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Plastic ingestion by seabirds in New Caledonia, South Pacific

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ABSTRACT

The accumulation of plastic pollutants in marine environments has many adverse effects on wildlife. In particular, marine predators are often exposed to accidental plastic ingestion, that may negatively affect survival due to the concentration of debris in the digestive tract. Among the species most vulnerable to plastic ingestion, seabirds are of major interest for conservation because of their wide foraging areas, long generation time and extended lifespan. We analysed stomach contents of 90 seabird specimens from 12 different species collected in New Caledonia to assess the local prevalence of plastic ingestion. Overall, we found plastic debris in 14.4% of sampled individuals, exclusively in procellariids: Gould's Petrel (41.2%, highest incidence), Tahiti Petrel (33.3%) and Wedge-tailed Shearwater (7.7%). To our knowledge, this study is the first characterization of plastic ingestion in seabirds from New Caledonia and our results show an overall lower ingestion prevalence compared to other assessments in the tropical Pacific.

The ever-growing concentration of plastic waste in marine environments is a major concern for wildlife (Derraik, 2002; Barnes et al., 2009; Eriksen et al., 2014; Gall and Thompson, 2015). Within the marine megafauna, seabirds are severely affected by the presence of debris in shallow waters (Ryan, 1987; Wilcox et al., 2015; Tavares et al., 2017). Their surface-feeding and resting behaviours make them highly susceptible to entanglement (Votier et al., 2011) and ingestion (Gregory, 2009; Roman et al., 2016), thus increasing mortality risks (Wilcox et al., 2015; Roman et al., 2019b). In particular, plastic ingestion has multiple deleterious effects: obstruction or damage of the intestinal tract (Kühn et al., 2015), dehydration and reduced food intake (Auman et al., 1998) and/or accumulation of plastic-derived chemicals in the body (Tanaka et al., 2013, 2015). Incidence, size and colour of ingested particles strongly differ across seabird species and geographic regions (Ryan, 1987; Ainley et al., 1989; Roman et al., 2016). This is thought to derive mostly from local variations of plastic abundance (van Franeker and Law, 2015; Thiel et al., 2018), diet specificities (Azzarello and Van Vleet, 1987; Savoca et al., 2016; Tavares et al., 2017) and taxonomic traits (Sileo et al., 1990; Roman et al., 2019a). Multispecies assessments are thus necessary for accurately characterizing ingestion risks in a given location (Gilbert et al., 2016; Basto et al., 2019) and developing relevant conservation responses

(Avery-Gomm et al., 2018).

New Caledonia, South Pacific (21.2° S, 165.9° E) is home to > 25 breeding seabird species (Spaggiari et al., 2006) among which the Tahiti Petrel (*Pseudobulweria rostrata*, NT), Gould's Petrel (*Pterodroma leucoptera*, VU) and the Fairy Tern (*Sternula nereis*, VU) exhibit extinction risks of concern in the IUCN RedList (IUCN, 2019). Its territorial waters also host a significant proportion of the global breeding population of the Wedge-tailed Shearwater (*Ardenna pacifica*, > 500,000 breeding pairs) (Benoit and Bretagnolle, 2002; Baudat-Franceschi et al., 2008), a species highly vulnerable to plastic ingestion (Kain et al., 2016; Lavers et al., 2018). While local impacts of invasive species are relatively well known (Palmas et al., 2017), no information on plastic-associated threats is currently available in this geographic area.

We present here the first characterization of the incidence of plastic ingestion in a set of seabird species breeding in New Caledonia. This work sets a baseline for future monitoring of the extent, variation and severity of plastic-associated risks for local breeding seabird populations.

Individual stomach contents were examined in 90 specimens collected between 2015 and 2018 from the following 12 seabird species: Wedge-tailed Shearwater (n = 52), Gould's Petrel (n = 17), Tahiti Petrel (n = 6), Black Noddy (*Anous minutus*; n = 4); Roseate Tern

Table 1

Occurrence and characteristics of plastics ingested by Gould's Petrel specimens (*Pterodroma leucoptera*, n = 17), by category. CI: Jeffrey's credible interval. Means, medians & ranges include all sampled individuals.

