WIRE INGESTION BY A RED-BILLED TROPICBIRD *PHAETHON AETHEREUS* CHICK ON SAN PEDRO MÁRTIR ISLAND, MEXICO

ALBERTO PIÑA-ORTIZ[1]*, VLADISLAV MARCUK[1], SALVADOR GÓMEZ-HERNÁNDEZ[2], JOSÉ ALFREDO CASTILLO-GUERRERO[2], & PETRA QUILLFELDT[1]

[1]*Department of Animal Ecology and Systematics, Justus Liebig University Giessen, Heinrich-Buff-Ring 26, 35392, Giessen, Germany*
**(Alberto.Pina-Ortiz@bio.uni-giessen.de)*
[2]*Departamento de Estudios para el Desarrollo Sustentable de la Zona Costera, Centro Universitario de la Costa Sur, Universidad de Guadalajara, Gómez Farías 82, San Patricio-Melaque, Municipio de Cihuatlán, Jalisco, 48980, Mexico*

Received 22 July 2024, accepted 30 August 2024

ABSTRACT

Piña-Ortiz, A., Marcuk, V., Gómez-Hernández, S., Castillo-Guerrero, J. A., & Quillfeldt, P. (2025). Wire ingestion by a Red-billed Tropicbird *Phaethon aethereus* chick on San Pedro Mártir Island, Mexico. *Marine Ornithology, 53*(1), 71–78. http://doi.org/10.5038/2074-1235.53.1.1615

We report the ingestion of wire by a Red-billed Tropicbird *Phaethon aethereus* chick at San Pedro Mártir Island, Gulf of California, Mexico. A scat sample collected from a four- to five-week-old chick contained a copper wire ~5.0 mm in length. Biologging revealed the previous foraging trips by one of the parents, and we ascertained the diet of birds in this colony through a molecular approach. From these data, we suggest why this individual was fed wire.

Key words: marine debris, Gulf of California, secondary ingestion, Red-billed Tropicbird, wire ingestion

RESÚMEN

Reportamos la ingestión de un alambre por un polluelo de Rabijunco Pico Rojo *Phaethon aethereus* en la Isla San Pedro Mártir, Golfo de California, México. Una excreta colectada de un polluelo de 4–5 semanas contenía un alambre de cobre de ~5.0 mm de longitud. Se registraron los viajes de forrajeo previos de uno de los progenitores y, mediante un enfoque molecular, determinamos la dieta de las aves de esta colonia. A partir de estos datos sugerimos como este individuo pudo ingerir el alambre.

Palabras clave: detrito marino, Golfo de California, ingestión secundaria, Rabijunco Pico Rojo, ingestión de alambre

INTRODUCTION

Despite significant efforts in recent decades to counteract the increasing pollution and deposition of non-degradable waste in the ocean (Kibria et al., 2023; Schmaltz et al., 2020; Wang et al., 2021; Willis et al., 2022), factors such as high consumption of disposable products, poor regional or local waste disposal control, and weak law enforcement have contributed to the rise of pollutants entering the ocean (Ostle et al., 2019; Sindermann, 1995). The cumulative effects of pollution are a major concern, necessitating an investigation into the impacts on the ecological functionality of marine ecosystems as well as the ecological and physiological consequences for marine wildlife (Cisneros-Montemayor et al., 2019; Sindermann, 1995).

According to the National Oceanic and Atmospheric Administration (NOAA), marine debris is defined as "any persistent solid material that is manufactured or processed directly or indirectly by anthropogenic activity and disposed or entering intentionally or unintentionally into marine or freshwater ecosystems" (NOAA, 2024). Marine debris ingestion has been documented in diverse marine wildlife, including invertebrates, fish, seabirds, sea turtles, and marine mammals (Laist, 1997; Nunes et al., 2021; Provencher et al., 2017; Ryan, 2016; Schuyler et al., 2014). In tropicbirds (family Phaethontidae), the ingestion of marine debris, particularly plastic, has been reported in all three species (Cartraud et al., 2019; Hyrenbach et al., 2013; Madden & Eggermont, 2020; Rapp et al., 2017; Robards, 1993; Sileo et al., 1990; Spear et al., 1995). There are no reports of any other kind of marine debris in tropicbirds.

The factors and pathways contributing to marine debris ingestion and accumulation in marine wildlife are not fully understood (Provencher et al., 2017). However, seabirds can acquire marine debris through direct or indirect ingestion or via the respiratory tract (see Hammer et al., 2016; Navarro et al., 2023; Tokunaga et al., 2023; Wayman et al., 2024). Additionally, environmental factors such as ocean currents, river discharge, wind, precipitation, and sediment processes, along with anthropogenic activities, increase the likelihood of debris ingestion or inhalation (Provencher et al., 2017; Su et al., 2022).

In this study, we report wire ingestion by a Red-billed Tropicbird chick on San Pedro Mártir Island, a protected insular ecosystem in the Gulf of California. This island hosts one of the largest colonies of the species in the region, with 150 pairs (Piña-Ortiz et al., 2018; Tershy & Breese, 1997). In addition to reporting this event, we combined geospatial tracking data and information on the main prey categories—fish and cephalopods—for this colony using DNA metabarcoding analysis. This information suggests a pathway leading to wire ingestion by the chick.

METHODS

Observations

From February to May 2021, we visited San Pedro Mártir Island (28°22′52″N, 112°18′23″W), a 1.9-km^2 landmass in the Gulf of California located about 50 km east and west from the Mexican states of Baja California and Sonora, respectively (Tershy & Breese, 1997). A seabird monitoring program allowed us to study the foraging ecology of several species breeding on the island (Castillo-Guerrero et al., 2022). Our tasks included measuring and weighing birds, deploying Global Positioning System (GPS) devices, collecting blood samples, and gathering scats (n = 71). Scats were collected opportunistically from both adults and chicks to perform molecular diet analysis (DNA metabarcoding; see Marcuk et al., 2024). All these activities, including wildlife handling and sample collection, were conducted with permission from the Subsecretaria de Gestión para la Protección Ambiental (SGPA, Mexico) and the Dirección General de Vida Silvestre (DGVS, Mexico) under permit SGPA/DGVS/02779/21. We adhered to all applicable institutional (Universidad de Guadalajara, Mexico; Justus Liebig University, Germany) and national (Secretaria de Medio Ambiente y Recursos Naturales, Mexico) guidelines relating to wildlife welfare and conservation.

