prey of terrestrial origin did not vary substantially between the two periods and in both was very low ($<10\%$).

3.2. Spatial ecology

The eight adult gulls marked in 2017 used an area comprising the coast and marine areas situated close to their breeding colonies, some inland places also situated near the colonies and some clear ways connecting the colonies with the main landfills within the region (**Figure 4**). Overall, these birds moved across a mean home range area of 711.5 ($SE = 182.6$) km^2 (95% kernel polygons). The 50% kernel polygons, however, revealed much smaller home ranges (51.4 ± 15.5 km^2).

Concerning the territory use, the majority (ca. 60%) of stationary positions were obtained at the colonies, followed by marine habitats (ca. 20%), urban zones (ca. 10%), and pastures and landfill sites (ca. 5% each) (**Figure 5**). Field observations show that the urban zones are used mostly for rest (e.g., roosting places at industrial buildings or pavilions, etc.), while pastures and landfill sites constitute foraging habitats. Sea areas would be used both to feed and rest (*sensu lato*, including sleeping, preening, etc.).

Distance from the colony tended to increase around midday (**Figure 6**). Positions at night or during both the first hours and the last ones of the day were detected at a mean distance of ca. 10 km. Moreover, males were found to reach shorter mean distances (8.2 km, $SE = 1.0$ km) than females (12.4 ± 4.3 km), but the difference was non-significant ($t = 0.485$, $P = 0.628$).

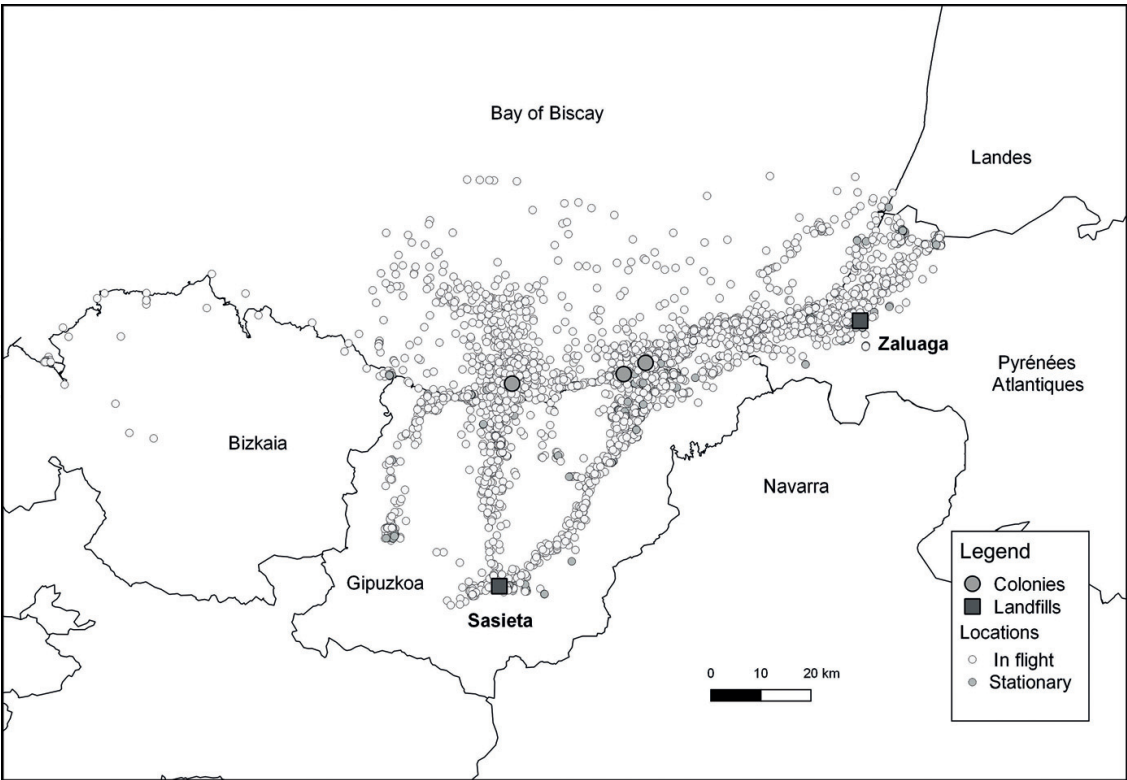


Figure 4. Geographic distribution (as provided by GPS devices) of adult yellow-legged gulls ($n = 8$) during breeding season of 2017. Adults were caught and marked at three colony sites in Gipuzkoa. The main still existing landfill sites within the region are Zaluaga and Sasieta (the last is theoretically closed).

