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Demographic impact of landfill closure on a resident opportunistic gull

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Abstract

The management of mixed municipal waste can have an impact on wildlife and ecosystems. Previous studies have investigated how opportunistic species like gulls can react very fast to new landfills; however, the impact of landfill closure on bird populations is less investigated. Yet, there is a need to understand how fast and to what extent, animal populations can be adapted to new scenarios where the waste will not be deposited in landfill sites anymore. The aim is to determine the influence of landfill closures on apparent survival of a resident Yellow-legged Gull (*Larus michahellis*) population, used as a model species showing short-distance foraging movements, and with a high dependence on local food subsidies. Complementarily, we built some basic population growth models in order to determine how potential changes in survival (before/after landfill closure) will impact on population growth rate. Using a data set of 4,437 Yellow-legged Gull chicks ringed in four colonies over a period of 13 years, we obtained evidence supporting that the apparent survival was affected by landfill closure, especially if the landfill was located within a buffer of 10 km around the colony. Landfill closure affected the survival of first-year gulls (with a mean decrease of ~ 0.5–0.36), but not of older birds. Consequently, we did not detect a remarkable effect of landfill closures on population growth rate, probably due to the lack of effect on adult survival rates except for one of the surveyed colonies, where we found an annual decline of 7%.

KEYWORDS

landfill, management, *Larus michahellis*, population dynamics, survival

1 | INTRODUCTION

The management of mixed municipal waste can have a very strong impact on wildlife and ecosystems (Hobson, Blight, & Arcese, 2015; Oro, Genovart, Tavecchia, Fowler, & Martínez-Abraín, 2013; Seif et al., 2018). Waste concentration produced by humans in landfill sites opens new opportunities for those species which are able to exploit this feeding resource. This superabundant food subsidy is clearly advantageous for them in terms of increasing reproductive outputs and survival prospect (Real et al., 2017; Weiser & Powell, 2010), but also has some, very critical disadvantages, including the ingestion of plastics (Seif et al., 2018; Witteveen, Brown, & Ryan, 2017) and the exposure to higher concentrations of pollutants or diseases (Monaghan, Shedden, Ensor, Fricker, &

Girdwood, 1985; Ramos, Cerda-Cuellar, Ramirez, Jover, & Ruiz, 2010; Roscales et al., 2016), among other threats. The presence of a landfill does not only change the diet of animals feeding on it, but also can alter their decision to breed in some places and not in others. Thus, several opportunistic species worldwide move to or concentrate at abnormally high densities near landfills (Belant, Ickes, & Seamans, 1998; Duhem, Roche, Vidal, & Tatoni, 2008; Gilbert et al., 2016; Hidalgo-Mihart, Cantú-Salazar, López-González, Fernandez, & González-Romero, 2004; Tortosa, Caballero, & Reyes-Lopez, 2002). Thus, landfill sites produce great impacts on the diet, demography and spatial distribution pattern.

The relationship between opportunistic species and landfills is particularly well documented in gulls, probably as a consequence of conflicts with the humans (Vidal, Medail, & Tatoni, 1998, but see Belant, 1997, Brown et al., 2001, Oro & Martinez-Abrain, 2007, Rock, 2005). Thus, several previous studies have investigated how landfills influence gulls' diet (Arizaga et al., 2013; Duhem, Vidal, Legrand, & Tatoni, 2003; Ramos, Ramirez, Sanpera, Jover, & Ruiz, 2009) or reproduction (Belant et al., 1998; Real et al., 2017; Steigerwald, Igual, Payo-Payo, & Tavecchia, 2015; Weiser & Powell, 2010). In general, these birds respond rather fast to new landfills and their populations, therefore, grow exponentially in relative short-time periods (Arizaga, Galarza, Herrero, Hidalgo, & Aldalur, 2009; Duhem et al., 2008). At the same time, however, the populations can become very landfill dependent, so very vulnerable to threats related to feed in such places (e.g., exposure to diseases, pollutants, or being hit by the heavy machinery). The impact of landfill closure on bird populations is, however, much less investigated than impacts when these sites are open (Payo-Payo et al., 2015; Steigerwald et al., 2015). Yet, there is a need to understand how fast and to what extent, animal populations can be adapted to new scenarios where the waste will not be deposited in open landfill sites anymore (for instance, see the European laws Directive 1999/31/UE, Directive 2008/98/CE).

