



HAL
open science

Chemical identification of microplastics ingested by Red Phalaropes (*Phalaropus fulicarius*) using Fourier Transform Infrared spectroscopy

Eloïse Teboul, Diane Orihel, Jennifer Provencher, Mark Drever, Laurie Wilson, Anna Harrison

► To cite this version:

Eloïse Teboul, Diane Orihel, Jennifer Provencher, Mark Drever, Laurie Wilson, et al.. Chemical identification of microplastics ingested by Red Phalaropes (*Phalaropus fulicarius*) using Fourier Transform Infrared spectroscopy. *Marine Pollution Bulletin*, 2021, 171, pp.112640. 10.1016/j.marpolbul.2021.112640 . hal-03870919

HAL Id: hal-03870919

<https://hal.science/hal-03870919>

Submitted on 24 Nov 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

1 **Chemical identification of microplastics ingested by Red Phalaropes**
2 **(*Phalaropus fulicarius*) using Fourier Transform Infrared spectroscopy**

3

4 Eloïse Teboul^a, Diane M. Orihel^{b,c}, Jennifer F. Provencher^d, Mark C. Drever^e, Laurie Wilson^e, Anna L.
5 Harrison^{b,f*,†}

6

7 ^a Department of Chemistry, Queen's University, Kingston, Ontario, Canada

8 ^b School of Environmental Studies, Queen's University, Kingston, Ontario, Canada

9 ^c Department of Biology, Queen's University, Kingston, Ontario, Canada

10 ^d Environment and Climate Change Canada, Canadian Wildlife Service, Gatineau, Quebec, Canada

11 ^e Environment and Climate Change Canada, Canadian Wildlife Service, Delta, British Columbia,
12 Canada

13 ^f Department of Geological Sciences and Geological Engineering, Queen's University, Kingston,
14 Ontario, Canada

15

16 * Corresponding author

17 †Current address:

18 Géosciences Environnement Toulouse (GET), Centre National de la Recherche Scientifique (CNRS),
19 Observatoire Midi-Pyrénées, 14 Ave Edouard Belin, Toulouse, France, 31400

20 Email: anna.harrison@get.omp.eu

21

22 **ABSTRACT**

23 Chemical characterization of plastics ingested by wildlife helps identify sources of plastic pollution in
24 nature and informs assessments of exposure risk to contaminants. In 2016, Red Phalaropes (*Phalaropus*
25 *fulicarius*) were found dead on the north coast of British Columbia, Canada, during their southward
26 migration. Previously, ingested particles suspected to be plastics were reported upon gut examination in
27 all carcasses collected (n=6), which likely contributed to mortality. Here, we provide chemical
28 identification of the ingested particles using Fourier Transform Infrared (FTIR) spectroscopy. Polymer
29 identification was successful for 41 of the 52 analyzed particles (79%): 41 (79%) were confirmed as
30 plastics, 6 (11%) were not plastics, and 5 (10%) could not be identified. The most commonly ingested
31 plastics were polyethylene (42%) and polypropylene (23%), both of which are known to float in the
32 marine environment. Our study highlights the vulnerability of surface foraging seabirds to plastic
33 pollution in the marine environment.

34

35 **KEYWORDS:**

36 Microplastics, FTIR spectroscopy, Polymer identification, Seabirds, Red Phalarope, *Phalaropus*
37 *fulicarius*

38

39

40 INTRODUCTION

41 Birds that forage in the marine environment are particularly susceptible to ingesting plastic debris.
42 Indeed, these birds may be exposed to floating or sinking debris through their feeding strategies: surface
43 feeding, plunging, and pursuit diving (Ashmole, 1971; Avery-Gomm, Provencher, Morgan, & Bertram,
44 2013). The low density of some plastic polymers, such as polypropylene (PP, density 0.92 g/cm³),
45 polyethylene (PE, density 0.95 g/cm³) or even polystyrene (PS, density 1.1 g/cm³) (GESAMP, 2015),
46 causes surface feeders to be predominantly exposed to these types of floating plastics (Moser & Lee,
47 1992). In addition, plastic distribution is not homogeneous at the surface of the ocean, as it is constantly
48 being either dispersed or concentrated by oceanographic currents (Auta, Emenike, & Fauziah, 2017).
49 This leads to greater concentrations of plastic particles closer to the coast, as well as in upwelling areas
50 offshore (Auta et al., 2017; Desforges, Galbraith, Dangerfield, & Ross, 2014; Williams, Ashe, &
51 O'Hara, 2011). Plastics can be considered as both macro and micro contaminants due to their ability to
52 cause physical and chemical harm (Avery-Gomm, Borrelle, & Provencher, 2018). While the physical
53 damage plastics cause as macro contaminants poses threats such as entanglement and starvation
54 (Acampora, Newton, & O'Connor, 2017), the ingested plastics might also be vectors of contaminants,
55 causing less obvious biochemical damage (Silva et al., 2018; Tanaka et al., 2015, 2013).

56 One marine bird that is particularly vulnerable to plastics is the Red Phalarope (*Phalaropus*
57 *fulicarius*). This species breeds across the Arctic regions of North America and Europe and has a trans-
58 oceanic migration each year that lasts 11 months (Tracy, Schamel, & Dale, 2002). Red Phalaropes are
59 surface feeders whose diet typically consists of zooplankton found offshore in upwelling areas, and of
60 adult and larval insects on their breeding grounds (Tracy et al., 2002). Red Phalaropes have a high risk
61 of exposure to microplastics through their feeding behaviour, and seem to mistake floating plastic pieces
62 for prey (Avery-Gomm et al., 2016; Moser & Lee, 1992; Provencher, Bond, & Mallory, 2015; Ryan,
63 1987). This risk may have been exacerbated when coming closer to shore in search for food (Drever et
64 al., 2018). Thus, it is crucial to not only evaluate the threat posed by plastic pollution to this species,
65 but the potential route of exposure to chemical contaminants associated with plastics.