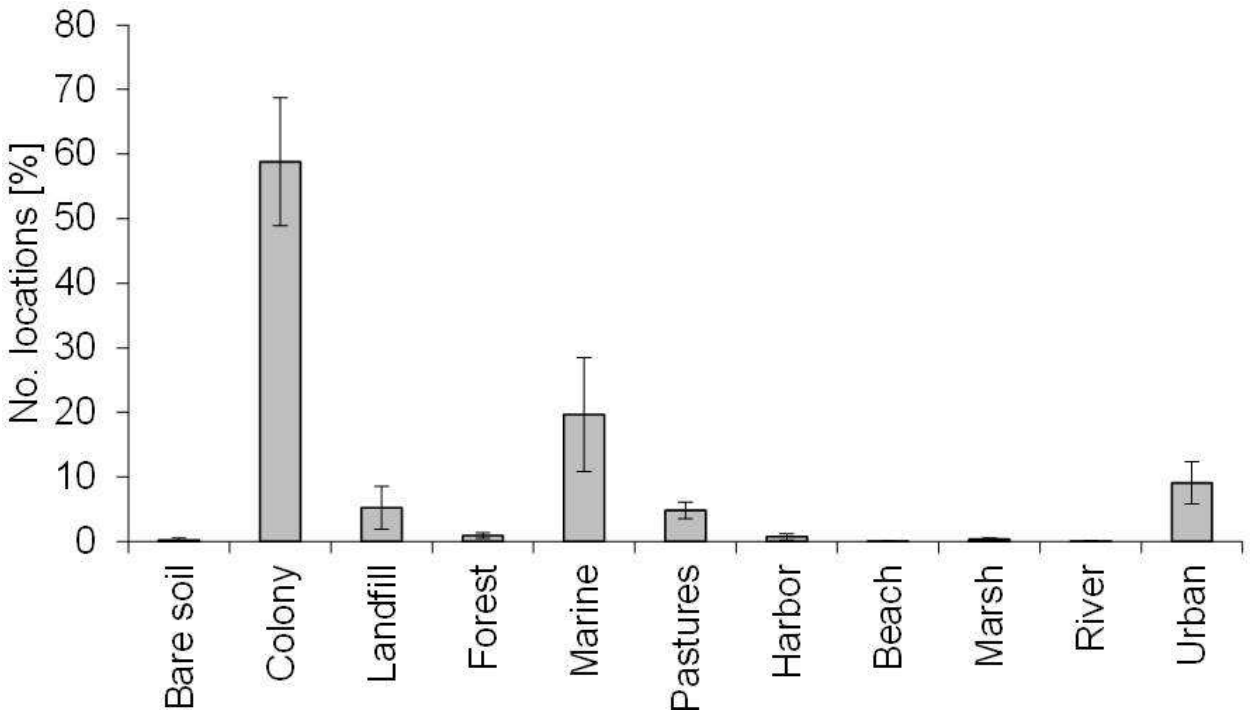


Figure 5. Mean (\pm SE) number of stationary positions of adult yellow-legged gulls during breeding period within each habitat type.