The closure of a landfill would have then both short- and long-term consequences in a gull population. First, those individuals which forage on this resource will have to find alternative food (Zorrozua, Aldalur, et al., 2020). In principle, it can be stated that this alternative food will be scarce or, directly, will not exist, since quite often the system had a carrying capacity much smaller than the one existing when the landfill was open (Duhem et al., 2008). Therefore, three potential scenarios might be possible: (1) if there is an alternative feeding resource in sufficient amount, the change may affect the diet but, presumably, may not have demographic consequences (unless the new resource has a different nutritional value with consequences in the reproduction and survival); (2) if there is an alternative feeding resource but not in sufficient amount, hence competition would increase/appear and only a fraction of the population may be able to change to this new resource and benefit from it; the remaining individuals, however, would be expected to leave the population, either because they disperse to other areas to survive or perish given the lack of food; and (3) if there is not an alternative food, then the population may be expected to collapse through density-dependent processes (Newton, 2013). All these scenarios should be more critical in resident populations that might show a much higher dependence on given local resources than populations that inhabit a given area only during part of the year.

In Scenarios 2 and 3, a critical aspect would be to estimate how survival is affected by landfill closure. In Scenario 2, the apparent survival (including survival and emigration) would be expected to decrease in those individuals with a subordinate status within the population, for example, the immature fraction compared to adults when both age classes feed on same feeding sources. In Scenario 3, however, the apparent survival would be expected to decrease markedly in all age classes.

Another, also critical question is to quantify the area of influence of a landfill. Landfills attract individuals from the surroundings and, even though this attraction will depend on species' movement capacity, there will be a maximum distance from which it would not be advantageous for an individual to travel and feed on a landfill (Egunez, Zorrozua, Aldalur, Herrero, & Arizaga, 2017). Determining this landfill area of influence is important as it has direct consequences on wildlife management and conservation measures, that is, which populations or individuals would be affected if a landfill is closed.

The aim of the present article is to determine the influence of landfill closures on the apparent survival of a resident Yellow-legged Gull (*Larus michahellis*) population, used here as a model species showing short-distance foraging movements, and with a very high dependence on local food subsidies, including landfills (Zorrozua, Egunez, et al., 2020). The specific hypotheses that we tested here were: (a) closure of those landfill sites located closer to the breeding colonies will have a higher impact on survival as compared to landfills located further away and (b) if there are no alternative and sufficient feeding sources, the impact on survival will decrease with the age of the individuals (i.e., from first-year birds to adults) if the older birds are able to compensate for the lack of landfill food, or alternatively all age classes will suffer similar effects on survival if all of them are not able to compensate for this food shortage. Complementarily, we built some basic population growth models in order to determine how potential changes in survival (before/after landfill closure) will impact on population growth rate (presumably, our population may pass from a stable/increasing status to decreasing). This last exercise was carried out with the aim of determining the demographic consequences of landfill management on our avian model.

2 | MATERIALS AND METHODS

2.1 | Model species

The Yellow-legged Gull is the most abundant gull within the southwestern Palearctic (Olsen & Larson, 2004). It is a partial migrant species, with the Atlantic populations that breed both along the coast of Iberia and Africa and in Macaronesia being resident, and the ones breeding in the Mediterranean showing partial migration (Cramp & Simmons, 1983; Galarza, Herrero, Domínguez, Aldalur, & Arizaga, 2012; Martinez-Abrain, Oro, & Carda, 2002; Olsen & Larson, 2004; Rodríguez & Muntaner, 2004; Romero et al., 2019). As other large gulls, the species has been adapted to feeding on landfills, a phenomenon that permitted a very fast population growth and, possibly, the colonization of new areas and the broadening of its distribution range (Castège, Milon, Lalanne, & D'Elbée, 2016; Skorka, Wojcik, & Martyka, 2005; Yésou, 1991).

