

Anthropogenic food subsidies shape parental foraging and offspring development in an opportunistic bird

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Open Research Statement

The movement data used in this study is available upon request in the Movebank study “Yellow-Legged Gull - France - Espagne -ID_PROG 990” (Movebank id: 2312018505). The datasets used in this study are available in Zenodo (DOI: 10.5281/zenodo.19631785).

Abstract

Humans are transforming ecosystems by providing predictable anthropogenic food subsidies (PAFS), such as at landfills, now used by multiple animal taxa. In breeding animals, parental landfill use can influence offspring development, yet few studies have quantified parental landfill use and linked it to parental care and offspring development, behaviour or survival, limiting our understanding of the population-level consequences of PAFS use.

Between 2021-2024, we GPS-tracked 56 adult and 79 juvenile Yellow-legged gulls (*Larus michahellis*) across five Mediterranean colonies. We also analysed the content of 373 pellets and the growth of 257 nestlings until fledging. Our aim here was to understand whether (i) PAFS use, particularly landfills, by breeding adults differed among colonies; (ii) landfill use affected parental foraging trips and plastic consumption; (iii) parental landfill use influenced chick growth and condition; and (iv) this affected post-fledging movements and survival of juveniles.

We found that adult landfill use varied among colonies, independently of the distance to the nearest landfills. Higher landfill use resulted in fewer and shorter foraging trips during chick rearing and increased consumption of anthropogenic materials. Chicks from high-use colonies developed and fledged in poorer body condition, which delayed the onset (but not the distance) of dispersal movements, without affecting post-fledging survival.

Our results reveal a potential trade-off in PAFS use, which may act as a time-saving foraging strategy for parents while compromising offspring body condition. This demonstrates how anthropogenic subsidies can shape the behaviour of breeding animals and generate carry-over effects on offspring development and early-life behaviour.

Introduction

Human-driven environmental change is reshaping ecosystems globally, producing increasingly extreme conditions that expose wildlife to novel stressors (Tylianakis et al. 2008). Yet, these changes may also generate new ecological opportunities for some species (Walther et al. 2009). Every year, humans produce over 2 billion tonnes of solid waste (Kaza et al. 2018), much of which is deposited in areas readily accessible to wildlife, such as rubbish bins and landfill sites. This waste is largely composed of organic matter and food remains, creating superabundant, predictable anthropogenic food subsidies (PAFS) that have become an important resource for generalist species and support population increases in several taxa (Oro et al. 2013; Plaza e Lambertucci 2017; Catry et al. 2025).

A wide range of animal species exploit PAFS, particularly those found at landfills and dumps, including insects, mammals, reptiles, amphibians, and birds (Plaza e Lambertucci 2017). Among these, birds have been the focus of many studies, revealing both positive and negative effects of using these resources. The high abundance and caloric value of food at landfills may allow individuals to reduce time and energy spent foraging (Soriano-Redondo et al. 2021, but see van Donk et al. 2019). However, these environments can also act as ecological traps: high densities of powerlines around landfills increases the risk of collision and electrocution (Joana Marcelino et al. 2021), while exposure to contaminants can compromise health (Adami et al. 2024; Sorais et al. 2021). Because birds are highly mobile, they may also act as vectors for the large scale dissemination of pathogens and contaminants, including plastics, picked up in discarded foods (Ahlstrom et al. 2021; Martín-Vélez et al. 2024; Nono Almeida et al. 2024).

The effects of anthropogenic subsidies can extend beyond the individual birds that directly exploit them. In nesting birds, parental use of landfills can influence the offspring even before the young have the opportunity to visit these areas themselves. For example, the use of PAFS may result in larger clutch sizes (Tortosa et al. 2003) and a higher hatching success (López-García et al. 2021). Proximity to landfills has also been associated with improved nutritional status and greater body mass in White stork (*Ciconia ciconia*) nestlings, despite increased exposure to bacteria (Pineda-Pampliega et al. 2021) and heavy metals (de la Casa-Resino et al. 2014). In contrast, Red-winged starling (*Onychognathus morio*) nestlings fed on urban anthropogenic food subsidies show lower body condition, possibly due to the poorer food quality provided by the parents (Catto et

al. 2021). Yet, most studies do not quantify the degree to which parents use landfills, limiting our ability to assess the mechanisms through which landfill foraging shapes parental care and nestling development. In addition, the long-term consequences of early-life consumption of landfill resources remain poorly understood.

The conditions experienced during early-life can carry over and shape juvenile and adult phenotypes, influencing key traits such as juvenile survival (Arizaga et al. 2015; Wintz et al. 2025) and lifetime fitness (Sergio et al. 2022; Wintz et al. 2025). Thus, both access to abundant food subsidies and exposure to associated plastics, pathogens, and other contaminants are likely to affect juvenile post-fledging behaviour and survival. In white storks, for example, chicks exposed to landfill resources were shown to have lower first-year apparent survival (López-García et al. 2021). Nevertheless, there is little evidence linking early-life exposure to PFAS and post-fledging movement behaviour or survival in birds. Addressing this gap is essential to fully understand the behavioural and population-level consequences of landfill use in avian populations.

In this study, we aimed to understand how the use of anthropogenic food subsidies, and particularly landfills, by breeding adults influences parental care, chick development, and the post-fledging movements and survival of juveniles. We focused on five Mediterranean colonies of Yellow-legged gulls (*Larus michahellis*), a generalist and opportunistic species known to rely extensively on anthropogenic subsidies (Lopes et al. 2021), including landfills (Duhem et al. 2005; Ramos et al. 2009), which may have potential implications for offspring development and survival. We tested: (i) whether the use of PAFS, and specifically landfills, by breeding adults differed among colonies; (ii) how landfill use during chick rearing affected the number and duration of foraging trips, as well as the amount of consumed plastic; (iii) the influence of parental landfill use on chick growth and body condition at fledging; and (iv) whether this then affected the timing and distance of post-fledging movements and the survival of juveniles. By examining these questions, this study provides new insights into the long-term consequences of anthropogenic food subsidies on opportunistic avian species.

Materials and Methods

Study area

This study took place in five Yellow-legged gull's colonies across the western Mediterranean basin (Figure 1). These colonies varied in size and surrounding habitats : i) Frioul (France, 43.264103, 5.288685 – ~5800 breeding pairs), a group of rocky islands close to the highly urbanized city of Marseille; ii) Medes (Spain, 42.047911°, 3.221512° - ~5000 breeding pairs), a group of small rocky islands offshore a small resort town and agricultural lands; iii) Planasse (France, 43.085112°, 2.998192° - ~1770 breeding pairs), a protected grassy island in the Bages-Sigean lagoon, close to the Sigean open-air African animal reserve; iv) Carteau (France, 43.377640°, 4.857583° - ~325 breeding pairs), a small islet in the Gulf of Fos, close to an industrial area; v) Piana (France, 41.373518°, 9.228286° - ~68 breeding pairs), a small sandy island near the popular beach of Piantarella (see Bosch et al. 2019 and Nono Almeida et al. 2024 for more details on colony habitat and sizes). Interestingly, these colonies are located within a gradient of distances to landfill sites: the nearest landfill is 6 km from Planasse, 7 km from Carteau, 10 km from Frioul, 31 km from Medes, and 39 km from Piana.

Capturing and tagging adult yellow-legged gulls

Between 2021-2024, we captured 56 breeding adults in the five colonies: 6 in Medes (2022 only), 16 in Carteau (2021-2024), 15 in Frioul (2022-2024), 11 in Planasse (2022-2024) and 8 in Piana (2022-2023). Captures were performed during mid-incubation (late March to early April) using tent spring traps. The birds were marked with PVC alphanumeric (or darvic) and metal rings, were weighed and measured for standard biometric parameters, and were equipped with GPS-GSM tracking devices from Interrex ('DEBUT 15', LEGO 2G') and Ornitela ('OT-20-4GC', 'OT-20-4GEC'). The tracking devices were deployed using a wing-loop harness and on average did not represent more than 2.97% of the bird's body mass (see Souc et al. 2024 for more details on the ringing and tagging procedures).

The tracking devices were programmed to record locations every 15-30min, with some periods at 1-min intervals. For this study, we standardized the dataset by subsetting the high-frequency data to 15-min intervals, the most prevalent schedule. In total, the breeding adults were tracked for an average of 367 days (sd = 350, range = 1-1009 days), covering up to 3 consecutive breeding seasons per individual.

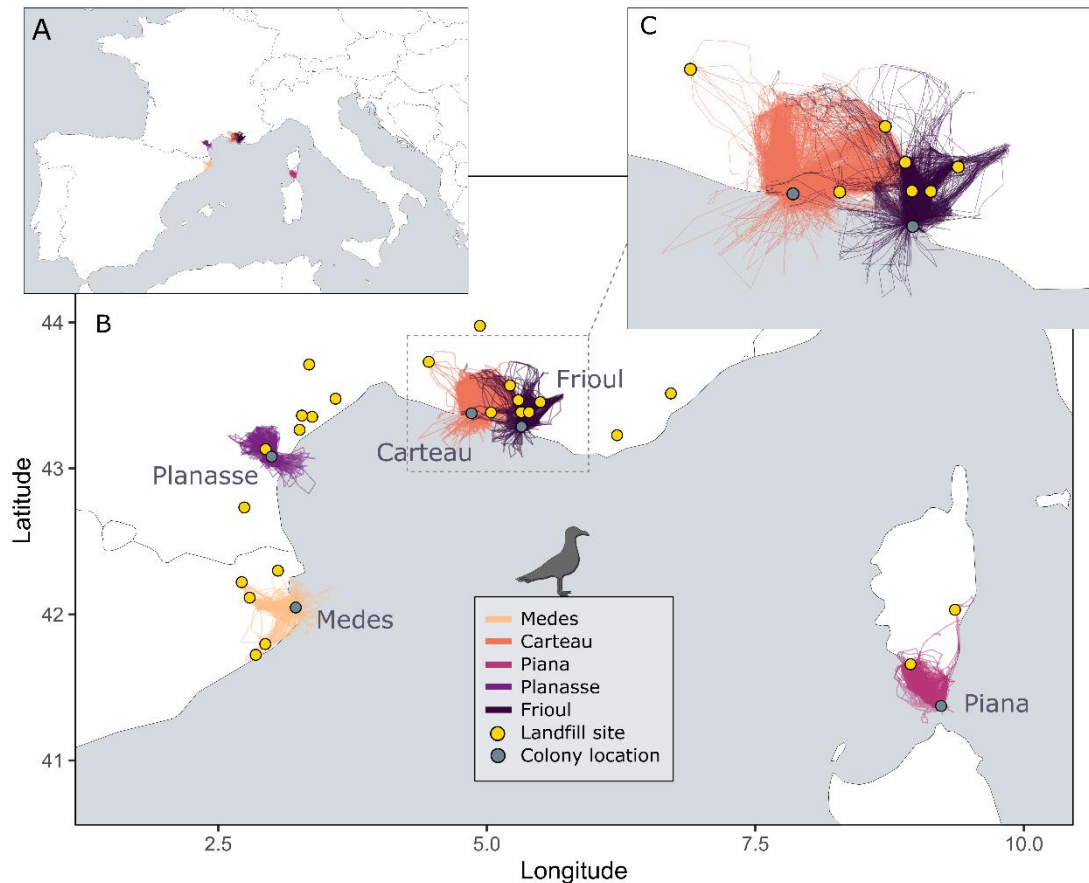


Figure 1 – GPS tracking of breeding yellow-legged gulls from the study colonies.

