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

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

3

4 **Running head:** Plastic ingestion in yellow-legged gulls

5

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17

18 **Abstract:**

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

31

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

34 1. Introduction

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

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

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

65 Many bird species are able to expel indigestible debris found in food items in
66 regurgitated pellets (Provencher et al., 2019), increasing the potential range of food sources
67 they can integrate into their diet. Studying this expelled material can be an extremely
68 informative and non-invasive method to assess resource use and monitor the presence of
69 pollutants in food materials, such as plastics (Bond et al. 2021). In addition, plastics found in
70 pellets are often large enough to confidently identify the type and potential source (AMAP,
71 2021). Studies to date suggest that susceptibility to plastic ingestion varies greatly among
72 seabird species (Franco et al., 2019), mainly due to differences in feeding ecology (Ryan, 1987).
73 For example, only 6% of great skua (*Stercorarius skua*) pellets contained plastics, with a
74 median of two plastic items per pellet; this species is an avian predator, scavenger and
75 kleptoparasite (Hammer et al. 2016). In contrast, shags and shearwaters, which hunt fish by
76 pursuit diving, contain large amounts of plastic; Álvarez et al. (2018) registered 63% of shag
77 pellets with plastic fibers, and Bond et al. (2021) found plastics in 100% of pellets from surface
78 feeding flesh-footed shearwaters (*Ardenna carneipes*). Large gulls tend to be opportunistic
79 feeders and, depending on colony location, different proportions of plastics have been
80 recorded in their pellets. Stewart et al. (2020) reported that 92.51% of Australian Pacific gull
81 (*Larus pacificus*) pellets contained anthropogenic debris, with 83.63% containing plastics.

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

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

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

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

113 **2. Materials & Methods**

114 **2.1. Pellet analysis**

115 Pellets were collected in the colony of Carteau, a small islet in the Gulf of Fos
116 (43°22'39"N 4°51'28"E) (**Erreur ! Source du renvoi introuvable.**). A population of about 300
117 breeding pairs of yellow-legged gull (*Larus michahellis*, Laridae, Charadriiformes) are the only
118 seabird occupants of this 1.36 ha islet. During the 2020 breeding season (March to June), 30
119 nests were randomly chosen and marked. Old pellets from the previous season were removed
120 and all new pellets were collected from a 1m radius around each nest during weekly surveys
121 from early April until mid-May (6 weeks). Only fresh and structurally intact pellets were
122 collected to ensure that results reflected the recent diet of the individuals, and to guarantee
123 that samples were not contaminated by environmental anthropogenic debris (Provencher et
124 al., 2019). Pellets were individually stored in labelled plastic bags until analyses.

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

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

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

152 resolution of 4cm^{-1} over the wavenumber range of 400 to 4000 cm^{-1} , applying 16 scans. Each
153 spectrum was compared with the reference spectra of synthetic polymers from commercially
154 available libraries using OMNIC software (Thermo Fisher Scientific). A similarity threshold of
155 70% was required to assign the chemical composition to a particle, otherwise it was
156 considered as non-identified.

157 **2.2. Statistical analysis**

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

$$160 \quad \text{FO}_i = n_i / n_{\text{total}} \times 100\%,$$

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

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

169 To determine if there was an overall change in the presence/absence of anthropogenic
170 debris in pellets between breeding periods, we used a generalized linear mixed model (GLMM)
171 with a binomial distribution. In this model, breeding period (pre or post-hatching) and foraging
172 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 Chi² 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).

195 **3. Results**

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

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

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

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

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

222 There was no significant effect of foraging habitat on the number of plastics per pellet
223 (Table 3). However, the best fit model (Table 3) included an effect of breeding period on the
224 amount of plastic per pellet, showing a slight decrease in the number of plastic items post-
225 hatching (p -value = 0.053), with 1.72 ± 1.50 (sd) items per pellet post-hatching ($n=58$) against
226 2.24 ± 1.78 (sd) items per pellet pre-hatching ($n=78$).

