

Title	Ingestion of anthropogenic debris by migratory barnacle geese <i>Branta leucopsis</i> on a remote north-eastern Atlantic island
Authors	Coughlan, Neil E.;Doyle, Susan;Baker-Arney, Connie;Griffith, Rose M.;Lyne, Linda;Williams, Hannah;Kelly, Thomas C.;McMahon, Barry J.;Dick, Jaimie T. A.;Cunningham, Eoghan M.
Publication date	2020-08-24
Original Citation	Coughlan, N. E., Doyle, S., Baker-Arney, C., Griffith, R. M., Lyne, L., Williams, H., Kelly, T. C., McMahon, B. J., Dick, J. T. A. and Cunningham, E. M. (2020) 'Ingestion of anthropogenic debris by migratory barnacle geese <i>Branta leucopsis</i> on a remote north-eastern Atlantic island', <i>Marine Pollution Bulletin</i> , 160, 111588 (5 pp). doi: 10.1016/j.marpolbul.2020.111588
Type of publication	Article (peer-reviewed)
Link to publisher's version	http://www.sciencedirect.com/science/article/pii/S0025326X20307062 - 10.1016/j.marpolbul.2020.111588
Rights	© 2020, Elsevier B.V. All rights reserved. This manuscript version is made available under the CC BY-NC-ND 4.0 license. - https://creativecommons.org/licenses/by-nc-nd/4.0/
Download date	2023-06-08 09:20:59
Item downloaded from	http://hdl.handle.net/10468/10606

1
2 Ingestion of anthropogenic debris by migratory barnacle geese *Branta leucopsis* on a
3 remote north-eastern Atlantic island
4

5 Neil E. Coughlan^{1,2,3,*}, Susan Doyle⁴, Connie Baker-Arney^{1,2}, Rose M. Griffith^{1,2}, Linda Lyne³,
6 Hannah Williams^{1,2}, Thomas C. Kelly³, Barry J. McMahon⁴, Jaimie T.A. Dick^{1,2} & Eoghan M.
7 Cunningham^{1,2,5}
8

9 ¹ Institute for Global Food Security, School of Biological Sciences, Queen's University Belfast, 19
10 Chlorine Gardens, Belfast, BT9 5DL, Northern Ireland, UK

11 ² Queen's Marine Laboratory, Queen's University Belfast, 12-13 The Strand, Portaferry, BT22 1PF,
12 Northern Ireland, UK

13 ³ School of Biological, Earth and Environmental Sciences, University College Cork, Distillery Fields,
14 North Mall, Cork, Ireland

15 ⁴ School of Agriculture & Food Science, University College Dublin, Belfield, Dublin, Ireland

16 ⁵ School of Biological and Environmental Sciences, Liverpool John Moores University, 3 Byrom St,
17 Liverpool L3 3AF, UK
18
19
20

21 *Corresponding author:

22 neil.coughlan.zoology@gmail.com
23
24
25
26
27
28
29
30
31
32

33

34 Abstract

35 Although seabirds are frequently used as sentinel species for anthropogenic pollution, the
36 extent and impacts of synthetic debris ingestion remains poorly studied for many water bird species.
37 Here, we assess ingestion of synthetic particles ($\geq 0.5\text{mm}$) by barnacle geese, *Branta leucopsis*,
38 wintering on a remote island. Faecal samples were collected over a period of four wintering
39 seasons. In total, 71 individual samples were assessed, with 79% of samples displaying at least one
40 debris particle (maximum lengths 0.5–5mm) from anthropogenic sources. The recovered synthetic
41 debris were identified as micro-fibres ($n= 166$) and micro-fragments ($n= 165$). The number of
42 synthetic particles detected per sample was generally low at 4.7 ± 0.9 , 43 (mean \pm SE, maximum):
43 micro-fibres 2.3 ± 0.3 , 10; micro-fragments 2.3 ± 0.8 , 40. Particle numbers detected per gram of
44 faecal sample differed amongst wintering seasons. Our results suggest that non-marine water birds
45 can frequently ingest low quantities of synthetic particles in remote coastal habitats.

46

47

48

49

50

51 Keywords: Anthropocene; micro-fibre; micro-fragment; plastic pollution; waterfowl; wetland bird,

52

53

54

55

56

57

58 1. Introduction

59 The ingestion of synthetic debris, i.e. debris composed fully or partially of synthetic
60 polymers, by birds can lead to increased rates of morbidity and mortality through physical damage,
61 reduced digestive capacity and appetite, and blockage of the gastrointestinal tract (Pierce et al.
62 2004; Lavers et al. 2014). Transmission of toxic chemicals from ingested synthetic debris,
63 especially plastic particles, can also have deleterious effects such as mortality or reduced
64 reproductive output (Tanaka et al. 2013; 2020). Although relatively large items (pieces > 5mm) of
65 synthetic debris are most frequently implicated as environmental pollutants, the ingestion of small
66 synthetic debris (pieces ≤ 5mm) by wildlife is of growing concern (Cole et al. 2011).