On 17 March 2021, we focused our field activities on Punta Rabijunco in the northeast of the island, the area with the highest nesting density for Red-billed Tropicbirds. In one nest cavity, we found a single adult and a four- to five-week-old chick. The adult was ringed, and a GPS tag (CatLog-S2; Perthold Engineering LLC; Dallas, USA) was attached using TESA® tape (Norderstedt, Germany) to the tops of four to five central rectrices directly below the uropygial gland. The total weight of the GPS tag, including the tape (12–13 g), was ~1.9% of the adult's body mass (635 g), which is below the recommended threshold (< 3% of body weight; Vandenabeele et al., 2012; Wilson & McMahon, 2006). Five days after deploying the GPS tracker, we revisited the nest and recovered the device. During the handling process, we collected a scat sample from the chick in a 1.5-ml plastic tube and preserved it via suspension in absolute ethanol (99.5% purity; J.T. Baker®). The sample was initially stored in a portable freezer (−2 °C; GoSun®; Cincinnati, USA) in the field and later frozen in the laboratory at −20 °C for further analysis.

Analysis of GPS tracking data

We employed the same methodology used by Piña-Ortiz et al. (2024). GPS tracking data obtained from the bird were visually reviewed using the software CatLog_Data-viewer (version 1.0, Catnip Technologies, Ltd.; Hong King, China), with anomalous trajectories and ground-level fixes removed. Fixes indicating an average speed exceeding 80 km/h, the species' flight speed threshold, were discarded. Foraging parameters were determined in R (version 4.3.1; R Core Team, 2023) with RStudio version 2023.06.1 + 524 'Mountain Hydrangea' (RStudio Team, 2023) using the *tripSplit* function of the "track2KBA" package (Beal et al., 2021). This function enabled us to divide the individual's GPS trajectories into multiple foraging trips, separated by the bird's return to the colony. For each foraging trip, we calculated the maximum linear distance from the colony, total trip duration, and total distance travelled. Incomplete foraging trips (those that could not be fully tracked before the individual's return to the colony) were discarded. To ensure accurate partitioning of individual foraging trips and to ensure subsequent trips by burrow-nesting species were not mistakenly grouped as a single trip, we applied a 1.5-km radius filter around the colony to identify arrivals to the colony as the endpoint of a trip (Beal et al., 2021).

DNA analysis of feces

The DNA metabarcoding analysis methods for feces are described in detail by Marcuk et al. (2024). Briefly, DNA isolation and library preparation were conducted using the Qiagen Fast DNA Stool Mini Kit (Qiagen; Hilden, Germany). For prey identification at the family level, we employed a metazoan cytochrome oxidase I (COI) primer set during polymerase chain reaction (PCR) amplifications (Leray et al., 2013). Additionally, two specific 16S rDNA primer pairs (Berry et al., 2017; Waap, 2015) were used to identify the main prey categories—fish and cephalopods—based on prior knowledge of the species' diet. The PCR reaction was set up with a 20 µL volume, including 10 µL Qiagen Multiplex PCR Buffer, primers, and a DNA template. A touchdown PCR protocol was used to optimize amplification, with products below 0.5 ng/µL being re-amplified. The resulting amplicons were purified using the illustra™ ExoProStar™ 1-Step kit (Cytiva; Amersham, UK), pooled, and prepared for Illumina sequencing using the Nextera XT DNA Library Preparation Kit (Illumina; San Diego, USA). Final sequencing was performed on an Illumina MiSeq desktop sequencer with 250-basepair (bp) paired-end reads.

To obtain a list of molecular operational taxonomic units (MOTUs), we employed a custom workflow (Masello et al., 2021) in GALAXY (Galaxy Community, 2022). MOTU sequences were matched to reference sequences in the National Center for Biotechnology Information (NCBI) GenBank nucleotide database using the Basic Local Alignment Search Tool algorithm for nucleotides (BLASTn), with a cut-off of 90% minimum sequence identity and a maximum e-value of 0.00001 (Altschul et al., 1990). Taxonomic assignments were made based on the percentage similarity between query and reference sequences, retaining BLASTn assignments with greater than 98% similarity and a minimum sequence length of 190 bp (Deagle et al., 2009; Vesterinen et al., 2013). MOTUs were assigned to the species level only when all retained hits corresponded to the same species. Otherwise, assignments were made to the lowest shared taxonomic level, such as genus or family.

The raw dataset included various unspecific or contaminant DNA sequences, such as human and bacterial DNA, which were excluded from potential prey taxa based on previous literature (Almaguer-Hernández, 2016; Castillo-Guerrero et al., 2011; Diop et al., 2018; Madden et al., 2022, 2023; Nelson, 2006; Stonehouse, 1962). Non-prey MOTUs, including taxa from the orders Insecta, Reptilia, and Aves, were omitted during validation as they were either ecologically irrelevant or had distant distribution ranges. Following the approach of Masello et al. (2021), our analysis excluded records with fewer than 10 reads and those in singular MOTUs where the read number accounted for less than 1% of the maximum count.

To analyze the dietary composition of the two main prey groups—fish and cephalopods—we calculated both the frequency of occurrence (FO) and the relative read abundance (RRA). The RRA was used to complement the interpretation of FO (Barrett et al., 2007; McInnes et al., 2017; Young et al., 2020). The FO was determined using the following formula:

$$FO = \left(\frac{n}{t}\right) \times 100$$

where n represents the number of samples in which prey DNA was detected and t is the total number of samples where DNA from the considered prey group was present.

The RRA was calculated with the formula:

$$RRA = \left(\frac{\text{number of reads for a specific prey MOTU}}{\text{total number of reads for all prey MOTUs}}\right) \times 100$$

This represents the percentage ratio of reads in relation to the total number of reads recorded for the respective MOTU. By using both FO and RRA, we aimed to provide a more comprehensive understanding of the prey composition in the diet of the studied species.