66 In this study, we determined the polymer composition of plastics ingested by Red Phalaropes
67 during their southward migration. Nine Red Phalaropes were collected on the north coast of British

68 Columbia, Canada, following a mortality event in the fall of 2016. Micro -and macro- plastic debris
69 were discovered upon gut examination in all carcasses, and the veterinary report indicated that the large
70 amount of ingested plastics contributed to mortality (Drever et al., 2018). Previously, Drever et al.,
71 (2018) reported the necropsy results and evaluated plastic ingestion through visual characterization of
72 the stomach contents. Here, we build on this previous work by chemically characterizing the suspected
73 plastics isolated from Red Phalaropes' stomachs using Fourier Transform Infrared (FTIR) spectroscopy
74 in Attenuated Total Reflectance (ATR) mode. The objectives of our study were: (i) to validate whether
75 visual characterization of stomach contents can accurately identify ingested particles as plastics; and (ii)
76 to determine the polymer composition of plastics ingested by Red Phalaropes as part of expanding our
77 knowledge of plastic pollution in the North Pacific. Elucidating which types of polymers are being
78 ingested may help trace sources of marine pollution and lends insights into what contaminants Red
79 Phalaropes are potentially exposed to via ingestion of plastics. Given that Red Phalaropes are surface
80 feeders, we predicted that the plastic pieces would be dominated by polymers that are commonly found
81 in surface waters (e.g. PP, PE and PS).

82

83 **MATERIALS AND METHODS**

84 *Sample collection & processing*

85 The Red Phalaropes examined in this study were collected following a mortality event off the
86 west coast of British Columbia, Canada. In the wake of the tug Nathan E. Stewart sinkage on October
87 13, 2016, an emergency oil spill response was put in place, including wildlife monitoring for one month.
88 The dead birds that were collected were not oiled, but all were severely underweight (47-64% of their
89 expected weight). Carcasses were frozen upon collection and defrosted 3 to 4 weeks later, prior to
90 necropsy. As per outlined for examining plastic pollution in seabirds in Provencher et al. (2019)
91 stomachs were dissected and particles were sieved to greater than 1 mm under a stream of deionized
92 water, to be visually sorted under a binocular microscope into industrial pellets or used debris (Drever
93 et al., 2018). Individual pieces were then measured, and sorted into eight colour categories using a
94 Munsell colour wheel reported in (Drever et al., 2018), and using the recommended protocol in
95 Provencher et al. (2017). Size distributions of particles are reported by Drever et al. (2018) and it was

96 determined that less than 1% of particles were less than 1 mm in size. Ingested particles visually
97 suspected to be plastics by Drever et al. (2018) from 6 Red Phalaropes were sent to Queen's University,
98 Canada for chemical characterization for the current study.

99 *Chemical identification of plastic polymers*

100 Chemical identification was performed using FTIR analysis, as it allows for easy identification
101 of carbon-based polymers (Shim, Hong, & Eo, 2017). Each plastic polymer possesses a unique infrared
102 spectrum that acts as a fingerprint (Hidalgo-Ruz, Gutow, Thompson, & Thiel, 2012). This method
103 provides confirmation of the type of polymer in a sample (Song et al., 2015) once the particle is dried
104 and cleaned (Löder & Gerdts, 2015).

105 A Perkin Elmer micro-FTIR Spectrometer Spotlight 150ir was used to collect spectra from 4000
106 cm^{-1} to 600 cm^{-1} with a data interval of 1 cm^{-1} . Resolution was set at 8 cm^{-1} , and 32 scans were recorded
107 for each analysis. The ATR germanium crystal was cleaned with ethanol and a background scan was
108 performed between each sample. A subset of samples was also analysed using a Bruker Alpha II FTIR,
109 equipped with a diamond ATR crystal. Spectra were collected from 4000 cm^{-1} to 450 cm^{-1} with a data
110 interval of 1 cm^{-1} . Resolution was set at 4 cm^{-1} , 8 scans were recorded, and a background scan was
111 performed between each sample. Identification was done using a polymer library provided by Perkin
112 Elmer, as well as an open source Bruker database provided by Primpke, Wirth, Lorenz & Gerdts (2018).
113 The integrated software matching algorithms were used to assess the accuracy of the matches, providing
114 either a correlation factor (Perkin Elmer), or a Hit Quality Index (HQI, Bruker). The majority of
115 identified plastics presented a correlation factor higher than 80% and/or an HQI higher than 700. In
116 addition, the protocol described by Jung et al. (2018) was used to differentiate two types of polyethylene
117 (PE) polymers. When a decision between high-density polyethylene (HDPE) and low-density
118 polyethylene (LDPE) could not be made based on visual examination of the spectra, the particle was
119 reported as only PE (Jung et al., 2018).

120

121 **RESULTS AND DISCUSSION**

122 All of the Red Phalaropes examined in this study (n=6) contained particles in their stomachs
123 visually suspected to be plastic (3 to 24 pieces per bird). As reported by Drever et al. (2018), Red

124 Phalarope stomachs contained a diversity of particles, including fragments, pellets, sheets, and foams
125 (Table 1, Figure 1e-f). Most were smaller than 5 mm, with the exception of two (a knot of intertwined
126 fibers (5.45 mm) and a plastic sheet (6.24 mm)). All 52 particles isolated from these birds were analysed
127 using FTIR spectroscopy (Table 1).

