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Changes in plastic ingestion by yellow-legged gulls (*Larus michahellis*) over the breeding season

Running head: Plastic ingestion in yellow-legged gulls

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Abstract:

Gulls can be particularly vulnerable to ingesting plastics when using anthropogenic food sources, with potential consequences on survival and reproductive success. Although birds are known to switch foraging habitat over the breeding season to provide higher quality food for chick provisioning, it is unclear what this means regarding the ingestion of plastics. Here, we tested whether breeding gulls decrease the amount of plastic ingested during reproduction by collecting pellets from a series of monitored nests at a large yellow-legged gull (*Larus michahellis*) colony in southern France. We found at least one plastic item in 83.9% of the analyzed pellets, with the most abundant plastic type being polyethylene-based sheet plastic. As predicted, we found a slight decrease in the number of plastic items in pellets at chick hatching. These results suggest that gulls, like other birds, may adjust foraging habits to provide more digestible, less risky, food to chicks.

Keywords: Chick provisioning, Foraging ecology, Laridae, Regurgitated pellets, Plastic pollution

1. Introduction

Over the last few decades, anthropogenic debris, and especially plastic pollution, has become a major environmental threat to biodiversity (Hernandez-Milian et al., 2019; Yorio et al., 2020). Every day, 20 million plastic items are released into the oceans (Bond et al. 2021) and global plastic production is predicted to reach 33 billion tons by 2050 (Kain et al., 2016), with approximatively 12,000 million metric tons of plastic waste predicted to be released into landfills and the environment (Geyer et al., 2017). Seabirds could be valuable biological indicators of marine plastic pollution as they feed at a broad range of trophic levels, encompass diverse feeding guilds and vary in their foraging habitats (Dänhardt et al. 2011, Rapp et al. 2017). Already in the 1990s, 44% of the world's seabird species were recorded to interact regularly with plastics through entanglement and ingestion (Laist, 1997). These figures seem to be closer to 60% in recent years (Battisti et al. 2019). Plastic ingestion can either be direct and intentional because plastic items are mistaken for prey, or indirect because plastic is accumulated through the trophic chain (Kühn et al. 2020b). Indeed, most seabirds are apex predators and therefore susceptible to accumulate toxins from their prey (Hammer et al., 2016). Plastic ingestion may have a multitude of negative effects, from direct mortality due to obstruction to reductions in body condition due to nutritional deprivation or decreased fat deposition, threatening population viability by reducing survival and/or breeding success (Kain et al. 2016, Lavers et al. 2014, Roman et al. 2020).

Breeding is a particularly energy-demanding period for seabirds, when individuals trade-off somatic and reproductive investments to optimize fitness (Dänhardt et al., 2011). Several studies have observed that breeders modify food sources to improve juvenile survival; selecting higher quality prey to feed their chicks, and keeping lower quality prey for themselves (Dänhardt et al. 2011, Kadin et al. 2016, Limmer & Becker 2009). Seagulls, in

particular, are known to reduce foraging trips to terrestrial food sources and switch to fish based sources at hatching (Alonso et al., 2015; Annett and Pierotti, 1989; Isaksson et al., 2016). However, individual variability in chick provisioning strategies has been observed in several species, including common terns (*Sterna hirundo*) and herring gulls (*Larus argentatus*), and may change with age and experience (Cristol et al. 2017, Limmer & Becker, 2009). Indeed, older individuals tend to access higher quality foraging sites, and provide a better diet to their offspring, and do so with reduced energy expenditure (Wunderle, 1991).

Many bird species are able to expel indigestible debris found in food items in regurgitated pellets (Provencher et al., 2019), increasing the potential range of food sources they can integrate into their diet. Studying this expelled material can be an extremely informative and non-invasive method to assess resource use and monitor the presence of pollutants in food materials, such as plastics (Bond et al. 2021). In addition, plastics found in pellets are often large enough to confidently identify the type and potential source (AMAP, 2021). Studies to date suggest that susceptibility to plastic ingestion varies greatly among seabird species (Franco et al., 2019), mainly due to differences in feeding ecology (Ryan, 1987). For example, only 6% of great skua (*Stercorarius skua*) pellets contained plastics, with a median of two plastic items per pellet; this species is an avian predator, scavenger and kleptoparasite (Hammer et al. 2016). In contrast, shags and shearwaters, which hunt fish by pursuit diving, contain large amounts of plastic; Álvarez et al. (2018) registered 63% of shag pellets with plastic fibers, and Bond et al. (2021) found plastics in 100% of pellets from surface feeding flesh-footed shearwaters (*Ardenna carneipes*). Large gulls tend to be opportunistic feeders and, depending on colony location, different proportions of plastics have been recorded in their pellets. Stewart et al. (2020) reported that 92.51% of Australian Pacific gull (*Larus pacificus*) pellets contained anthropogenic debris, with 83.63% containing plastics.

Human garbage was found in 42% of herring gull (*Larus argentatus*) pellets from eastern Canada in 2012 (Bond, 2016). In contrast, a study in the USA recorded 12.2% of glaucous-winged gull (*Larus glaucescens*) pellets with plastics (Lindborg et al., 2012). Yorio et al. (2020) registered only 3.2% of kelp gull (*Larus dominicanus*) pellets with plastics in Argentina.