RESULTS

Further examination of the feces sample collected from the chicks revealed a copper wire fragment compressed into a circular shape. The extracted wire was 0.3 mm thick and had a maximum deformed diameter of 2.7 mm. When fully extended, it measured 4.9 mm in length (Fig. 1).

The wire was noticed during sample collection, and a routine visual assessment of the chick immediately after confirmed no bleeding or external injuries. Its body mass was consistent with that of other chicks of the same age (620 g vs. 614 ± 37.3 g (mean ± standard error); n = 12), suggesting that the chick was in average body condition. No other plastic debris or wire fragments were present near or inside the nest cavity. Subsequent visits to assess the breeding success of the active nests in this area allowed us to confirm that the chick reached a fledgling age of 89 days (Nelson, 2006; Stonehouse, 1962) and departed the nest around mid-May 2021.

GPS tracking showed that the female parent made six foraging trips during the five days of tag deployment. Foraging trips occurred in two directions, to the northeast and southeast (Table 1, Fig. 2).

Regarding the diet analysis, DNA metabarcoding showed that Red-billed Tropicbirds at this colony prey predominately on fish (FO = 100%), followed by cephalopods (FO = 6.5%). An unidentified mackerel species *Scomber* sp. and Pacific chub mackerel *Scomber japonicus* (Scombridae; FO = 32.3% and FO = 12.9%, respectively), California anchovy *Engraulis mordax* (Engraulidae, FO = 45.2%), and South American pilchard *Sardinops sagax* (Clupeidae, FO = 22.6%) contributed the most frequently in the scat samples (n = 31). Otherwise, the RRA for fish prey families included Atherinopsidae (RRA = 45.3%), Scombridae (RRA = 21.7%), and Engraulidae (RRA = 12.9%; Table 2).

DISCUSSION

This study reports the ingestion of a section of copper wire by a Red-billed Tropicbird chick. A single previous report of marine debris ingestion by a Red-billed Tropicbird had included only plastic, and that was in a five- to six-week-old chick at St. Eustatius Island in the Caribbean (Madden & Eggermont, 2020). Plastic ingestion by marine wildlife has been widely reported (Laist, 1997; Ryan, 2016). Ingestion of wire, however, has been rarely documented, though there are some records in such seabirds as Black-browed Albatross *Thalassarche melanophris* (Petry et al., 2007), Kelp Gull *Larus dominicanus* (Yorio et al., 2020), Common Eider *Somateria mollissima* (Holland et al., 2016), Northern Fulmar *Fulmarus glacialis* (van Franeker & Meijboom, 2002); as well as Australian Pelican *Pelecanus conspicillatus*, Fairy Prion *Pachyptila turtur*, Slender-billed Prion *Pachyptila belcheri*, Fluttering Shearwater *Puffinus gavia*, Little Shearwater *Puffinus assimilis*, Short-tailed Shearwater *Ardenna tenuirostris*, Westland Petrel *Procellaria westlandica*, Little Black Cormorant *Phalacrocorax sulcirostris*, and Australian Pied Cormorant *Phalacrocorax varius* (Roman et al., 2016). It should be noted that Roman et al., grouped marine debris such as hooks and metal wires into "fishing" and "other" categories, respectively. Therefore, it is impossible to discriminate which species actually ingested this kind of metal debris.

The recorded diet spectrum indicated that fish represent the predominant prey for Red-billed Tropicbirds at San Pedro Mártir Island, which is consistent with prey preferences recorded for this species at other breeding colonies (Almaguer-Hernández, 2016; Castillo-Guerrero et al., 2011; Diop et al., 2018; Madden et al., 2022, 2023; Marcuk et al., 2024; Nelson, 2006). None of the prey previously cited or identified in this study resembles the characteristics of the wire fragment in size or color, which could rule out ingestion based on inappropriate prey recognition. As no traces of any other form of marine debris were found near or inside the nest cavity, direct ingestion by the adult or chick at the nest can be ruled out as a plausible origin.

The likely rational explanation is secondary ingestion of a prey item (probably a fish) swallowed by one of the parents and subsequently fed to the chick. All the main fish prey we detected obtain food by filter-feeding but switch to particulate feeding when prey densities are low (Castro-Hernández & Santana-Ortega, 2000; Hunter & Dorr, 1982; O'Connell & Zweifel, 1972; van der Lingen, 1994).

Fig. 1. Fragment of copper wire (4.9 mm long, 0.3 mm thick) obtained from the scat of a 4- to 5-week-old Red-billed Tropicbird *Phaethon aethereus* chick at San Pedro Mártir Island, Mexico.

TABLE 1
GPS tracking data for a single female Red-billed Tropicbird *Phaethon aethereus* on San Pedro Mártir Island, Mexico, during the 2021 breeding season. Data are summarized for six foraging trips over a five-day deployment.

	Median	Maximum	Minimum
Duration	9.1 h	42.7 h	2.4 h
Total distance	126.5 km	399.3 km	57.7 km
Maximum distance from colony	44.5 km	158.4 km	28.4 km