We worked here with a resident Yellow-legged Gull population situated in the Bay of Biscay (Spain). Individuals from this population move a mean distance of less than 50 km from their natal colony sites, and they had/have are highly dependent on landfill food (Arizaga et al., 2013; Egunez et al., 2017; Zorrozua, Egunez, et al., 2020). During the last decades between the last and the current century, the existence of several landfills located near the main breeding colonies of this species within the region favored the increase of its population (Arizaga et al., 2009). However, the landfill use decreased with distance to the colony and temporal landfill closures were associated with increasing movement distances (Arizaga et al., 2014; Egunez et al., 2017). Furthermore, one of the colonies within the region was observed to decrease fast when a landfill situated nearby was closed (Galarza, 2015). There was, therefore, previous evidence supporting that the area of influence of the landfills was relatively local.

2.2 | Study area and data collection

This research was carried out in the main four Yellow-legged Gull colonies in the Basque coast, southeastern part of the Bay of Biscay (from east to west): Izaro island (with ~ 400 adult breeding pairs censused in 2017), Getaria (165 pairs), Santa Clara (100 pairs) and Ulia (660 pairs) (Figure 1). Overall, these colonies host >80% of the Yellow-legged Gull population within the region (Arizaga et al., 2009).

Every year between 2006 and 2018, chicks of approximately 20 days old were ringed by the end of June with both an official metallic ring in one of leg and a second ring with an alphanumeric code (to be read at distance) in the other leg (provider: R. Juvaste). After fledging, these ringed birds were seen during the study period by multiple observers ("gull-watchers"), in many zones. We retained the observation made from April to June, from 2007 to 2019 and coded them into capture histories of individual birds (Table 1). We considered sighting data obtained in as well as outside the colonies.

2.3 | Landfill management

For this resident Yellow-legged Gull population (Egunez et al., 2017), we considered the eight landfill sites situated within 50 km from the four colonies (Figure 1; Supporting Information 1). During the research period six landfills were closed gradually (Supporting Information 2); the first one to be closed was S. Marcos (in October of 2008), followed by Igorre, Jata, Urteta, Sasieta and Lapatz. Jata, however, was reopened in 2016. Zaluaga and Artigas remained open during this study. Overall, therefore, we obtained a combination of open/closed landfill sites situated at different distances from the four colonies where the birds were ringed. This distance matrix was used as external covariates when modeling gull transitions.

2.4 | Statistical modeling

To assess the effect of landfill management on survival we built Cormack–Jolly–Seber (CJS) models in MARK (White & Burnham, 1999). These models permit to estimate apparent survival (φ, probability that a bird survives from t to $t + 1$) and the probability of recapture (p, the probability that a bird estimated to be alive at time t is seen at $t + 1$) separately. Basic assumptions of capture–mark–recapture analysis were evaluated with a goodness-of-fit (GOF) test of a general model assuming all parameters time dependent (the CJS) using U-CARE 2.3 (Choquet, Lebreton, Gimenez, Reboulet, & Pradel, 2009). The global GOF test was not statistically significant ($\chi^2 = 82.009$, $p = 0.999$, $df = 142$), nor the specific Z test used to detect trap dependence ($p > 0.636$) or transients ($p > 0.464$) indicating that the CJS model explained fitted to the data adequately. We contrast this model with simper ones assuming time-dependent φ and p, alternatively and a set of models with an effect of the colony of origin (colony-