(A) Location of the overall study area in western Europe. (B) GPS tracks of breeding adults from the five colonies between 2021-2024: Medes (light orange), Carteau (orange), Piana (dark pink), Planasse (purple) and Frioul (dark purple). (C) Details of two nearby colonies (Carteau and Frioul) showing contrasting landfill use by breeding adults.

[Use of anthropogenic food subsidies by breeding adult yellow-legged gulls](#)

An overview of all analyses performed in this study is provided in Sup. Material Figure S1. We started by identifying the nesting locations for all birds and years using nestR (Picardi et al. 2024). Since adult gulls were captured on their nests, we know the real nesting location on the year of tag deployment, but not on subsequent years. The real nesting coordinates allowed us to validate the nestR predictions by calculating the distance between the real nests and the calculated nests. Overall, this distance was 15 m (sd = 8m, range = 1-30m). We defined the breeding period as starting on the 1st of March

and running until the 30th of June, or until the last date a bird remained in the nest before leaving for more than 2 consecutive 24h periods. We excluded from the analysis individual breeding-years with fewer than 15 tracking days or fewer than 100 GPS locations ($n = 11$ individuals excluded). In the end, the dataset contained 74 breeding-years from 45 individuals.

To identify the foraging habitats of breeding adult gulls, we excluded locations within a 500m buffer around the nest, as well as commuting flights between the colony and the foraging location. To distinguish commuting from foraging locations, we applied a two-state hidden Markov Model (HMM), using R package *moveHMM* (Michelot et al. 2016). We calculated the step length and turning angle between consecutive 15-min locations, with commuting flights expected to show larger step lengths and lower turning angles, and foraging locations expected to show lower step lengths and larger turning angles (Sup. Material Figure S2). We ran 20 iterations of the HMMs using random, but biologically realistic, sets of initial parameters, and selected the model with the lowest AIC. While we could not distinguish foraging from resting locations, we assumed that most non-commuting positions outside the colonies represented foraging activity. 15% of the locations could not be classified as foraging or commuting due to GPS intervals > 15mins; we therefore complemented the classification with GPS ground speed (ground speed of foraging locations < 0.6 m/s, Sup. Material Figure S3).

We annotated the foraging locations with habitat categories from Corine Land Cover 2018 (European Environment Agency 2019) and completed this information with a layer of landfill polygons found within the study area. Habitats were grouped into seven categories: agricultural areas, forests, industrial sites, landfills, marine environments, urbanized and recreational areas, and wetlands (Sup. Material Table S1). We considered landfills and urbanized and recreational areas as anthropogenic habitats where gulls could potentially forage. We then tested whether the use of anthropogenic foraging habitats differed among colonies. To do so, we ran a binomial generalized linear mixed model (GLMM) with a logit link function, using the proportion of foraging locations within and outside anthropogenic habitats as the response variable. Colony, year (both as factors), and the number of tracked days per individual-year were included as fixed effects. This last variable was included as a quadratic term to account for the non-linearity shown by the DHARMA (Hartig 2022) residual diagnostics. Individual identity was included as a random intercept.

We built two additional models to assess whether potential colony differences in the use of anthropogenic habitats were driven by the differential use of urbanized and recreational areas or landfills. These models had the same structure as the previous one, but the response variables were the proportion of foraging locations inside and outside urbanized and recreational areas, and the proportion of foraging locations inside and outside landfills, respectively. The predictors were the same as before, but the number of tracked days was included only as a linear term (excluding the quadratic), and in the landfill model we also included the distance to the closest landfill used by each individual as an additional predictor. To compare the use of landfills among colonies, we performed a post-hoc Tukey test.

Finally, we conducted a sensitivity analysis to test whether the classification of foraging locations using both the HMM model and speed filters affected the results. To do so, we repeated all three models using two alternative datasets: one in which foraging locations were classified exclusively with the HMM, and another in which they were classified solely based on the speed filter.

Use of landfills and parental care

The previous analyses indicated significant differences in landfill use between colonies, with two groups of colonies, with “higher” and “lower” landfill use. Thus, we hypothesized that adult reliance on landfills during the breeding season affects parental care, either decreasing (Soriano-Redondo et al. 2021) or increasing (van Donk et al. 2019) the time and energy of foraging trips. To test this, we started by identifying the foraging trips. A trip began when an adult left the nest for more than two consecutive GPS locations and ended on the first location back at the nest. We excluded trips that were exceptionally long (>1 day, $n = 50$), trips during which GPS fixes were recorded at intervals longer than 45 minutes on average ($n = 188$), and trips with fewer than 4 GPS locations ($n = 3,949$). After applying these filters, the final dataset included 13,995 foraging trips from 74 adults across the five breeding colonies. We calculated the duration of each foraging trip and the maximum distance from the nest. A trip was classified as a “landfill trip” when at least half of its foraging locations occurred within a landfill.

We then built two models. First, we examined the relationship between parental landfill use and the number of foraging trips per breeding season, using a Poisson GLMM

with a log link function. The number of foraging trips per season was the response variable, and the proportion of landfill use per individual-year, year, minimum distance to a landfill and the number of tracked days and its quadratic term were fixed effects. Individual and colony were random intercepts. Second, to test the relationship between the type of trip (“landfill trip” or not) and the duration of the trip, we fitted a linear mixed model (LMM), with a gaussian distribution and identity link. The log-transformed duration of the foraging trip was the response variable, and the type of trip (“landfill trip” or not), the maximum distance from the nest (and its quadratic term), the minimum distance from a landfill and year were fixed effects. We also included the day of the year and its quadratic term as fixed effects to account for changes in trip duration across the chick-rearing period. We included individual and colony as random intercepts.

Finally, we tested whether colonies differing in landfill use also differed in the number of anthropogenic items present in the regurgitated pellets of breeding adults. During weekly visits from incubation to hatching, we prospected the area within a 1m radius of each nest for pellets produced by the breeding adults. Only fresh and intact pellets were collected. During the 2022 (all colonies) and 2024 (Carteau, Frioul, and Planasse) breeding seasons, we collected a total of 373 pellets from 30 randomly selected nests per colony. The pellet composition was analysed following Nono Almeida et al. 2023, 2024. The individual items found in the pellets were classified as natural (food items, as well as rocks and other indigestible natural material) or anthropogenic (plastics, cotton, glass, metal and paper). We then built a negative binomial GLMM, with a log link, using the number of anthropogenic items per pellet as the response variable. The fixed effects were the landfill use of adults breeding in the colony (“low” vs “high”, as determined in the previous analysis), year, the condition of the pellets (a factor varying between 1-4, in which 1 is a fresh and structurally intact pellet and 4 a broken down pellet, Provencher et al. 2019), and the total mass of the pellet and its quadratic term. The nest number (a unique identifier for each nest in a given year) was included as a random intercept.

Effect of parental landfill use on chick body condition

Between 2022 and 2024, we monitored the growth of 257 chicks in 30 randomly selected nests per year in four of the five colonies (Medes, Carteau, Planasse and Frioul). In Piana,

it was not possible to monitor nests as frequently as in the other colonies, resulting in less precise estimates of hatching dates; therefore, this colony was excluded from the analysis. The colony of Medes was monitored only in 2022, whereas Carteau, Planasse, and Frioul were followed in all three years.

We monitored the nests from hatching (March) to fledging (June), or until the last date the chick was found alive. After hatching, chicks were initially marked with temporary plastic rings and later with permanent metal and darvic rings. Hatching dates were estimated based on egg observations: if no cracks were observed during one visit but chicks had hatched by the next, the hatching date was assumed to be the median day between visits; if the egg was cracked, the hatching date was set for three days later; if a small opening was visible, for two days later. In all colonies, the nests were visited weekly and the chicks were weighed (to the nearest gram) and their tarsus length was measured (to the nearest millimetre). For more details see Buysse et al. 2025.

We calculated a body mass index (BMI) as the ratio between the chick's weight and their tarsus length. We then examined the relationship between this index and the landfill use of adults breeding in each colony. Only chicks measured at least twice were included in the analysis ($n = 256$). We fitted a LMM with a gaussian distribution and identity link, using BMI as the response variable. The fixed effects were the landfill use of adults of the colony ("low" and "high"), the age of the chicks (in days since hatching) and its quadratic term, and their interaction. Year and the number of measurements per chick were also included as fixed effects, to account for possible yearly differences in body condition, or by differences driven by individuals with fewer measurements. We included nest number per year as a random intercept (to account for siblings) and included individual and age as a random slope.

To test whether differences in chick body condition between colonies with lower and higher landfill use were also detectable at hatching and at fledging, we created two additional datasets. The first included only the earliest measurement for each individual taken before 10 days of age ($n = 242$), and the second included only the final measurement recorded after 40 days of age ($n = 106$). For each dataset, we fitted a linear regression with BMI as the response variable and colony landfill use ("low" vs "high") and year as fixed effects, and nest as a random effect.

Relationship between juvenile body condition and post-fledging movements and survival

Between 2022 and 2024, we deployed GPS–GSM tracking devices on 79 fledglings across the five colonies: 27 in Carteau, 22 in Planasse, 20 in Frioul, 6 in Medes, and 4 in Piana. The devices were identical in model, weight, and tracking frequency to those used for adults. The harness was similar to that of the adults but included a weak link. We excluded all locations recorded before fledging, which was defined as the first date a bird spent more than 1h30 at least 200m away from the nest. On average, the juveniles fledged 19 days after tag deployment (sd = 9; range = 0-41 days) and were tracked for an average of 241 days after fledging (sd = 247, range = 3-929 days). Juveniles do not usually leave the colony directly after fledging.

We examined the relationship between the juvenile's BMI at fledging and their movement behaviour and survival during the first 30 days post-fledging. We calculated three movement metrics to describe the amplitude and timing of movements: daily displacement, first departure date from the colony, and the maximum distance from the nest. We defined daily displacement as the sum of distances between all consecutive locations recorded in a day. Since this metric is influenced by the number of locations per day, we excluded days with fewer than 45 locations (number of days excluded = 13; mean number of locations per day after removal = 91, sd = 11, range = 45-97). The first departure date was defined as the first day an individual moved more than 50km from its nest, and the maximum distance was calculated as the furthestmost distance between the nest and any other location. We excluded birds whose maximum distance from the nest was shorter than 1km. Finally, we determined survival within the first 30 days after fledging. Mortality events (n = 9) were identified based on a lack of movement indicated by the GPS and acceleration data and were confirmed in the field. If the transmitter stopped working without apparent reason or if the mortality was not confirmed in the field, the deployment outcome was classified as “unknown” (n = 1).