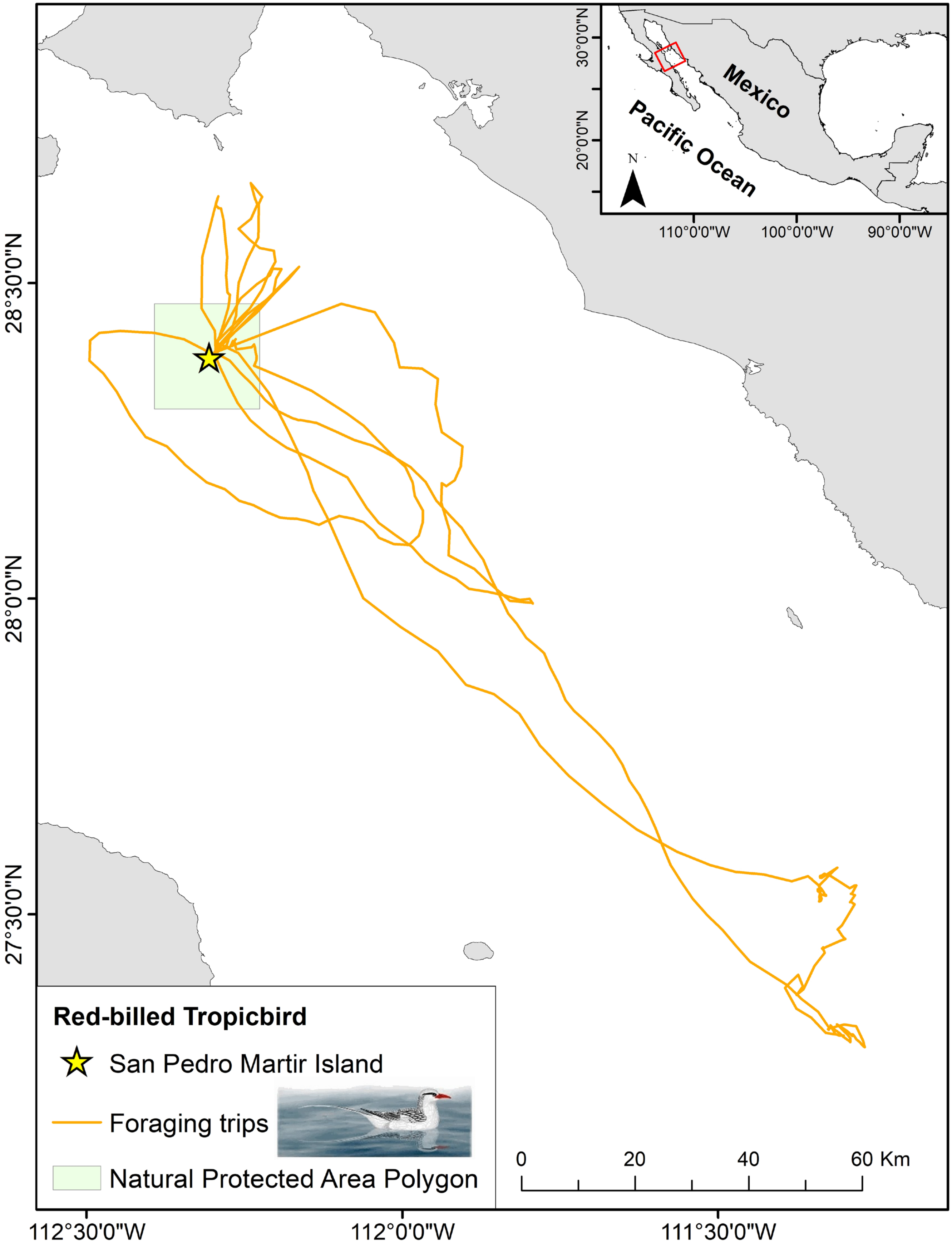

Fig. 2. Foraging trips made by the Red-billed Tropicbird *Phaethon aethereus* female parent from its nest on San Pedro Mártir Island, Mexico, prior to its chick excreting a wire fragment on 17 March 2021. The polygon of the Natural Protected Area is indicated in light green (Diario Oficial de la Federación, 2002).

TABLE 2
Summary of the frequency of occurrence (FO) and relative read abundance (RRA) of the dominant fish families in the prey of Red-billed Tropicbirds *Phaethon aethereus* on San Pedro Mártir Island, Mexico, during the 2021 breeding season.

Taxa	FO (% samples) *n* = 31	RRA (% reads) *n* = 51,679
OSTEICHTHYES		
Scombridae	45.2	21.7
Engraulidae	45.2	12.9
Carangidae	35.5	0.5
Clupeidae	32.3	5.2
Exocoetidae	29.0	7.1
Atherinopsidae	19.4	45.2
Clupeidae	12.9	5.2
Mullidae	9.7	2.1
Batrachoididae	9.7	0.9
Hemiramphidae	6.5	0.3

Food particle size is the prime determinant of the feeding mode (Louw et al., 1998). Based on size and buoyancy, most marine debris is found in the water column and is subject to water mass transport and mixing (Su et al., 2022). Therefore, in the case of copper wire, due to its length and weight, it is difficult to envision how it could enter the individual through filter-feeding. Some element of water mass dynamics could have been involved.

Adult foraging trips of the Red-billed Tropicbirds breeding on the study island overlapped with regional fisheries. All predominant fish prey taxa we found in the diet of the San Pedro Mártir birds are exploited by the fishing industry, like Pacific chub mackerel (Cisneros et al., 1990; Lo et al., 2010), Californian anchovy (Cisneros et al., 1990; Schwartzkopf et al., 2022; Velarde et al., 2013), and South American pilchard (Cisneros-Mata et al., 1995; Nevárez-Martínez et al., 2001; Velarde et al., 2013). Since 0.3-mm-thick copper wire is widely used in electrical wiring and in the operation of ship and small-boat engines, it is possible that a fragment from a vessel could be found floating in the ocean. That would support our hypothesis that the fragment was first ingested by a fish and then later by one of the tropicbird parents during a foraging trip.

As another possibility, ingestion of the wire could have come from baitfish. Sport fishermen often use small pieces of wire to secure bait, such as anchovies, ensuring that the fish remains on the hook while trolling. If bait is discarded with such a wire then consumed by an adult seabird during a foraging trip, the wire could have been incidentally ingested and subsequently fed to the chick. This possibility highlights the potential threats of fishing practices and their unintended impact on marine wildlife.

Considering the size of the wire fragment and the chick's subsequent development and assumed fledging, there appears to have been no consequent damage to the individual. However, in the absence of quantitative records that would allow more detailed interpretations of the direct and indirect risks of marine debris by these tropicbirds, no further assumptions or conclusions can be drawn regarding subsequent effects of ingestion.

The incidence of marine debris in the scat samples was considerably low (*ca*. 1.5%, 1 out of 71 samples). However, other approaches such as necroscopy or data from regurgitates could offer a better approximation of marine debris ingestion by these birds. Therefore, we suggest the establishment of a long-term monitoring scheme that includes the incidence of marine debris ingestion by seabirds in order to assess the level of impact of this threat on the health and breeding parameters of seabird populations in the Gulf of California.