	Frequency of occurrence (%; 95% CI)	Number of plastic items			Mass of plastic items		
		Mean (n; \pm sd; \pm se)	Median	Range	Mean (g, \pm sd, \pm se)	Median	Range
Global	41.18 (20.68; 64.41)	1.12 (\pm 1.54; \pm 0.37)	0	0–4	0.0018 (\pm 0.0024; \pm 0.0006)	0	0–0.0078
User	41.18 (20.68; 64.41)	1.12 (\pm 1.54; \pm 0.37)	0	0–4	0.0018 (\pm 0.0024; \pm 0.0006)	0	0–0.0078
Industrial	0 (0; 13.55)	0	0	0	0	0	0
Sheetlike	0 (0; 13.55)	0	0	0	0	0	0
Threadlike	17.65 (5.23; 40.01)	0.29 (\pm 0.77; \pm 0.19)	0	0–3	0.0004 (\pm 0.0011; \pm 0.0003)	0	0–0.0037
Foam	0 (0; 13.55)	0	0	0	0	0	0
Fragment	35.29 (16.29; 58.86)	0.82 (\pm 1.38; \pm 0.33)	0	0–4	0.0014 (\pm 0.0020; \pm 0.0005)	0	0–0.0063
Other	0 (0; 13.55)	0	0	0	0	0	0

(*Sterna dougallii*; n = 4), Red-footed booby (*Sula sula*; n = 1), Silver Gull (*Larus novaehollandiae*; n = 1), Brown noddy (*Anous stolidus*; n = 1), Bridled Tern (*Onychoprion anaethetus*; n = 1), Sooty Tern (*Onychoprion fuscatus*; n = 1), Fairy Tern (*Sternula nereis*; n = 1) and Greater Crested Tern (*Thalasseus bergii*; n = 1). Carcasses were collected opportunistically, either on monitored breeding sites (south-western and north-western lagoons, southern Caledonian chain) or after collision events (roadkill, light-induced misorientation) near urban or industrialized areas. After collection, each specimen received an individual identification number and was stored at -20°C until dissection.

Dissections were performed following the standard dissection protocol of van Franeker (Van Franeker and Meijboom, 2002). Due to heterogeneous sampling, corpse preservation varied to some extent across specimens and prevented exhaustive characterization of weight and body condition. Specimen age (adult/fledgling/chick) was determined through the examination of the plumage and/or the state of gonad development. The digestive tract (proventriculus, gizzard) was then extracted and its contents were rinsed and filtrated using a 0.5 mm sieve. Remaining fragments were exposed to two consecutive digestive treatments: 30% H_2O_2 at 60°C (24 h) and 10% HNO_3 at room temperature (5 min) in order to remove organic matter from the samples (Lusher et al., 2017). When present, plastic debris were then collected, dried overnight (60°C) and weighed to the nearest 0.0001 g.

Following the standardized methodology of Provencher et al. (2017), plastic items were characterized by type (user/industrial; sheetlike/threadlike/foamed/fragment/other), maximum length (microplastics: 1–5 mm/mesoplastics: 5–20 mm/macropastics: 20–100 mm), and colour (off/white-clear/grey-silver/black/blue-purple/green/orange-brown/red-pink/yellow). For each species, the percentage Frequency of Occurrence (FO – proportion of individuals having ingested plastic debris) was reported along with Jeffrey's 95% credible interval, and the average number and mass of plastic items per specimen (with standard error and deviation, including zeros) were calculated. These estimates were further assessed for two separate age classes: adult specimens (autonomous feeding) and chicks/fledglings (parental feeding).

Table 2

Occurrence and characteristics of plastics ingested by Tahiti Petrel specimens (*Pseudobulweria rostrata*, n = 6), by category. CI: Jeffrey's credible interval. Means, medians & ranges include all sampled individuals.