128 Overall, 79% of particles in Red Phalarope stomachs suspected to be plastics (based on visual
129 characterization) were confidently classified as plastics when analyzed by FTIR (Figure 2). We
130 identified the particles to be plastics based upon algorithm matching in addition to manual comparison
131 of the acquired spectra to various libraries available. Representative spectra of the most commonly found
132 polymers can be seen on Figure 1 (a-d). However, determination of the specific polymer composition
133 was not always achievable. For instance, searching through the Perkin Elmer polymer database resulted
134 in very similar correlations between several sample spectra and both PE and polyamide (PA) reference
135 spectra. In addition, the use of several libraries led to different results for some plastics. In cases where
136 we were not able to reach a decision, both potential results are reported (Table 1). As per Drever et al.
137 (2018), 92% of the microplastics were characterized as user plastic upon visual observation, as opposed
138 to industrial virgin pellets (Provencher et al., 2017). Thus, these plastics are likely to contain a multitude
139 of additives introduced throughout their industrial transformation, and to have been manufactured from
140 several polymers (Marturano, Cerruti, & Ambrogi, 2017). The industrial alterations the ingested plastics
141 possibly underwent could result in different FTIR spectra than virgin industrial polymer pellets often
142 used in polymer libraries, which complicates identification.

143 Surprisingly, among the four samples that were easily visually identified as industrial pellets, two
144 identical looking spheres did not lead to any conclusive polymer identification following FTIR analysis.
145 Given their distinctive shape as industrial pellets of plastic, this suggests that polymer libraries may not
146 be comprehensive. Alternatively, environmental exposure may have altered these polymers beyond
147 recognition by the tools employed in this study (Brandon, Goldstein, & Ohman, 2016; Silva et al., 2018).
148 This suggests that both visual and chemical identification of debris pieces may be needed to quantify
149 and understand plastic ingestion in seabirds.

150 As expected, microplastics in Red Phalarope stomachs were largely PP and PE (Figure 2; Figure
151 3). Indeed, 42% of the ingested particles were identified as PE (Figure 2), 23% as PP, and 10% are

152 suspected to be co-polymers made of ethylene and propylene monomers. The majority of birds studied
153 had ingested PP (5 out of 6 birds; Figure 3). Only one bird had ingested polystyrene (PS), and only one
154 had ingested ethylene/polypropylene/diene monomer (EPDM). The most common polymers identified
155 in the Red Phalaropes align with other studies of marine debris (Andrady, 2011; Browne, Galloway, &
156 Thompson, 2010; Smith et al., 2018). As different plastic formulations result in differences in buoyancy,
157 plastics are heterogeneously repartitioned throughout the water column (Cole, Lindeque, Halsband, &
158 Galloway, 2011). Due to their respective densities, polymers such as PP and PE are prone to floating at
159 the surface of the ocean, while PA and PS tend to sink. Polyvinylchloride (PVC) and polyester are most
160 likely to be found at the bottom of the water column. Consequently, the larger proportion of PE and PP
161 identified in the Red Phalaropes stomachs is consistent with previous studies in which it is observed that
162 these birds mistake plastic debris for prey while surface feeding (Drever et al., 2018; Provencher et al.,
163 2015). Moreover, Moser & Lee (1992) reported that Red Phalaropes also likely ingest denser plastics
164 compared to other bird species, as PA and PS, where these polymers tend to be brought to the surface
165 along upwelling areas. PE, PP and PS are three of the most demanded polymers on the market at a global
166 scale (Hahladakis, Velis, Weber, Iacovidou, & Purnell, 2018), therefore they are most likely to be found
167 as waste in the environment, corroborating our findings.

168 Based on FTIR analysis, 12% of the analysed particles are non-plastics (Figure 2) but a decision
169 could not be reached for the remaining 10% of the particles, which are thus labeled “inconclusive”
170 (Figure 2). We identified particles as “non-plastics” when they had an acceptable quality of spectrum
171 but did not exhibit characteristic plastic features. At least four of the non-plastic particles were identified
172 to likely be carbonate minerals, mainly dolomite. This is consistent with sightings of these birds on
173 shore, and their tendency to ingest small rocks and pebbles to help break down food. In addition, one of
174 the particles identified as non-plastic did not absorb IR radiation at all, despite being analyzed by two
175 operators and on two different instruments. The presence of non-plastics would suggest a potential
176 overestimation of the number of plastic particles during visual characterisation. Such an overestimation
177 has been documented in previous studies (Shim et al., 2017; Silva et al., 2018; Zarfl, 2019; Zeng, 2018).
178 We used the term “inconclusive” to designate particles believed to be plastics through visual
179 examination, that could not be identified as either plastics or non-plastics following FTIR analysis.