Here, we focus on the yellow-legged gull (*Larus michahellis*), a common seabird of the Mediterranean region with an opportunistic feeding ecology. These gulls can use both natural and anthropogenic food items, but individuals may specialize on particular foraging zones (Duhem et al., 2005; Navarro et al., 2017). Natural food sources include fishes, crustaceans, molluscs and planktonic organisms (Mendes, 2017), whereas human-derived sources vary from fishing offal to any type of food waste found in garbage. Large population sizes, combined with a close proximity to urban areas and landfills, make these birds highly susceptible to plastic ingestion (Lenzi et al., 2016; Lopes et al., 2021; Mendes, 2017; Ramos et al., 2009a; Stewart et al., 2020; Yorio et al., 2020). Indeed, Lopes et al. (2021) found that yellow-legged gull pellets collected in urbanized areas of Portugal contained more plastic debris than those collected from natural areas. These authors further suggested that the amount of plastic in pellets was directly linked to the food source used, with less plastic present when natural food items were present in the pellet. As these gulls are opportunistic feeders, variation in food source use could be expected over time, including variation in plastic ingestion. This may be particularly the case during chick rearing when poor quality food items could be detrimental for chick survival and growth (Ceia et al. 2014, Duhem et al. 2005, Mendes 2017).

The main goal of the present study was to investigate the quantity and types of anthropogenic debris ingested by breeding yellow-legged gulls during the early part of

reproduction, from incubation to mid-chick rearing, using information obtained from pellets regurgitated at a series of monitored nest sites. We specifically focused on plastic exposure, considering both the amount and types of plastic expelled. We examined plastic composition using FTIR characterization in order to infer the source of the ingested plastic. We tested the hypothesis that birds change food sources at chick hatching to improve chick survival. We expected breeders to provision young chicks with high quality marine prey or more digestible anthropogenic food items and therefore, to find less plastic debris in the pellets post-hatching compared to pre-hatching.

2. Materials & Methods

2.1. Pellet analysis

Pellets were collected in the colony of Carteau, a small islet in the Gulf of Fos (43°22'39"N 4°51'28"E) (**Erreur ! Source du renvoi introuvable.**). A population of about 300 breeding pairs of yellow-legged gull (*Larus michahellis*, Laridae, Charadriiformes) are the only seabird occupants of this 1.36 ha islet. During the 2020 breeding season (March to June), 30 nests were randomly chosen and marked. Old pellets from the previous season were removed and all new pellets were collected from a 1m radius around each nest during weekly surveys from early April until mid-May (6 weeks). Only fresh and structurally intact pellets were collected to ensure that results reflected the recent diet of the individuals, and to guarantee that samples were not contaminated by environmental anthropogenic debris (Provencher et al., 2019). Pellets were individually stored in labelled plastic bags until analyses.

In the laboratory, pellets were broken apart using forceps and carefully examined (Figure 2). Anthropogenic materials were separated from natural items using a stereomicroscope, when necessary, and dried at room temperature for 2 days. Items were

grouped by category (natural, anthropogenic non-plastic or plastic) and weighted to the nearest 0.0001g. The total weight of the pellet was calculated as the sum of the weights of each category. Depending on the presence and composition of natural items in the pellets, a foraging habitat was assigned: marine, terrestrial, terrestrial+marine, or anthropogenic only (see Table S2 in supplementary materials). Anthropogenic materials were then sorted and categorized into type and colour following standardized procedures established by Provencher et al. (2017). Categories of anthropogenic non-plastic debris included glass, aluminum foil, fabric and paper. Plastics were sub-divided into six different morphological categories: sheet plastics (e.g., plastic bags and cling film), threadlike plastics (e.g., fishing lines, plastic strings, and ribbons), hard fragments (unidentifiable fragments from the breakdown of larger plastic items, as well as intact items), foamed synthetics (e.g., styrofoam), industrial plastics (e.g., beads) and other miscellaneous items (see Table 1). The colour of each plastic item was classified using the eight categories recommended by Provencher et al. (2017) : off/white-clear, grey-silver, black, blue-purple, green, orange-brown, red-pink and yellow. An extra category was added for items with more than one colour (Lopes et al., 2021). Plastic item size was categorized as macro (>2cm), meso (2 to 0.5cm) and micro (<0.5cm). Items were sorted visually by one operator, so particles below 1mm may not have been detected. Every plastic item from each category was weighed to the nearest 0.0001g using a precision balance (Mettler Toledo, AG245).

The chemical characterization of each plastic item was performed by attenuated total reflectance Fourier transformed infrared spectroscopy (ATR-FTIR, Thermo Nicolet 6700, Thermo Fisher Scientific) using a diamond crystal. The ATR crystal was cleaned with ethanol between each particle identification and plastic items were gently cleaned with water and a cleanroom wipe prior to analyses (Jung et al., 2018). The IR spectra were obtained with a

resolution of 4cm^{-1} over the wavenumber range of 400 to 4000 cm^{-1} , applying 16 scans. Each spectrum was compared with the reference spectra of synthetic polymers from commercially available libraries using OMNIC software (Thermo Fisher Scientific). A similarity threshold of 70% was required to assign the chemical composition to a particle, otherwise it was considered as non-identified.

2.2. Statistical analysis

The percent frequency of occurrence of each type of plastic (FO %) was calculated using the formula

$$\text{FO}_i = n_i / n_{\text{total}} \times 100\%,$$

where i represents a specific category of plastic, n_i is the number of pellets in which i is present and n_{total} corresponds to the total number of analysed pellets.

From our pellet analysis, we obtained information on both the number of plastic items and the overall mass of these items per pellet. Therefore, to determine which response variables to use in our statistical analyses, we first tested for a correlation between the number of plastics and the mass of pellets using a Kendall correlation test. To ensure that pellet size was not a confounding factor in the analyses, we also performed a Kruskal-Wallis test to compare pellet size pre and post-hatching.

To determine if there was an overall change in the presence/absence of anthropogenic debris in pellets between breeding periods, we used a generalized linear mixed model (GLMM) with a binomial distribution. In this model, breeding period (pre or post-hatching) and foraging habitat (as defined by pellet content) were treated as fixed effects and the nest site was

173 included as a random effect to correct for pseudo-replication of pellets sampled from the
174 same nest.