ACKNOWLEDGMENTS

We thank Departamento de Estudios para el Desarrollo Sustentable de Zonas Costeras CUCSUR – Universidad de Guadalajara and Comisión Nacional de Áreas Naturales Protegidas (CONANP – Islas del Golfo de California – Reserva de la Biósfera Isla San Pedro Mártir) for logistical support in the field, specially J. Ventura-Trejo. We also thank Captain E. Ramírez-León for helping us access the island and S. Hernández-Vázquez, M. García-Zamora, and J. Martín-Moreno for their help during fieldwork. Funding was provided by Sonoran Joint Venture (MBJV / F20AP11531-00) and Universidad de Guadalajara. APO was financed by a CONACYT scholarship for doctoral studies abroad (No. 795355) and by a student research grant from the Pacific Seabird Group [PSG SRGA 2021]. VM was granted by the Deutsche Ornithologische Gesellschaft (DOG) with a Forschungsföderung (2021) to cover the costs of the metabarcoding analyses. We also would like to thank Sabine Wagner for the support during the laboratory work. Reviewers and D. Ainley provided valuable comments that helped us to improve the paper. The authors have no competing interests to declare with respect to this work.

AUTHOR CONTRIBUTIONS

AP-O: Conceptualization, fieldwork, formal analysis and investigation, methodology, writing—original draft preparation, writing—review and editing, visualization, funding acquisition, resources. VM: Conceptualization, fieldwork, formal analysis and investigation, writing—original draft preparation, writing—review and editing, visualization, funding acquisition, validation. SG-H: Fieldwork, Formal analysis and investigation, writing—review and editing. JAC-G: Conceptualization, fieldwork, investigation, methodology, writing—review and editing, supervision, project administration, funding acquisition, resources. PQ: Conceptualization, formal analysis and investigation, methodology, writing—review and editing, supervision, funding acquisition, resources.

REFERENCES

Almaguer-Hernández, A. M. (2016). *Ecología Reproductiva y Trófica del Rabijunco Pico Rojo* Phaethon aethereus *(Linnaeus, 1758) en la Isla Peña Blanca, Colima, México* [Bachelor's thesis, Universidad de Guadalajara].

Altschul, S. F., Gish, W., Miller, W., Myers, E. W., & Lipman, D. J. (1990). Basic local alignment search tool. *Journal of Molecular Biology, 215*(3), 403–410. https://doi.org/10.1016/S0022-2836(05)80360-2

Barrett, R. T., Camphuysen, C. J., Anker-Nilssen, T., Chardine, J. W., Furness, R. W., Garthe, S., Hüppop, O., Leopold, M. F., Montevecchi, W. A., & Veit, R. R. (2007). Diet studies of seabirds: A review and recommendations. *ICES Journal of Marine Science, 64*(9), 1675–1691. https://doi.org/10.1093/icesjms/fsm152

Beal, M., Oppel, S., Handley, J., Pearmain, E. J., Morera-Pujol, V., Carneiro, A. P. B., Davies, T. E., Phillips, R. A., Taylor, P. R., Miller, M. G. R., Franco, A. M. A., Catry, I., Patrício, A. R., Regalla, A., Staniland, I., Boyd, C., Catry, P., & Dias, M. P. (2021). track2KBA: An R package for identifying important sites for biodiversity from tracking data. *Methods in Ecology and Evolution, 12*(12), 2372–2378. https://doi.org/10.1111/2041-210X.13713

Berry, T. E., Osterrieder, S. K., Murray, D. C., Coghlan, M. L., Richardson, A. J., Grealy, A. K., Stat, M., Bejder, L., & Bunce, M. (2017). DNA metabarcoding for diet analysis and biodiversity: A case study using the endangered Australian Sea Lion (*Neophoca cinerea*). *Ecology and Evolution, 7*(14), 5435–5453. https://doi.org/10.1002/ece3.3123

Cartraud, A. E., Le Corre, M., Turquet, J., & Tourmetz, J. (2019). Plastic ingestion in seabirds of the western Indian Ocean. *Marine Pollution Bulletin, 140*(March), 308–314. https://doi.org/10.1016/j.marpolbul.2019.01.065

Castillo-Guerrero, J. A., Guevara-Medina, M. A., & Mellink, E. (2011). Breeding ecology of the Red-billed Tropicbird *Phaethon aethereus* under contrasting environmental conditions in the Gulf of California. *Ardea, 99*(1), 61–71. https://doi.org/10.5253/078.099.0108

Castillo-Guerrero, J. A., Piña-Ortiz, A., Ventura-Trejo, J., & Zatarain-González, D. J. (2022, May 24). *Population status and priority marine areas for seabirds on San Pedro Mártir Island*. Sonoran Joint Venture. https://sonoranjv.org/seabirds-san-pedro-martir-island/

Castro-Hernández, J. J., & Santana-Ortega, A. T. (2000). *Synopsis of biological data on the Chub Mackerel (*Scomber japonicus *Houttuyn, 1782)*. FAO Fisheries Synopsis No. 157. Food and Agriculture Organization of the United Nations. https://www.fao.org/4/x4287e/x4287e.pdf

Cisneros, M. A., Estrada, J., & Montemayor, G. (1990). Growth, mortality and recruitment of exploited small pelagic fishes in the Gulf of California, Mexico. *Fishbyte, 8*(1), 15–17. https://hdl.handle.net/20.500.12348/3174

Cisneros-Mata, M. A., Nevárez-Martínez, M. O., & Hammann, M. G. (1995). *The rise and fall of the Pacific sardine,* Sardinops sagax caeruleus *Girard, in the Gulf of California, Mexico*. *CalCOFI Reports, 36*, 136–143. https://calcofi.org/downloads/publications/calcofireports/v36/CalCOFI_Rpt_Vol_36_1995.pdf

Cisneros-Montemayor, A. M., Cheung, W. W. L., & Ota, Y. (Eds.). (2019). *Predicting future oceans: Sustainability of ocean and human systems amidst global environmental change*. Elsevier Science. https://doi.org/10.1016/C2018-0-02416-0