67 To date, although seabirds are frequently used as indicator species for anthropogenic
68 pollution, ingestion of synthetic debris by shorebirds and other water birds remains poorly studied
69 (Lourenço et al. 2017; Reynolds & Ryan 2018; Rossi et al. 2019). Accordingly, the extent to
70 which synthetic debris is ingested by water birds inhabiting a combination of terrestrial, freshwater
71 and marine habitats in coastal areas remains largely unknown (English et al. 2015). Further, the
72 majority of studies that detail the ingestion of synthetic debris by birds have only focused data
73 acquisition through necropsies and examination of regurgitation pellets, i.e., boluses comprised of
74 items that cannot be digested such as shell fragments and stones (Provencher et al. 2017; 2018).
75 Despite this, birds can also egest synthetic debris that are small enough to pass through the entire
76 gastrointestinal tract (Reynolds & Ryan 2018; Provencher et al. 2018). As such, the lack of studies
77 attempting to report ingestion of synthetic debris through assessment of bird faecal samples is a
78 missed opportunity for environmental monitoring (Provencher et al. 2018), especially as many bird
79 species will not be readily available for necropsy in sufficient numbers to provide a meaningful
80 sample size. In addition, as the contents of regurgitated pellets will only correspond to the most
81 recent meal or meals consumed throughout the previous day, detection of synthetic debris in
82 regurgitated pellets does not reliably represent the quantities of debris that are retained for an
83 extended period of time within the gastrointestinal tract (Johnstone et al. 1990; Acampora et al.
84 2017a). Further, for many species, pellets are often egested relatively quickly, synthetic debris
85 recovered from regurgitated pellets are not necessarily representative of the shape-types or sizes of
86 debris that are entering more delicate sections of the gastrointestinal tract where absorption of
87 contaminants or physical blockages could more readily occur. Synthetic debris recovered from
88 egested faecal samples could be more representative of non-retained debris, i.e. items that pass
89 through the gastrointestinal tract relatively quickly with digestive boluses, and larger debris items
90 that have been broken down to smaller pieces that can pass through the gut and intestines
91 (Provencher et al. 2018; Le Guen et al. 2020).

92 Barnacle geese, *Branta leucopsis*, inhabit a mixture of marine, freshwater and terrestrial
93 habitats (Black et al. 2014). As obligate herbivores, *B. leucopsis* traditionally graze on the leaves,
94 stems, roots and seeds of *Plantago/Bellis/Festuca* swards, however, they are increasingly observed
95 to forage on semi-improved agricultural grasslands (Cabot & West 1973; Mason et al. 2017).
96 Between October and April, migratory *B. leucopsis* are found wintering in north-western locations
97 of Ireland and Scotland, where flocks typically forage in coastal pastures, salt marshes, river
98 estuaries, tidal mud flats and offshore islands (Doyle et al. 2018; Mitchell & Hall 2018). Like most
99 obligate herbivores, the digestive system of *B. leucopsis* is relatively inefficient with a low
100 assimilation efficiency of ~30%, i.e. ~70% of ingested food items rapidly moves through the gut
101 undigested (Owen 1971; Black et al. 2014). In general, *B. leucopsis* have gut retention times of
102 between 1.9–3.1 hrs (Prop & Vulink 1992). Accordingly, we suspect that *B. leucopsis* could act as
103 a sentinel species for the presence of synthetic debris in coastal environments through non-
104 invasive analysis of egested faecal samples. Therefore, in the present study, we assess *B. leucopsis*
105 faecal samples for the presence of synthetic debris across multiple sampling periods, from 2015–
106 2019. Faecal samples were obtained from a *B. leucopsis* wintering on a remote, offshore north-
107 eastern Atlantic island. As the geese tend to remain on the island for the duration of their wintering
108 season and given their gut retention times, any recovered egested synthetic debris are most likely
109 representative of on-island pollution.

110 This study focused on the detection of synthetic particles ≥ 0.5 mm in size, as the analysis of
111 smaller synthetic particles is considered problematic given uncertainties around airborne
112 contamination by ultra-small micro-fibres (Torre et al. 2016). Here, we add to the current paucity
113 of studies that have attempted to quantify the extent of synthetic debris in bird faecal samples. In
114 addition, to our knowledge, the ingestion of synthetic debris by *B. leucopsis* has been documented
115 for the first time.

116

117 2. Methods

118 2.1 Sample collection

119 A total of 71 faecal samples were collected from adult or first-winter *B. leucopsis* wintering
120 on Inishkea Islands, situated in the north-east Atlantic Ocean off the west coast of Ireland
121 ($54^{\circ}07'30.2''\text{N}$; $10^{\circ}12'31.9''\text{W}$; Figure 1). Samples were collected from the south island (1.84 km²).
122 Faecal samples were collected in March 2015 ($n = 17$), November 2016 ($n = 14$), April and
123 November 2017 ($n = 13$ and 7 , respectively), and March 2019 ($n = 20$). Samples obtained in 2015,
124 2016 and 2017 were taken directly from individual birds captured during routine population
125 monitoring. In 2019, fresh faecal samples were collected from a monospecific roosting site. These
126 samples were collected at distances of at least one metre apart, to ensure that they were produced

127 by different individual birds. Samples collected in 2019 were refrigerated (≤ 4 months), while all
128 others were kept frozen ($-20\text{ }^{\circ}\text{C}$) until required. All birds were handled under licence from the
129 National Parks and Wildlife Service of the Government of Ireland (Section 32, Wildlife Acts
130 1976–2012), with relevant ringing permits from the British Trust of Ornithology.

131

132 2.2 Digestion, separation and microscopy

133 Samples were transferred into individual glass beakers and weighed on an analytical balance
134 (0.01 g). To eliminate labile organic matter (including non-synthetic anthropogenic debris deriving
135 from a natural source, e.g. 100% cotton, linen or wool fibres), samples were digested in solutions
136 of Iron(II) sulfate heptahydrate ($\text{FeH}_{14}\text{O}_{11}\text{S}$) and 30% hydrogen peroxide (H_2O_2) at $60\text{ }^{\circ}\text{C}$ (0.75 g
137 of $\text{FeH}_{14}\text{O}_{11}\text{S}$ per 50 mL H_2O_2), until total digestion had occurred (Masura et al. 2015). An
138 approximate application ratio of 20 mL per 10 g of faecal sample was employed. Following
139 digestion, a density based separation technique was used to isolate synthetic debris from denser
140 undigested mineral components through flotation, using a saturated solution of NaCl, i.e. 360 g L^{-1} .
141 The resulting supernatant was carefully decanted and vacuum filtered onto filter pads (Whatman
142 41, 47 mm, $20\text{ }\mu\text{m}$ pore). All filter pads were placed in clean glass petri dishes and dried at room
143 temperature. All samples were then examined under a stereomicroscope (Olympus SZX16). All
144 synthetic debris particles were visually identified using the criteria outlined by Zhao et al. (2016).
145 Recovered synthetic debris was classified into shape-type categories (e.g. fibre, fragment), size
146 range and colour tone (Provencher et al. 2017; Bessa et al. 2019).