175 We tested whether plastic exposure declined post-hatching using a GLMM with a
176 negative binomial distribution. In this test, the response variable was the number of plastic
177 items per pellet and the model included the fixed effects of the breeding period (pre or post-
178 hatching) and the foraging habitat. The model again took into account the random effect of
179 the nest. Pellets with no information on the foraging habitat, as they only contained
180 anthropogenic items, were excluded from the analysis. We also tested if breeding pairs were
181 changing foraging habitat pre and post-hatching using a χ^2 test.

182 For both GLMMs, the first step was to create an overall model which included all
183 possible effects and their interactions. Different variants on this model were then compared.
184 The residuals of each model were evaluated to examine model fit and we retained the most
185 relevant statistical model according to the conditional Akaike criterium (see details in
186 Supplementary Script 1, parts 1 and 2).

187 Finally, in order to explore how plastic exposure varied between pre-hatching and
188 post-hatching periods, we carried out a multiple correspondence analysis (MCA), considering
189 the type, composition, colour, size and mass of each plastic item.

190 The R statistical program v3.6.3 (R Core Team, 2019) was used in all analyses. GLMMs
191 were performed using the lme4_1.1.30 R package (Bates et al., 2015) and the glmmTMB_1.1.4
192 R package (Brooks et al., 2017). Model selection was performed using DHARMa 0.4.6 R
193 package (Hartig, 2022). The MCA was performed using the FactoMineR_2.6 and the
194 factoextra_1.0.7 R packages (Kassambara and Mundt, 2020; Le et al., 2008).

3. Results

A total of 143 pellets were collected and examined from the Carteau gull colony during the 2020 breeding season, 82 from the pre-hatching period and 61 from the post-hatching period. On average, 2.89 ± 2.23 (sd) pellets per nest were collected from the pre-hatching period and 2.18 ± 2.34 (sd) pellets per nest from the post-hatching period.

The mass of a pellet was, on average, made-up of 49% natural elements, 35% non-plastic debris and 16% plastic (Figure 3A). Data on the mean load (number of items and relative mass) of each debris category found in pellets for each breeding period is provided in Table S1 of the supplementary materials. We found a positive correlation between the number of plastic items and the mass of plastics per pellet ($\tau=0.47$, $p\text{-value}<0.01$, see supplementary script 1, part 1). Only the number of plastic items was thus used as a response variable in subsequent analyses to avoid redundancy. No difference in pellet size pre ($n=82$) and post hatching ($n=61$) was found (Kruskal-Wallis; $X\text{-squared} = 0.16438$, $p\text{-value} = 0.6852$).

The presence of anthropogenic debris in pellets was similar during both breeding periods and among foraging habitats (see Supplementary Script 1, part 2), with 93.9% of pellets containing at least one anthropogenic debris item pre-hatching ($n=77$) and 91.8% post-hatching ($n=56$).

At least one plastic item was present in 83.9% of the collected pellets (confirmed by FTIR). A total of 284 plastic items were collected (characteristics in Table 1), with 2.01 ± 1.68 (sd) items per pellet on average. Despite aging effects and chemical alterations due to the ingestion of the plastics by the gulls, FTIR characterization was very successful in identifying plastic composition; only 5 plastics could not be identified. Polymers grouped into eight main categories: polyethylene (PE), polypropylene (PP), polystyrene (PS), Polyester (PET),

poly(ethylene:vinyl acetate:vinyl chloride) (PEVA/PVC), poly(ethylene vinyl acetate) (PEVA), polyvinyl chloride (PVC) and miscellaneous composed for example of polyurethane, nylon, polyacrylate, polytetrafluoroethylene (PTFE), polydimethylsiloxane or polyacetal. Plastics from pellets were mainly composed of PE. Details are reported in Table 2.

There was no significant effect of foraging habitat on the number of plastics per pellet (Table 3). However, the best fit model (Table 3) included an effect of breeding period on the amount of plastic per pellet, showing a slight decrease in the number of plastic items post-hatching (p -value = 0.053), with 1.72 ± 1.50 (sd) items per pellet post-hatching ($n=58$) against 2.24 ± 1.78 (sd) items per pellet pre-hatching ($n=78$).

There was no shift in foraging habitats used by breeding pairs pre and post-hatching ($X^2 = 0.32364$, p -value = 0.8506). Based on pellet content, yellow-legged gulls foraged more in terrestrial habitats, with 54% of pellets containing only terrestrial items pre-hatching and 59% post-hatching. 36% of pellets contained both terrestrial and marine items pre-hatching and 33% post-hatching, whereas 10% of pellets contained only marine items pre-hatching and 8% post-hatching (Figure 3B). Details on the natural items found in the pellets are reported in Table S2 in supplementary materials.

For both periods, sheet plastic was the most abundant plastic type, with 62.6% pre-hatching and 72.4% post-hatching (Figure 3C). Plastic polymers were mainly polyethylene (PE), with 41.9% pre-hatching and 52.4% post-hatching (Figure 3D). The main plastic colour was white/transparent, with 57.5% pre-hatching and 72.4% post-hatching (Figure 3E). There were no obvious differences in the frequency of occurrence of different plastic categories, polymer compositions, colour, size or total plastic mass in pellets between pre-hatching and post-hatching periods. Only 18.6% of the total variance was explained by the first (10.6%) and

second (8%) dimensions of the MCA analysis (Figure 4). However, the pre-hatching period tended to have a larger range of items than the post hatching period.

4. Discussion

Plastics are ubiquitous in the environment nowadays, and fewer and fewer seabirds are able to avoid this type of pollution when feeding (Battisti et al. 2019, Ryan 2008). Here, we examined changes in ingested plastics by yellow-legged gulls over the course of a breeding season by collecting and examining regurgitated pellets from a series of nests. We tested whether breeding birds adapt to the presence of young chicks by switching the foraging habitat at hatching to provide higher quality food, and thus, providing food with lower amounts of anthropogenic debris, and particularly plastics.