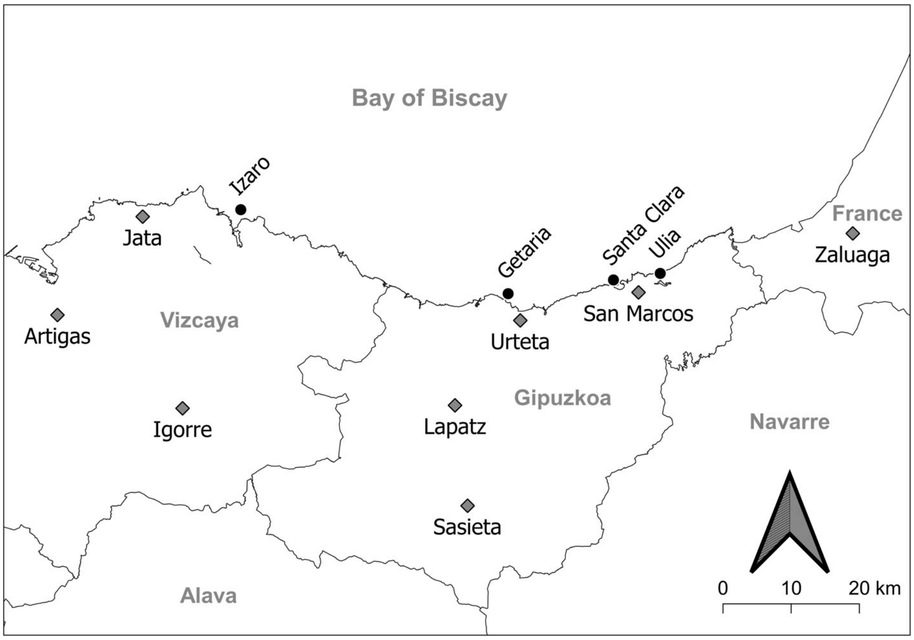

FIGURE 1 Location (circles) of the four-sampling Yellow-legged Gull colonies in the Bay of Biscay and all the landfill sites situated at 50 km or less from each colony (diamonds). These remained either open or were closed along the study period (2006–2018; for details, see Supporting Information 2)

TABLE 1 Number of chicks ringed during the breeding period in four Yellow-legged Gull colonies in the Bay of Biscay during the period 2006–2018. In parenthesis, we also show the percentage of individual birds that were seen after they fledged from their natal colony

Year	Izaro	Getaria	Santa Clara	Ulia
2006	232 (3.9)	30 (33.3)	69 (34.8)	147 (37.4)
2007	103 (6.8)	10 (40.0)	85 (30.6)	202 (37.1)
2008	49 (22.5)	38 (31.6)	55(38.2)	208 (41.4)
2009	30 (36.7)	20 (35.0)	50 (22.0)	258 (41.1)
2010	105 (33.3)	59 (39.0)	43 (18.6)	221 (29.9)
2011	90 (33.3)	32 (18.8)	37 (29.6)	185 (31.4)
2012	58 (12.1)	109 (12.8)	86 (20.9)	168 (28.6)
2013	38 (2.6)	50 (32.0)	52 (32.7)	68 (27.9)
2014	45 (15.6)	50 (12.0)	59 (23.7)	151 (22.5)
2015	62 (16.1)	50 (14.0)	32 (21.9)	141 (15.6)
2016	68 (42.7)	54 (24.1)	40 (30.0)	158 (17.7)
2017	54 (11.1)	52 (15.4)	27 (14.8)	81 (13.6)
2018	56 (1.8)	49 (4.1)	51 (19.6)	170 (8.2)