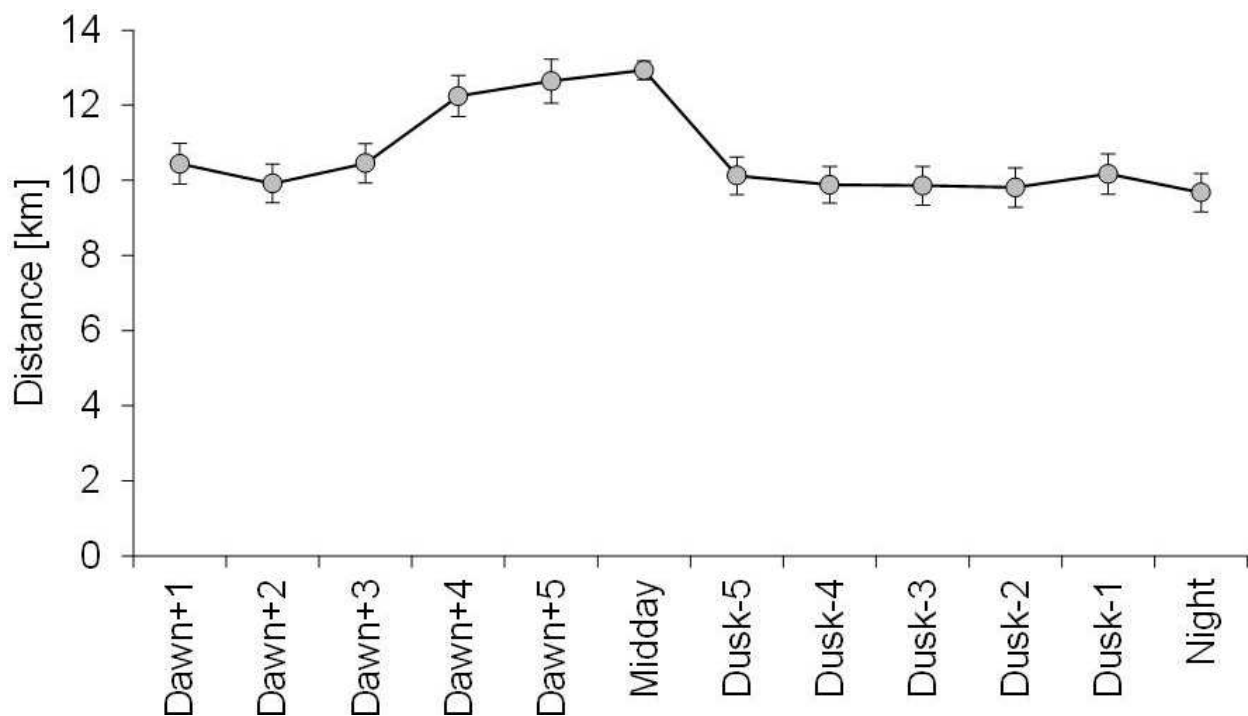


Figure 6. Mean (\pm SE) distance to the origin colony of adult yellow-legged gulls during breeding period and in relation to the hour of the day (dawn+1 stands for the first hour after dawn; data around midday and at night are shown pooled).

4. Discussion

The closure of open-air landfill sites in Europe is expected to have a deep impact on opportunistic species exploiting this resource, and our experience from a resident yellow-legged gull population within a region in northern Iberia reflects relevant changes in trophic ecology. When the use of open-air landfills was a widespread phenomenon within the region (period 2007–2009), ca. 40–60% of the diet was based on food of landfill origin. However, during the period 2014–2016, mixing models revealed that the proportion of this resource in the diet fell up to 20–40%, both in summer and in winter, in chicks and adults. This decrease in the importance of refuse food on the diet was compensated by a higher consumption of prey of marine origin in winter (from ca. 40 to 60%), but not in summer time, when both chicks and adults tended to forage on prey of terrestrial origin (ca. 40%, as compared to ca. 10% during the period 2007–2009). Thus, the response provided by local gulls to an apparently relevant shortage in what was one of their main preys (refuse food) varied seasonally and revealed high plasticity in the use and exploitation of alternative feeding sources.

Diet reconstruction suggests that adults forage on a higher proportion of terrestrial prey during summer but, interestingly, not in winter. In this last season, gulls were found to still forage on a higher proportion of landfill (as far as they can) as well as marine prey, probably by reaching foraging places situated at longer distances and/or that cannot be used in summer, when adults must feed their chicks; hence, they cannot look for food if this is situated too far [17]. In addition, in winter, earthworms become less accessible, hence forcing gulls to exploit a

smaller range of feeding sources. Results from spatial analyses confirm the presence of local breeding gulls on pastures in summer, where field observations indicate intense foraging at this habitat type.

Movement and territory use analyses also showed that two of the landfill sites existing within the region were visited very frequently. Even though one of these is still open and in use (Zaluaga), the other one (Sasieta) is closed, in theory. The high number of data (positions) from this last landfill site suggests that some food must be available in the zone [18], which might be because in practice the landfill was active [19] or because food from past times was still available.

Habitat partitioning analysis revealed that positions at two of the target foraging habitats (landfills, pastures) summed ca. 10% of all the detected stationary positions. This suggests that, at least in these habitats, gulls seemed to invest a relatively small amount of time, which might support the idea that they were able to obtain food in a fast way and, probably, from resources that they know well and have a predictable spatial distribution. By contrast, the number of positions in the sea was much higher (20%). Even though a fraction of such positions may not correspond with foraging activity (but resting, sleeping and preening), others would reveal active foraging [20].

Daily patterns of distance from the colony had an expected unimodal curve, since positions around midday were situated at a mean longer distance than positions during other parts of the day. However, early and late positions during the day, as well as positions at night, were found at a mean distance of 10 km, which is an unexpected result, since birds at that time should be expected to be at the colony (incubation, chicks' attendance, etc.). Causes explaining such results are unknown to us; hence, we can no more than attempt some possible hypotheses. Thus, foraging outside daylight periods cannot be rejected, since gulls have been reported to feed very actively at night [21], for example, when they follow fishing vessels or use the high amount of light around the cities. Due to data selection carried out before the spatial analyses, it is less likely that some birds might abandon the nest and, therefore, would start to exploit areas further away from the colonies and even sleep in other places.

In conclusion, the closure of several landfill sites across the region where the study was carried out was mainly compensated by a significantly higher intake of food of terrestrial origin (mainly earthworms), and not of marine origin, though only in summer. The exploitation of terrestrial prey tended to be very marginal in winter and seasonal trophic differences emerged, unlike the lack of seasonal dietary variations found in the previous period when landfills were open. The fact that earthworms in winter become less accessible and that gulls would be able to exploit resources farther from the colony may explain such seasonal variations observed after landfill closure.

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