In our study, 93% of pellets contained anthropogenic debris items, most of which were plastics. By mass, the non-plastic anthropogenic debris, such as glass, aluminum paper or paper, represented on average 35.61% of the pellet composition, against 15.75% for the plastics; however, non-plastic anthropogenic items tend to be heavier than plastic. Aluminum foil and paper are often use to wrap food and could be accidentally ingested by gulls when reaching the food inside. Glass items could be mistaken for rocks or voluntarily ingested to help the gulls with digestion (Stewart et al., 2020). These types of items could have adverse effects on the birds, causing gut obstruction or damage. Lopes et al. (2021) also found a similar percentage of pellets containing anthropogenic debris items in an urban colony in Porto, Portugal. However, the average number of plastic items per pellet was much lower in Carteau than in Porto over the reproductive period (respectively, 2.01 and 33.35 items/pellet). The difference between these two colonies could be explained by their relative geographic positions and the types of ingested plastics. The Carteau colony is located on an islet close to

the small town of Port-Saint-Louis-du-Rhône (8624 inhabitants), with active agricultural and port-related activities close by, and lies about 40 km away from France's second largest city, Marseille (>860 000 inhabitants in 2021). Plastic exposure in birds from Carteau could be lower than in Porto if gulls do not go all the way to Marseille to forage. Indeed, during breeding, these gulls may take advantage of agricultural and fishing activities which are closer at hand, even if landfills are also readily available (see below). The difference in the number of plastic items per pellet could also be due to the types of plastic found in each location and their rate of fragmentation. We found that gulls at Carteau mainly ingested sheet plastics from food packaging or agricultural plastic mulching (as discussed below), whereas gulls in Porto mostly ingested foamed plastics during the breeding season, such as styrofoam, that are easily fragmented into small pieces. Indeed, if we look at the mean mass of plastics in pellets, gulls from Carteau seemed to ingest heavier pieces of plastic than those from Porto (respectively 0.32g and 0.12g). Thus, the absolute exposure of gulls at the two sites may be very similar, even if the nature of the plastics are different.

Pellets from yellow-legged gulls at Carteau were most frequently formed by sheet plastics and were mainly composed of polyethylene (PE). However, the types of ingested plastics can vary greatly among species. Hammer et al. (2016) observed a high prevalence of beads and hard fragments in great skua pellets, which were suggested to originate from the avian prey of these birds via biomagnification. Bond et al. (2021) also noted a high prevalence of hard fragments in flesh-footed shearwater pellets. These fragments most likely came from the ocean surface where floating plastics are abundant and can be ingested while surface-feeding birds like shearwaters are foraging. In contrast, the sheet plastic from food packaging and bags ingested by yellow-legged gulls probably comes directly from terrestrial sources of anthropogenic waste – street garbage and landfills. However, sheet plastic can also be found

in agricultural fields where it is used as mulching film; the likelihood of gulls ingesting mulching plastic is unknown. We used FTIR characterization to help identify plastic sources and therefore provide information on the foraging ecology of gulls. However, both garbage bags and plastic mulching film have similar compositions (unpublished results). Therefore, the source of the sheet plastics found in gull pellets could not be discriminated. Sheet plastic was also the dominant plastic category found in glaucous-winged gull pellets from Canada (Lindborg et al., 2012). However, it was only rarely found in yellow-legged gull pellets in Portugal during the breeding season (Lopes et al., 2021), even though sheet items were frequent in pellets at resting sites during non-breeding. Thus, plastic load and type may depend on both the locality and the period of the year, in addition to the foraging ecology of the seabird species. As such, examining pellets collected in a standardized way from diverse seabird species may be particularly useful for tracking different local sources of plastic pollution in the environment.

We found that plastic items in the pellets from Carteau were mainly transparent/white, followed by black, matching other studies from seabirds (Hammer et al., 2016; Kain et al., 2016; Lavers et al., 2014; Lopes et al., 2021). The source of these items could be either from directly ingesting a discarded food item with its wrapping, or from the mistaken ingestion of plastics taken as prey food. Indeed, food packaging and garbage bags are mainly white/transparent or black, whereas plastic mulching film is black. If we examine plastic colours after removing sheet plastics, white is still the dominant colour (white = 64 items, green = 9 items, black = 6 items). More generally, light/white plastics have been found to be dominant in the marine environment (Lavers et al., 2014), in part due to the fact that discarded coloured plastics erode and bleach during transport at sea. It remains unknown whether seabirds specifically choose lighter plastics, or whether the number of white/transparent

plastics found in birds simply represents the proportion of coloured plastics discarded in the environment.

We did not find a significant nest effect on the number of plastics per pellet, even if some nests had higher plastic loads than others (see Script 1 part 1 and Figure S3 in supplementary materials). This suggests that individuals within a colony had similar feeding strategies. Exposure to plastic may be particularly harmful during development, when birds are small and require high quality food to grow. Indeed, several studies have highlighted a switch to fish-based food sources at hatching to provide chicks with more digestible and higher quality diets (Alonso et al., 2015; Annett and Pierotti, 1989). Surprisingly, our study demonstrated no change in the presence/absence of anthropogenic debris between pre and post-hatching periods. We did, however, find a change in the nature of this debris, with a slight decrease in the number of plastic items per pellet post-hatching, a period when chicks could have trouble dealing with the elimination of non-digestible items. This change could reflect an adaptive switch of adults to select a higher quality diet to better fulfill the nutritional needs of young birds (Ramos et al., 2009b), thus increasing survival rates. Alternatively, it could represent the inability of adult birds to make long foraging trips, imposing locally available food sources on hatchlings and thus a potential change in resource use. However, we found no evidence of a change in foraging habitats between pre and post-hatching periods, with items from terrestrial habitats dominating pellet content in both pre and post-hatching periods. However, it may be that adult gulls select different types of terrestrial food sources to feed their chicks, such as earthworms (Pennycott et al., 2020), reducing their exposure to plastic, without changing their general foraging habitat. Detailed biologging data should help us evaluate this possibility. Another possible explanation for the reduction in the number of plastic items is a temporal shift in the availability of different food sources; more detailed data

on digestible food items would be required to test this hypothesis. Finally, it could be that post-hatching pellets are produced by chicks. In this case, we would expect smaller pellets to be produced, with an associated drop in the number of plastic items, as chicks should have smaller meal sizes than adults. However, we found no difference in pellet size pre and post-hatching.