We built 4 (G)LMMs to examine the relationship between juvenile BMI and post-fledging movements and survival. In the first model (LMM), the response variable was the log-transformed daily displacement, and the predictors were the BMI, the number of days since fledging (and its quadratic term), and their interaction. We also included the number of locations per day and year as additional covariates, and individual and colony as random intercepts. In the second model (negative binomial GLMM with a log link),

the response variable was the number of days since fledging (i.e., when the bird first moved more than 50km from the nest). The predictors were BMI and year, and colony was included as a random intercept. The third model (LMM) included the maximum distance from the nest as the response variable and the BMI, the total number of tracked days and year as predictors, and colony as random intercept. Finally, in the fourth model (binomial GLMM with a logit link), survival during the first 30 days post-fledging (1 = survived; 0 = died) was the response variable, with BMI and year as predictors and colony as a random intercept. To assess the robustness of our results, we conducted sensitivity analyses by repeating the daily displacement, maximum distance, and survival models using data collected up to 60- and 90-days post-fledging, and by repeating the timing model using alternative thresholds of 5km and 25km for the first departure from the colony.

All analysis were performed using R Version 4.4.2 (R Core Team 2024). All models were performed using glmmTMB (Brooks et al. 2017), the model fit and residuals were assessed with DHARMA and performance (Lüdecke et al. 2021), and the post-hoc tests were performed using emmeans (Lenth 2024).

Results

Use of anthropogenic food subsidies by breeding adult yellow-legged gulls

Between 2021 and 2024, we GPS-tracked 45 adult breeding yellow-legged gulls across five Mediterranean colonies for up to three consecutive years (total of 74 breeding-years). Using HMMs and the ground-speed measured by the GPS devices, we identified 68,266 foraging locations in seven different habitat categories, including anthropogenic habitats (landfills and urbanised and recreational areas). During the breeding season, urbanised and recreational areas were the most frequently used habitat type (n = 15,654 foraging locations). However, there were differences between colonies in the categories of used habitats (Sup. Material Figure S4). The use of anthropogenic foraging habitats differed significantly among colonies, with Medes showing the lowest and Frioul the highest use of anthropogenic areas (Sup. Material Figure S5 and Table S2). These differences were primarily driven by landfill use (even after accounting for the distance between colonies and the nearest landfill), rather than by variation in the use of urbanised or recreational areas, for which there were no significant differences between colonies (Figure 2, Sup. Material Table S3 and Table S4). We identified two groups of colonies based on the

landfill use of the breeding adults: colonies with lower (Medes and Carteau) and with higher (Piana, Planasse and Frioul) landfill use (Figure 2, Sup. Material Table S5). These results were consistent regardless of the classification method used to identify foraging locations (HMMs only, GPS speed only, or the combined approach, Sup. Material Figure S6).

Use of landfills and parental care

We identified 13,995 foraging trips by 74 breeding gulls between 2021 and 2024. On average, we recorded 189 foraging trips per individual-year ($sd = 86$, range = 10-394), with trips lasting on average 186 mins ($sd = 167$, range = 43-1,392 mins). Landfill use by breeding adults was correlated with both the number and duration of foraging trips: individuals that used landfills more frequently performed fewer trips (estimate = -0.391, $se = 0.153$, Sup. Material Table S6), and trips in which landfills were the main foraging habitats were shorter in duration (estimate = -0.112, $se = 0.012$, Sup. Material Table S7). Colony landfill use was also linked to the number of anthropogenic items found in adult pellets. In total, we analysed 373 pellets, which contained an average of 4 anthropogenic items ($sd = 5$, range = 0–39). Colonies with higher landfill use had significantly more anthropogenic items per pellet than colonies with lower landfill use (estimate = -0.350, $se = 0.133$; Figure 3, Sup. Material Table S8). The pellet condition (factor varying between 1 and 4) also influenced the number of anthropogenic items found, with intact pellets containing more items (Sup. Material Table S8). However, it is unclear whether this reflects item loss prior to pellet collection or if the plastics and other items help compacting the pellets.

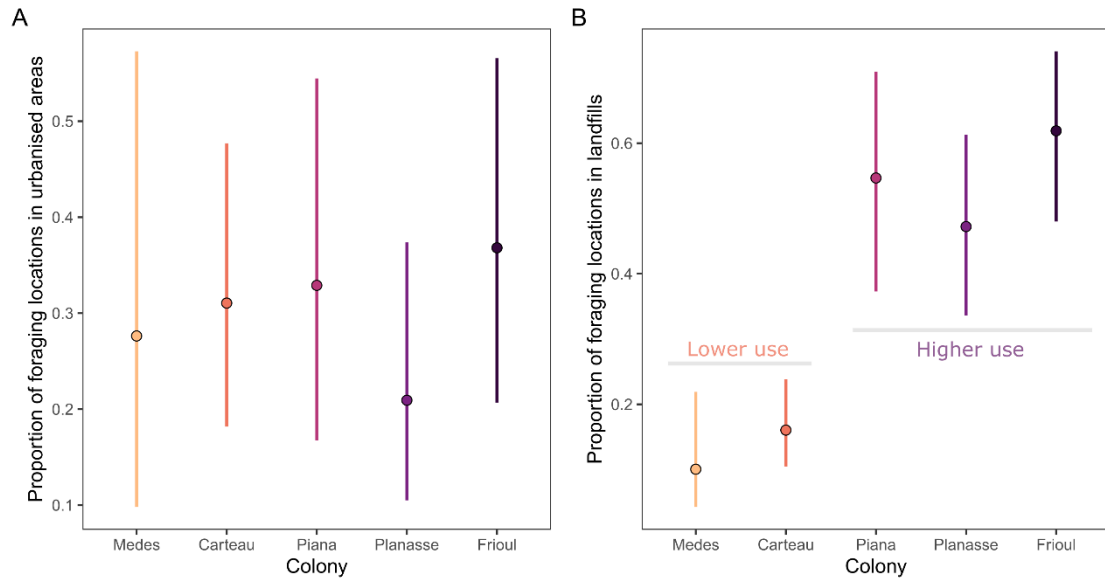


Figure 2 - Proportion of foraging locations in (A) urbanised/recreational areas and (B) landfills for yellow-legged gulls breeding in different colonies. Circles show mean predicted values from the generalized linear mixed models, and error bars represent 95% confidence intervals. Note the significant differences in landfill use between two groups of colonies: Medes and Carteau, with lower use of landfills, and Piana, Planasse and Frioul, with a higher use of landfills.

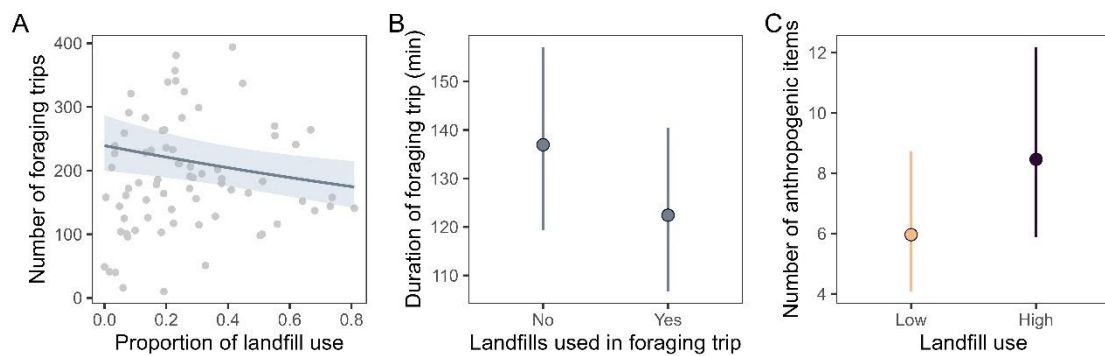


Figure 3 – Use of landfills during the breeding season changes adult foraging behaviour and increases the number of anthropogenic materials in pellets. (A) Relationship between the number of foraging trips and the proportion of landfill use during the breeding season. (B) Duration of foraging trips according to whether landfills were the main foraging habitat or not during the trip. (C) Number of anthropogenic items (plastic, glass, metal, paper) in adult pellets from colonies with lower (light orange) and higher (dark purple) landfill use. All panels show model predictions and 95% confidence

intervals from the corresponding (G)LMMs. In (A) the light circles represent the raw data points.

Effect of parental landfill use on nestling's body condition during development

Between 2022 and 2024, we monitored nestling growth in four colonies: Medes (2022 only), Carteau, Planasse and Frioul (2022-2024). In total, we collected 1,056 measurements from 256 individuals. We found that nestlings from colonies with higher parental landfill use had lower BMI during development compared with those from colonies with lower landfill use (estimate = 1.178, se = 0.160; Sup. Material Table S9). While these differences were not apparent at hatching (n = 242, estimate = 0.002, se = 0.143, Sup. Material Table S10), by fledging juveniles from high landfill-use colonies were significantly lighter than those from low landfill-use colonies (n = 106; estimate = -1.157, se = 0.450; Figure 4, Sup. Material Table S11).

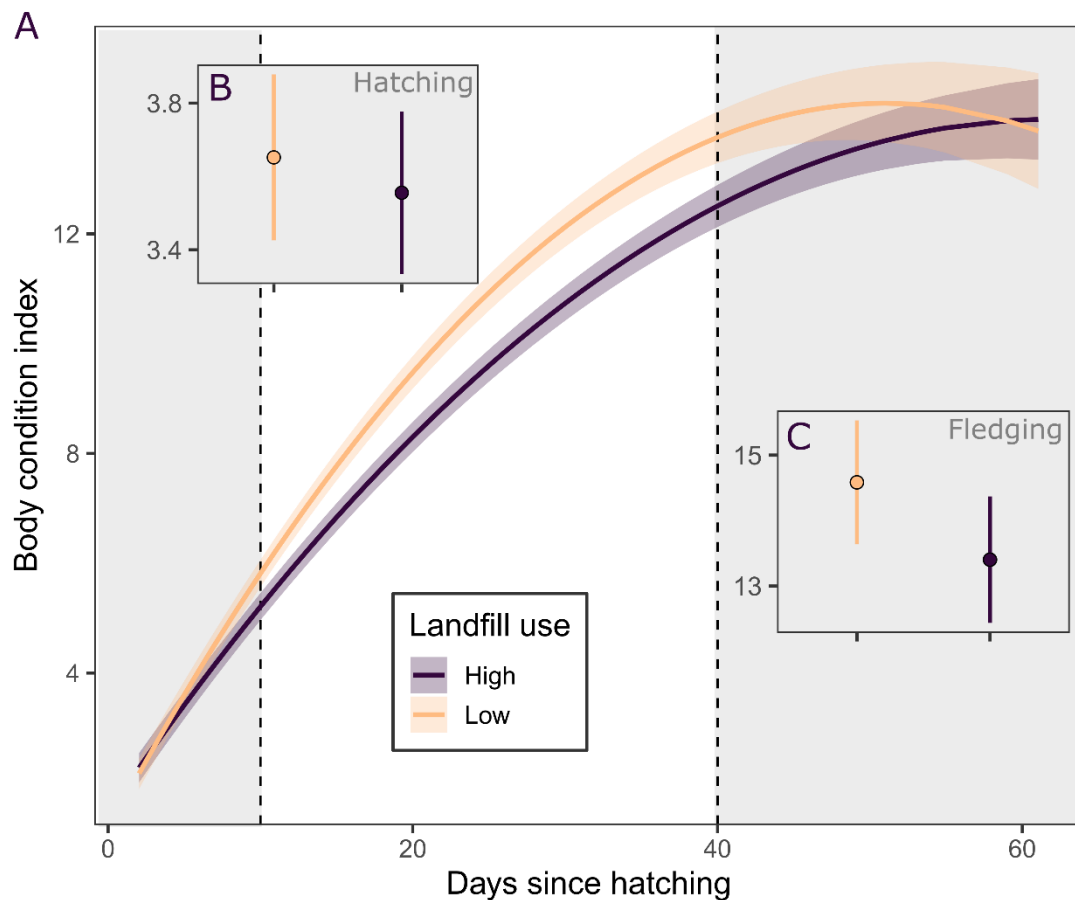


Figure 4 – Parental landfill use negatively correlates with nestling body condition during development. (A) Predicted changes in body mass index from hatching to

fledging in colonies with lower (light orange) and higher (dark purple) landfill use. Lines show model predictions, with shaded areas representing 95% confidence intervals. (B) Body condition at hatching, showing no differences between low- and high-landfill-use colonies. (C) Body condition at fledging, with chicks from high-landfill-use colonies fledging about 10% lighter. In (B) and (C) the circles indicate the model predictions, and the error bars indicate the 95% confidence intervals.