	Frequency of occurrence (%; 95% CI)	Number of plastic items			Mass of plastic items		
		Mean (n; \pm sd; \pm se)	Median	Range	Mean (g, \pm sd, \pm se)	Median	Range
Global	33.33 (7.68; 71.36)	0.50 (\pm 0.84; \pm 0.42)	0	0–4	0.0020 (\pm 0.0036; \pm 0.0018)	0	0–0.009
User	33.33 (7.68; 71.36)	0.50 (\pm 0.84; \pm 0.42)	0	0–4	0.0020 (\pm 0.0036; \pm 0.0018)	0	0–0.009
Industrial	0 (0; 33.04)	0	0	0	0	0	0
Sheetlike	16.67 (1.86; 55.81)	0.17 (\pm 0.41; \pm 0.20)	0	0–1	0.0005 (\pm 0.0012; \pm 0.0006)	0	0–0.003
Threadlike	33.33 (7.68; 71.36)	0.33 (\pm 0.52; \pm 0.26)	0	0–3	0.0015 (\pm 0.0037; \pm 0.0018)	0	0–0.009
Foam	0 (0; 33.04)	0	0	0	0	0	0
Fragment	0 (0; 33.04)	0	0	0	0	0	0
Other	0 (0; 33.04)	0	0	0	0	0	0

All statistical analyses were conducted using R. 3.6.0.

Plastic debris were found in stomach contents of 13 birds out of the 90 examined (FO = 14.4%). All three procellariid species had ingested plastic items: Gould's Petrel (average of 1.12 ± 0.37 plastic items per specimen), Tahiti Petrel (0.5 ± 0.42) and Wedge-tailed Shearwater (0.12 ± 0.06) (Tables 1 to 3, mean \pm standard error). Individuals from non-procellariid species (n = 15) showed no sign of plastic ingestion. Percentage FO was significantly higher for Gould's Petrel than for Wedge-tailed Shearwater specimens (41.18% vs 7.69% respectively, pairwise proportion test: $P < 0.001$). FO estimate for Tahiti Petrel yielded an intermediate value (33.33%) but did not differ significantly from the other two species, likely due to small sample size (six specimens only, $P > 0.05$). Additionally, FO estimates did not vary significantly between chicks/fledglings and adults for all three species ($P > 0.05$), thus indicating indirect transmission of plastic litter through regurgitation.

All debris were categorized as user plastics, with a majority of fragment and thread-like items (Tables 1 to 3). Microplastics were the most represented size range, followed by meso- and macropastics (Table 4). Off/white-clear was the most abundant colour among ingested items (53.6% - Table 4). Due to small sample size, no colour-based selection of ingested plastics across species could be firmly demonstrated. Only black and off/white-clear items were retrieved in Tahiti Petrels and Wedge-tailed Shearwaters, while debris found in Gould's Petrels exhibited more diverse colours (off/white-clear/black/blue-purple/green/yellow).

Risks of plastic ingestion exist for all groups of seabird species but they are most severe in procellariiforms (Ryan, 1987; Thiel et al., 2018; Roman et al., 2019a). Their high vulnerability toward plastic ingestion is generally associated with their pelagic foraging (van Franeker and Law, 2015; Tavares et al., 2017), surface feeding behaviour (Roman et al., 2016) and sensitivity to olfactory cues mimicked by decaying debris (Savoca et al., 2016; Savoca, 2018). Our findings are coherent with these expectations, as ingested plastics were exclusively found in procellariid species in this study. Intraspecific differences in plastic occurrence (Table 5) may account for differences in diet selectivity

Table 3

Occurrence and characteristics of plastics ingested by Wedge-tailed Shearwater specimens (*Ardenna pacifica*, n = 52), by category. CI: Jeffrey's credible interval. Means, medians & ranges include all sampled individuals. *mass < 0.0001 g.