Deagle, B. E., Kirkwood, R., & Jarman, S. N. (2009). Analysis of Australian Fur Seal diet by pyrosequencing prey DNA in faeces. *Molecular Ecology, 18*(9), 2022–2038. https://doi.org/10.1111/j.1365-294X.2009.04158.x

Diario Oficial de la Federación. (2002, June 13). *Decreto por el que se declara área natural protegida con la categoría de reserva de la biosfera, la región denominada Isla San Pedro Mártir, ubicada en el Golfo de California, frente a las costas del Municipio de Hermosillo, Estado de Sonora, con una superficie total de 30,165-23-76.165 hectáreas*. https://simec.conanp.gob.mx/pdf_decretos/25_decreto.pdf

Diop, N., Zango, L., Beard, A., Ba, C. T., Ndiaye, P. I., Henry, L., Clingham, E., Oppel, S., & González-Solís, J. (2018). Foraging ecology of tropicbirds breeding in two contrasting marine environments in the tropical Atlantic. *Marine Ecology Progress Series, 607*, 221–236. https://doi.org/10.3354/meps12774

Galaxy Community. (2022). The Galaxy platform for accessible, reproducible and collaborative biomedical analyses: 2022 update. *Nucleic Acids Research, 50*(W1), W345–W351. https://doi.org/10.1093/nar/gkac247

Hammer, S., Nager, R. G., Johnson P. C. D., Furness, R. W., & Provencher, J. F. (2016). Plastic debris in Great Skua (*Stercorarius skua*) pellets corresponds to seabird prey species. *Marine Pollution Bulletin, 103*(1–2), 206–210. https://doi.org/10.1016/j.marpolbul.2015.12.018

Holland, E. R., Mallory, M. L., & Shutler, D. (2016). Plastics and other anthropogenic debris in freshwater birds from Canada. *Science of the Total Environment, 571*, 251–258. https://doi.org/10.1016/j.scitotenv.2016.07.158

Hunter, J. R., & Dorr, H. (1982). Thresholds for filter feeding in Northern Anchovy, *Engraulis mordax*. *CalCOFI Reports, 23*, 198–204. https://calcofi.org/downloads/publications/calcofireports/v23/CalCOFI_Rpt_Vol_23_1982.pdf

Hyrenbach, K. D., Hester, M. M., Johnson, J. A., Lyday, S., Bingham, S., & Pawloski, J. (2013). First evidence of plastic ingestion by White-tailed Tropicbirds from Oʻahu, Hawaiʻi. *Marine Ornithology, 41*(2), 167–169. http://doi.org/10.5038/2074-1235.41.2.1035

Kibria, M. G., Masuk, N. I., Safayet, R., Nguyen, H. Q., & Mourshed, M. (2023). Plastic waste: Challenges and opportunities to mitigate pollution and effective management. *International Journal of Environmental Research, 17*, Article 20. https://doi.org/10.1007/s41742-023-00507-z

Laist, D. W. (1997). Impacts of marine debris: Entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records. In J. M. Coe & D. B. Rogers (Eds.), *Marine debris: Sources, impacts, and solutions* (pp. 99–139). Springer. https://doi.org/10.1007/978-1-4613-8486-1_10

Leray, M., Yang, J. Y., Meyer, C. P., Mills, S. C., Agudelo, N., Ranwez, V., Boehm, J. T., & Machida, R. J. (2013). A new versatile primer set targeting a short fragment of the mitochondrial COI region for metabarcoding metazoan diversity: Application for characterizing coral reef fish gut contents. *Frontiers in Zoology, 10*, Article 34. https://doi.org/10.1186/1742-9994-10-34

Lo, N. C. H., Dorval, E., Funes-Rodríguez, R., Hernández-Rivas, M. E., Huang, Y., & Fan, Z. (2010). Utilities of larval densities of Pacific Mackerel (*Scomber japonicus*) off California, USA, and west coast of Mexico from 1951 to 2008, as spawning biomass indices. *Ciencia Pesquera, 18*(2), 59–75. https://www.gob.mx/imipas/documentos/revista-ciencia-pesquera-volumen-18-numero-2

Louw, G. G., van der Lingen, C. D., & Gibbons, M. J. (1998). Differential feeding by Sardine *Sardinops sagax* and Anchovy *Engraulis capensis* recruits in mixed shoals. *South African Journal of Marine Science, 19*(1), 227–232. https://doi.org/10.2989/025776198784126647

Madden, H., Boehm, H., & Mielke, L. (2023). Foraging ecology of Red-Billed Tropicbirds on Saba, Caribbean Netherlands, during early chick-rearing. *Ardea, 111*(2), 463–475. https://doi.org/10.5253/arde.2022.a14

Madden, H., & Eggermont, E. (2020). First evidence of plastic ingestion by Red-billed Tropicbirds *Phaethon aethereus* from St. Eustatius, Caribbean Netherlands. *Marine Ornithology, 48*(2), 157–160. https://doi.org/10.5038/2074-1235.48.2.1366

Madden, H., Satgé, Y., Wilkinson, B., & Jodice, P. G. R. (2022). Foraging ecology of Red-billed Tropicbird *Phaethon aethereus* in the Caribbean during early chick rearing revealed by GPS rracking. *Marine Ornithology, 50*(2), 165–175. https://doi.org/10.5038/2074-1235.50.2.1486

Marcuk, V., Piña-Ortiz, A., Castillo-Guerrero, J. A., Masello, J. F., Bustamante, P., Griep, S., & Quillfeldt, P. (2024). Trophic plasticity of a tropical seabird revealed through DNA metabarcoding and stable isotope analyses. *Marine Environmental Research, 199*(July), Article 106627. https://doi.org/10.1016/j.marenvres.2024.106627

Masello, J. F., Barbosa, A., Kato, A., Mattern, T., Medeiros, R., Stockdale, J. E., Kümmel, M. N., Bustamante, P., Belliure, J., Benzal, J., Colominas-Ciuró, R., Menéndez-Blázquez, J., Griep, S., Goesmann, A., Symondson, W. O. C., & Quillfeldt, P. (2021). How animals distribute themselves in space: Energy landscapes of Antarctic avian predators. *Movement Ecology 9*, Article 24. https://doi.org/10.1186/s40462-021-00255-9