Relationship between juvenile body condition and post-fledging movements and survival

We tracked the movements of 79 juveniles after fledging to investigate how BMI at fledging influenced post-fledging movement behaviour. On average, juveniles moved 45km per day during the first 30 days after fledging (sd = 72, range = 0–799km), left the colony after an average of 18 days after fledging (sd = 10, range = 0–55 days), and reached a maximum distance of 368km from the nest (sd = 312, range = 2–961km). Juveniles with lower BMI moved significantly shorter distances per day (estimate = 0.193, se = 0.077, Sup. Material Table S12) and delayed their departure from the colony (estimate = -0.190, se = 0.069, Sup. Material Table S13) compared to heavier individuals (Figure 5). However, the sensitivity analysis indicated that differences in daily travelled distance dissipated with time after fledging, and by 60- and 90-days post-fledging, there was no effect of BMI on travelled distances, suggesting that lighter juveniles were able to compensate for their initial lower mobility over time (Sup. Material Figure S7). BMI remained negatively correlated with the timing of colony departure when considering a threshold distance of 25km, but not at 5km, indicating that poorer body condition only affected the onset of larger dispersal movements (Sup. Material Figure S8). We did not find an effect of BMI on the maximum distance moved from the nest (estimate = 0.188, se = 0.142, Sup. Material Table S14) or on post-fledging survival (estimate = 0.244, se = 0.429, Figure 5, Sup. Material Table S15), irrespective of the number of post-fledging days considered (Sup. Material Figure S9 and Figure S10).

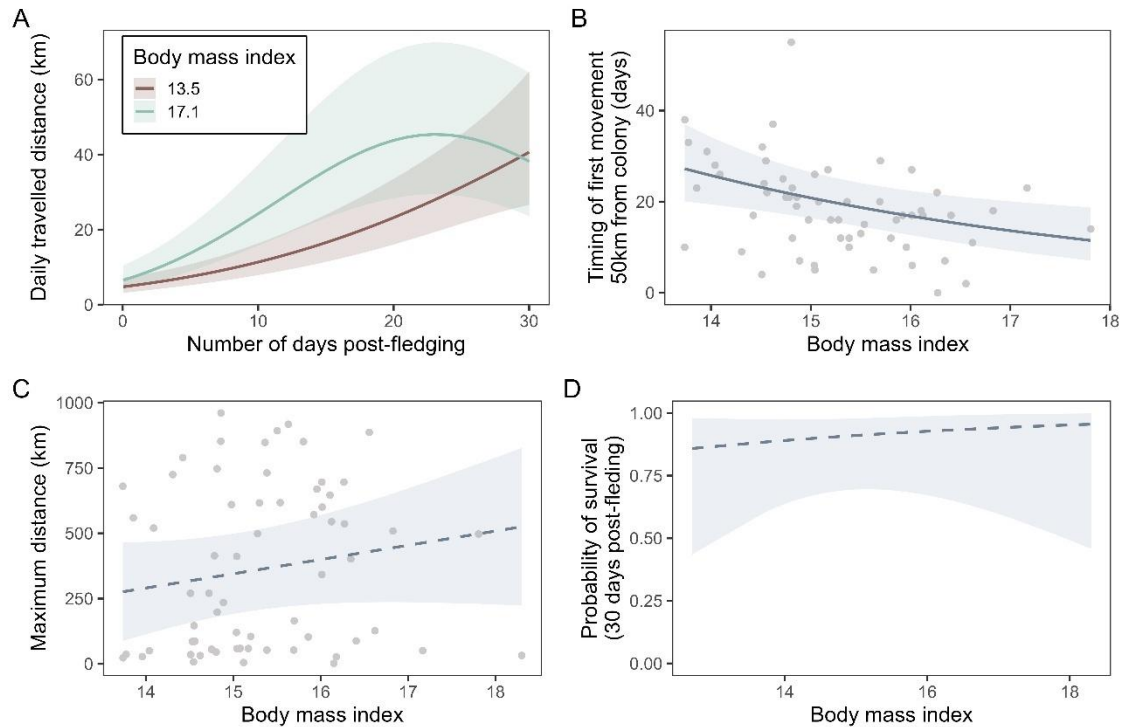


Figure 5 – Relationship between fledging body mass index and post-fledging movements and survival. (A) Relationship between daily travelled distance (kms) and the interaction between the timing of movements (in days after fledging) and body mass index, showing that lighter individuals (dark red) travelled shorter distances per day during the first month after fledging, compared to heavier individuals (green). The two body mass index values shown represent the approximate range of observed body mass indices (B) Relationship between timing of departure from the colony and body mass index, showing that lighter individuals leave the colony later. (C) No significant relationship between the maximum travelled distance from the colony during the first month after fledging and body mass index. (D) No significant relationship between the body mass index and survival during the first month after fledging. All panels show model predictions and 95% confidence intervals from the corresponding GLMMs and LMMs. In (B) and (C) the light circles represent the raw data points.

Discussion

Humans are transforming ecosystems at an unprecedented pace, and the intentional and unintentional provision of food subsidies is one of the most pervasive ways in which human activities now affect wildlife (Oro et al. 2013; Plaza e Lambertucci 2017). In this

paper, we show that Yellow-legged gulls across five Mediterranean breeding colonies rely on anthropogenic food, obtained not only from urban and recreational areas but also from landfills. Landfill use varied among colonies, independently of the distance between colonies and landfills, and this variation influenced parental care, reducing both the number and duration of foraging trips and increasing the number of anthropogenic materials present in pellets. Despite the increased presence of parents in the colonies, higher landfill use by adults lead to chicks which developed and fledged with lower body condition and delayed the onset (but not the distance) of their post-fledging movements. Overall, our results reveal how reliance on landfill resources can shape the behaviour of opportunistic birds and generate carry-over effects on chick development and early-life behaviour.

Foraging on landfills is a widespread behaviour across multiple gull species and locations: for example, Black-headed gulls (*Chroicocephalus ridibundus*, Martín-Vélez et al. 2024) and Audouin's gulls (*Ichthyaelus audouinii*, Vilaplana et al. 2024) in Europe; Ring-billed gulls (*Larus delawarensis*, Sorais et al. 2021) and Glaucous-winged gulls (*Larus glaucescens*) and Glaucous gulls (*Larus hyperboreus*, Ahlstrom et al. 2021) in North America; and Kelp gulls (*Larus dominicanus*) in both South America (Adami et al. 2024) and South Africa (Reusch et al. 2020), amongst many others. However, to assess how this behaviour affects breeding, most studies have relied on the distance between colonies and landfills as a proxy for access to anthropogenic food. While distance to landfills can indeed shape foraging behaviour (Duhem et al. 2005; Egunez et al. 2018), our results show colony-specific differences that cannot be explained by distance alone. For example, Yellow-legged gulls in Carteau spent less than 20% of their foraging time at landfills, whereas gulls in Frioul spent over 60%, despite both colonies being located at similar distances from the nearest landfill (roughly 10 km). In addition, gulls in Piana spent a similarly high proportion of time at landfills as gulls in Frioul, even though the nearest landfill was located roughly 40 km from the colony (Figure 1, Figure 2). Such decisions could depend on multiple factors, such as local environmental conditions and alternative natural habitats (Evans e Gawlik 2020), as well as landfill size and overall availability of anthropogenic resources (Payo-Payo et al. 2015), but may also arise from social processes, such as conspecific attraction or social learning (Monier 2024), which could be influenced by colony size.

Parental use of landfills during the breeding season can shape chick development and health long before the chicks visit these sites themselves (de la Casa-Resino et al. 2014; Pineda-Pampliega et al. 2021). We show that Yellow-legged gull chicks from colonies with higher parental landfill use gained less weight during development and fledged in poorer body condition than those from colonies with lower landfill use. This contrasts with studies relying solely on distance to landfills, rather than actual parental foraging behaviour, which often report better chick body condition and better nutritional status near landfills (e.g., Pineda-Pampliega et al. 2021). Our results also indicate differences in parental care: adults with higher landfill use performed fewer foraging trips, and trips dominated by landfill foraging were shorter in duration, consistent with a potential “time and energy saving strategy” (Soriano-Redondo et al. 2021). However, it remains unclear whether these parents bring similar quantities or quality of food to their chicks. Although we did not assess chick nutritional status, previous work shows that adult gulls feeding at landfills may have poorer nutritional condition, suggesting lower-quality diets (Adami et al. 2024). The higher number of anthropogenic items in pellets from high-landfill-use colonies further suggests that chicks may be receiving more anthropogenic waste, like plastic, which can negatively affect condition and even cause mortality (Lavers et al. 2014; Murphy et al. 2025). Despite the correlations we found at the colony-level, future work should directly quantify parental foraging behaviour alongside their offspring’s physiological and nutritional condition, to establish a causal link between landfill use by the parents and offspring development.

Early-life conditions can carry-over well beyond the rearing period. For example, in Little Penguins *Eudyptula minor*, chicks that developed more slowly had lower first-year survival, whereas fast-growing chicks matured earlier and produced more offspring over their lifetimes (Wintz et al. 2025). In our study, chicks that fledged in poorer body condition, likely reflecting parental reliance on landfill resources, travelled fewer kilometres per day during the first month after fledging and delayed dispersal from the colony compared with chicks in better condition. Nevertheless, the total dispersal distance between gulls in poorer and better condition were similar. This suggests that, even if compromised, gulls can still disperse across large areas. These patterns can have several important implications for gull ecology and disease epidemiology. For example, remaining closer to the natal colony may reduce mortality risk during the first year after fledging (Cheng et al. 2019). In addition, and since juveniles exposed to landfills during

early-life may carry higher loads of pathogens of human interest (Vittecoq et al. 2017), fewer displacements may reduce pathogen transmission probability outside the natal colony and reduce widescale spread of pathogenic agents (Ahlstrom et al. 2021).