Although there was a reduction in the number of plastic items in pellets post-hatching, gull chicks were still exposed to some plastics suggesting that breeders do not completely change resource use at hatching. It may be that most adult birds from Carteau use landfills as their principal foraging zone throughout the season. There are eight landfills within the presumed foraging range of this colony, the nearest being only 15km away; yellow-legged gulls can travel up to 40km to forage (Duhem et al., 2008). Given this short distance to a landfill, it is unlikely that birds would be unable to access this site, even at hatching. Previous studies have also suggested that yellow-legged gulls are highly dependent on landfills for foraging, with some individuals specializing on these resources (Duhem et al. 2003, Ramos et al. 2009b, Lopez et al. 2021). Therefore, rather than change foraging zones, yellow-legged gulls may differentially select food items within the foraging area. In this case, we would expect an overall increase in the time required to select food items. It should be kept in mind that anthropogenic sources do not necessarily equate with poor quality food. Pork, chicken and beef scraps, all highly digestible and energy rich, are frequently found in chick regurgitates (Duhem et al. 2005, Ramos et al. 2009a; pers. obs.). However, quantifying the range of digestible food materials given to chicks is impossible using only pellet data because we only identify non-digestible materials in these pellets. To get rid of this limitation, other approach are necessary such as regurgitate studies, but these are invasive and time-consuming (Provencher et al. 2019), or DNA metabarcoding studies on pellet remains that may provide

detail on digested food items. Isotopes studies comparing profiles from down and flight feathers of the same chick may also provide information on general shifts among foraging environments over the breeding period, complementing direct observations from pellet studies and avoiding digestible material bias.

Although we did not observe a change in foraging habitat, the observed reduction in the number of plastic items post-hatching may still be linked to food availability. Indeed, Ceia et al. (2014) highlighted inter-annual differences in the foraging behaviour of breeding yellow-legged gulls at Berlenga Island (Portugal) depending on food availability around the colony. Similarly, an observational study noted that breeding female gulls began to forage on *Cystoseira algae* after chick hatching and related this behaviour to the critical need to supply key B vitamins to young chicks (Bartoli and Combes, 1997). Such changes would lower the quantity of plastics given to chicks, even if only one of the two parents altered their foraging zone. However, to date, there is an overall lack of information on foraging patterns over the breeding season and, more specifically between pre and post-hatching periods, when the presence of young chicks may limit the time that adults spend away from the colony. As central-place foragers, we should expect yellow-legged gulls to trade-off the gain in obtaining high quality food with the costs associated with its acquisition (i.e, flight distances, competition, etc). Detailed data on gull movements and activities from biologgers, would enable us to evaluate these different hypotheses.

As we do not yet know what percentage of ingested plastics is effectively expelled in pellets, the high exposure rate we found in the present study underlines the need for more detailed work on the physiological impact of plastic ingestion for bird health. Indeed, plastics possess additives (e.g., plasticizers, UV stabilizers, brominated flame retardants or

antioxidants) that give them particular properties required for their use. These additives can be absorbed and accumulate in vital organs (Sühring et al., 2022), with potential toxicological effects for individuals, such as developmental inhibition, endocrine disruption, or even direct mortality (Kühn et al. 2020a, Pennino et al. 2020, Provencher et al. 2020, Teuten et al. 2009). Furthermore, plastics are able to adsorb a significant amount of pollutants from the environment (e.g., PCBs, mercury, and even antibiotics) due to their high surface to volume ratio and the hydrophobic nature of the compounds, increasing the potential adverse effects of plastic ingestion (Guo et al. 2020, Provencher et al. 2020). Gulls can also be exposed indirectly to aerosol pollutants and additives when feeding in landfills. Indeed, Sorais et al. (2020) showed that ring-billed gulls (*Larus delawarensis*) around Montreal were exposed to polybrominated diphenyl ethers (PBDEs) and, to a lesser degree, halogenated flame retardants (HFRs) through atmospheric exposure while foraging in landfills. Therefore, even if gulls choose higher quality food items with lower plastic content, the time alone that individuals spend foraging in landfill areas may affect their general health.

As plastic and other pollutants accumulate in the environment and natural food resources become more limited, wild populations will be increasingly confronted with the use of anthropogenic food sources. Some species may be well-adapted to deal with such highly modified environments. Our result suggest that yellow-legged gulls of the Carteau colony access higher quality terrestrial/anthropogenic foods with less plastic debris at the time when chicks are most susceptible to food quality, thus promoting chick survival and growth. This hypothesis now requires more general testing, both across years and across colony locations, to determine the degree to which the pattern we found is colony- and/or time-dependent. Detailed studies of chick growth and survival for breeding individuals using different food sources will also be essential to evaluate the relative costs and benefits of anthropogenic food

sources in seabird diets and to better understand how birds may cope with a changing environment.

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Table 1: Morphological description of the plastic items found in yellow-legged gull pellets from the Carteau colony, with the mean mass, its standard deviation (\pm SD) and range, and the total number of items.