180 Various factors could explain the inconclusive results, such as the poor quality of the spectra, or the lack
181 of an exhaustive library. Poor quality spectra might be due to rough and abnormal particle shapes that
182 inhibit good contact between the germanium ATR crystal and the sample surface. It is important to note
183 that all of the particles were weathered (had rounded edges), suggesting an alteration of the material's
184 surface. The particles may have been in the environment for years and were known to be exposed to the
185 digestive tract of birds and thus exposed to weathering conditions. This weathering can make the
186 analysis process particularly challenging as ATR-FTIR focuses on the object's surface: when the particle
187 is weathered, it can impede proper contact with the instrument. In addition, the quality of the spectra
188 might decrease in cases when interfering signals are present (Silva et al., 2018; Teuten et al., 2009).
189 Weathering of plastics in oceanic conditions has been demonstrated to impact FTIR spectra (Brandon
190 et al., 2016). In particular, the appearance of hydroxyl, carbonyl, and carbon-oxygen bonds has been
191 demonstrated in weathered HDPE, LDPE, and PP (Brandon et al., 2016). Several of the samples
192 analyzed in the present study did have bands that could be attributed to hydroxyl, carbonyl, and carbon-
193 oxygen (c.f., Brandon et al., 2016). Few available libraries possess reference spectra of weathered
194 polymers (Cai et al., 2019), consequently, good matches are more challenging to obtain, as the surface
195 spectra of weathered polymers differ from virgin polymer standards. As previously discussed, plastic
196 particles are likely to contain a variety of additives and to be composed of several polymers, further
197 hindering analysis. Despite some documented analytical challenges with ATR-FTIR, chemical
198 characterization is useful not only to access supplementary information about the type of polymer or the
199 potential presence of additives, but also to produce reliable results regarding the amount of plastics
200 ingested. While FTIR analysis is often referred to as a non-destructive analytical technique (Shim et al.,
201 2017; Zarfl, 2019), weathered plastics are likely to be more fragile (Brandon et al., 2016), and several
202 particles were destroyed when we analysed them indicating that they were indeed highly weathered.
203 Thus, although reflectance and transmittance modes might be non-destructive, it is important to be aware
204 that it is not the case for ATR mode, should this be a criterion when choosing an analytical method to
205 characterize microplastics. Additional characterization could be performed in this scenario using
206 techniques such as pyrolysis Gas Chromatography Mass Spectrometry (py-GCMS) or Raman
207 spectroscopy (Hartmann et al., 2019; Shim et al., 2017).

208 The chemical identification of microplastic debris ingested by Red Phalaropes allows us to shed
209 light on this particular exposure route to plastic-associated chemical contaminants. Indeed, different
210 polymer types can be linked to various additives and sorbed environmental contaminants (Acampora et
211 al., 2017; Avery-Gomm et al., 2018; Provencher et al., 2015; Rochman et al., 2019; Teuten et al., 2009).
212 Chemical additives allow for the enhancement of polymer properties, along with increased durability of
213 plastic products (Hahladakis et al., 2018). Consequently, sorbed or incorporated contaminants might be
214 released into organisms following ingestion as the plastic gets partially degraded throughout the
215 gastrointestinal tract. It has been observed that plastics sorb a variety of contaminants throughout their
216 environmental weathering (Provencher et al., 2017; Rochman, Hoh, Hentschel, & Kaye, 2013). Among
217 our particles, 71% of the plastics displayed signs of weathering-induced “yellowing” (Drever et al.,
218 2018) (Table 1), which could suggest the potential for sorption of polychlorinated biphenyls (PCBs)
219 during the aging process (Ogata et al., 2009). Although the release mechanisms of these chemicals into
220 the organism following ingestion remain largely unknown, the high proportion of both PE and PP found
221 in the Red Phalaropes stomachs raises questions about contaminant exposure and would suggest the
222 need for further monitoring. Through the knowledge of their migratory patterns and variety of feeding
223 modes, marine birds can be a valuable indicator of plastic pollution globally (Nevins et al., 2005).

224 This study contributes to the body of literature about plastic pollution in the north-eastern Pacific
225 Ocean, and specifically the plastic pollution that marine birds are exposed to. Knowledge of plastic
226 ingestion across Canadian seabird species, in particular, is very limited (Provencher et al., 2015). Our
227 results are consistent with the findings of Desforges et al. (2014), who reported large amounts of
228 microplastics closer to the shore of British Columbia. In addition, Williams et al. (2011) found a high
229 occurrence of Styrofoam, plastic bottles and plastic bags during a survey of floating marine debris in the
230 same geographic area. These objects are often made from PS and HDPE respectively, which
231 corroborates the polymer types found in the Red Phalaropes’ stomachs. This indicates that a proportion
232 of microplastics found at the surface of the ocean might originate from the decomposition of these plastic
233 debris.

234 Our findings in this study, along with others reporting on plastic-related contaminants found in
235 marine birds (Tanaka et al., 2013), or more broadly plastic ingestion (Poon, Provencher, Mallory,

236 Braune, & Smith, 2017) indicate the need for further monitoring as marine birds are undeniably exposed
237 to plastic pollution. Only a few of the plastic ingestion studies published to date include details about
238 the type of polymers encountered, yet polymer identification provides valuable information on the
239 possible types of chemicals to which marine birds might be exposed as well as the types of plastics that
240 are impacting seabirds. Polymer identification along with physical characteristics are valuable data that
241 facilitate tracking plastic sources more broadly (e.g., Rochman et al., 2019). While opportunistic
242 sampling of a small number of individuals offers an insight of the situation of exposure of Red
243 Phalaropes to microplastic pollution, broader studies are necessary to assess the threat posed by
244 microplastics and their associated contaminants to seabirds.

245

246 **CONCLUSION**

247 Seabirds are particularly vulnerable to marine plastic pollution. Here, we provide chemical
248 characterization of particles found in the stomachs of dead Red Phalaropes, suspected to be plastics upon
249 visual examination. All examined Red Phalaropes (n=6) had ingested polymers consistent with plastic
250 debris, mainly in the form of microplastic fragments. However, following FTIR analysis, we reported
251 a slightly lower level of ingested plastic than was estimated upon physical characterisation by Drever et
252 al., (2018). We positively identified 79% of the examined particles as plastics, with the remainder of the
253 particles remaining unidentified. Of the unidentified, we classified 10% as non-plastic based on the lack
254 of spectral bands expected for plastic materials, and 11% were inconclusive and could not be identified
255 as plastic with certainty. Of the plastic particles, the dominant polymer types were PE and PP. Ingestion
256 appears to occur through the scavenging of floating plastics, ingested along with food. Our findings
257 suggest that Red Phalaropes could be exposed to various contaminants such as polychlorinated
258 biphenyls following plastic ingestion. Further analysis of these birds' liver and muscle tissue could
259 provide additional details as to the level of threat this species, and other marine birds, are facing from
260 microplastic-sorbed contaminants. Finally, the use of ATR-FTIR alone proved to have certain
261 limitations, and consequently, we suggest using a combination of analytical techniques for future work
262 to ensure all particles can be identified.