	Frequency of occurrence (%; 95% CI)	Number of plastic items			Mass of plastic items		
		Mean (n, \pm sd; \pm se)	Median	Range	Mean (n, \pm sd, \pm se)	Median	Range
Global	7.69 (2.65; 17.25)	0.12 (\pm 0.43; \pm 0.06)	0	0–2	0.0007 (\pm 0.0038; \pm 0.0005)	0	0–0.0239
User	7.69 (2.65; 17.25)	0.12 (\pm 0.43; \pm 0.06)	0	0–2	0.0007 (\pm 0.0038; \pm 0.0005)	0	0–0.0239
Industrial	0 (0; 4.69)	0	0	0	0	0	0
Sheetlike	0 (0; 4.69)	0	0	0	0	0	0
Threadlike	1.92 (0.21; 8.63)	0.04 (\pm 0.27; \pm 0.04)	0	0–2	0*	0	0*
Foam	0 (0; 4.69)	0	0	0	0	0	0
Fragment	5.77 (1.65; 14.60)	0.08 (\pm 0.33; \pm 0.05)	0	0–2	0.0007 (\pm 0.0038; \pm 0.0005)	0	0–0.0239
Other	0 (0; 4.69)	0	0	0	0	0	0

Table 4

Size and colour characteristics of plastic debris ingested by three procellariid species.

Species	Plastic size category (%)			Plastic colour (%)				
	Microplastics (1–5 mm)	Mesoplastics (5–20 mm)	Macroplastics (20–100 mm)	Off/White-clear	Black	Blue-purple	Green	Yellow
All	60.71	32.14	7.14	53.57	14.29	17.86	10.71	3.57
Gould's Petrel	73.68	21.05	5.26	47.37	5.26	26.32	15.79	5.26
Tahiti Petrel	0	66.67	33.33	100	0	0	0	0
Wedge-tailed Shearwater	50	50	0	50	50	0	0	0

and/or existence of separate foraging areas (Ainley et al., 1989; Roman et al., 2019a).

We found few previous records of plastic ingestion for Gould's Petrel and Tahiti Petrel in the tropical Pacific (Spear et al., 1995; Roman et al., 2016) and only one study mentioned the precise localisation of sampled specimens (Roman et al., 2016) (Table 5). In the latter, FO estimates of plastic ingestion were evaluated using only one specimen of Tahiti Petrel (FO = 0%) and two specimens of Gould's Petrel (FO = 100%), thus giving poor statistical support to the comparison of ingestion risks across geographic regions. Conversely, plastic ingestion by Wedge-tailed Shearwaters has been more documented in recent years (Hutton

et al., 2008; Gilbert et al., 2016; Kain et al., 2016; Lavers et al., 2018; Roman et al., 2019a). For either chick/fledglings or adults, our results showed the lowest FO estimates of plastic ingestion as well as the least number of ingested particles per specimen when compared to previously published data on necropsied birds in the tropical Pacific (Table 5). The risk of plastic ingestion may therefore be smaller for New-Caledonia Shearwaters, likely due to plastic debris being less abundant in neighbouring foraging areas (Sebillé et al., 2015; Roman et al., 2019a).

To our knowledge, only one study mentions positive plastic ingestion records in some of the other, non-procellariid species that were

Table 5

Summary of post-2000 plastic ingestion studies (necropsy-based) in the tropical Pacific area for adults (A) and chicks/fledglings (F) of three procellariid species: Wedge-tailed Shearwater, Gould's Petrel and Tahiti Petrel.