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

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

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

243 **4. Discussion**

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

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

264 the small town of Port-Saint-Louis-du-Rhône (8624 inhabitants), with active agricultural and
265 port-related activities close by, and lies about 40 km away from France's second largest city,
266 Marseille (>860 000 inhabitants in 2021). Plastic exposure in birds from Carteau could be lower
267 than in Porto if gulls do not go all the way to Marseille to forage. Indeed, during breeding,
268 these gulls may take advantage of agricultural and fishing activities which are closer at hand,
269 even if landfills are also readily available (see below). The difference in the number of plastic
270 items per pellet could also be due to the types of plastic found in each location and their rate
271 of fragmentation. We found that gulls at Carteau mainly ingested sheet plastics from food
272 packaging or agricultural plastic mulching (as discussed below), whereas gulls in Porto mostly
273 ingested foamed plastics during the breeding season, such as styrofoam, that are easily
274 fragmented into small pieces. Indeed, if we look at the mean mass of plastics in pellets, gulls
275 from Carteau seemed to ingest heavier pieces of plastic than those from Porto (respectively
276 0.32g and 0.12g). Thus, the absolute exposure of gulls at the two sites may be very similar,
277 even if the nature of the plastics are different.

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

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

301 We found that plastic items in the pellets from Carteau were mainly
302 transparent/white, followed by black, matching other studies from seabirds (Hammer et al.,
303 2016; Kain et al., 2016; Lavers et al., 2014; Lopes et al., 2021). The source of these items could
304 be either from directly ingesting a discarded food item with its wrapping, or from the mistaken
305 ingestion of plastics taken as prey food. Indeed, food packaging and garbage bags are mainly
306 white/transparent or black, whereas plastic mulching film is black. If we examine plastic
307 colours after removing sheet plastics, white is still the dominant colour (white = 64 items,
308 green = 9 items, black = 6 items). More generally, light/white plastics have been found to
309 dominant the marine environment (Lavers et al., 2014), in part due to the fact that discarded
310 coloured plastics erode and bleach during transport at sea. It remains unknown whether
311 seabirds specifically choose lighter plastics, or whether the number of white/transparent

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

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

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

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

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

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

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

383 antioxidants) that give them particular properties required for their use. These additives can
384 be absorbed and accumulate in vital organs (Sühring et al., 2022), with potential toxicological
385 effects for individuals, such as developmental inhibition, endocrine disruption, or even direct
386 mortality (Kühn et al. 2020a, Pennino et al. 2020, Provencher et al. 2020, Teuten et al. 2009).
387 Furthermore, plastics are able to adsorb a significant amount of pollutants from the
388 environment (e.g., PCBs, mercury, and even antibiotics) due to their high surface to volume
389 ratio and the hydrophobic nature of the compounds, increasing the potential adverse effects
390 of plastic ingestion (Guo et al. 2020, Provencher et al. 2020). Gulls can also be exposed
391 indirectly to aerosol pollutants and additives when feeding in landfills. Indeed, Sorais et al.
392 (2020) showed that ring-billed gulls (*Larus delawarensis*) around Montreal were exposed to
393 polybrominated diphenyl ethers (PBDEs) and, to a lesser degree, halogenated flame
394 retardants (HFRs) through atmospheric exposure while foraging in landfills. Therefore, even if
395 gulls choose higher quality food items with lower plastic content, the time alone that
396 individuals spend foraging in landfill areas may affect their general health.

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

407 sources in seabird diets and to better understand how birds may cope with a changing
408 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