263

264 **DECLARATION OF COMPETING INTEREST**

265 The authors declare that they have no known competing financial interests or personal relationships that
266 could have appeared to influence the work reported in this paper.

267

268 **ACKNOWLEDGEMENTS**

269 This work was supported by Environment and Climate Change Canada (to Orihel) and the Canadian
270 Foundation for Innovation (to Harrison). We acknowledge the helpful comments of four anonymous
271 reviewers and the editorial handling of this manuscript by Huahong Shi that improved this study. Many
272 thanks to Igor Kozin (Queen's University, Kingston, ON) for his help with FTIR analysis. We are
273 grateful to the Enforcement Branch of Environment and Climate Change Canada (J. Hunt), and
274 emergency response teams for the search efforts following the sinking of the Nathan E. Stewart vessel,
275 including L. Battaglia, C. Battaglia, M. Travers, J. Rios, and J-F. Aublet.

276 **AUTHOR CONTRIBUTIONS**

277 Eloïse Teboul, Anna L. Harrison, Diane M. Orihel and Jennifer F. Provencher conceived the study.
278 Laurie Wilson coordinated logistics regarding carcasses. Jennifer F. Provencher recovered the plastics
279 and performed visual identification. Mark C. Drever analysed the initial data. Eloïse Teboul conducted
280 the FTIR analysis and analysed the data. Eloïse Teboul wrote the manuscript, with contributions from
281 all authors. All authors contributed to editing and revising. Diane M. Orihel and Anna L. Harrison
282 acquired the funding.

283

284 **REFERENCES**

- 285 Acampora, H., Newton, S., & O'Connor, I. (2017). Opportunistic sampling to quantify plastics in the
286 diet of unfledged Black Legged Kittiwakes (*Rissa tridactyla*), Northern Fulmars (*Fulmarus*
287 *glacialis*) and Great Cormorants (*Phalacrocorax carbo*). *Marine Pollution Bulletin*, 119(2), 171–
288 174. <https://doi.org/10.1016/j.marpolbul.2017.04.016>
- 289 Andrady, A. L. (2011). Microplastics in the marine environment. *Marine Pollution Bulletin*, 62(8),
290 1596–1605. <https://doi.org/10.1016/j.marpolbul.2011.05.030>

291 Ashmole, N. P. (1971). Seabird ecology and the marine environment. In D. S. Farner & J. R. King
292 (Eds.), *Avian Biology 1* (pp. 223–286). <https://doi.org/10.1111/jav.00958View/save>

293 Auta, H. S., Emenike, C. U., & Fauziah, S. H. (2017). Distribution and importance of microplastics in
294 the marine environmentA review of the sources, fate, effects, and potential solutions.
295 *Environment International*, *102*, 165–176. <https://doi.org/10.1016/j.envint.2017.02.013>

296 Avery-Gomm, S., Borrelle, S. B., & Provencher, J. F. (2018). Linking plastic ingestion research with
297 marine wildlife conservation. *Science of the Total Environment*, *637–638*, 1492–1495.
298 <https://doi.org/10.1016/j.scitotenv.2018.04.409>

299 Avery-Gomm, S., Provencher, J. F., Morgan, K. H., & Bertram, D. F. (2013). Plastic ingestion in
300 marine-associated bird species from the eastern North Pacific. *Marine Pollution Bulletin*, *72*(1),
301 257–259. <https://doi.org/10.1016/j.marpolbul.2013.04.021>

302 Avery-Gomm, S., Valliant, M., Schacter, C. R., Robbins, K. F., Liboiron, M., Daoust, P. Y., ... Jones,
303 I. L. (2016). A study of wrecked Dovekies (*Alle alle*) in the western North Atlantic highlights the
304 importance of using standardized methods to quantify plastic ingestion. *Marine Pollution*
305 *Bulletin*, *113*(1–2), 75–80. <https://doi.org/10.1016/j.marpolbul.2016.08.062>

306 Brandon, J., Goldstein, M., & Ohman, M. D. (2016). Long-term aging and degradation of microplastic
307 particles: Comparing in situ oceanic and experimental weathering patterns. *Marine Pollution*
308 *Bulletin*, *110*(1), 299–308. <https://doi.org/10.1016/j.marpolbul.2016.06.048>

309 Browne, M. A., Galloway, T. S., & Thompson, R. C. (2010). Spatial patterns of plastic debris along
310 estuarine shorelines. *Environmental Science and Technology*, *44*(9), 3404–3409.
311 <https://doi.org/10.1021/es903784e>

312 Cai, H., Du, F., Li, L., Li, B., Li, J., & Shi, H. (2019). A practical approach based on FT-IR
313 spectroscopy for identification of semi-synthetic and natural celluloses in microplastic
314 investigation. *Science of the Total Environment*, *669*, 692–701.
315 <https://doi.org/10.1016/j.scitotenv.2019.03.124>

316 Cole, M., Lindeque, P., Halsband, C., & Galloway, T. S. (2011). Microplastics as contaminants in the
317 marine environment: A review. *Marine Pollution Bulletin*, *62*(12), 2588–2597.
318 <https://doi.org/10.1016/j.marpolbul.2011.09.025>