The timing of juvenile dispersal and migration can shape the environmental conditions they encounter, as shown for White storks, where later-departing juveniles experienced poorer weather, spent more energy in flight, and migrated shorter distances (Acácio et al. 2022; Bontekoe et al. 2023). However, in Yellow-legged gulls, we did not detect an effect of body condition on post-fledging distance travelled or survival up to 90 days post-fledging, and differences in daily travel distance were restricted to the first month after fledging. Together, these results suggest that juveniles can potentially compensate for poor early-life conditions after fledging. A similar compensatory pattern has been observed in white storks, where lighter juveniles performed more stopovers, mostly at landfills, and ultimately achieve similar survival during migration compared to heavier conspecifics (J. Marcelino et al. 2023). Future studies should evaluate whether juvenile yellow-legged gulls adopt similar behavioural adjustments to compensate for their fledging condition. In addition, although we detected no effect on post-fledging survival, effects may have occurred earlier, during the pre-fledging period. Indeed, a previous comparison of breeding success among these colonies found that Carteau had the highest fledging success (mean = 0.89; 95% CI = 0.76-1.02), followed by Frioul (0.70; 0.53-0.87) and Planasse (0.67; 0.46-0.87), whereas Medes had the lowest fledging success (0.54; 0.34-0.73) (Souc et al. 2024). These contrasting patterns suggest that breeding success is likely correlated with multiple factors, not solely with landfill use. Finally, if poor body condition at fledging reflects inferior food quality and/or higher pathogen exposure during development, longer-term fitness consequences cannot be ruled out (Sergio et al. 2022). Likewise, understanding the long-term effects of lifelong exposure to pathogens and contaminants remains essential.

In conclusion, we show that breeding yellow-legged gulls depend heavily overall on anthropogenic food subsidies, particularly from landfills, but that this relationship varies among colonies. A high use of landfills by parents negatively affects chick growth, which in turn delays departure from the colony and alters post-fledging movements. However, no obvious effect on post-fledging survival was found. Despite the possible negative effects of using landfills, yellow-legged gull's population increases have been associated with landfills (Duhem et al. 2005), as with other landfill-reliant species (Cattr

et al. 2025). European waste-management policies (1999/31/EU and 2018/850/EU) are slowly reducing the amount of refuse deposited in landfills, and many remaining sites are implementing deterrence measures to limit bird use. Previous studies evaluating the effects of landfill closure on yellow-legged gulls suggest that closures are associated with increases in foraging effort and higher physiological stress (Pereira et al. 2025), with breeding females being smaller, and laying fewer and smaller eggs (Steigerwald et al. 2015). There may therefore be a trade-off in PFAS use, with better condition and reproductive effort in adults, but lower juvenile condition. However, as juvenile survival is normally very low, this effect may be negligible in terms of population dynamics. These effects, combined with the species high foraging flexibility (Delgado et al. 2021; Zorrozueta et al. 2020) may push birds toward greater use of urban and recreational areas, potentially intensifying human–wildlife conflict (Coccon e Zucchetto 2025). This underscores the need to understand how declines in anthropogenic food subsidies will affect yellow-legged gull and other waste-reliant species across all life stages, from early-life development to adult survival and reproduction.

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Author contributions

Karen D. McCoy and Marion Vittecoq conceived the sampling design and obtained funding for research, and Carole Leray, Thomas Blanchon, Raül Ramos and Jean-Baptiste Lanfranchi coordinated the collection and processing of samples. The current approach was designed by Marta Acácio, Karen D. McCoy and Charly Souc. Marta Acácio, Charly Souc and Florence Nono Almeida analysed the data. Marta Acácio led the writing of the manuscript, with contributions from all authors.

Conflict of interest Statement

The authors have no conflicts of interest to declare.

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Ethics

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Supplementary Materials

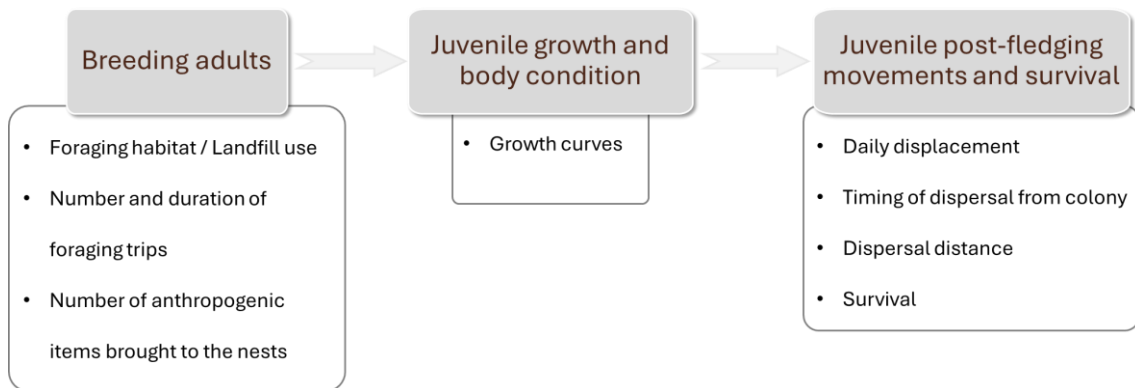


Figure S1 – Overall diagram of the analysis performed in this study.

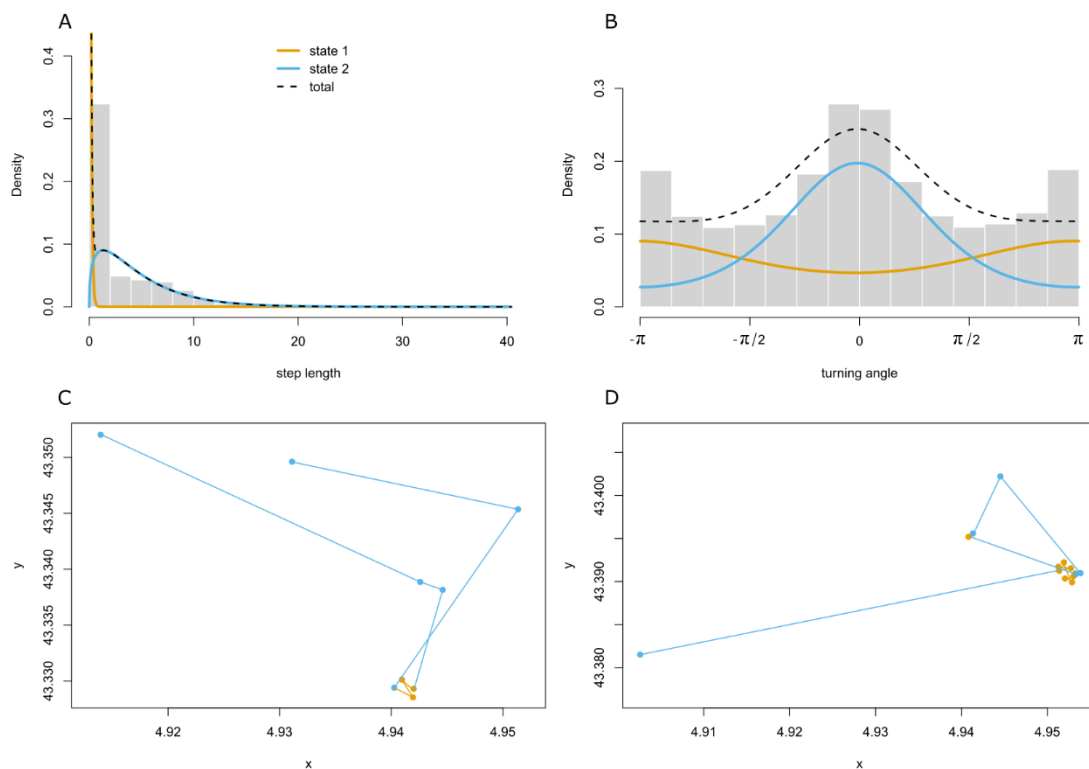


Figure S2 – Distribution of step lengths (A) and turning angles (B), and examples of the two behavioural states identified by the best-fitting Hidden Markov Model (C, D). State 1 (orange) is characterised by short step lengths and large turning angles, corresponding to potential foraging areas of yellow-legged gulls. State 2 (blue) is characterised by long step lengths and short turning angles, likely corresponding to commuting flights.

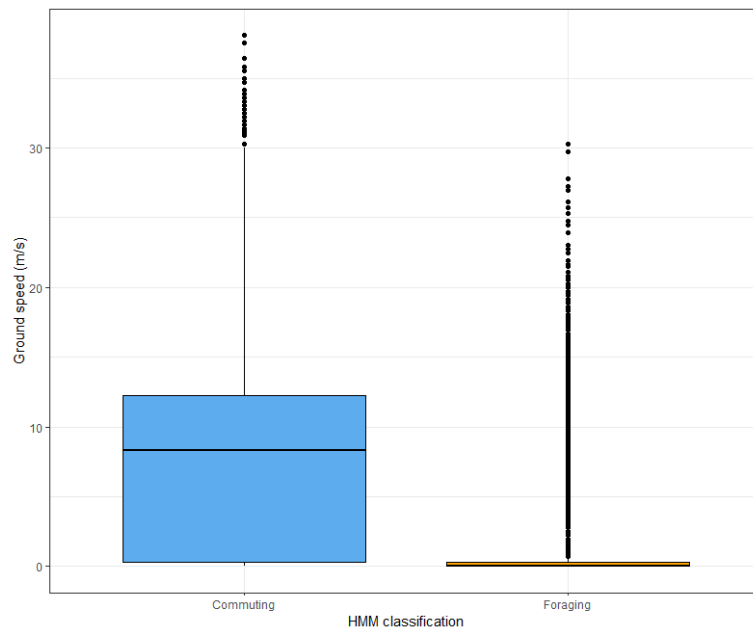


Figure S3 – Ground speed (m/s) of locations classified as “commuting” and “foraging” by the Hidden Markov Model.