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599

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

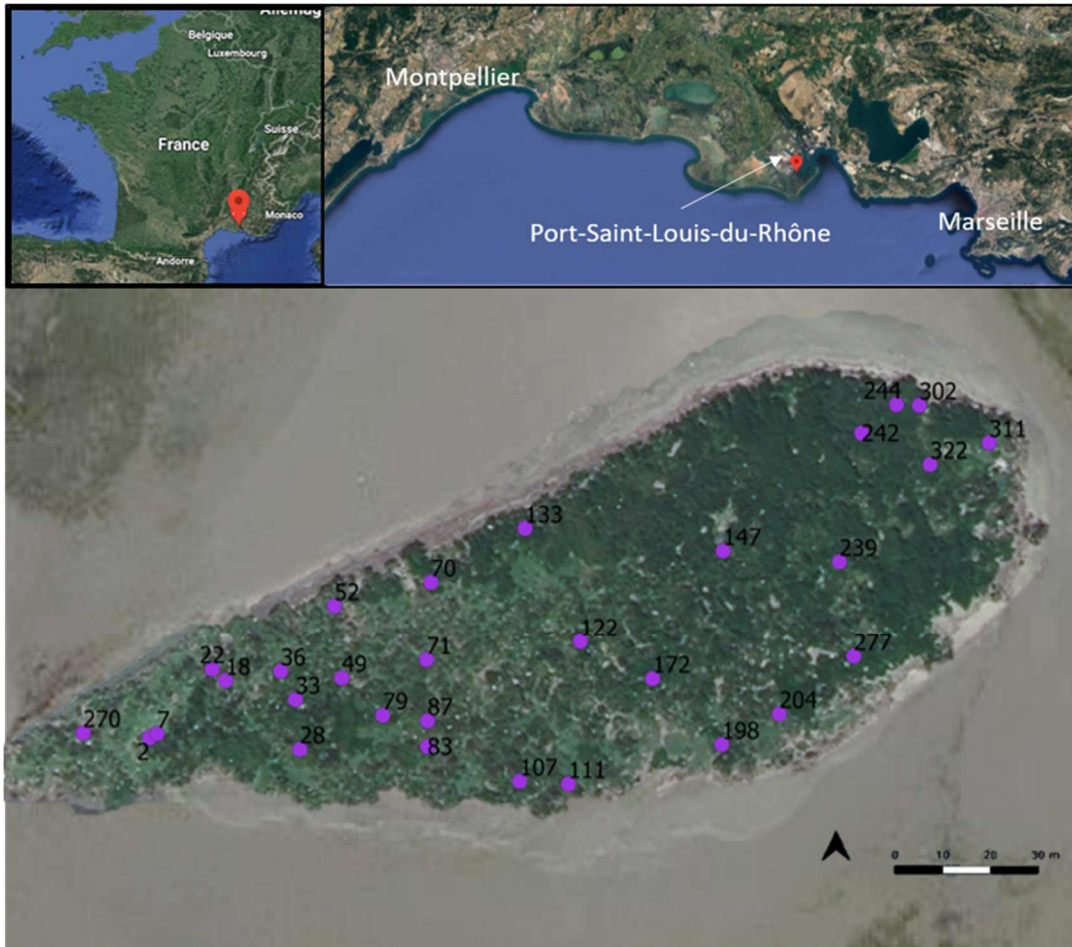
Breeding period	Plastic composition	Percentage of identification		Total number of plastics
		mean	\pm SD	
Pre-hatching n = 82 pellets	PE	93.54	4.05	75
	PP	90.34	7.45	27
	PET	83.64	5.28	21
	PS	91.28	7.43	29
	PEVA/PVC	79.34	7.93	6
	PEVA	93.02	NA	1
	PVC	71.45	NA	1
	Miscellaneous	88.94	10.32	17
	Unknown	NA	NA	2
Post hatching n = 61 pellets	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