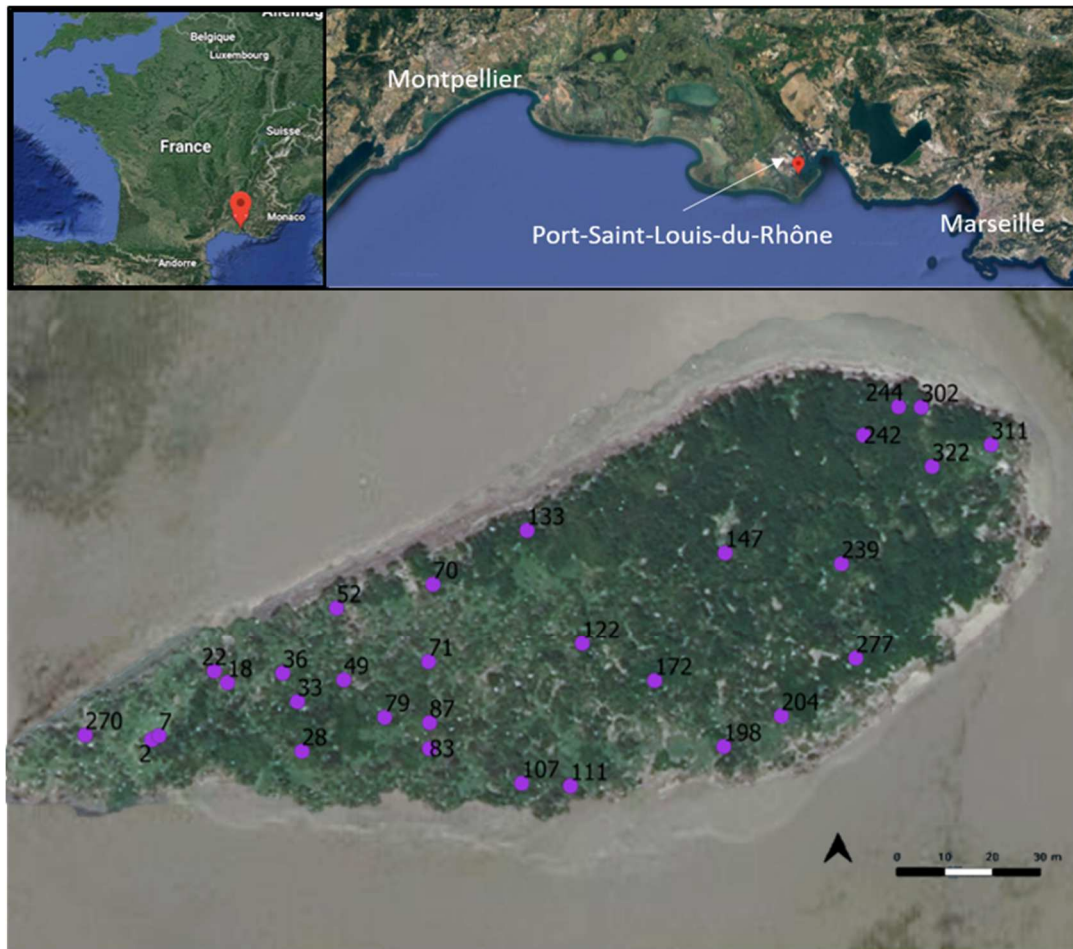
Breeding period	Plastic type	Plastic mass (g)			Total items
		Mean	\pm SD	Range	
Pre-hatching n = 82 pellets	Bead	0.0234	0.0026	0.0215-0.0252	2
	Foamed synthetic	0.0048	0.0079	0.0005-0.0340	21
	Hard fragment	0.0534	0.0967	0.0067-0.0478	13
	Sheet plastic	0.1100	0.2440	0.0001-1.3649	112
	Threadlike plastic	0.1140	0.2680	0.0002-0.3017	18
	Miscellaneous	0.3100	0.7490	0.0020-2.7761	13
Post hatching n = 61 pellets	Bead	0.0221	0.0069	0.0161-0.0296	3
	Foamed synthetic	0.0091	0.0240	0.0006-0.0773	10
	Hard fragment	0.0323	0.0420	0.0043-0.1017	5
	Sheet plastic	0.2410	0.9590	0.0001-7.0510	76
	Threadlike plastic	0.5630	0.7700	0.0014-1.6133	8
	Miscellaneous	0.4710	0.1910	0.3387-0.6901	3
Total for both periods		0.3175	0.7854	0.0001-7.0510	284

Table 2: The composition of plastic items found in yellow-legged gull pellets from the Carteau colony, with the mean percentage of identification (\pm SD) and number of items per polymer type. Polyethylene (PE), Polypropylene (PP), Polyester (PET), Polystyrene (PS), Poly(ethylene:vinyl acetate:vinyl chloride) (PEVA/PVC), Poly(ethylene vinyl acetate) (PEVA), Polyvinyl chloride (PVC), Miscellaneous (e.g. Polyurethane, Nylon, Polyacrylate, Polytetrafluoroethylene (PTFE), Polydimethylsiloxane, Polyacetal). The unknown category refers to polymers which could not be identified above the 70% threshold.

Breeding period	Plastic composition	Percentage of identification		Total number of plastics
		mean	\pm SD	
Pre-hatching n = 82 pellets	PE	93.54	4.05	75
	PP	90.34	7.45	27
	PET	83.64	5.28	21
	PS	91.28	7.43	29
	PEVA/PVC	79.34	7.93	6
	PEVA	93.02	NA	1
	PVC	71.45	NA	1
	Miscellaneous	88.94	10.32	17
Post hatching n = 61 pellets	Unknown	NA	NA	2
	PE	93.18	4.35	55
	PP	92.29	6.59	17
	PET	86.13	7.18	11
	PS	91.04	6.74	12
	PEVA/PVC	81.35	3.32	4
	PVC	81.57	NA	1
	Miscellaneous	76.52	8.03	2
	Unknown	NA	NA	3

Table 3: Results of the two top GLMMs examining the number of plastic items per pellet. Model 1 included only the fixed effect of reproductive period (pre or post-hatching), whereas model 2 included both the reproductive period and the foraging habitat (terrestrial, marine or marine+terrestrial). * The reference states are the pre-hatching period and terrestrial food sources. IRR refers to the Incidence Rate Ratio and CI to the Confidence Interval. Details on model selection are found in Supplementary Script 1, part 1.