319 Desforges, J. P. W., Galbraith, M., Dangerfield, N., & Ross, P. S. (2014). Widespread distribution of
320 microplastics in subsurface seawater in the NE Pacific Ocean. *Marine Pollution Bulletin*, 79(1–
321 2), 94–99. <https://doi.org/10.1016/j.marpolbul.2013.12.035>

322 Drever, M. C., Provencher, J. F., O’Hara, P. D., Wilson, L., Bowes, V., & Bergman, C. M. (2018). Are
323 ocean conditions and plastic debris resulting in a ‘double whammy’ for marine birds? *Marine*
324 *Pollution Bulletin*, 133(March), 684–692. <https://doi.org/10.1016/j.marpolbul.2018.06.028>

325 GESAMP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection.
326 (2015). Sources, fate and effects of microplastics in the marine environment: a global
327 assessment”. *Reports and Studies GESAMP*, 90, 96. <https://doi.org/10.13140/RG.2.1.3803.7925>

328 Hahladakis, J. N., Velis, C. A., Weber, R., Iacovidou, E., & Purnell, P. (2018). An overview of
329 chemical additives present in plastics: Migration, release, fate and environmental impact during
330 their use, disposal and recycling. *Journal of Hazardous Materials*, 344, 179–199.
331 <https://doi.org/10.1016/j.jhazmat.2017.10.014>

332 Hartmann, N. B., Hüffer, T., Thompson, R. C., Hassellöv, M., Verschoor, A., Daugaard, A. E., ...
333 Wagner, M. (2019). Are We Speaking the Same Language? Recommendations for a Definition
334 and Categorization Framework for Plastic Debris. *Environmental Science and Technology*, 53(3),
335 1039–1047. <https://doi.org/10.1021/acs.est.8b05297>

336 Hidalgo-Ruz, V., Gutow, L., Thompson, R. C., & Thiel, M. (2012). Microplastics in the marine
337 environment: A review of the methods used for identification and quantification. *Environmental*
338 *Science and Technology*, 46(6), 3060–3075. <https://doi.org/10.1021/es2031505>

339 Jung, M. R., Horgen, F. D., Orski, S. V., Rodriguez C., V., Beers, K. L., Balazs, G. H., ... Lynch, J.
340 M. (2018). Validation of ATR FT-IR to identify polymers of plastic marine debris, including
341 those ingested by marine organisms. *Marine Pollution Bulletin*, 127(December 2017), 704–716.
342 <https://doi.org/10.1016/j.marpolbul.2017.12.061>

343 Löder, M. G. J., & Gerdt, G. (2015). Methodology Used for the Detection and Identification of
344 Microplastics—A Critical Appraisal. In *Marine Anthropogenic Litter* (pp. 201–227).
345 https://doi.org/10.1007/978-3-319-16510-3_8

346 Marturano, V., Cerruti, P., & Ambrogi, V. (2017). Polymer additives. *Physical Sciences Reviews*, 2(6),

347 1–20. <https://doi.org/10.1515/psr-2016-0130>

348 Moser, M. L., & Lee, D. S. (1992). A Fourteen-Year Survey of Plastic Ingestion by Western North
349 Atlantic Seabirds. *Colonial Waterbirds*, 15(1), 83–94. Retrieved from
350 <https://www.jstor.org/stable/1521357>

351 Nevins, H., Hyrenbach, D., Keiper, C., Stock, J., Hester, M., & Harvey, J. (2005). Seabirds as
352 indicators of plastic pollution in the North Pacific. *Plastic Debris, Rivers to Sea Conference*
353 *Proceedings*, 7th to 9th September. Retrieved from
354 http://www.oikonos.org/papers/Nevins_etal_2005.pdf.

355 Ogata, Y., Takada, H., Mizukawa, K., Hirai, H., Iwasa, S., Endo, S., ... Thompson, R. C. (2009).
356 International Pellet Watch: Global monitoring of persistent organic pollutants (POPs) in coastal
357 waters. 1. Initial phase data on PCBs, DDTs, and HCHs. *Marine Pollution Bulletin*, 58(10),
358 1437–1446. <https://doi.org/10.1016/j.marpolbul.2009.06.014>

359 Poon, F. E., Provencher, J. F., Mallory, M. L., Braune, B. M., & Smith, P. A. (2017). Levels of
360 ingested debris vary across species in Canadian Arctic seabirds. *Marine Pollution Bulletin*,
361 116(1–2), 517–520. <https://doi.org/10.1016/j.marpolbul.2016.11.051>

362 Primpke, S., Wirth, M., Lorenz, C., & Gerdt, G. (2018). Reference database design for the automated
363 analysis of microplastic samples based on Fourier transform infrared (FTIR) spectroscopy.
364 *Analytical and Bioanalytical Chemistry*, 410(21), 5131–5141. [https://doi.org/10.1007/s00216-](https://doi.org/10.1007/s00216-018-1156-x)
365 [018-1156-x](https://doi.org/10.1007/s00216-018-1156-x)

366 Provencher, J. F., Bond, A. L., Avery-Gomm, S., Borrelle, S. B., Bravo Rebolledo, E. L., Hammer, S.,
367 ... Van Franeker, J. A. (2017). Quantifying ingested debris in marine megafauna: A review and
368 recommendations for standardization. *Analytical Methods*, 9(9), 1454–1469.
369 <https://doi.org/10.1039/c6ay02419j>

370 Provencher, J. F., Bond, A. L., & Mallory, M. L. (2015). Marine birds and plastic debris in Canada: A
371 national synthesis and a way forward. *Environmental Reviews*, 23(1), 1–13.
372 <https://doi.org/10.1139/er-2014-0039>