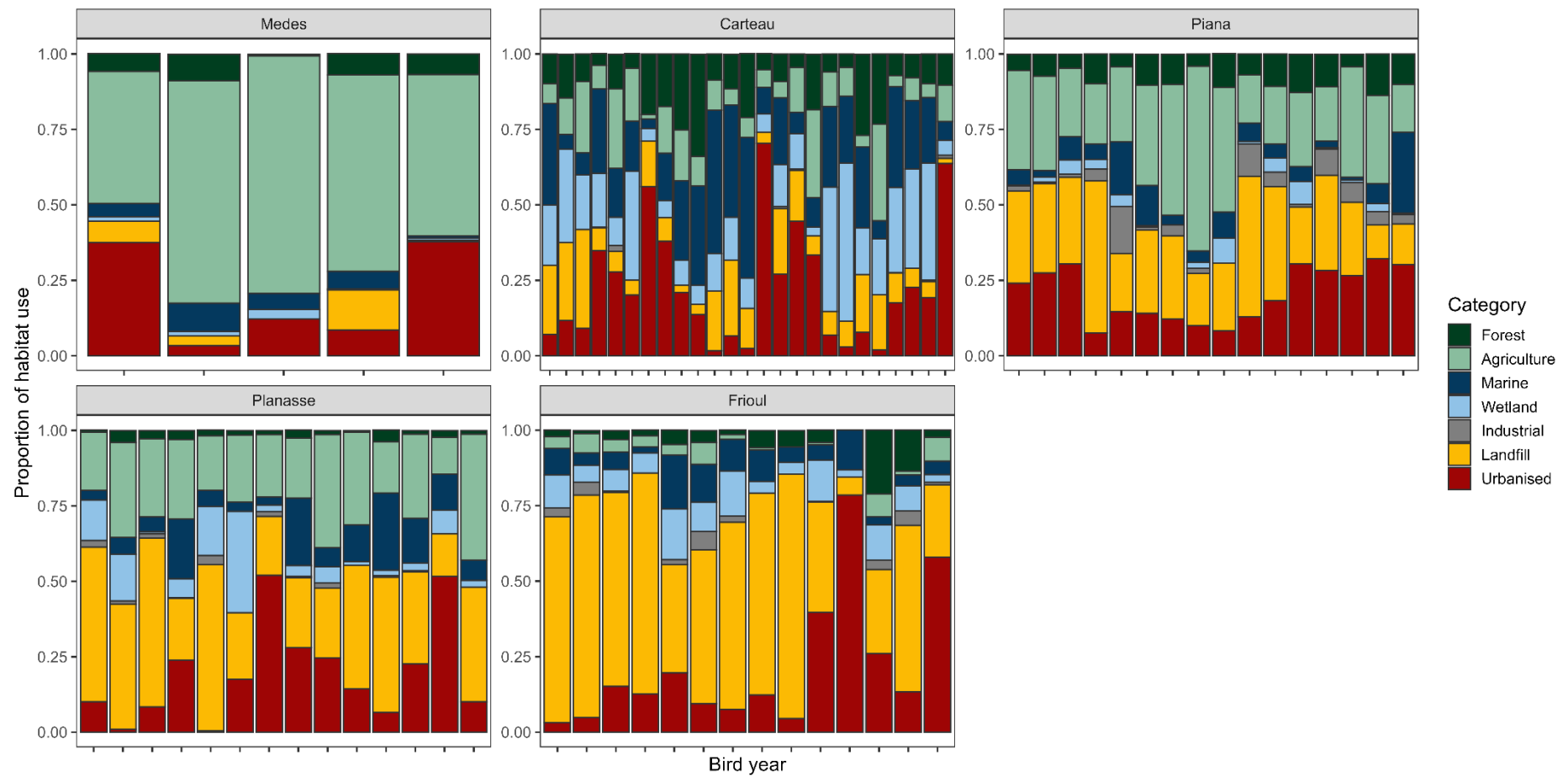


Figure S4 – Differences in foraging habitat use within and between the five Mediterranean colonies and the 45 breeding Yellow-legged gulls (74 bird-years). Proportion of foraging locations within each of the seven habitat categories: forest (dark green), agricultural areas (light green), marine environments (dark blue), wetlands (light blue), industrial sites (grey), landfills (yellow) and urbanised and recreational areas (red).

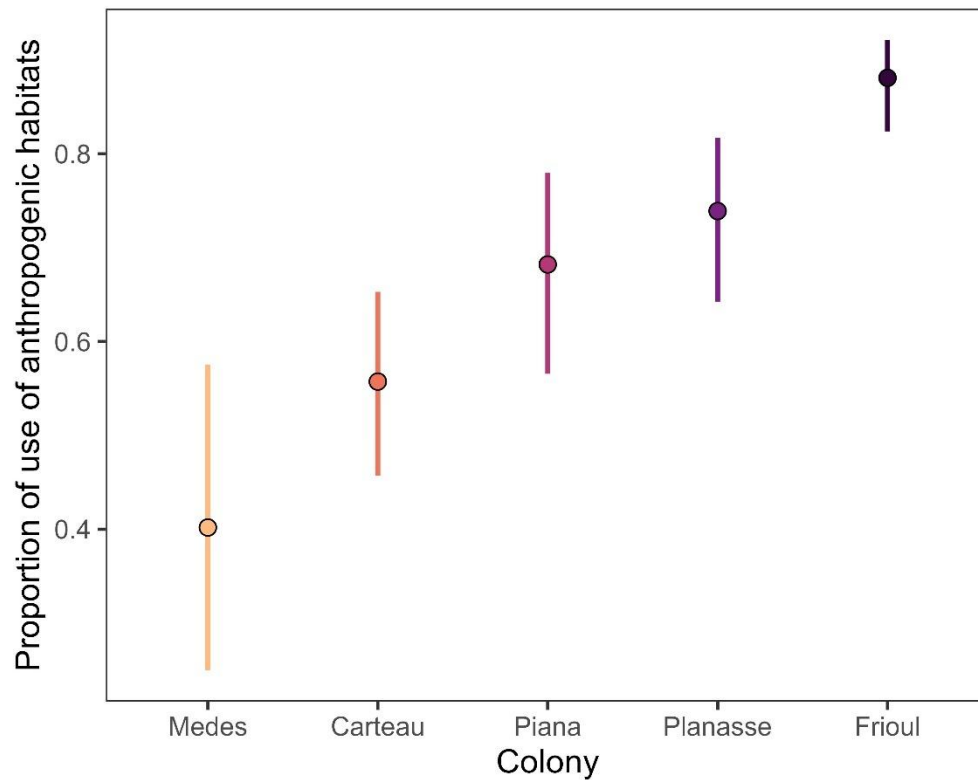


Figure S5 – Proportion of foraging locations in anthropogenic habitats (landfills and urbanised and recreational areas) of yellow-legged gulls breeding in five Mediterranean colonies. Circles show mean predicted values from the generalized linear mixed models, and error bars represent 95% confidence intervals.

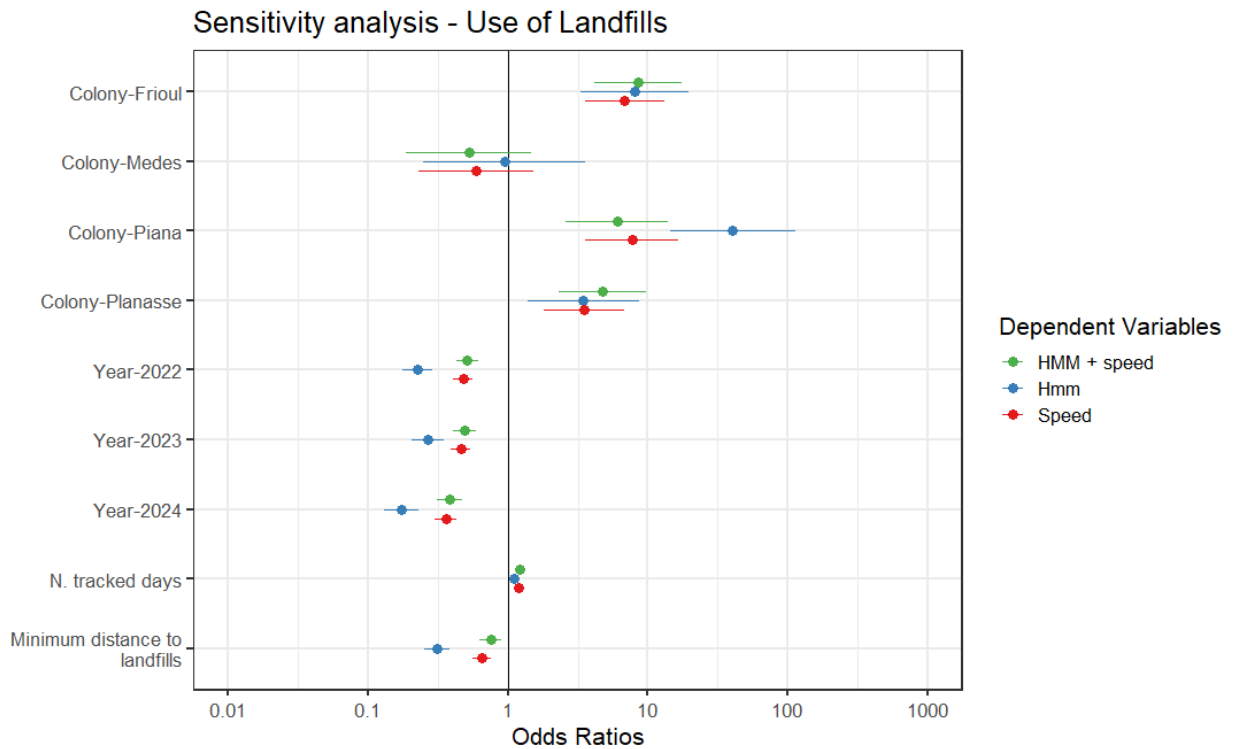


Figure S6 – Comparison of three binomial GLMMs evaluating the effect of colony, year, number of tracked days and distance to the landfill on the proportion of foraging locations on landfills. The foraging locations were calculated using a combination of Hidden Markov Models (HMMs) and the GPS ground-speed (green), using solely the HMMs (blue) and using only the ground-speed (red).

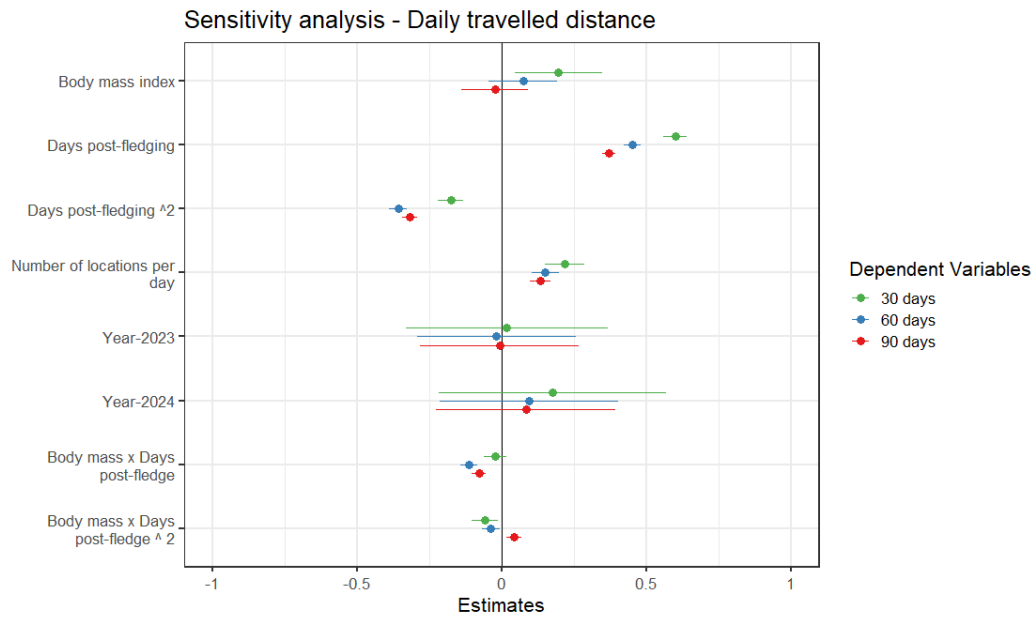


Figure S7 – Comparison of three LMMs evaluating the effect of body mass index (BMI) on the daily travelled distance during the 30- (green), 60- (blue) and 90-days (red) post-fledging period. The models accounted for the number of locations collected per day and the year, and individual and colony were included as random effects.