Predictors	Model 1			Model 3		
	IRR	CI	p-value	IRR	CI	p-value
Post-hatching*	0.76	0.57 – 1	0.053	0.76	0.58 – 1	0.052
Food Source (marine)*				0.77	0.47-1.30	0.334
Food Source (marine + terrestrial)*				1.22	0.92-1.63	0.160
Number of nests		28			28	
Number of pellets		136			136	
AICc		502.5737			503.1879	



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Figure 1: Geographic location of the Carteau colony in the Gulf of Fos with different zoom (both insets) and placement of the monitored nests (purple points).

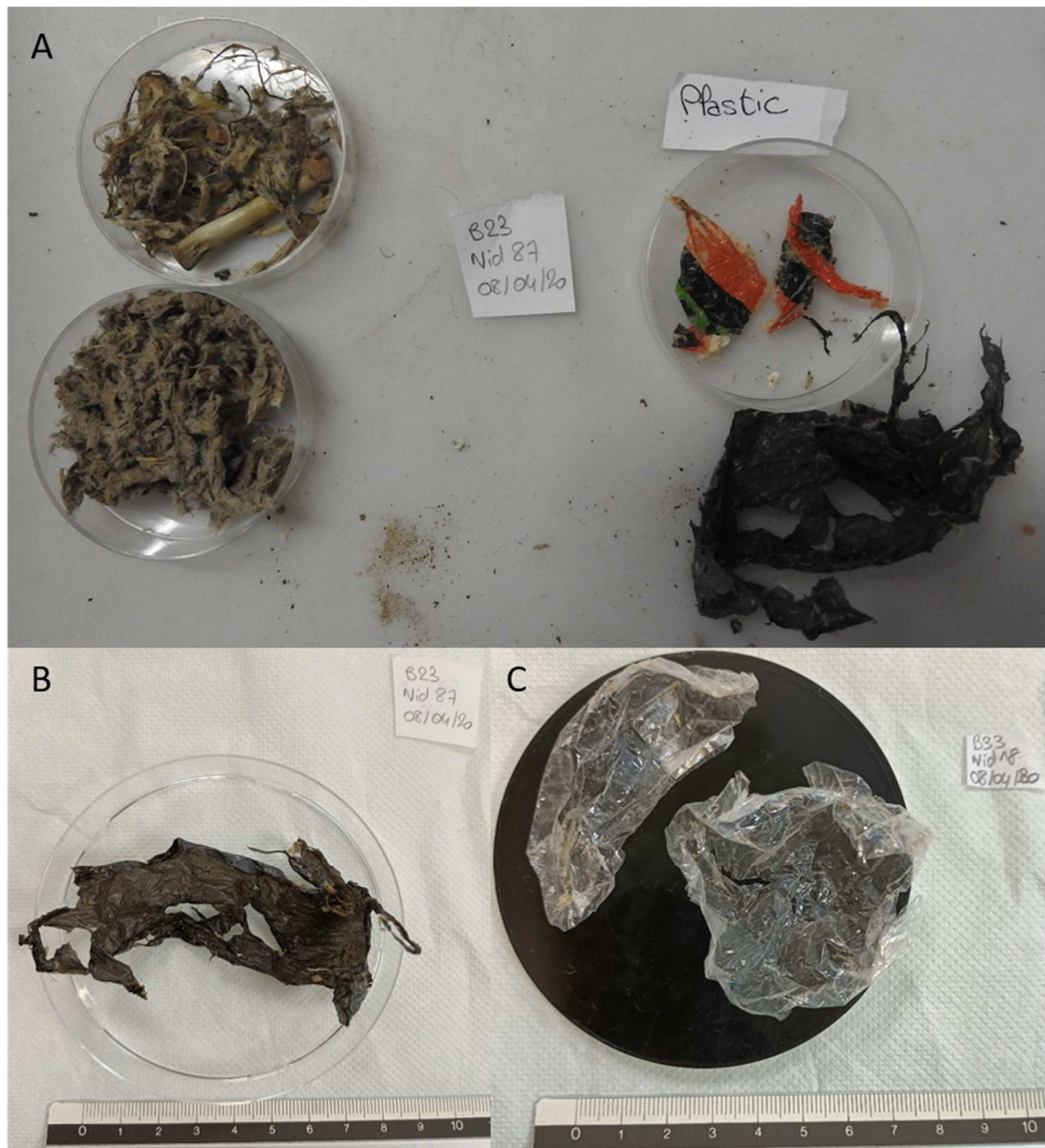


Figure 2: (A) Composition of pellet 23 from nest 87, with « natural » debris on the top left including bones, vegetal and rocks, anthropogenic non plastic debris on the bottom left including tissue and glass and plastic debris on the right side sheet and foamed types. Examples of (B) black sheet plastic and (C) transparent sheet plastic, the two most common plastic types and colours found in pellets.