373 Provencher, J. F., Borrelle, S. B., Bond, A. L., Lavers, J. L., van Franeker, J. A., Kühn, S., ... Mallory,
374 M. L. (2019). Recommended best practices for plastic and litter ingestion studies in marine birds:

375 Collection, processing, and reporting. *Facets*, 4(1), 111–130. <https://doi.org/10.1139/facets->
376 2018-0043

377 Rochman, C. M., Hoh, E., Hentschel, B. T., & Kaye, S. (2013). Long-term field measurement of
378 sorption of organic contaminants to five types of plastic pellets: Implications for plastic marine
379 debris. *Environmental Science and Technology*, 47(3), 1646–1654.
380 <https://doi.org/10.1021/es303700s>

381 Rochman, C.M., Brookson, C., Bikker, J., Djuric, N., ... Hung, C. (2019). Rethinking microplastics as
382 a diverse contaminant suite. *Environmental Toxicology and Chemistry*, 38, 703-711.

383 Ryan, P. G. (1987). The incidence and characteristics of plastic particles ingested by seabirds. *Marine*
384 *Environmental Research*, 23(3), 175–206. [https://doi.org/10.1016/0141-1136\(87\)90028-6](https://doi.org/10.1016/0141-1136(87)90028-6)

385 Shim, W. J., Hong, S. H., & Eo, S. E. (2017). Identification methods in microplastic analysis: A
386 review. *Analytical Methods*, 9(9), 1384–1391. <https://doi.org/10.1039/c6ay02558g>

387 Silva, A. B., Bastos, A. S., Justino, C. I. L., da Costa, J. P., Duarte, A. C., & Rocha-Santos, T. A. P.
388 (2018). Microplastics in the environment: Challenges in analytical chemistry - A review.
389 *Analytica Chimica Acta*, 1017, 1–19. <https://doi.org/10.1016/j.aca.2018.02.043>

390 Smith, M., Love, D.C., Rochman, C.M., and Neff, R. A. (2018) Microplastics in seafood and the
391 implications for human health. *Food, Health, and the Environment*, 5, 375-386.

392 Song, Y. K., Hong, S. H., Jang, M., Han, G. M., Rani, M., Lee, J., & Shim, W. J. (2015). A
393 comparison of microscopic and spectroscopic identification methods for analysis of microplastics
394 in environmental samples. *Marine Pollution Bulletin*, 93(1–2), 202–209.
395 <https://doi.org/10.1016/j.marpolbul.2015.01.015>

396 Tanaka, K., Takada, H., Yamashita, R., Mizukawa, K., Fukuwaka, M. A., & Watanuki, Y. (2015).
397 Facilitated Leaching of Additive-Derived PBDEs from Plastic by Seabirds' Stomach Oil and
398 Accumulation in Tissues. *Environmental Science and Technology*, 49(19), 11799–11807.
399 <https://doi.org/10.1021/acs.est.5b01376>

400 Tanaka, K., Takada, H., Yamashita, R., Mizukawa, K., Fukuwaka, M. aki, & Watanuki, Y. (2013).
401 Accumulation of plastic-derived chemicals in tissues of seabirds ingesting marine plastics.
402 *Marine Pollution Bulletin*, 69(1–2), 219–222. <https://doi.org/10.1016/j.marpolbul.2012.12.010>

403 Teuten, E. L., Saquing, J. M., Knappe, D. R. U., Barlaz, M. A., Jonsson, S., Björn, A., ... Takada, H.
404 (2009). Transport and release of chemicals from plastics to the environment and to wildlife.
405 *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364(1526), 2027–2045.
406 <https://doi.org/10.1098/rstb.2008.0284>

407 Tracy, D. M., Schamel, D., & Dale, J. (2002). Red Phalarope (*Phalaropus fulicarius*).
408 <https://doi.org/10.2173/bna.698>

409 Williams, R., Ashe, E., & O'Hara, P. D. (2011). Marine mammals and debris in coastal waters of
410 British Columbia, Canada. *Marine Pollution Bulletin*, 62(6), 1303–1316.
411 <https://doi.org/10.1016/j.marpolbul.2011.02.029>

412 Zarfl, C. (2019). Promising techniques and open challenges for microplastic identification and
413 quantification in environmental matrices. *Analytical and Bioanalytical Chemistry*, 3743–3756.
414 <https://doi.org/10.1007/s00216-019-01763-9>

415 Zeng, E. Y. (2018). 2.4.1 Visual identification. In Elsevier (Ed.), *Microplastic Contamination in*
416 *Aquatic Environments: An emerging matter of environmental urgency* (p. 35).
417
418

419 **Table 1.** Characterisation of 52 particles ingested by six (6) Red Phalaropes collected following a
 420 mortality event in the Fall 2016. Physical characterisation was performed by Drever et al., 2018
 421 following the guidelines of Provencher et al., 2017. Confidence level that the examined particle is a
 422 plastic polymer was determined upon FTIR analysis coupled with physical characterisation. Polymer
 423 attribution is based upon algorithm matching in addition to manual comparison of acquired spectra to
 424 various libraries available.