147 Glassware rather than plastic apparatus was used throughout, and was acid washed prior to
148 use. Glassware was covered with fresh aluminium foil to minimise potential contamination during
149 the entire extraction procedure. Further, where possible, apparatus were periodically checked by
150 stereomicroscope for the presence of synthetic particles prior to sample processing. In addition,
151 immediately before processing the first sample of each batch, all glassware were double rinsed
152 with distilled water and a procedural control sample was processed using this distilled water. This
153 damp filter pad was then placed in a petri-dish and used as a laboratory contamination control,
154 whereby it was placed directly alongside the benchtop area in use and remained exposed to the
155 laboratory air during sample processing ($n = 5$). Additionally, 100% cotton lab coats and nitrile
156 gloves were used during the sample analysis to reduce potential human contamination.

157

158 2.3 Statistical Analyses

159 All data were assessed for normality of residual distributions (Shapiro-Wilk test, $P > 0.05$)
160 and homoscedasticity of variances (Fligner-Killeen, $P > 0.05$). As all data were non-normal ($P <$
161 0.05), separate Kruskal–Wallis test with a Dunn’s post hoc were used to examine total count data

162 in relation to the dependent variable of winter season. Wintering season spans the months of
163 October to April, inclusive, and represents the time period for which the *B. leucopsis* population
164 dwells on Inishkea Islands. Where residuals did not meet homoscedasticity assumptions ($P <$
165 0.05), a White-adjusted ANOVA with Tukey LSM post hoc tests were employed instead.
166 Similarly, the number of synthetic particles per gram of faecal sample was also assessed in relation
167 to the dependent variable of winter season. The biomass of collected faecal samples was also
168 considered in relation to winter season using Kruskal–Wallis tests. All statistical analyses were
169 performed using R version 3.5.3 (R Core Team 2019).

170

171 3. Results

172 In total, 331 synthetic particles were detected; 166 were micro-fibres and 165 were micro-
173 fragments. However, while 79% of samples were found to contain synthetic particles, the number
174 detected per sample was generally low at 4.7 ± 0.9 , ranging from 0–43 particles (mean \pm SE):
175 micro-fibres 2.3 ± 0.3 (0–10); micro-fragments 2.3 ± 0.8 (0–40) (Figure 2). When standardised in
176 relation to the quantity of faecal mass per sample, synthetic particles were detected at a mean
177 (\pm SE) frequency of 0.67 ± 0.12 particles g^{-1} , ranging from 0–4.88 particles g^{-1} . Micro-fibres and
178 micro-fragments were observed at a frequency of 0.52 ± 0.12 particles g^{-1} (0–4.88) and 0.15 ± 0.05
179 (0–2.10), respectively. Potential laboratory contamination was low, with only three micro-fibres
180 being detected by control filter pads, i.e. 0.04 per processed faecal sample, therefore no
181 adjustments to the results were made. All synthetic particles recovered from faecal samples had a
182 maximum length within the size range of 0.5–5 mm, and therefore, could be categorised as either
183 micro-fibres or micro-fragments (Torre et al. 2016; Zhao et al. 2016). Micro-fibres had dark (92%;
184 e.g. navy-blue, black, dark red) or mid colour tones (8%; e.g. blue, red), while micro-fragments
185 consisted of mid (13%; e.g. blue, blue-green) or light (87%; e.g. clear, white-blue, yellow) colour
186 tones.

187 The total number of synthetic particles recovered in wintering seasons significantly
188 decreased over the sampling period (ANOVA $F = 3.49$, $df = 3, 67$, $P < 0.05$), as did the number of
189 detected micro-fragments (ANOVA $F = 3.15$, $df = 3, 67$, $P < 0.05$: Figure 3). However, the
190 number of detected micro-fibres did not differ (KW; $P > 0.05$). The total number of synthetic
191 particles observed per gram significantly differed amongst wintering seasons, which was driven by
192 a substantial increase of particles in 2019 samples (ANOVA; $F = 10.62$, $df = 3, 67$, $P < 0.001$:
193 Figure 3). The number of micro-fibres recovered per gram of faecal sample also significantly
194 differed amongst wintering seasons due to greater detection of micro-fibres in 2019 samples
195 (ANOVA; $F = 9.28$, $df = 3, 67$, $P < 0.001$), whilst micro-fragments detected per gram of faecal
196 sample did not significantly differ amongst wintering seasons (ANOVA; $P > 0.05$: Figure 3).

197 There was no apparent difference in the biomass of collected faecal samples amongst winter
198 seasons (KW; $P > 0.05$).