605

606 Table 3: Results of the two top GLMMs examining the number of plastic items per pellet. Model 1 included only the fixed effect
 607 of reproductive period (pre or post-hatching), whereas model 2 included both the reproductive period and the foraging habitat
 608 (terrestrial, marine or marine+terrestrial). * The reference states are the pre-hatching period and terrestrial food sources. IRR
 609 refers to the Incidence Rate Ratio and CI to the Confidence Interval. Details on model selection are found in Supplementary
 610 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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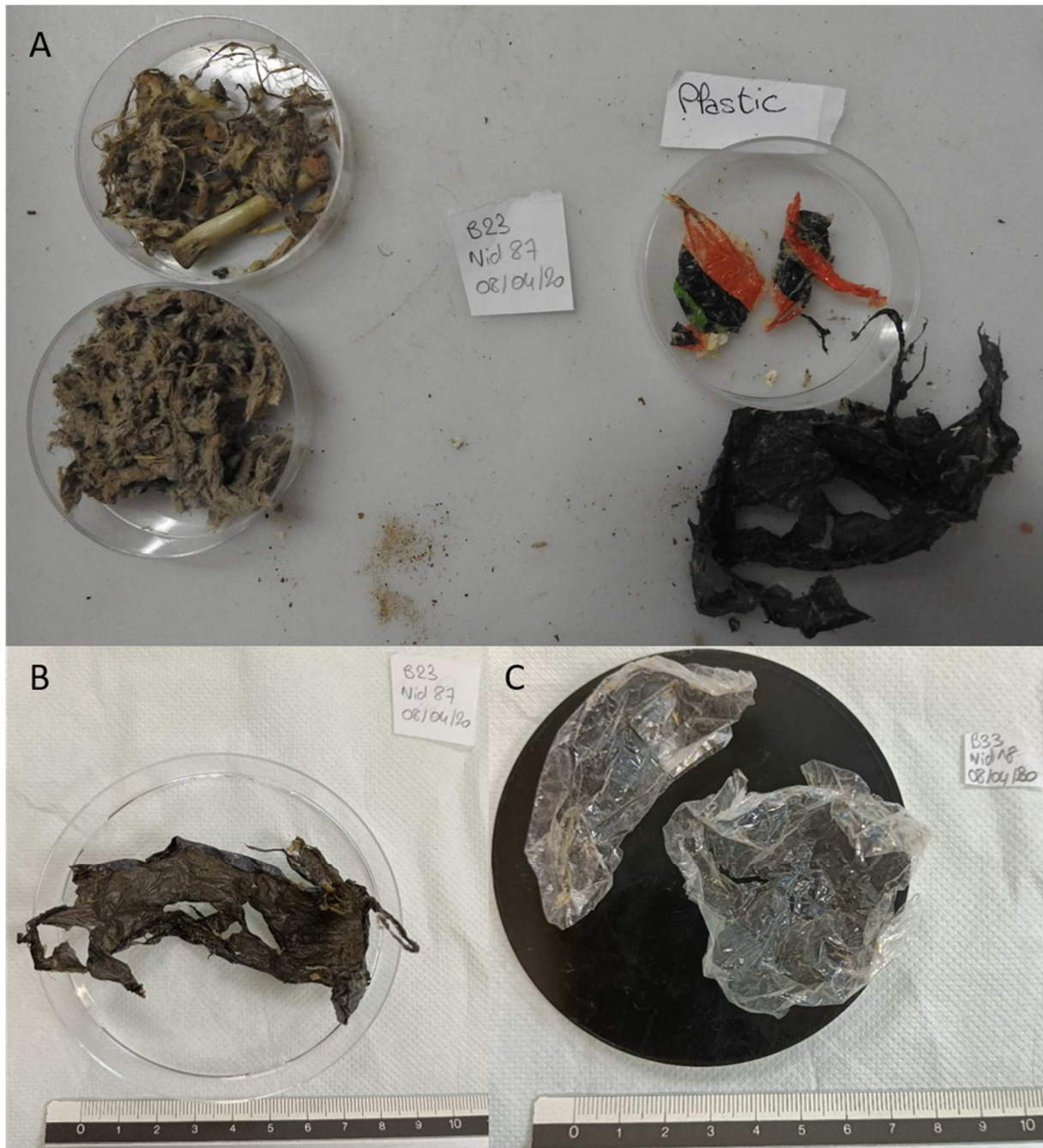


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Figure 1: Geographic location of the Carteau colony in the Gulf of Fos with different zoom (both insets) and placement of the monitored nests (purple points).