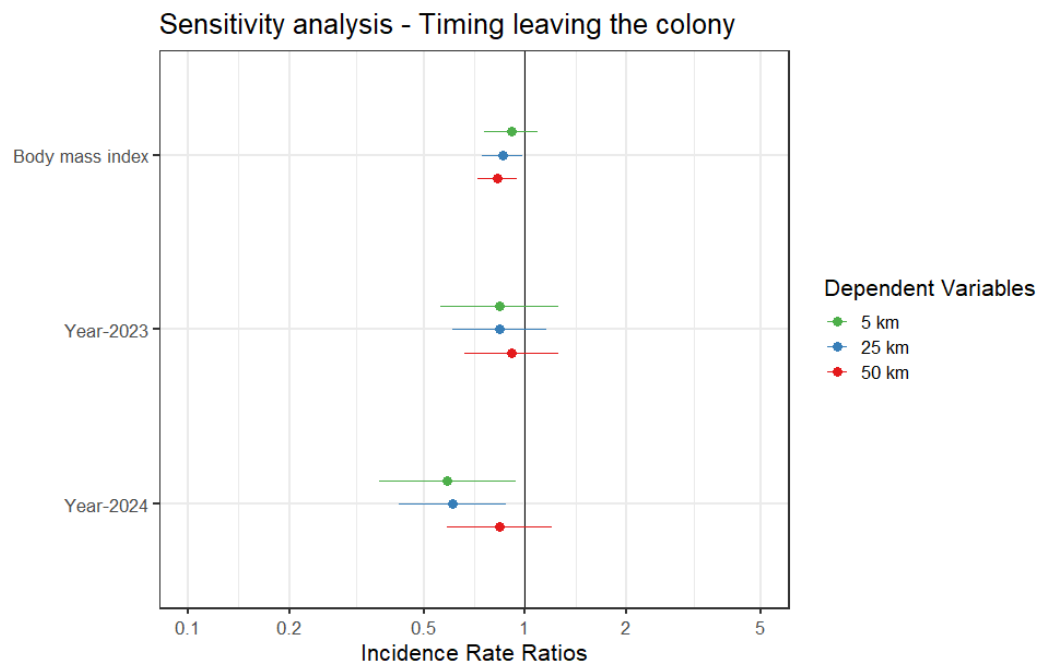


Figure S8 – Comparison of three negative binomial GLMMs evaluating the effect of body mass index (BMI) effect of body mass index (BMI) on the timing of leaving the colony (number of days post-fledging). Timing of leaving the colony was calculated as the first time the individual moved 5km (green), 25km (blue) and 50km (red) from the colony. The models accounted for the year and colony, included as random effect.

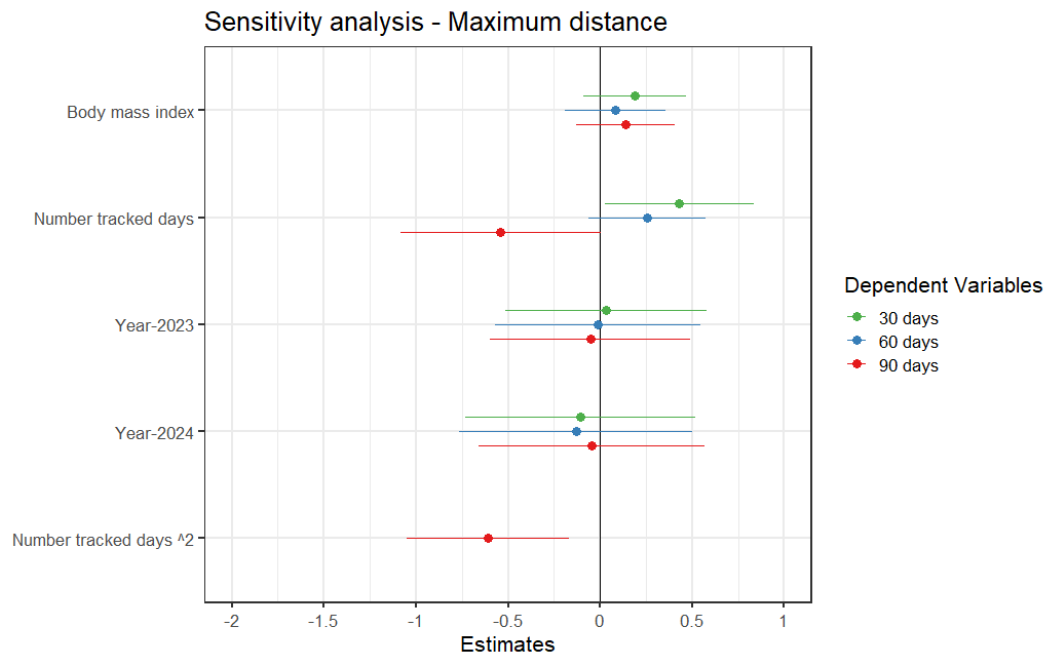


Figure S9 – Comparison of three LMMs evaluating the effect of body mass index (BMI) effect of body mass index (BMI) on the maximum dispersal distance from the nest on the 30- (green), 60- (blue), and 90-day (red) post-fledging period. The models accounted for the year and colony, included as random effect.

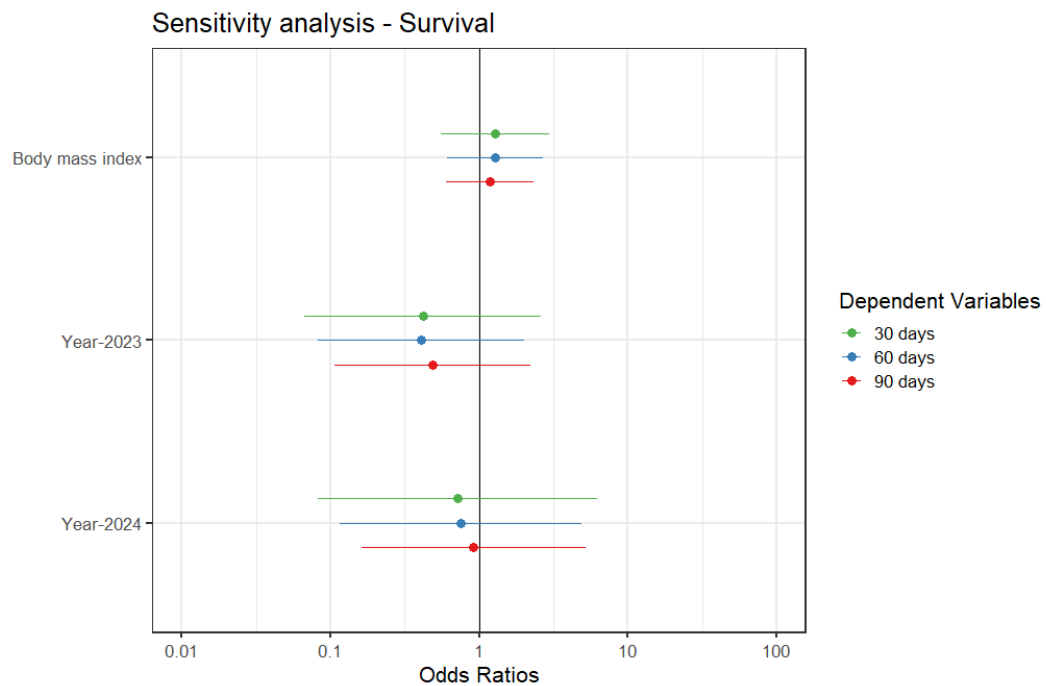


Figure S10 – Comparison of three binomial GLMMs evaluating the effect of body mass index (BMI) effect of body mass index (BMI) on survival on the 30- (green), 60- (blue), and 90-day (red) post-fledging period. The models accounted for the year and colony, included as random effect.

40 **Table S1 – Categories of landcover with corresponding Corine Landcover 2018 codes and**
41 **description (CLC18).**

Landcover category	CLC18 code	CLC18 description
Agricultural areas	2.1.1.	Non-irrigated arable land
	2.1.2.	Permanently irrigated land
	2.1.3.	Rice fields
	2.2.1.	Vineyards
	2.2.2.	Fruit trees and berry plantations
	2.2.3.	Olive groves
	2.3.1.	Pastures
	2.4.1.	Annual crops associated with permanent crops
	2.4.2.	Complex cultivation patterns
	2.4.3.	Land occupied by agriculture and significant natural areas
Forested areas	2.4.4.	Agro-forestry areas
	3.1.1.	Broad-leaved forest
	3.1.2.	Coniferous forest
	3.1.3.	Mixed forest
	3.2.1.	Natural grassland
	3.2.2.	Moors and heathland
	3.2.3.	Sclerophyllous vegetation
	3.2.4.	Transitional woodland-scrub
	3.3.2.	Bare rocks
	3.3.3.	Sparsely vegetated areas
	3.3.4.	Burnt areas
	3.3.5.	Glaciers and perpetual snow
Industrial sites	1.2.2.	Road and rail networks and associated land
	1.3.1.	Mineral extraction sites
	1.3.3.	Construction sites
Landfills	1.3.2.	Dump sites
Marine	5.2.1.	Coastal lagoons
	5.2.2.	Estuaries
	5.2.3.	Sea and ocean
Urbanized and recreational areas	1.1.1.	Continuous urban fabric
	1.1.2.	Discontinuous urban fabric
	1.2.1.	Industrial or commercial units
	1.2.3.	Port areas
	1.2.4.	Airports
	1.4.1.	Green urban areas
	1.4.2.	Sport and leisure facilities
	3.3.1.	Beaches, dunes, sands
Wetlands	4.1.1.	Inland marshes
	4.1.2.	Peat bogs
	4.2.1.	Salt marshes
	4.2.2.	Salines
	4.2.3.	Intertidal tides
	5.1.1.	Water courses
	5.1.2.	Water bodies

42 **Table S2 – Summary of the binomial GLMM evaluating the effect of colony, year and**
43 **number of tracked days on the proportion of foraging locations on anthropogenic habitats**

(landfills and urbanised and recreational areas). Individual was included as a random effect. The intercept represents the reference levels “Carteau” for colony and “2021” for year.

	Estimate	Std. Error	z value	p-value	
(Intercept)	0.230	0.205	1.124	0.261	
Colony - Frioul	1.771	0.299	5.926	<0.001	***
Colony - Medes	-0.628	0.405	-1.551	0.121	
Colony - Piana	0.533	0.319	1.673	0.094	.
Colony - Planasse	0.810	0.299	2.709	0.007	**
Year - 2022	-0.671	0.054	-12.414	<2e-16	***
Year - 2023	-0.944	0.060	-15.774	<2e-16	***
Year - 2024	-1.064	0.068	-15.700	<2e-16	***
Number tracked days	0.094	0.026	3.644	<0.001	***
Number tracked days (quadratic)	0.023	0.023	0.994	0.320	
Random effects	Variance	Std. Deviation			
Individual	0.493	0.702			

Table S3 – Summary of the binomial GLMM evaluating the effect of colony, year and number of tracked days on the proportion of foraging locations on urbanised and recreational areas. Individual was included as a random effect. The intercept represents the reference levels “Carteau” for colony and “2021” for year.