dependence). Note here that in this case we assigned each individual bird to one out of the four categories of origin (i.e., ringing colony). Thereafter, we built more models to test for the effect of landfill management (open vs. close). Landfill management, we considered for each colony if it had had an open landfill within a radius of 10, 20, 30, 40 or 50 km each year (spanning from July of year *t*-1 to June of year *t*). If one landfill was closed along a given year, that year was considered to have an open landfill. Landfill management, therefore, was treated as a binary variable (0, closed; 1, open landfill) within an original matrix assuming that φ was time and colony dependent. Despite GOF tests did not indicate a statistically significant effect of age, we considered up to three groups of age, assuming that φ (or *p*) showed different values in first year birds (i.e., annual survival from hatching year to the next year), subadults (annual survival from the second year of life to the fourth one) and adults (annual survival in older birds). Colonies were lumped into categories of (a) colonies with negative versus stable or positive population trends (Izaro vs. rest of colonies), and (b) colonies with a higher dependence on marine prey (Getaria), landfill food (Santa Clara, Ulia) or an intermediate contribution of these two types of prey (Izaro). All the alternative models were ranked based on their small-sample sized corrected Akaike Information Criterion values (AICc; White & Burnham, 1999). Models with AICc values differing in less than 2 in relation to the top-ranked one (i.e., the one with the smallest AICc) were considered to create an averaged model with which to obtain the survival and recapture probability estimates.

To estimate a long-term population growth rate (λ) based on the previously assessed survival values, we built a 5 × 5 postbreeding population model as shown by Caswell (2001) (Equation (1)):

$$\begin{bmatrix} 0 & 0 & 0 & FS_{\mathrm{fY}} & FS_{\mathrm{AD}} \\ S_{\mathrm{FY}} & 0 & 0 & 0 & 0 \\ 0 & S_{\mathrm{SY}} & 0 & 0 & 0 \\ 0 & 0 & S_{\mathrm{TY}} & 0 & 0 \\ 0 & 0 & 0 & S_{\mathrm{FY}} & S_{\mathrm{AD}} \end{bmatrix}, \tag{1}$$

where S_{FY} $S_{SY,}$ S_{TY} and S_{AD} are the apparent survival rate of first-, second-, third-year birds and adults, respectively, F is the mean number of females fledged in relation to each breeding female (it is calculated as half of mean clutch size) multiplied by breeding success (Hiraldo, Negro, Donazar, & Gaona, 1996). The mean clutch size (2.8 number eggs/nest) and the breeding success (0.60) were inferred from one of our colonies (Ulia), where intense fieldwork to estimate these basic breeding parameters was carried out in 2018 and 2019 (S. D., unpublished data). Our population models were run using the library for R "PopBio" (Stubben & Milligan, 2007). Positive λ values indicate population increase; negative values, population decrease, and when $\lambda = 1$ the population is stable.

3 | RESULTS

Overall, we ringed 4,437 chicks (Table 1): Ulia, 2,158 chicks (48.7%); Izaro, 990 (22.3%); Santa Clara, 686 (15.4%) and Getaria, 603 (13.6%). These ringed birds provided 2,245 resightings along the study period. The proportion of individual birds that were seen at least once after they left the colony ranged from 18.34% (Izaro) to 27.10% (Ulia; for further details, see Table 1).

We obtained a total of three top-ranked models differing in less than 2 AICc values in relation to the first one (Table 2). These models shared that the apparent survival was influenced by landfill management at a distance of less than 10 km from the colonies and by the age of the individuals (first year birds, immature and adults). For the colonies of Ulia, Santa Clara and Getaria there was just one landfill within a radius of 10 km from each colony (S. Marcos for the first two colonies; Urteta for Getaria). Izaro, however, did not have a landfill within such buffer area (Supporting Information 1). Moreover, the first model included an effect of the main prey consumed within each colony on survival, while the second one included an effect of population trends on survival. The third model included an effect of colony on survival. The parameter estimates of these last effects, however, had an associated 95% confidence interval that included zero, so it can be concluded that the effect of main prey consumed, population trends and colony on survival were statistically negligible. Apart from this, we also detected that survival was age dependent; particularly it varied between first-year, immature and adult birds (Table 2), increasing gradually from the first age category to adults (Figure 2).

Regarding p, the best ranked models considered time-dependence on this parameter, ranging between 0.21 (in 2012) and 0.47 (in 2011; for further details see Supporting Information 3).