McInnes, J. C., Alderman, R., Lea, M.-A., Raymond, B., Deagle, B. E., Phillips, R. A., Stanworth, A., Thompson, D. R., Catry, P., Weimerskirch, H., Suazo, C. G., Gras, M., & Jarman, S. N. (2017). High occurrence of jellyfish predation by Black-browed and Campbell albatross identified by DNA metabarcoding. *Molecular Ecology, 26*(18), 4831–4845. https://doi.org/10.1111/mec.14245

National Oceanic and Atmospheric Administration. (2024, March 22). *What is marine debris?* Marine Debris Program. https://marinedebris.noaa.gov/discover-marine-debris/what-marine-debris

Navarro, A., Pérez Luzardo, O., Gómez, M., Acosta-Dacal, A., Martínez, I., de la Rosa, J. F., Macías-Montes, A., Suárez-Pérez, A., & Herrera, A. (2023). Microplastics ingestion and chemical pollutants in seabirds of Gran Canaria (Canary Islands, Spain). *Marine Pollution Bulletin, 186*(January), Article 114434. https://doi.org/10.1016/j.marpolbul.2022.114434

Nelson, J. B. (2006). *Pelicans, cormorants, and their relatives: The Pelecaniformes*. Oxford University Press. https://global.oup.com/academic/product/pelicans-cormorants-and-their-relatives-9780198577270

Nevárez-Martínez, M. O., Lluch-Belda, D., Cisneros-Mata, M. A., Santos-Molina, J. P., Martínez-Zavala, M. A., & Lluch-Cota, S. E. (2001). Distribution and abundance of the Pacific Sardine (*Sardinops sagax*) in the Gulf of California and their relation with the environment. *Progress in Oceanography, 49*(1–4), 565–580. https://doi.org/10.1016/S0079-6611(01)00041-6

Nunes, L. S., Silva, A. G., Espínola, L. A., Blettler, M. C. M., & Simões, N. R. (2021). Intake of microplastics by commercial fish: A Bayesian approach. *Environmental Monitoring and Assessment 193*, Article 402. https://doi.org/10.1007/s10661-021-09156-1

O'Connell, C. P., & Zweifel, J. R. (1972). A laboratory study of particulate and filter feeding of the Pacific Mackerel, *Scomber japonicus*. *Fishery Bulletin, 70*(4), 973–981. https://swfsc-publications.fisheries.noaa.gov/publications/CR/1972/7230.pdf

Ostle, C., Thompson, R. C., Broughton, D., Gregory, L., Wootton, M., & Johns, D. G. (2019). The rise in ocean plastics evidenced from a 60-year time series. *Nature Communications, 10*, Article 1622. https://doi.org/10.1038/s41467-019-09506-1

Petry, M. V., da Silva Fonseca, V. S., & Scherer, A. L. (2007). Analysis of stomach contents from the Black-Browed Albatross, *Thalassarche melanophris*, on the coast of Rio Grande do Sul, Southern Brazil. *Polar Biology, 30*, 321–325. https://doi.org/10.1007/s00300-006-0186-6

Piña-Ortiz, A., González-Zamora, D. A., Paz, J. A., Hernández-Vázquez, S., Mellink, E., Bustamante, P., Quillfeldt, P., & Castillo-Guerrero, J. A. (2024). Parental duties and foraging strategies of a tropical pelagic seabird (*Phaethon aethereus*, Aves: Phaethontidae) during the breeding season. *Marine Biology, 171*, Article 64. https://doi.org/10.1007/s00227-023-04375-1

Piña-Ortiz, A., Hernández-Vázquez, S., Fernández, G., & Castillo-Guerrero, J. A. (2018). Distribution and population size of the Red-billed Tropicbird (*Phaethon aethereus*) in Mexico. *Waterbirds, 41*(2), 135–144. https://doi.org/10.1675/063.041.0204

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

R Core Team. (2023). *R* (version 4.3.1) [Computer software]. The R Foundation for Statistical Computing. https://www.r-project.org/

Rapp, D. C., Youngren, S. M., Hartzell, P., & Hyrenbach, K. D. (2017). Community-wide patterns of plastic ingestion in seabirds breeding at French Frigate Shoals, Northwestern Hawaiian Islands. *Marine Pollution Bulletin, 123*(1–2), 269–278. https://doi.org/10.1016/j.marpolbul.2017.08.047

Robards, M. D. (1993). *Plastic ingestion by North Pacific seabirds*. Report NOAA-43ABNF203014. US Department of Commerce.

Roman, L., Schuyler, Q. A., Hardesty, B. D., & Townsend, K. A. (2016). Anthropogenic debris ingestion by avifauna in eastern Australia. *PLOS One, 11*(8), Article e0158343. https://doi.org/10.1371/journal.pone.0158343

RStudio Team. (2023). *RStudio Desktop* (version 2023.06.1 + 524 'Mountain Hydrangea') [Computer software]. RStudio. https://posit.co/download/rstudio-desktop/

Ryan, P. G. (2016). Ingestion of plastics by marine organisms. In H. Takada & H. K. Karapanagioti (Eds.), *Hazardous chemicals associated with plastics in the marine environment* (pp. 235–266). Springer Cham. https://doi.org/10.1007/698_2016_21

Schmaltz, E., Melvin, E. C., Diana, Z., Gunady, E. F., Rittschof, D., Somarelli, J. A., Virdin, J., Dunphy-Daly, M. M. (2020). Plastic pollution solutions: Emerging technologies to prevent and collect marine plastic pollution. *Environment International, 144*(November), Article 106067. https://doi.org/10.1016/j.envint.2020.106067

Schuyler, Q., Hardesty, B. D., Wilcox, C., & Townsend, K. (2014). Global analysis of anthropogenic debris ingestion by sea turtles. *Conservation Biology, 28*(1), 129–139. https://doi.org/10.1111/cobi.12126

Schwartzkopf, B. D., Dorval, E., James, K. C., Walker, J. M., Snodgrass, O. E., Porzio, D. L., & Erisman, B. E. (2022). *A summary report of life history information on the central subpopulation of Northern Anchovy (*Engraulis mordax*) for the 2021 stock assessment*. NOAA Technical Memorandum NMFS-SWFSC-659. Southwest Fisheries Science Center, National Oceanic and Atmospheric Administration. https://doi.org/10.25923/ckvg-va49

Sileo, L., Sievert, P. R., Samuel, M. D., & Fefer, S. I. (1990). Prevalence and characteristics of plastic ingested by Hawaiian seabirds. In R. S. Shomura & M. L. Godfrey (Eds.), *Proceedings of the 2nd International Conference on Marine Debris, 02–07 April 1989, Honolulu, Hawai'i* (pp. 665–681). NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-154. US Department of Commerce, National Oceanic and Atmospheric Administration.