	Estimate	Std. Error	z value	p-value	
(Intercept)	-0.798	0.360	-2.215	0.027	*
Colony - Frioul	0.257	0.539	0.478	0.633	
Colony - Medes	-0.165	0.731	-0.226	0.821	
Colony - Piana	0.085	0.575	0.148	0.883	
Colony - Planasse	-0.532	0.543	-0.979	0.327	
Year - 2022	-0.567	0.061	-9.293	<2e-16	***
Year - 2023	-0.930	0.068	-13.674	<2e-16	***
Year - 2024	-0.855	0.076	-11.209	<2e-16	***
Number tracked days	0.002	0.027	0.067	0.946	
Random effects	Variance	Std. Deviation			
Individual	1.620	1.273			

Table S4 - Summary of the binomial GLMM evaluating the effect of colony, year, number of tracked days and distance to the landfill on the proportion of foraging locations on landfills. Individual was included as a random effect. The intercept represents the reference levels “Carteau” for colony and “2021” for year.

	Estimate	Std. Error	z value	p-value	
(Intercept)	-1.642	0.251	-6.530	<0.001	***
Colony - Frioul	2.147	0.364	5.891	<0.001	***
Colony - Medes	-0.638	0.525	-1.215	0.224	
Colony - Piana	1.797	0.431	4.170	<0.001	***
Colony - Planasse	1.554	0.366	4.245	<0.001	***
Year - 2022	-0.668	0.092	-7.296	<0.001	***
Year - 2023	-0.705	0.098	-7.221	<0.001	***
Year - 2024	-0.964	0.106	-9.101	<2e-16	***
Number tracked days	0.202	0.031	6.576	<0.001	***
Minimum distance to landfill	-0.282	0.090	-3.138	0.002	**
Random effects	Variance	Std. Deviation			
Individual	0.733	0.856			

Table S5 – Results of post-hoc Tukey test, comparing the landfill use of individuals from different colonies.

Contrast	Estimate	Std. Error	z ratio	p-value	
Carteau - Frioul	-2.147	0.364	-5.891	<0.001	***
Carteau - Medes	0.638	0.525	1.215	0.743	
Carteau - Piana	-1.797	0.431	-4.170	<0.001	***
Carteau - Planasse	-1.554	0.366	-4.245	<0.001	***
Frioul - Medes	2.784	0.544	5.122	<0.001	***
Frioul - Piana	0.350	0.454	0.770	0.939	
Frioul - Planasse	0.593	0.387	1.533	0.541	
Medes - Piana	-2.435	0.535	-4.548	<0.001	***
Medes - Planasse	-2.192	0.553	-3.966	0.001	***
Piana - Planasse	0.243	0.467	0.521	0.985	

Table S6 - Summary of the Poisson GLMM evaluating the effect of the proportion of landfill use on the number of foraging trips of breeding yellow-legged gulls. We accounted for year, number of tracked days and distance to the landfill, and individual and colony were included as random effects. The intercept represents the reference level “2021” for year.

	Estimate	Std. Error	z value	p-value	
(Intercept)	5.477	0.093	59.210	<2e-16	***
Proportion landfill use	-0.391	0.153	-2.560	0.010	*
Year - 2022	-0.090	0.055	-1.640	0.102	
Year - 2023	-0.054	0.060	-0.900	0.369	
Year - 2024	-0.114	0.068	-1.680	0.093	.
Minimum distance to landfill	-0.178	0.042	-4.230	<0.001	***
Number tracked days	0.396	0.019	21.170	<2e-16	***
Number tracked days (quadratic)	-0.175	0.015	-11.810	<2e-16	***
Random effects	Variance	Std. Deviation			
Individual	0.05	0.22			
Colony	0.01	0.09			

Table S7 – Summary of the LMM evaluating the effect of the use of landfills on the log-transformed foraging trip duration, while accounting for the maximum distance moved from the nest, the distance to the closest landfill, the average GPS frequency during the trip, the day of the year and year. Individual and colony were included as random effects. The intercept represents the reference levels “0” for with landfill (i.e., landfills were not used on the foraging trip) and “2021” for year.

	Estimate	Std. Error	z value	p-value	
(Intercept)	4.920	0.070	70.260	<2e-16	***
With landfill ("1")	-0.112	0.012	-9.100	<2e-16	***
Maximum distance to nest	0.543	0.009	63.380	<2e-16	***
Maximum distance to nest (quadratic)	-0.105	0.005	-19.850	<2e-16	***
Minimum distance to landfill	0.073	0.031	2.400	0.016	*
Average GPS frequency	0.086	0.007	11.760	<2e-16	***
Day of the year	0.174	0.006	31.540	<2e-16	***
Day of the year (quadratic)	0.078	0.005	17.030	<2e-16	***
Year - 2022	0.084	0.033	2.570	0.010	*
Year - 2023	0.151	0.033	4.620	<0.001	***
Year - 2024	0.161	0.036	4.460	<0.001	***
Random effects	Variance	Std. Deviation			
Individual	0.083	0.288			
Colony	0.009	0.094			

Table S8 – Summary of the Poisson GLMM evaluating the effect of the use of landfills on the number of anthropogenic items in pellets, while accounting for year, the pellet condition

and the total mass of the pellet. Nest was included as random effect. The intercept represents the reference levels “High” for landfill use and “2022” for year.

	Estimate	Std. Error	z value	p-value	
(Intercept)	2.134	0.186	11.473	<2e-16	***
Landfill use - Low	-0.350	0.133	-2.626	0.009	**
Year - 2024	-0.343	0.142	-2.414	0.016	*
Pellet condition - 2	-0.118	0.160	-0.737	0.461	
Pellet condition - 3	-0.623	0.163	-3.815	<0.001	***
Pellet condition - 4	-1.045	0.255	-4.101	<0.001	***
Pellet mass	0.560	0.051	11.038	<2e-16	***
Pellet mass (quadratic)	-0.171	0.024	-7.155	<0.001	***
Random effects	Variance	Std. Deviation			
Nest	0.305	0.552			

Table S9 – Summary of the LMM evaluating the effect of parental use of landfills on the body mass index (BMI) of nestlings during development, while accounting for year and the number of observations. We included individual as a random intercept, allowing for variation in slope according to the age of the individual (days since hatching). Nest was also included as a random intercept. The intercept represents the reference levels “High” for landfill use and “2022” for year.

	Estimate	Std. Error	z value	p-value	
(Intercept)	9.162	0.214	42.810	<2e-16	***
Landfill use - Low	1.178	0.160	7.350	<0.001	***
Days since hatching	3.722	0.061	61.290	<2e-16	***
Days since hatching (quadratic)	-0.610	0.034	-17.780	<2e-16	***
Year - 2023	0.039	0.143	0.280	0.783	
Year - 2024	0.070	0.144	0.480	0.629	
Number observations	-0.147	0.047	-3.110	0.002	**
Landfill use [Low] x Days	0.515	0.102	5.060	<0.001	***
Landfill use [Low] x Days (quadratic)	-0.328	0.062	-5.260	<0.001	***
Random effects	Variance	Std. Deviation			
Individual (intercept)	0.934	0.966			
Days since hatching (slope)	0.409	0.640			
Nest (intercept)	0.169	0.411			

Table S10 – Summary of the LMM evaluating the effect of parental use of landfills on the body mass index (BMI) of hatchlings (≤ 10 days old), while accounting for year and nest (as

random intercept). The intercept represents the reference levels “High” for landfill use and “2022” for year.

	Estimate	Std. Error	z value	p-value	
(Intercept)	3.566	0.128	27.815	<2e-16	***
Landfill use - Low	0.002	0.143	0.012	0.991	
Year - 2023	-0.514	0.165	-3.107	0.002	**
Year - 2024	-0.351	0.164	-2.143	0.032	*
Random effects	Variance	Std. Deviation			
Nest	0.496	0.704			

Table S11 – Summary of the LMM evaluating the effect of parental use of landfills on the body mass index (BMI) of fledglings (≥ 40 days old), while accounting for year and nest (as random intercept). The intercept represents the reference levels “High” for landfill use and “2022” for year.

	Estimate	Std. Error	z value	p-value	
(Intercept)	14.566	0.489	29.789	<2e-16	***
Landfill use - Low	-1.157	0.450	-2.570	0.010	*
Year - 2023	-0.284	0.576	-0.494	0.622	
Year - 2024	-0.542	0.526	-1.031	0.302	
Random effects	Variance	Std. Deviation			
Nest	0.364	0.603			

Table S12 – Summary of the LMM evaluating the effect of body mass index (BMI) on the daily travelled distance during the 30 days post-fledging period, while accounting for the number of locations collected per day and the year. The individual and colony were included as random effects. The intercept represents the level “2022” for year.

	Estimate	Std. Error	z value	p-value	
(Intercept)	3.169	0.138	22.910	<2e-16	***
BMI	0.193	0.077	2.524	0.012	*
Days post-fledge	0.596	0.021	28.835	<2e-16	***
Days post-fledge (quadratic)	-0.176	0.022	-7.887	<0.001	***
Number of locations	0.198	0.031	6.339	<0.001	***
Year - 2023	0.018	0.178	0.099	0.921	
Year - 2024	0.175	0.200	0.877	0.381	
BMI x Days	-0.023	0.020	-1.153	0.249	
BMI x Days (quadratic)	-0.057	0.022	-2.573	0.010	*
Random effects	Variance	Std. Deviation			
Individual	<0.001	0.570			
Colony	<0.001	0.001			

Table S13 – Summary of the negative binomial GLMM evaluating the effect of body mass index (BMI) on the timing of leaving the colony (number of days post-fledging), while

accounting for year and colony, included as random effect. The intercept represents the level “2022” for year.

	Estimate	Std. Error	z value	p-value	
(Intercept)	2.979	0.124	23.942	<2e-16	***
BMI	-0.190	0.069	-2.752	0.006	**
Year - 2023	-0.093	0.164	-0.568	0.570	
Year - 2024	-0.172	0.183	-0.943	0.346	
Random effect	Variance	Std. Deviation			
Colony	<0.001	<0.001			

Table S14 – Summary of the LMM evaluating the effect of body mass index (BMI) on the maximum dispersal distance from the nest on the 30 days post-fledging period, while accounting for year and colony, included as random effect. The intercept represents the level “2022” for year.

	Estimate	Std. Error	z value	p-value	
(Intercept)	-0.057	0.254	-0.222	0.824	
BMI	0.188	0.142	1.321	0.187	
Number tracked days	0.431	0.207	2.084	0.037	*
Year - 2023	0.033	0.278	0.118	0.906	
Year - 2024	-0.107	0.319	-0.336	0.737	
Random effects	Variance	Std. Deviation			
Colony	0.067	0.260			

Table S15 – Summary of the binomial GLMM evaluating the effect of body mass index (BMI) on the survival on the 30 days post-fledging period, while accounting for year and colony, included as random effect. The intercept represents the level “2022” for year.

	Estimate	Std. Error	z value	p-value	
(Intercept)	2.363	0.784	3.014	0.003	**
BMI	0.244	0.429	0.568	0.570	
Year - 2023	-0.865	0.935	-0.925	0.355	
Year - 2024	-0.338	1.103	-0.306	0.760	
Random effects	Variance	Std. Deviation			
Colony	<0.001	<0.001			