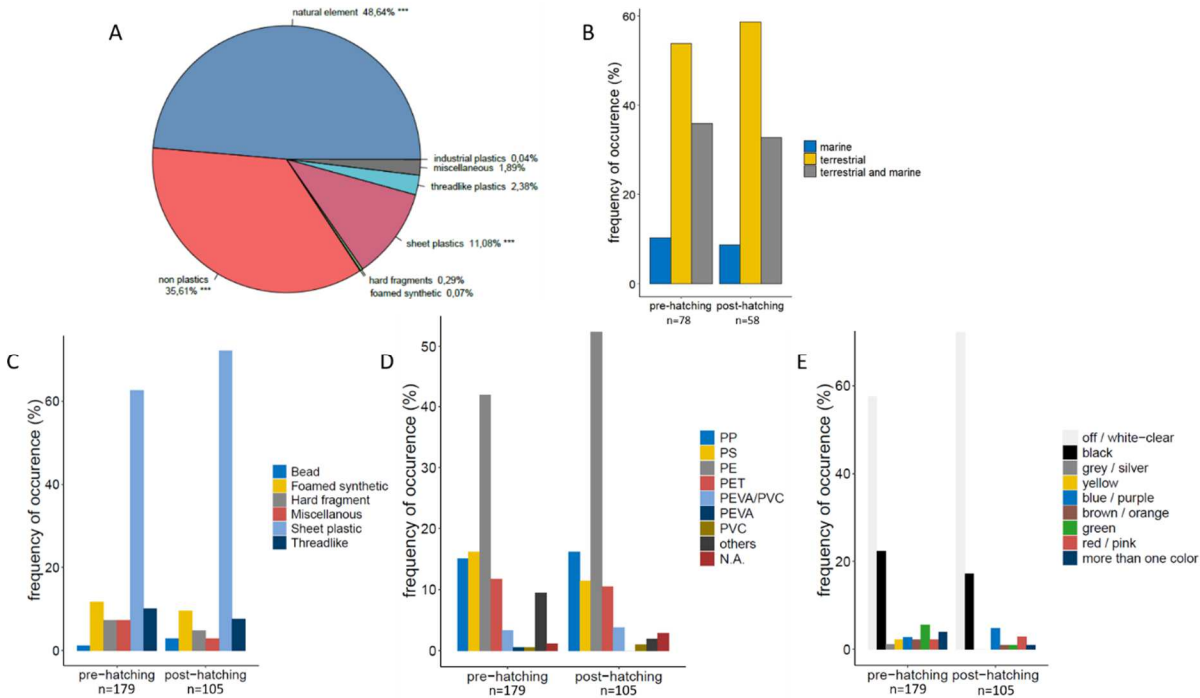
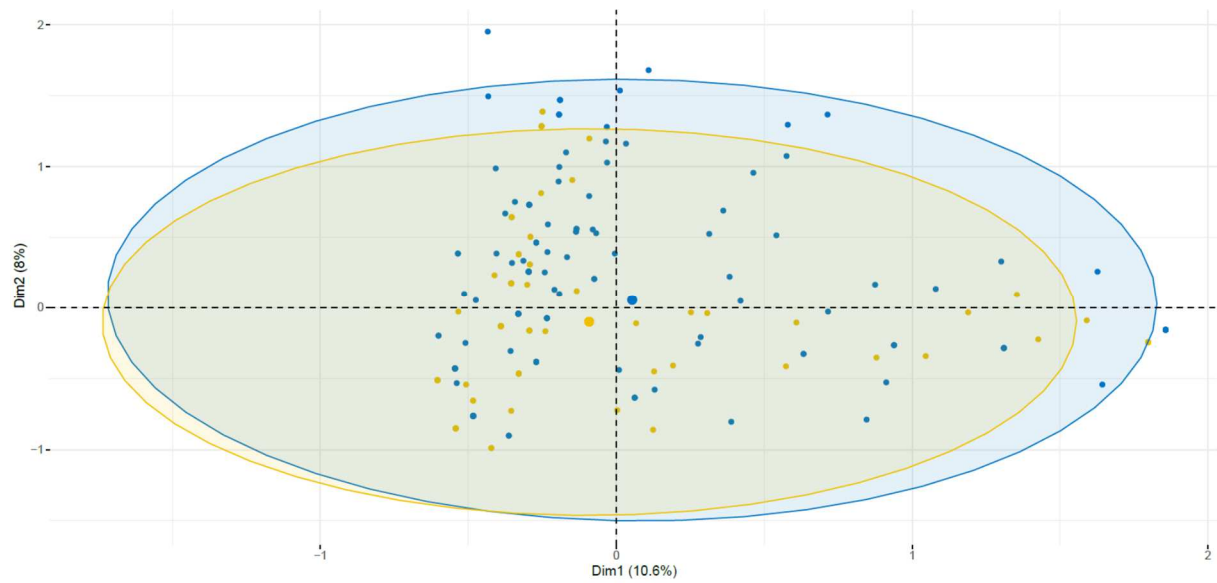


Figure 3: (A) Average composition of a pellet. (B) Percent frequency of occurrence (% FO) of natural items isolated from pre- and post-hatching pellets, grouped by foraging habitats used by the gulls. (C) Percent frequency of occurrence (% FO) of different plastic types among plastic items (N=284) isolated from pre- and post-hatching pellets. (D) Percent frequency of occurrence (% FO) of different plastic polymers among plastic items (N=284) isolated from pre- and post-hatching pellets: polypropylene (PP), polystyrene (PS), polyethylene (PE), polyester (PET), Poly(ethylene:vinyl acetate:vinyl chloride) (PEVA/PVC), Poly(ethylene vinyl acetate) (PEVA), polyvinyl carbonate (PVC). (E) Percent frequency of occurrence (% FO) of the different plastic colour categories among plastic items (N=284) isolated from pre- and post-hatching pellets.



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Figure 4: Multiple correspondence analysis (MCA) comparing pellet plastic composition pre (blue) and post (yellow) hatching. Plastic composition included the morphological type, the chemical composition, the colour, the size and the mass of each item within a pellet.