TABLE 2 Ranking of the best models used to assess the effect of landfill management on the apparent survival (φ) of a resident Yellow-legged Gull population. Survival varied between age classes (φ_{FY}, annual survival in first year birds, that is, from hatching year to the next one; φ_{IM}, annual survival in immature birds; φ_{AD}, annual survival in adult birds), as well as in relation to landfill management (open/closed) at a distance of 10 km from each colony (10KM), colony (COLO), main prey consumed within a colony (DIET), demographic trends (DEMO)

Models	AICc	ΔAICc	AICc weights	*np*	Deviance
Model 1: φ_{FY} (10KM + DIET), φ_{IM} (10KM + DIET), φ_{AD} (10KM + DIET) p(t)	13,095.85	0.00	0.49	27	2,881.93
Model 2: φ_{FY} (10KM + DEMO), φ_{IM} (10KM + DEMO), φ_{AD} (10KM+ DEMO) p(t)	13,096.97	1.12	0.28	22	2,893.13
Model 3: φ_{FY} (10KM + COLO), φ_{IM} (10KM + COLO), φ_{AD} (10KM + COLO) p(t)	13,097.31	1.46	0.23	32	2,873.30
Other models					
φ (time), p (time)	13,618.52	425.49	0.00	25	3,408.64
Φ, p	13,810.84	617.81	0.00	2	3,647.16

Note: Other abbreviations—AICc, small sample sizes-corrected Akaike Information Criterion; ΔAICc, difference in AICc between each model and the first one; *np*, number of parameters.

Given the survival values obtained for each colony after model-averaging (for details, see Table 2), we did not detect a remarkable effect of landfill closures on assessed population growth rate, except for the Izaro colony, where we would obtain an annual decreasing rate of 7% (Table 3). For the colonies of Ulia and Santa Clara, models predicted a decrease of 0.5 (5%) and 0.2, respectively, which still was not as high as to generate a negative growth rate in Ulia (which would reach a value of 1.02, i.e., a positive annual growth rate of 2%). In Santa Clara, that growth rate would fall up to 0.98 (i.e., a negative annual growth rate of 2%). In Getaria, interestingly, the growth rate even increased slightly after landfill closure, passing from 0.97 to 1.00. In these three colonies, however, if we consider the confidence interval associated to survival estimation, all estimates may fall within a range which would include 1, indicating that the size of these colonies would have remained stable independently of landfill management. In Izaro, however, we detected a substantial decline of this colony (95%, CI: 3–10%).