199

200 4. Discussion

201 Here, to our knowledge, ingestion of synthetic debris by *B. leucopsis* has been recorded for
202 the first time. Further, it is clear that this phenomenon has been ongoing over a number of years at
203 an isolated and remote location. Although this is the first record of synthetic debris ingestion by
204 Anatidae in Ireland, previous records have documented ingestion of debris by Anatidae dwelling
205 within anthropogenically disturbed sites across continental Europe (Gil-Delgado et al. 2017),
206 North America (English et al. 2015; Holland et al. 2016), and South Africa (Reynolds & Ryan
207 2018). In addition, a variety of coastal dwelling seabird species have previously been recorded to
208 ingest synthetic debris in coastal locations of Ireland, in-line with international trends for debris
209 ingestion by seabird species (Acampora et al. 2016; 2017a,b). Nevertheless, this is the first study
210 to consider multiyear assessment for a single population of a non-obligate marine bird species
211 residing within a remote area, with 4–8 years of sampling being needed to reveal possible trends
212 (e.g. van Franeker & Meijboom 2002). For example, although the total number of synthetic
213 particles detected decreased between 2015/16–2018/19 wintering seasons, the total number
214 particles recovered per gram of faecal sample has generally remained the same across the
215 wintering seasons, suggesting that synthetic particles are ubiquitous on the Inishkea Islands.
216 Although 2018/19 samples do suggest an increase in the number of particles detected per gram,
217 this appears to be an artefact of the 2019 samples, which were taken from a unique sample location
218 (i.e. a roosting site), as well as this relationship being largely driven by three outlier samples.
219 However, it is worth noting that a truly accurate assessment of any change in debris ingestion
220 frequencies (e.g. $\pm 5\%$ detection rate with a sampling power of 80%) would likely require annual
221 sampling of $>14,000$ birds (Lavers & Bond 2016), which is simply not feasible for the vast
222 majority of study systems.

223 In the present study, a relatively high frequency of synthetic debris ingestion by *B. leucopsis*
224 was recorded, with 79% of samples having at least one synthetic particle. However, for Anatidae,
225 frequency of ingestion appears to vary amongst species and sampling locations, e.g. 4.3–53.8%
226 (English et al. 2015), 0–50% (Holland et al. 2016), 43.8–60% (Gil-Delgado et al. 2017), and 0–
227 17% (Reynolds & Ryan 2018). However, despite outliers, the mean number of debris items
228 recovered per sample tended to be similar, if slightly higher, to amounts reported by other studies
229 (e.g. English et al. 2015; Gil-Delgado et al. 2017). To date, studies assessing waterfowl faecal
230 samples for the presence of synthetic debris, including the present study, have not considered
231 possible in-field contamination. This is particularly problematic for micro-fibres, as wind or soil-

232 surface borne micro-fibres could theoretically attach to faecal samples prior to collection.
233 Therefore, we argue that future studies should consider back-ground levels of wind and soil-
234 surface borne synthetic debris, as contamination prior to collection could inflate water bird debris
235 consumption data. Nevertheless, in some instances, the ingestion of synthetic debris by water birds
236 has been linked to the availability of historical or current sources of synthetic debris at study sites
237 (e.g. Gil-Delgado et al. 2017; Reynolds & Ryan 2018). Although the Inishkea Islands have
238 become a key wintering site for *B. leucopsis* since the last islanders were evacuated by the Irish
239 Government in 1932 (Cabot 1963), and despite being rarely visited by people, an extensive
240 amount of synthetic debris has been washed in from the sea along low lying shoreline (e.g.
241 domestic waste and fishing gear) (S.D. pers. obs.). In addition, this synthetic debris can be pushed
242 further inland during storm conditions, and is sometimes found in *B. leucopsis* foraging areas.
243 Accordingly, we argue that ingestion of synthetic debris by *B. leucopsis* is most likely linked to the
244 prevalence of pelagic synthetic debris that is deposited by tidal forces.

245 Interestingly, synthetic debris >5 mm in length was not detected by the present study.
246 However, micro-fibres and micro-fragments can result from the fragmentation of larger particles
247 due to biotic and abiotic effects (e.g. Mateos-Cárdenas et al. 2020). Including within digestive
248 tracts of birds (Provencher et al. 2018), especially granivorous waterfowl with strong gizzards
249 (Mayhew & Houston 1993), that are potentially capable of mechanically disintegrating larger
250 synthetic debris items over time (Reynolds & Ryan 2018). However, species-specific gut retention
251 times of synthetic debris remain poorly understood (but see Charalambidou et al. 2005). In
252 addition, the abundance of debris in bird gastrointestinal tracts is largely determined by their
253 retention period (Holland et al. 2016; Ryan 2016). Further, longer retention times may aid inter-
254 habitat dispersal of synthetic debris by water birds (Coughlan et al. 2017). In particular, as a long-
255 distance migrant, Ireland's wintering *B. leucopsis* population originates exclusively from remote
256 areas of north-east Greenland with staging grounds in Iceland, unlike Scottish populations that
257 arrive from both Greenland and Svalbard (Wernham et al. 2002). As such, despite generally short
258 gut retention times for food items (i.e. 1.9–3.1 hrs; Prop & Vulink 1992), *B. leucopsis* could be a
259 potential vector of synthetic debris and other contaminants amongst remote areas of Greenland,
260 Iceland and Ireland, if ingested synthetic debris remains within the gastrointestinal tract for an
261 extended period of time.

262 Whilst the present study demonstrates frequent and sustained ingestion of synthetic debris by
263 a migratory water bird species inhabiting marine coastal habitats, more in-depth assessments are
264 required to ascertain the overall impacts of synthetic debris ingestion on water bird health. In
265 particular, greater quantification of the amounts and types of synthetic debris available in coastal
266 environments is required, as well as the rates of ingestion and retention by water bird species

267 (English et al. 2015; Holland et al. 2016; Reynolds & Ryan 2018). Although visual identification
268 is considered relatively reliable (Zhao et al. 2016; Reynolds & Ryan 2018; Stanton et al. 2019),
269 there remains a risk that some misidentification of natural fibres as synthetic fibres could have
270 occurred in the present study. This is especially relevant given that a growing number of studies
271 have documented a higher prevalence of natural textile based micro-fibres than synthetic micro-
272 fibres in freshwater and marine ecosystems (see Stanton et al. 2019; Suaria et al. 2020).
273 Accordingly, future research should consider the use of analytical chemistry techniques (e.g.
274 Raman and FTIR) to ascertain polymer identification, thereby reducing the potential for
275 misidentification of debris (Zhao et al. 2016; Stanton et al. 2019). Yet, natural micro-fibres such as
276 textiles also represent a harmful environmental contaminant (e.g. Stone et al. 2020). In addition,
277 the extent of absorption and subsequent impacts of chemical contaminants requires greater
278 consideration. Nevertheless, our findings suggest that synthetic debris could be a problematic
279 pollutant for non-marine coastal dwelling water birds, with possible bird-mediated dissemination
280 of synthetic debris to remote arctic regions by from *B. leucopsis* wintering grounds.