Red Phalarope ID	<i>Physical characterisation¹</i>			<i>Chemical characterisation</i>	
	User/industrial plastic	Type of particle	Pigmentation	Polymer attributed	Confidence level that the particle is a plastic polymer
Bird C WHN16-276	user	foamed	black	PP ²	Medium
	user	foamed	black	PP	High
	user	fragment	black	Inconclusive	Medium
Bird D WHN16-276	industrial	pellet	off white/clear	HDPE ³	High
	user	fragment	yellow	PP	High
	user	fragment	off white/clear	HDPE	High
	user	sheet	black	PA ⁴ or co PP-PE ⁵	High
	industrial	pellet	black	HDPE	High
	user	fragment	grey/silver	co PP-PE	High
	industrial	pellet	black	Inconclusive	Low
	user	rubber	black	HPDE	High
	user	rubber	black	PA or co PP-PE	High
	user	fragment	off white/clear	Non-plastic ⁶	None
	user	foamed	off white/clear	PS ⁷	High
	user	fragment	off white/clear	Non-plastic ⁶	None
	user	fragment	off white/clear	Non-plastic ⁶	None
user	sheet	black	Non-plastic	None	
user	fragment	off white/clear	Non-plastic ⁶	None	
Bird E WHN16-276	user	fiber	brown	PP	High
	user	fragment	brown	PA or co PP-PE	High
	user	fragment	black	PA or co PP-PE	High
Bird F WHN16-276	user	wax	off white/clear	PE ⁸	High
	user	fragment	orange/brown	LDPE ⁹	High
	industrial	pellet	orange/brown	Inconclusive	Low
Bird G WHN16-276	user	fragment	off white/clear	Inconclusive	Inconclusive
	user	sheet	orange/brown	PE	High
	user	fragment	yellow	PP	High
Bird I WHN16-277	user	fragment	off white/clear	PP	High
	user	fragment	off white/clear	HDPE	High
	user	fragment	off white/clear	PP	High
	user	fragment	off white/clear	Inconclusive	Inconclusive
	user	fragment	blue/purple	PE	High
	user	fragment	off white/clear	PE	High
	user	fragment	off white/clear	Non-plastic	None
	user	fragment	off white/clear	PE	High
	user	fragment	off white/clear	LDPE	High
	user	fragment	off white/clear	PP	Medium

user	fragment	off white/clear	HDPE	High
user	fragment	off white/clear	HDPE	High
user	fragment	off white/clear	PP	High
user	fragment	off white/clear	LDPE	High
user	fragment	off white/clear	PP	High
user	fragment	off white/clear	EPDM ¹⁰	Medium
user	fragment	off white/clear	PE	High
user	fragment	off white/clear	PP	High
user	fragment	off white/clear	PE	High
user	fragment	off white/clear	LDPE	High
user	fragment	off white/clear	PP	High
user	fragment	off white/clear	PE	High
user	fragment	off white/clear	PE	High
user	fragment	off white/clear	HDPE	High
user	fragment	off white/clear	PE	High

425

426 ¹ Data from Drever et al., 2018

427 ² Polypropylene

428 ³ High Density Polyethylene

429 ⁴ Polyamide

430 ⁵ Propylene-Ethylene copolymer

431 ⁶ Believed to be dolomite

432 ⁷ Polystyrene

433 ⁸ Polyethylene

434 ⁹ Low Density Polyethylene

435 ¹⁰ Ethylene/Propylene/Diene monomer

436 **FIGURE CAPTIONS**

437 **Figure 1** Fourier Transform Infrared (FTIR) spectroscopy results of a representative panel of plastics
438 found in Red Phalaropes stomachs. **a.** Spectrum collected using a Perkin Elmer micro-FTIR Spectrometer
439 Spotlight 150ir in ATR mode. Resolution 8 cm⁻¹, 32 scans. Matched with High Density Polyethylene
440 (correlation=0.91). **b.** Spectrum collected using a Perkin Elmer micro-FTIR Spectrometer Spotlight 150ir
441 in ATR mode. Resolution 8 cm⁻¹, 32 scans. Matched with Polypropylene (correlation=0.80). **c.** Spectrum
442 collected using a Bruker Alpha II FTIR in ATR mode. Resolution 4 cm⁻¹, 8 scans. Matched with Low
443 Density Polyethylene (Hit Quality Index=743). **d.** Spectrum collected using a Bruker Alpha II FTIR in
444 ATR mode. Resolution 4 cm⁻¹, 8 scans. Matched with an Ethylene-Propylene copolymer (Hit Quality
445 Index=398). **e.** Suspected plastics isolated from Red Phalarope “D” following visual examination. **f.**
446 Suspected plastics isolated from Red Phalarope “I” following visual examination.

447

448 **Figure 2** Chemical identification of particles ingested by six Red Phalaropes using Fourier Transform
449 Infrared spectroscopy. PP=polypropylene, PE=polyethylene, EPDM=ethylene/propylene/diene
450 monomer, PA=polyamide, co PP-PE=polypropylene/polyethylene copolymer, PS=polystyrene.
451 “Inconclusive” designates particles believed to be plastics through visual examination that have not been
452 confirmed through FTIR analysis due to the poor quality of the spectra obtained (likely linked to particle
453 weathering) and/or the lack of an acceptable library match.
454 Inset: Distribution of polyethylene (PE) by type. Total of 22 plastics recovered from Red Phalaropes
455 stomachs were identified as PE following ATR-FTIR analysis. Differentiation based on library matches
456 and the method described by Jung et al, 2018. HDPE=High Density Polyethylene, LDPE=Low Density
457 Polyethylene, PE=undifferentiated type of Polyethylene.

458

459 **Figure 3** Relative distribution of plastic polymers ingested by Red Phalaropes. Total of 52 particles
460 ingested by six birds. Polymer types identified using Fourier Transform Infrared spectroscopy.
461 PP=polypropylene, PE=polyethylene, EPDM=ethylene/propylene/diene monomer, PA=polyamide, co
462 PP-PE=polypropylene/polyethylene copolymer, PS=polystyrene.