Year	Location	Age	n	FO	Mean # of pieces \pm sd	Range	Mean mass \pm sd (mg) ^a	Range (mg) ^a	Source
Wedge-tailed Shearwater									
2005	Lord Howe Is., Australia	F	22	13.6					Hutton et al. (2008)
2006–2013	Tern Island, USA	All	4	75.0					Rapp et al. (2017)
2011–2012	Southeastern Australia	F	2	50.0	1	0–2	13.8	0–27.5	Gilbert et al. (2016)
2011–2014	Kaua'i, USA	All	32	56.3	3.11	0–40			Kain et al. (2016)
2011–2013	Kaua'i, USA	F	13	76.9	2.38 \pm 1.94	0–31	30.0 \pm 30.0	0–130.0	Kain et al. (2016)
2011–2014	Kaua'i, USA	A	19	42.1	3.68 \pm 9.29	0–40			Kain et al. (2016)
2013–2018	Lord Howe Is., Australia	F	65	44.6	1.08	0–9	113.0	0–1410.0	Lavers et al. (2018)
2013	Eastern Australia	ND	28	14.3	0.46				Roman et al. (2016)
2015–2018	New Caledonia	All	52	7.7	0.12 \pm 0.43	0–2	0.7 \pm 3.8	0–23.9	This study
2015–2018	New Caledonia	F	18	11.1	0.17 \pm 0.51	0–2	< 0.1	0–0.5	This study
2015–2018	New Caledonia	A	34	5.9	0.09 \pm 0.38	0–2	1.1 \pm 4.7	0–23.9	This study
Gould's Petrel									
2013	Eastern Australia	ND	2	100.0	1.5	1–2			Roman et al. (2016)
2015–2018	New Caledonia	All	17	41.2	1.12 \pm 1.54	0–4	1.8 \pm 2.4	0–7.8	This study
2015–2018	New Caledonia	F	3	66.7	2 \pm 2	0–4	4.7 \pm 4.1	0–7.8	This study
2015–2018	New Caledonia	A	14	35.7	0.93 \pm 1.44	0–4	1.1 \pm 1.6	0–4.1	This study
Tahiti Petrel									
2013	Eastern Australia	ND	1	0.0			0		Roman et al. (2016)
2015–2018	New Caledonia	All	6	33.3	0.5 \pm 0.84	0–2	2.0 \pm 3.6	0–9	This study
2015–2018	New Caledonia	F	1	0.0	0		0		This study
2015–2018	New Caledonia	A	5	40.0	0.6 \pm 0.89	0–2	2.4 \pm 3.9	0–9	This study

Data from the current study converted to italic font.

FO: percentage Frequency of Occurrence (%); ND: No available data.

^a To allow for easier comparison between studies (i.e. high vs low levels of plastic ingestion), mass of plastic debris is reported in milligrams (mg).

sampled: a specimen of Brown Noddy and one of Red-footed Booby were found to have ingested plastic on Tern Island, Hawaii during the 2006–2013 period (out of 18 and 19 necropsied birds respectively) (Rapp et al., 2017). Since most of these sampled taxa are coastal foragers, they are likely less exposed to ingestion risks from pelagic pollution than procellariids (Thiel et al., 2018).

It should be noted that post-mortem examination of stomach content does not account for all ingested plastics: debris can be partially regurgitated to chicks (Ryan, 1988; Carey, 2011) or excreted to some extent (Ryan, 2015; Provencher et al., 2018). Additionally, the detection of ultrafine/nanoplastics requires more precise detection methods (Provencher et al., 2017; O'Hanlon et al., 2017). Exposure to ingestion risk is thus usually under-evaluated.

Further developments of this work include (1) aggregation of more ingestion data through future specimen collection; (2) analysis of local foraging patterns and (3) assessment of temporal trends of plastic ingestion (long-term study).

CRediT authorship contribution statement

Tristan Berr: Conceptualization, Validation, Resources, Formal analysis, Data curation, Writing - original draft, Writing - review & editing. **Jeanne Naudet:** Methodology, Investigation, Writing - original draft. **Cynthia Lagourgue:** Methodology, Investigation, Formal analysis, Data curation. **Kiara Vuibert:** Investigation. **Karen Bourgeois:** Conceptualization. **Éric Vidal:** Conceptualization, Resources, Supervision, Project administration.

Declaration of competing interest

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

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References

Ainley, D.G., Spear, L.B., Beach, S., 1989. The incidence of plastic in the diets of pelagic seabirds in the Eastern Equatorial Pacific region. In: Shomura, R.S., Godfrey, M.L. (Eds.), Presented at the Second International Conference on Marine Debris, pp. 12 Honolulu, Hawaii.

Auman, H.J., Ludwig, J.P., Giesy, J.P., 1998. Plastic ingestion by Laysan Albatross chicks on Sand Island, Midway Atoll, in 1994 and 1995. In: Albatross Biology and Conservation. Roberston, Graham and Rosemary Gales.

Avery-Gomm, S., Borrelle, S.B., Provencher, J.F., 2018. Linking plastic ingestion research with marine wildlife conservation. *Sci. Total Environ.* 637–638, 1492–1495. <https://doi.org/10.1016/j.scitotenv.2018.04.409>.