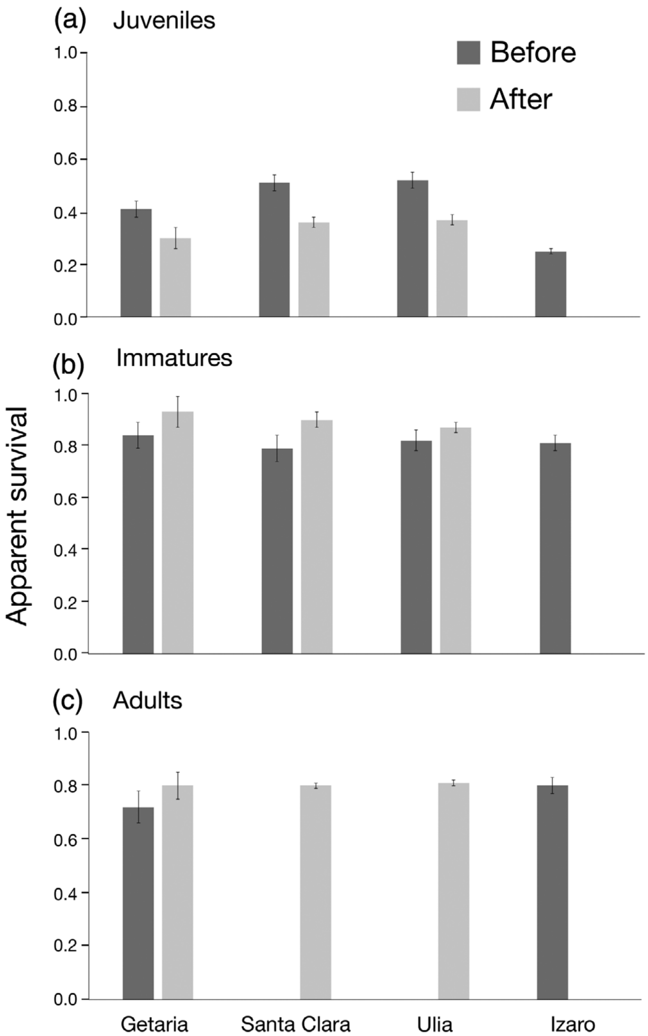

FIGURE 2 Apparent survival estimation (±*SE*), obtained after model-averaging (Models 1–3 from Table 2) in relation to age, colony and the existence of an open/closed (i.e., before/after) landfill within a buffer of 10 km around each colony

4 | DISCUSSION

Using a data set of 4,437 Yellow-legged Gull chicks ringed in four colonies over a period of 13 years, we obtained evidence supporting that the apparent survival was affected by landfill closure, especially if the landfill was located within a buffer of 10 km around the colony. Models considering an effect of landfill management at longer distances from the colonies had weaker support. These results suggest that the effect of landfills on the population dynamics of an opportunistic species like the -Yellow-legged Gull is manifested within a relatively small geographic range. Previous research within the region demonstrated that the proportion of landfill food in the diet had a strong relationship with the landfill-colony distance, indicating that the exploitation of a food resource is heterogeneous across the landscape, existing distance dependency even at very small geographic scales (Zorrozua, Egunez, et al., 2020).

When age classes were considered, we observed that, interestingly, landfill closure affected the apparent survival of first-year gulls (with a mean decrease of ~ 0.5–0.36), but not of older birds. Chicks were ringed at a mean age of approximately 20 days, so at least partially, this survival would include a period before fledging. Mortality by landfill management on first-year birds, therefore, may not be only associated to after-fledging survival. Also, we should consider survival between the ringing and fledging date may be impacted, if food shortage affects parents provisioning their offspring. It is true, in addition, that most landfills were closed during the first years and, therefore, we were not able to properly

	Ulia	Santa Clara	Getaria	Izaro
Before	1.07 (1.00, 1.09)	1.00 (0.95, 1.05)	0.97 (0.87, 1.00)	0.93 (0.90, 0.97)
After	1.02 (0.99, 1.03)	0.98 (0.93, 1.03)	1.00 (0.94, 1.04)	

TABLE 3 Lambda values and 95% confidence interval (representing the global population trends) obtained for the fitted models including scenarios before/after the closure of open-air landfills at a distance of 10 km of less from the colonies

estimate the impact of landfill management on adult survival in some colonies (Figure 2). Anyhow, the fall in survival estimation in adults would never be as high as in first-year birds, so it is clear that it is in this age class where the impact of landfill closure was greater. Likely, the experience and knowledge of the territory has a key role in this process. Our results suggest that (a) the carrying capacity of the region has probably reached its maximum, because landfill closure reveals a significant fall of the survival prospect of first-year gulls; (b) there might be alternative food (e.g., fish discards, etc.) (Arizaga et al., 2013; Zorrozua, Aldalur, et al., 2020), available in limited amounts; hence, this food would be exploited mostly by more experienced birds and those maybe being able to specialize in very particular feeding sources (Tyson, Shamoun-Baranes, van Loon, Camphuysen, & Hintzen, 2015; van Donk, Shamoun-Baranes, Bouten, van der Meer, & Camphuysen, 2020). First-year gulls, however, would probably lack enough experience to exploit these scarcer, probably also less predictable resources, which might result in the observed decreasing survival prospect in this age class. Therefore, our results may support Scenario 2 stated in Section 1. To what extent this lower apparent survival rate was due to true mortality or to an increasing emigration rate is an aspect that deserves further studies. Previously, we observed that gulls increased their spatial range when landfills were closed (Arizaga et al., 2014), so it is likely that a fraction of the observed lower apparent survival rates would indeed be caused by emigration from our survey region, but higher mortality cannot be excluded either. Detailed analyses on the territory use and spatial ecology of first-year birds will be crucial to disentangle the behavior and determining the potential mortality of juvenile Yellow-legged Gull once they fledge and leave their natal colonies (Hake, Kjellén, & Alerstam, 2003; Klaassen et al., 2014).