281

282 5. Acknowledgements

283 The authors acknowledge support from the G. & M. Williams Research Fund, Queen's
284 Marin Laboratory, and the Irish Research Council. We gratefully thank Ryan Johnston and Craig
285 Holmes for assisting this study, and Patrick Manley and Brian Burke for assistance collecting
286 samples. We also gratefully acknowledge support for Dr Katherine Booth-Jones and the British
287 Trust for Ornithology. In particular, we thank Emma Healey and Allen Whitaker for technical
288 support, and Ricky Whelan, Marcel Jansen and Alicia Mateos-Cárdenas for encouraging
289 discussions.

290

291 6. References

- 292 Acampora, H., Berrow, S., Newton, S., O'Connor, I., 2017a. Presence of plastic litter in pellets from
293 great ormorant (*Phalacrocorax carbo*) in Ireland. *Marine Pollution Bulletin*. 117, 512-514.
- 294 Acampora, H., Lyashevskaya, O., Van Franeker, J.A., O'Connor, I., 2016. The use of beached bird
295 surveys for marine plastic litter monitoring in Ireland. *Marine Environmental Research*. 120,
296 e87–e91.
- 297 Acampora, H., Newton, S., O'Connor, I., 2017b. Opportunistic sampling to quantify plastics in the
298 diet of unfledged black legged kittiwakes (*Rissa tridactyla*), northern fulmars (*Fulmarus*
299 *glacialis*) and great cormorants (*Phalacrocorax carbo*). *Marine Pollution Bulletin*. 119, 171-
300 174.

301 Bessa, F., Frias, J., Kögel, T., Lusher, A., Andrade, J., Antunes, J., Sobral, P., Pagter, E., Nash, R.,
302 O'Connor, I., Pedrotti, M.L., Keros, E., León, V.M., Tirelli, V., Suaria, G., Lopes, C.,
303 Raimundo, J., Caetano, M., Gago, J., Viñas, L., Carretero, O., Magnusson, K., Granberg, M.,
304 Dris, R., Fischer, M., Scholz-Böttcher, B. M., Lorenzo, S.M., Grueiro, G., Fernández-
305 González, V., Palzzo, L., Camedda, A., de Lucia, G.A., Avio, C.G., Gorbi, S., Pittura, L.,
306 Regoli, F., Gerdts, Gunnar, 2019. Harmonized protocol for monitoring microplastics in biota.
307 JPI-Oceans BASEMAN project. 10.13140/RG.2.2.28588.72321/1.

308 Black, J. M., Prop, J., & Larsson, K., 2014. The Barnacle Goose (1st ed.). London: T & AD Poyser.

309 Cabot, D. 1963. Barnacle geese in Ireland. Wildfowl Trust Annual Report. 14, 104–106.

310 Cabot, D., West B. 1973. Population dynamics of barnacle geese, *Branta leucopsis*, in Ireland.
311 Proceedings of the Royal Irish Academy B. 73, 415–43.

312 Charalambidou, I., Santamaría, L., Jansen, C. & Nolet, B.A. 2005. Digestive plasticity in mallard
313 ducks modulates dispersal probabilities of aquatic plants and crustaceans. Functional Ecology.
314 19, 513– 519.

315 Cole, M., Lindeque, P., Halsband, C., Galloway, T.S., 2011. Microplastics as contaminants in the
316 marine environment: a review. Marine Pollution Bulletin. 62, 2588–2597.

317 Coughlan, N.E., Kelly, T.C., Davenport, J., Jansen, M.A.K., 2017. Up, up and away: bird-mediated
318 ectozoochorous dispersal between aquatic environments. Freshwater Biology. 62, 631–648.

319 Doyle, S., Walsh, A., McMahon, B. J., Tierney, T.D., 2018. Barnacle geese *Branta leucopsis* in
320 Ireland: results of the 2018 census. Irish Birds. 11, 23-28.

321 English, M.D., Robertson, G.J., Avery-Gomm, S., Pirie-Hay, D., Roul, S., Ryan, P.C., Wilhelm,
322 S.I., Mallory, M.L., 2015. Plastic and metal ingestion in three species of coastal waterfowl
323 wintering in Atlantic Canada. Marine Pollution Bulletin. 98, 349–353.

324 Gil-Delgado, J.A., Guijarro, D., Gosálvez, R.U., López-Iborra, G.M., Ponz, A., Velasco, A., 2017.
325 Presence of plastic particles in waterbirds faeces collected in Spanish lakes. Environmental
326 Pollution. 220, 732–736.

327 Holland, E.R., Mallory, M.L., Shutler, D., 2016. Plastics and other anthropogenic debris in
328 freshwater birds from Canada. Science of the Total Environment. 571, 251–258.

329 Johnstone, I.G., Harris, M.P., Wanless, S., Graves, J., 1990. The usefulness of pellets for assessing
330 the diet of adult shags *Phalacrocorax aristotelis*. Bird Study. 37, 37–41.