Azzarello, M., Van Vleet, E., 1987. Marine birds and plastic pollution. *Mar. Ecol. Prog. Ser.* 37, 295–303. <https://doi.org/10.3354/meps037295>.

Barnes, D.K.A., Galgani, F., Thompson, R.C., Barlaz, M., 2009. Accumulation and fragmentation of plastic debris in global environments. *Philos. Trans. R. Soc. Lond. Ser. B Biol. Sci.* 364, 1985–1998. <https://doi.org/10.1098/rstb.2008.0205>.

Basto, M.N., Nicastro, K.R., Tavares, A.I., McQuaid, C.D., Casero, M., Azevedo, F., Zardi, G.I., 2019. Plastic ingestion in aquatic birds in Portugal. *Mar. Pollut. Bull.* 138, 19–24. <https://doi.org/10.1016/j.marpolbul.2018.11.024>.

Baudat-Franceschi, J., Spaggiari, J., Barré, N., 2008. Oiseaux Nicheurs d'Intérêt Pour la Conservation. In: A Rapid Marine Biodiversity Assessment of the Coral Reefs of the

Northwest Lagoon, Between Koumac and Yandé, Province Nord, New Caledonia, RAP Bulletin of Biological Assessment. Conservation International, pp. 136–142. <https://doi.org/10.1896/054.053.0114>.

Benoit, M.P., Bretagnolle, V., 2002. Seabirds of the Southern Lagoon of New Caledonia; distribution, abundance and threats. *Waterbirds* 25, 202–213.

Carey, M.J., 2011. Intergenerational transfer of plastic debris by Short-tailed Shearwaters (*Ardenna tenuirostris*). *Emu - Austral Ornithology* 111, 229–234. <https://doi.org/10.1071/MU10085>.

Derraik, J.G.B., 2002. The pollution of the marine environment by plastic debris: a review. *Mar. Pollut. Bull.* 44, 842–852. [https://doi.org/10.1016/S0025-326X\(02\)00220-5](https://doi.org/10.1016/S0025-326X(02)00220-5).

Eriksen, M., Lebreton, L.C.M., Carson, H.S., Thiel, M., Moore, C.J., Borroro, J.C., Galgani, F., Ryan, P.G., Reisser, J., 2014. Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. *PLoS One* 9, e111913. <https://doi.org/10.1371/journal.pone.0111913>.

van Franeker, J.A., Law, K.L., 2015. Seabirds, gyres and global trends in plastic pollution. *Environ. Pollut.* 203, 89–96. <https://doi.org/10.1016/j.envpol.2015.02.034>.

Gall, S.C., Thompson, R.C., 2015. The impact of debris on marine life. *Mar. Pollut. Bull.* 92, 170–179. <https://doi.org/10.1016/j.marpolbul.2014.12.041>.

Gilbert, J.M., Reichelt-Brushett, A.J., Bowling, A.C., Christidis, L., 2016. Plastic ingestion in marine and coastal bird species of southeastern Australia. *Mar. Ornithol.* 44, 21–26.

Gregory, M.R., 2009. Environmental implications of plastic debris in marine settings—entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. *Philosophical Transactions of the Royal Society B: Biological Sciences* 364, 2013–2025. <https://doi.org/10.1098/rstb.2008.0265>.

Hutton, I., Carlile, N., Priddel, D., 2008. Plastic ingestion by Flesh-footed Shearwaters, Puffinus carneipes, and Wedge-tailed Shearwaters, Puffinus pacificus. *Pap. Proc. R. Soc. Tasmania* 142, 67–72. <https://doi.org/10.26749/rstpp.142.1.67>.

IUCN, 2019. The IUCN Red List of Threatened Species. Version 2019-3. <http://www.iucnredlist.org>.

Kain, E.C., Lavers, J.L., Berg, C.J., Raine, A.F., Bond, A.L., 2016. Plastic ingestion by Newell's (Puffinus newelli) and wedge-tailed shearwaters (*Ardenna pacifica*) in Hawaii. *Environ. Sci. Pollut. Res.* 23, 23951–23958. <https://doi.org/10.1007/s11356-016-7613-1>.