Sindermann, C. J. (Ed.). (1995). *Ocean pollution: Effects on living resources and humans*. CRC Press.

Spear, L. B., Ainley, D. G., & Ribic, C. A. (1995). Incidence of plastic in seabirds from the tropical Pacific, 1984–91: Relation with distribution of species, sex, age, season, year and body weight. *Marine Environmental Research, 40*(2), 123–146. https://doi.org/10.1016/0141-1136(94)00140-K

Stonehouse, B. (1962). The tropic birds (genus *Phaethon*) of Ascension Island. *Ibis, 103B*(2), 124–161. https://doi.org/10.1111/j.1474-919X.1962.tb07242.x

Su, L., Xiong, X., Zhang, Y., Wu, C., Xu, X., Sun, C., & Shi, H. (2022). Global transportation of plastics and microplastics: A critical review of pathways and influences. *Science of the Total Environment, 831*(July), Article 154884. https://doi.org/10.1016/j.scitotenv.2022.154884

Tershy, B. R., & Breese, D. (1997). The birds of San Pedro Mártir Island, Gulf of California, Mexico. *Western Birds, 28*(2), 96–107. https://westernfieldornithologists.org/publications/journal/journal-volume-28-2/

Tokunaga, Y., Okochi, H., Tani, Y., Niida, Y., Tachibana, T., Saigawa, K., Katayama, K., Moriguchi, S., Kato, T., & Hayama, S. (2023). Airborne microplastics detected in the lungs of wild birds in Japan. *Chemosphere, 321*(April), Article 138032. https://doi.org/10.1016/j.chemosphere.2023.138032

Vandenabeele, S. P., Shepard, E. L., Grogan, A., & Wilson, R. P. (2012). When three per cent may not be three per cent: Device-equipped seabirds experience variable fight constraints. *Marine Biology, 159*, 1–14. https://doi.org/10.1007/s00227-011-1784-6

van der Lingen, C. D. (1994). Effect of particle size and concentration on the feeding behaviour of adult pilchard *Sardinops sagax. Marine Ecology Progress Series, 109*(1), 1–13. https://doi.org/10.3354/meps109001

van Franeker, J. A., & Meijboom, A. (2002). *LITTER NSV: Marine litter monitoring by Northern Fulmars (A pilot study*). Alterra-rapport No. 401. Alterra. https://edepot.wur.nl/45695

Velarde, E., Ezcurra, E., & Anderson, D. W. (2013). Seabird diets provide early warning of sardine fishery declines in the Gulf of California. *Scientific Reports 3*, Article 1332. https://doi.org/10.1038/srep01332

Vesterinen, E. J., Lilley, T., Laine, V. N., & Wahlberg, N. (2013). Next generation sequencing of fecal DNA reveals the dietary diversity of the widespread insectivorous predator Daubenton's Bat (*Myotis daubentonii*) in southwestern Finland. *PLOS One, 8*(11), Article e82168. https://doi.org/10.1371/journal.pone.0082168

Waap, S. (2015). *Trophic relationships among pelagic predators of the deep seas of the Madeira islands* [Doctoral dissertation, Cardiff University]. Online Research @ Cardiff. https://orca.cardiff.ac.uk/id/eprint/75359/

Wang, G.-X., Huang, D., Ji, J.-H., Völker, C., & Wurm, F. R. (2021). Seawater-degradable polymers—fighting the marine plastic pollution. *Advanced Science, 8*(1), Article 2001121. https://doi.org/10.1002/advs.202001121

Wayman, C., Fernández-Piñas, F., Fernández-Valeriano, R., García-Baquero, G. A., López-Márquez, I., González-González, F., Rosal, R., & González-Pleiter, M. (2024). The potential use of birds as bioindicators of suspended atmospheric microplastics and artificial fibers. *Ecotoxicology and Environmental Safety, 282*(September), Article 116744. https://doi.org/10.1016/j.ecoenv.2024.116744

Willis, K. A., Serra-Gonçalves, C., Richardson, K., Schuyler, Q. A., Pedersen, H., Anderson, K., Stark, J. S., Vince, J., Hardesty, B. D., Wilcox, C., Nowak, B. F., Lavers, J. L., Semmens, J. M., Greeno, D., MacLeod, C., Frederiksen, N. P. O., & Puskic, P. S. (2022). Cleaner seas: Reducing marine pollution. *Reviews in Fish Biology and Fisheries, 32*, 145–160. https://doi.org/10.1007/s11160-021-09674-8

Wilson, R. P., & McMahon, C. R. (2006). Measuring devices on wild animals: What constitutes acceptable practice? *Frontiers in Ecology and the Environment, 4*(3), 147–154. https://doi.org/10.1890/1540-9295(2006)004[0147:MDOWAW]2.0.CO;2

Yorio, P., Marinao, C., Kasinsky, T., Ibarra, C., & Suárez, N. (2020). Patterns of plastic ingestion in Kelp Gull (*Larus dominicanus*) populations breeding in northern Patagonia, Argentina. *Marine Pollution Bulletin, 156*(July), 111240. https://doi.org/10.1016/j.marpolbul.2020.111240

Young, M. J., Dutoit, L., Robertson, F., van Heezik, Y., Seddon, P. J., & Robertson, B. C. (2020). Species in the faeces: DNA metabarcoding as a method to determine the diet of the endangered Yellow-eyed Penguin. *Wildlife Research, 47*(6), 509–522. https://doi.org/10.1071/WR19246