331 Lavers, J.L., Bond, A.L., 2016. Ingested plastic as a route for trace metals in Laysan albatross
332 (*Phoebastria immutabilis*) and Bonin petrel (*Pterodroma hypoleuca*) from Midway Atoll.
333 Marine Pollution Bulletin. 110, 493–500.

- 334 Lavers, J.L., Bond, A.L., Hutton, I., 2014. Plastic ingestion by flesh-footed shearwaters (*Puffinus*
335 *carneipes*): implications for fledgling body condition and the accumulation of plastic-derived
336 chemicals. *Environmental Pollution*. 187, 124–129.
- 337 Le Guen, C., Suaria, G., Sherley, R.B., Ryan, P.G., Aliani, S., Boehme, L., Brierley, A.S., 2020.
338 Microplastic study reveals the presence of natural and synthetic fibres in the diet of King
339 Penguins (*Aptenodytes patagonicus*) foraging from South Georgia. *Environmental*
340 *International*. 134, 105303.
- 341 Lourenço, P.M., Serra-Gonçalves, C., Ferreira, J.L., Catry, T., Granadeiro, J.P., 2017. Plastic and
342 other microfibers in sediments, macroinvertebrates and shorebirds from three intertidal
343 wetlands of southern Europe and west Africa. *Environmental Pollution*. 231, 123–133.
- 344 Mason, T.H.E., Keane, A., Redpath, S.M., Bunnefeld, N., 2017. The changing environment of
345 conservation conflict: geese and farming in Scotland. *Journal of Applied Ecology*. 55, 651–
346 62.
- 347 Masura, J., Baker, J., Foster, G., Arthur, C., 2015. Laboratory methods for the analysis of
348 microplastics in the marine environment: Recommendations for quantifying synthetic
349 particles in waters and sediments. NOAA Technical Memorandum. NOS-OR&R-48.
- 350 Mateos-Cárdenas, A., O'Halloran, J., van Pelt, F.N.A.M., Jansen M.A.K. 2020. Rapid
351 fragmentation of microplastics by the freshwater amphipod *Gammarus duebeni* (Lillj.).
352 *Scientific Reports*, 10, 12799.
- 353 Mayhew, P., Houston, D., 1993. Food throughput time in European wigeon *Anas Penelope* and other
354 grazing waterfowl. *Wild*. 44, 174–177.
- 355 Mitchell, C., Hall, C., 2018. Greenland barnacle geese *Branta leucopsis* in Britain and Ireland:
356 results of the international census, spring 2018. Slimbridge, UK.
- 357 Owen, M., 1971. The selection of feeding site by white-fronted geese in winter. *Journal of Applied*
358 *Ecology*. 8, 905-917.
- 359 Pierce, K.E., Harris, R.J., Larned, L.S., Pokras, M.A., 2004. Obstruction and starvation associated
360 with plastic ingestion in a northern gannet *Morus bassanus* and a greater shearwater *Puffinus*
361 *gravis*. *Marine Ornithology*. 32, 187–189.
- 362 Prop, J., Vulink, T., 1992. Digestion by barnacle geese in the annual cycle: the interplay between
363 retention time and food quality. *Functional Ecology*. 6, 180–189.
- 364 Provencher, J., Bond, A., Aver-Gomm, S., Borrelle, S., Bravo Rebolledo, E., Hammer, S., Kuhn, S.,
365 Lavers, J., Mallory, M., Trevail, A., van Franeker, J., 2017. Quantifying ingested debris in
366 marine megafauna: a review and recommendations for standardization. *Analytical Methods*.
367 9, 1454–1469.

368 Provencher, J.F., Vermaire, J.C., Avery-Gomm, S., Braune, B.M., Mallory, M.L., 2018. Garbage in
369 guano? Microplastic debris found in faecal precursors of seabirds known to ingest plastics.
370 Science of the Total Environment. 644, 1477-1484.

371 Reynolds, C., Ryan, P.G., 2018. Micro-plastic ingestion by waterbirds from contaminated wetlands
372 in South Africa. Marine Pollution Bulletin. 126, 330–333.

373 Rossi, L.C., Scherera, A.L., Petrya, M.V., 2019. First record of debris ingestion by the shorebird
374 American oystercatcher (*Haematopus palliatus*) on the Southern coast of Brazil. Marine
375 Pollution Bulletin. 138, 235–240.

376 Ryan, P.G., 2016. Ingestion of plastics by marine organisms. In: Takada, H., Karapanagioti, H.
377 (Eds.), Hazardous Chemicals Associated with Plastics in the Environment. Springer,
378 Heidelberg, pp. 1–32. http://dx.doi.org/10.1007/698_2016_21.

379 Stanton, T., Johnson, M., Nathanail, P., MacNaughtan, W., Gomes, R.L., 2019. Freshwater and
380 airborne textile fibre populations are dominated by ‘natural’, not microplastic, fibres. Science
381 of the Total Environment. 666, 377–389.

382 Stone, C, Windsor, F.M., Munday, M., Durance, I., 2020. Natural or synthetic – how global trends
383 in textile usage threaten freshwater environments. Science of the Total Environment. 718,
384 134689.

385 Suaria, G., Achtypi, A., Perold, V., Lee, J.R., Pierucci, A., Bornman, T.G., Aliani, S., Ryan, P.G.,
386 2020. Microfibers in oceanic surface waters: a global characterization. Science Advances 6:
387 eaay8493. DOI: 10.1126/sciadv.aay8493

388 Tanaka, K., Takada, H., Yamashita, R., Mizukawa, K., Fukuwaka, M., Watanuki, Y., 2013.
389 Accumulation of plastic-derived chemicals in tissues of seabirds ingesting marine debris.
390 Marine Pollution Bulletin. 69, 219-222.