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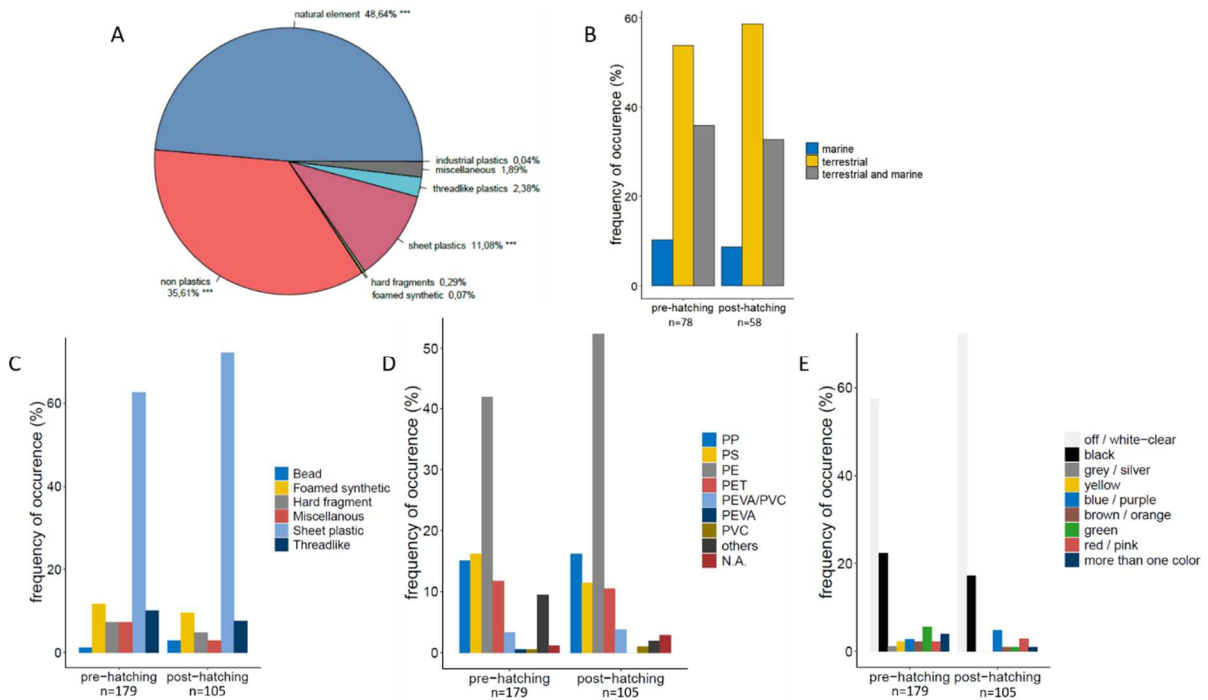
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Figure 2: (A) Composition of pellet 23 from nest 87, with « natural » debris on the top left including bones, vegetal and rocks, anthropogenic non plastic debris on the bottom left including tissue and glass and plastic debris on the right side sheet 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.

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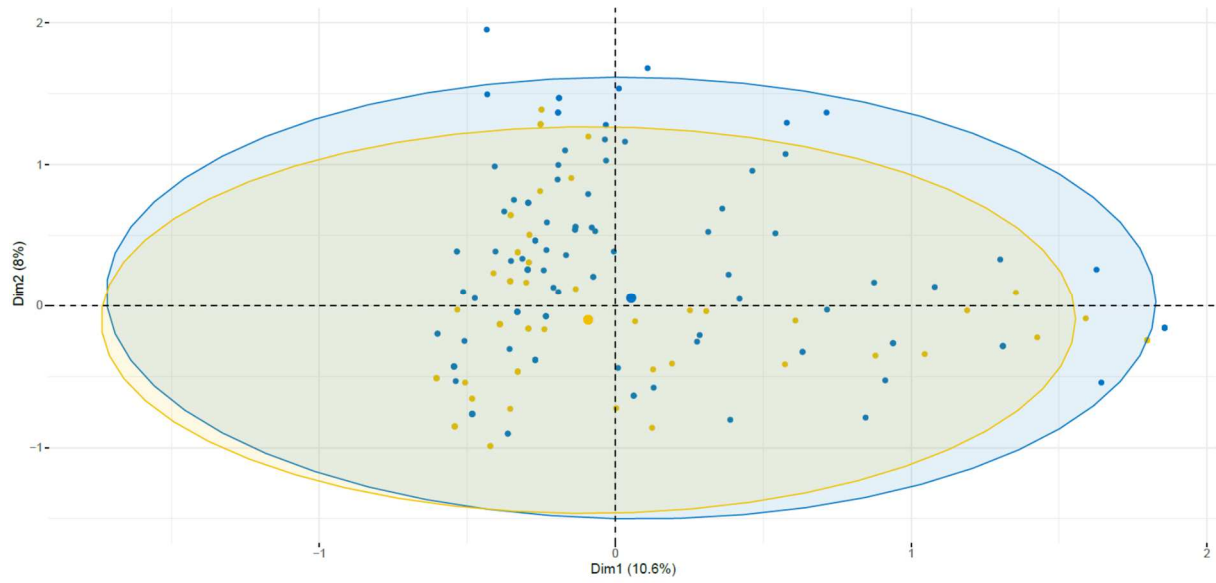


621

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

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