Kühn, S., Bravo Rebolledo, E.L., van Franeker, J.A., 2015. Deleterious effects of litter on marine life. In: Bergmann, M., Gutow, L., Klages, M. (Eds.), *Marine Anthropogenic Litter*. Springer International Publishing, Cham, pp. 75–116. https://doi.org/10.1007/978-3-319-16510-3_4.

Lavers, J.L., Hutton, I., Bond, A.L., 2018. Ingestion of marine debris by Wedge-tailed Shearwaters (*Ardenna pacifica*) on Lord Howe Island, Australia during 2005–2018. *Mar. Pollut. Bull.* 133, 616–621. <https://doi.org/10.1016/j.marpolbul.2018.06.023>.

Lusher, A.L., Welden, N.A., Sobral, P., Cole, M., 2017. Sampling, isolating and identifying microplastics ingested by fish and invertebrates. *Anal. Methods* 9, 1346–1360. <https://doi.org/10.1039/C6AY02415G>.

O'Hanlon, N.J., James, N.A., Masden, E.A., Bond, A.L., 2017. Seabirds and marine plastic debris in the northeastern Atlantic: a synthesis and recommendations for monitoring and research. *Environ. Pollut.* 231, 1291–1301. <https://doi.org/10.1016/j.envpol.2017.08.101>.

Palmas, P., Jourdan, H., Rigault, F., Debar, L., De Meringo, H., Bourguet, E., Mathivet, M., Lee, M., Adjouhgniope, R., Papillon, Y., Bonnaud, E., Vidal, E., 2017. Feral cats threaten the outstanding endemic fauna of the New Caledonia biodiversity hotspot. *Biol. Conserv.* 214, 250–259. <https://doi.org/10.1016/j.biocon.2017.08.003>.

F. Provencher, J., L. Bond, A., Avery-Gomm, S., B. Borrelle, S., Rebolledo, E.L.B., Hammer, S., Kühn, S., L. Lavers, J., L. Mallory, M., Trevail, A., van Franeker, J.A., 2017. Quantifying ingested debris in marine megafauna: a review and recommendations for standardization. *Anal. Methods* 9, 1454–1469. doi:<https://doi.org/10.1039/C6AY02419J>.

Provencher, J.F., Vermaire, J.C., Avery-Gomm, S., Braune, B.M., Mallory, M.L., 2018. Garbage in guano? Microplastic debris found in faecal precursors of seabirds known to ingest plastics. *Sci. Total Environ.* 644, 1477–1484. <https://doi.org/10.1016/j.scitotenv.2018.07.101>.

Rapp, D.C., Youngren, S.M., Hartzell, P.L., Hyrenbach, K.D., 2017. Community-wide patterns of plastic ingestion in seabirds breeding at French Frigate Shoals, Northwestern Hawaiian Islands. *Mar. Pollut. Bull.* 123, 269–278. <https://doi.org/10.1016/j.marpolbul.2017.08.047>.

Roman, L., Schuyler, Q.A., Hardesty, B.D., Townsend, K.A., 2016. Anthropogenic debris ingestion by avifauna in eastern Australia. *PLoS One* 11. <https://doi.org/10.1371/journal.pone.0158343>.

Roman, L., Bell, E., Wilcox, C., Hardesty, B.D., Hindell, M., 2019a. Ecological drivers of marine debris ingestion in Procellariiform Seabirds. *Sci. Rep.* 9, 916. <https://doi.org/10.1038/s41598-018-37324-w>.

Roman, L., Hardesty, B.D., Hindell, M.A., Wilcox, C., 2019b. A quantitative analysis linking seabird mortality and marine debris ingestion. *Sci. Rep.* 9, 3202. <https://doi.org/10.1038/s41598-018-36585-9>.

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

Ryan, P.G., 1988. Intraspecific variation in plastic ingestion by seabirds and the flux of plastic through seabird populations. *Condor* 90, 446–452. <https://doi.org/10.2307/1368572>.

Ryan, P.G., 2015. How quickly do albatrosses and petrels digest plastic particles? *Environ. Pollut.* 207, 438–440. <https://doi.org/10.1016/j.envpol.2015.08.005>.