391 Tanaka, K., Watanuki, Y., Takada, H., Ishizuka, M., Yamashita, R., Kazama, M., Hik,i N.,
392 Kashiwada, F., Mizukawa, K., Mizukawa, H., Hyrenbach, D., Hester, M., Ikenaka, Y.,
393 Nakayama, S.M.M., 2020. In vivo accumulation of plastic-derived chemicals into seabird
394 tissues. Current Biology. 30, 723–728.

395 Torre, M., Digka, N., Anastasopoulou, A., Tsangaris, C., Mytilineou, C., 2016. Anthropogenic
396 microfibres pollution in marine biota. A new and simple methodology to minimize airborne
397 contamination. Marine Pollution Bulletin. 113, 55–61.

398 van Franeker, J.A., Meijboom, A. 2002. Litter NSV - marine litter monitoring by northern fulmars:
399 a pilot study. ALTERRA-Rapport 401. Alterra, Wageningen.

400 Wernham, C., Toms, M., Marchant, J., Clark, J., Siriwardina, G., Baillie, S. 2002. The Migration
401 Atlas: Movement of birds of Britain and Ireland. London. Poyser.

402 Zhao, S., Zhu, L., Li, D., 2016. Microscopic anthropogenic litter in terrestrial birds from Shanghai,
403 China: not only plastics but also natural fibers. *Science of the Total Environment*. 550, 1110–
404 1115.
405

406

407 Figure 1: Yearly faecal sampling sites for Barnacle geese, *Branta leucopsis*, wintering on Inishkea
408 Islands. The islands are situated in the north-east Atlantic Ocean off the west coast of Ireland
409 (54°07'30.2"N; 10°12'31.9"W). Grazing *B. leucopsis* are shown, as is a collection of very large
410 debris items washed ashore by tidal forces (i.e. a large wooden beam, a tractor machinery tyre, and
411 a regular car tyre). Photo credits: Susan Doyle.

412

413 Figure 2: Median counts with interquartile ranges (IQR), and maximum and minimum IQR values,
414 are shown for the total number of recovered synthetic particles, micro-fibres, and micro-fragments.
415 Outlier values are shown.

416

417 Figure 3: Median counts for the total number of recovered synthetic particles, micro-fibres, and
418 micro-fragments in relation to winter season are shown (A, B, C, respectively), as are median
419 counts per gram of faecal sample (D, E, F). Interquartile ranges (IQR), maximum and minimum
420 IQR values, and outlier values are denoted. NS = non-significant, * = $P < 0.05$, ** = $P < 0.01$, ***
421 = $P < 0.001$.