Gulls are long-lived species whose population dynamics are not so dependent on juvenile, first-year survival, but on the survival of adult birds (Newton, 2013). As landfill closure did not seem to have a remarkable impact on adult survival rates, models estimating the population growth rate using these survival rates were unable to detect a clear fall in the growth rates after landfill closure.

The dynamics observed for the Izaro colony requires special mention. As compared to the other three colonies, Izaro did not have a landfill within a buffer of 10 km. This forced us to estimate a single survival value for the whole period considered in this work (for details, see Supporting Information 1 and 2). Previous works, however, suggested a very high dependence of this colony to Jata (Galarza, 2015), a landfill located at 15 km from Izaro. This colony, in addition, was by far the largest Yellow-legged Gull colony of the Basque coast, reaching a size of approximately 1,300 adult breeding pairs in 2007 (Arizaga et al., 2009). The closure of Jata in 2013 triggered a cascade of effects on Izaro, where the productivity was found to crash and the number of adult breeding pairs in the colony was observed to decrease year after year (Galarza, 2015); in 2013/2014, the size of the colony was 795 pairs (Galarza, 2015), and in 2017, 409 pairs (A. Galarza, pers. comm.). In this particular case, even Scenario 3 hypothesized in Section 1 may be also possible. Scenario 2, anyhow, would be fully supported by the data: due to low productivity and also low juvenile survival, in an environment with a presumably very high competition for food. Very few birds may recruit in the colony and this may explain the steep decline found in the colony, at least in part.

Apart from landfill management, we also explored whether survival was influenced by aspects related to each colony, more particularly the degree of dependence on main feeding sources (trophic ecology), the colony size growth rate and the colony itself. Alternative models assuming in each case one of such factors were equally supported, so overall it can be concluded that apart from landfill closure apparent survival was also influenced by colony. The variance explained by the colony may probably respond to several factors that, overall, conform the particular characteristics of a colony, including its dependence on certain key feeding resources (e.g., landfill vs. fishing harbor), its dynamics and degree of density-dependent effects on such dynamics.

Landfills have a clear impact on animal populations able to exploit this food subsidy. We demonstrate that landfill closure affected the apparent survival of a resident Yellow-legged Gull population, especially by reducing survival in first-year individuals. This impact, in addition, seemed to have a relatively local influential range, suggesting strong landfill-colony distance relationships. Landfills can increase the survival prospect of gulls during the non-breeding season, especially if animals can move long distances to exploit this kind of food subsidies (Jordi, Herrero, Aldalur, Cuadrado, & Arizaga, 2014). However, the dynamics of focal breeding colonies, and particularly the survival of first-year birds, was influenced by landfills at a rather local spatial scale. From a management standpoint, the closure of the open-air landfills existing within the region is having a positive effect on the surveyed population, in the sense that the carrying capacity of the system is reduced and, probably through density-dependent processes. The population may return to a scenario which would reflect dynamics more typical of what would be a Yellow-legged Gull population in a more natural scenario without food subsidies of artificial origin. Note, however, that discarded fish is also a food subsidy that still remains within the system. In a nearby future, the only landfill still open will reduce the amount of food available to gulls up to zero. Under such scenario, we expect to find a steeper decrease of survival expectancy in young gulls, and also maybe in adult individuals. Overall, we expect that even those colonies which currently show stable trends will likely start to decline, probably suffering a process similar to the one observed at Izaro colony.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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