Savoca, M., 2018. The ecology of an olfactory trap. *Science* 362, 904–A. <https://doi.org/10.1126/science.aav6873>.

Savoca, M.S., Wohlfeil, M.E., Ebeler, S.E., Nevitt, G.A., 2016. Marine plastic debris emits a

- keystone infochemical for olfactory foraging seabirds. *Sci. Adv.* 2, e1600395. <https://doi.org/10.1126/sciadv.1600395>.
- Sebillé, E. van, Wilcox, C., Lebreton, L., Maximenko, N., Hardesty, B.D., Franeker, J.A. van, Eriksen, M., Siegel, D., Galgani, F., Law, K.L., 2015. A global inventory of small floating plastic debris. *Environ. Res. Lett.* 10, 124006. <https://doi.org/10.1088/1748-9326/10/12/124006>.
- Sileo, L., Sievert, P.R., Samuel, M.D., 1990. In: Shomura, R.S., Godfrey, M.L. (Eds.), *Prevalence and Characteristics of Plastic Ingested by Hawaiian Seabirds*. US Department of Commerce, Honolulu, Hawaii.
- Spaggiari, J., Barré, N., Baudat-Franceschi, J., Borsa, P., Colin, F., 2006. *New Caledonian seabirds*. In: Payri, C., Richer de Forges, B. (Eds.), *Compendium of Marine Species From New Caledonia, Documents Scientifiques et Techniques*. IRD, Nouméa, pp. 371–384.
- Spear, L.B., Ainley, D.G., Ribic, C.A., 1995. Incidence of plastic in seabirds from the tropical Pacific, 1984–1991: relation with distribution of species, sex, age, season, year and body weight. *Mar. Environ. Res.* 40, 123–146. [https://doi.org/10.1016/0141-1136\(94\)00140-K](https://doi.org/10.1016/0141-1136(94)00140-K).
- Tanaka, K., Takada, H., Yamashita, R., Mizukawa, K., Fukuwaka, M., Watanuki, Y., 2013. Accumulation of plastic-derived chemicals in tissues of seabirds ingesting marine plastics. *Mar. Pollut. Bull.* 69, 219–222. <https://doi.org/10.1016/j.marpolbul.2012.12.010>.
- Tanaka, K., Takada, H., Yamashita, R., Mizukawa, K., Fukuwaka, M., Watanuki, Y., 2015. Facilitated leaching of additive-derived PBDEs from plastic by seabirds' stomach oil and accumulation in tissues. *Environ. Sci. Technol.* 49, 11799–11807. <https://doi.org/10.1021/acs.est.5b01376>.
- Tavares, D.C., de Moura, J.F., Merico, A., Siciliano, S., 2017. Incidence of marine debris in seabirds feeding at different water depths. *Mar. Pollut. Bull.* 119, 68–73. <https://doi.org/10.1016/j.marpolbul.2017.04.012>.
- Thiel, M., Luna-Jorquera, G., Álvarez-Varas, R., Gallardo, C., Hinojosa, I.A., Luna, N., Miranda-Urbina, D., Morales, N., Ory, N., Pacheco, A.S., Portflitt-Toro, M., Zavalaga, C., 2018. Impacts of marine plastic pollution from continental coasts to subtropical gyres—fish, seabirds, and other vertebrates in the SE Pacific. *Front. Mar. Sci.* 5 (238). <https://doi.org/10.3389/fmars.2018.00238>.
- Van Franeker, J.A., Meijboom, A., 2002. Litter NSV; marine litter monitoring by northern fulmars (a pilot study). *Alterra-rapport*(401).
- Votier, S.C., Archibald, K., Morgan, G., Morgan, L., 2011. The use of plastic debris as nesting material by a colonial seabird and associated entanglement mortality. *Mar. Pollut. Bull.* 62, 168–172. <https://doi.org/10.1016/j.marpolbul.2010.11.009>.
- Wilcox, C., Sebillé, E.V., Hardesty, B.D., 2015. Threat of plastic pollution to seabirds is global, pervasive, and increasing. *PNAS* 112, 11899–11904. <https://doi.org/10.1073/pnas.1502108112>.