422

423

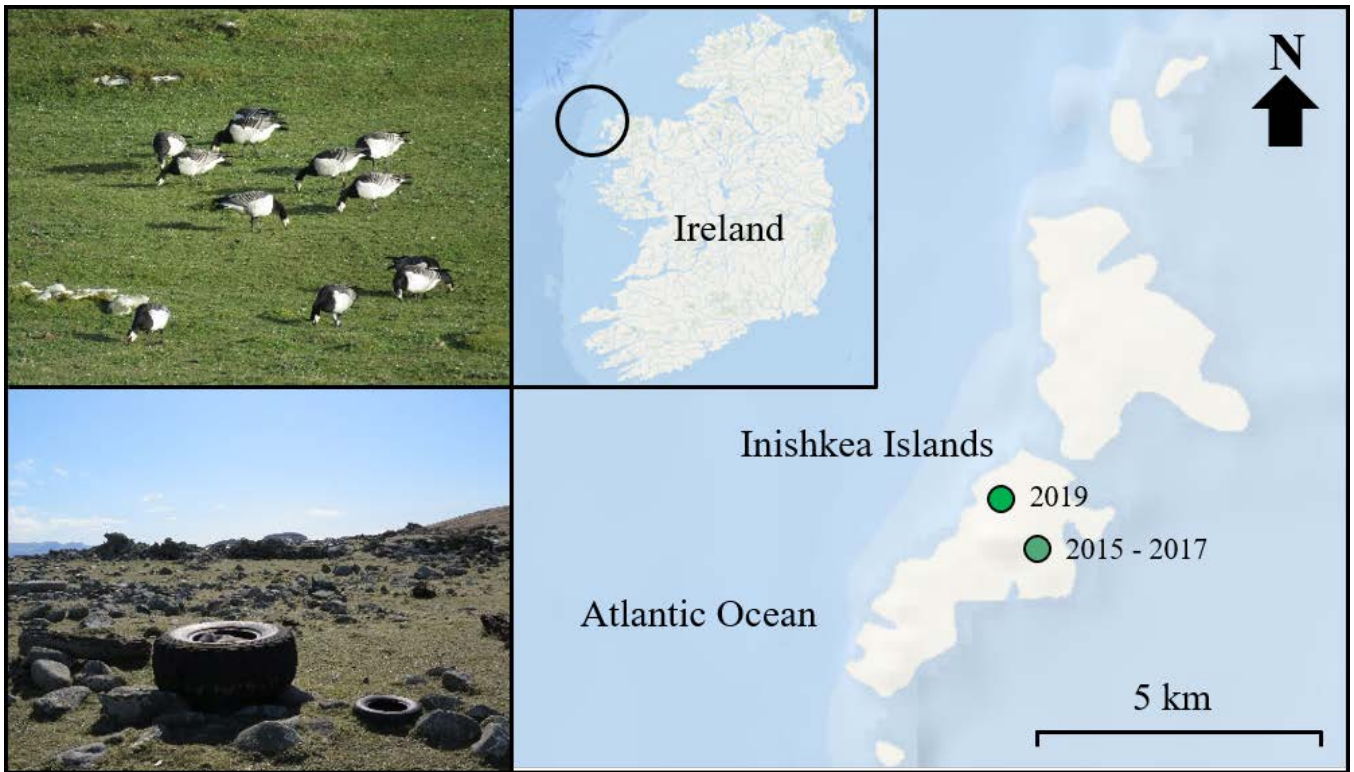
424

425

426

427 Figure 1:

428



429

430

431

432

433

434

435

436

437

438

439

440

441

442

443

444

445

446

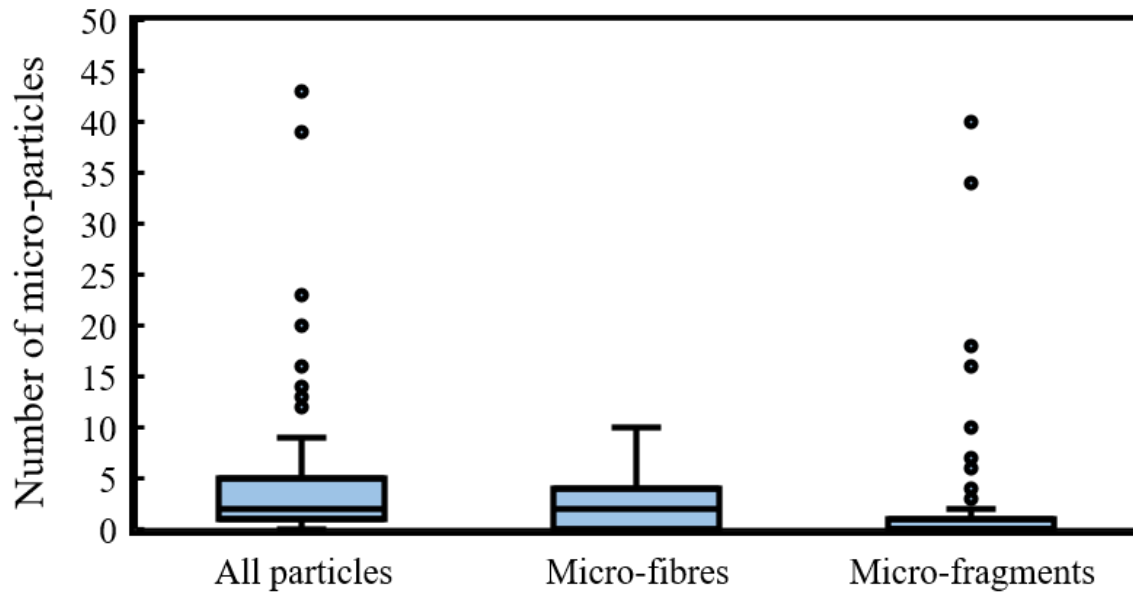
447

448

449 Figure 2:

450

451



452

453

454

455

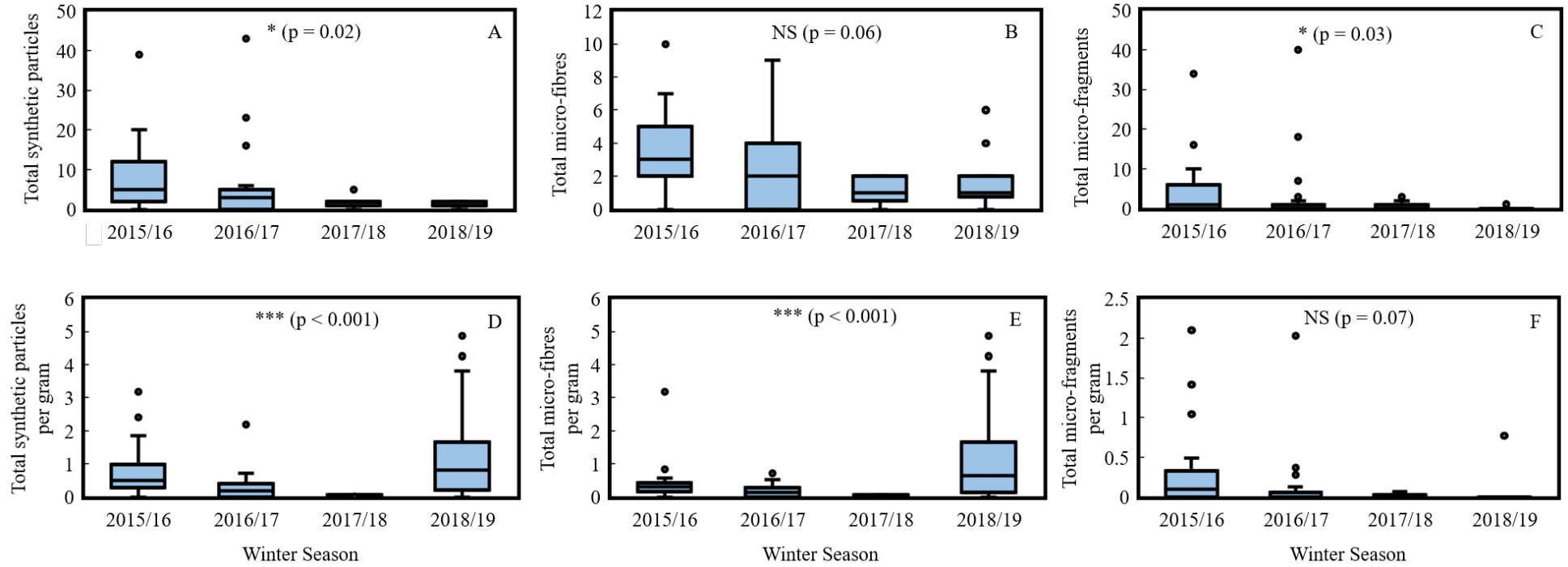
456

457

458

459 Figure 3:

460



461