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Review

Plastics and waterbirds in Brazil: A review of ingestion, nest materials and entanglement reveals substantial knowledge gaps and opportunities for research☆

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ABSTRACT

Plastic pollution is an increasing global problem, especially in aquatic environments. From invertebrates to vertebrates, many aquatic species have been affected by plastic pollution worldwide. Waterbirds also interact with plastics, mainly by ingesting them or using them as nest material. Brazil has one of the largest aquatic environment areas, including the most extensive wetland (the Pantanal) and biggest river (the Amazon), and a ~7500 km long coastline, which hosts a remarkable waterbird diversity with more than 200 species from 28 bird families. Here, we synthesise published and grey literature to assess where, how, and which waterbirds (marine and continental) interact with plastics in Brazil. We found 96 documents reporting interaction between waterbirds and plastics. Only 32% of the occurring species in the country had at least one individual analysed. Plastic ingestion was reported in 67% of the studies, and seabirds were the study subject in 79% of them. We found no reports in continental aquatic environments, unveiling entire regions without any information regarding interactions. Consequently, this geographic bias drew a considerable taxonomic bias, with whole families and orders without information. Additionally, most studies did not aim to search for plastic interactions, which had a twofold effect. First, studies did not report their findings using the proposed standard metrics, hampering thus advances in understanding trends or defining robust baselines. Second, as it was not their main objective, plastics were not mentioned in titles, abstracts, and keywords, making it difficult to find these studies. We propose means for achieving a better understanding of waterbird-plastic interactions in space and time, and recommend searching for sentinel species and for allocating research grants.

1. Introduction

It is estimated that about 8.3 billion metric tons of virgin plastic were produced from 1950 to 2015, of which 60% have been largely discarded in the natural environment (Geyer et al., 2017). Water bodies have been shown to be the main plastic sinks incorrectly discarded from industrial or domestic sources (Browne et al., 2011). Therefore, plastic materials have been detected in lakes (Driedger et al., 2015), rivers (Morritt et al., 2014; Gallitelli et al., 2020), beaches (Browne et al., 2011) and ocean basins (Eriksen et al., 2014), from Arctic to Antarctica (Barnes et al., 2010; Collard and Ask, 2021). These environments are transport routes (Schmidt et al., 2017) and the destination of incorrectly disposed plastic materials (Jambeck et al., 2015), increasing the extent of pollution and impact on aquatic wildlife (Sigler, 2014; Bergmann et al., 2015; Gall and Thompson, 2015).

There is an extensive and growing body of studies reporting interactions of birds and plastics, with biased contamination towards species depending on aquatic environments (reviewed in Battisti et al., 2019). Plastic contamination in waterbirds is so marked that the group has been used as sentinel for pollution of areas used for foraging activities and nest material collection (Reynolds and Ryan, 2018; Phillips and Waluda, 2020). Waterbirds can be impacted by plastic pollution mainly through entanglement and ingestion (Gall and Thompson, 2015), which in turn can lead to the gastrointestinal tract lesions and obstruction, and

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accumulation of chemical additives in the liver and adipose tissues (Tanaka et al., 2020). Among waterbirds, research has shown that seabirds make up the most heavily impacted group by plastic pollution (Wilcox et al., 2015; Battisti et al., 2019), which may be due to the marked contamination of the oceans (van Sebille et al., 2015), or the relatively small effort to understand plastic pollution in freshwater systems and associated avifauna (Blettler et al., 2018; Battisti et al., 2019; Azevedo-Santos et al., 2021).

Brazil has almost 2000 bird species recorded, representing around 20% of global avifauna (Gill et al., 2020; Pacheco et al., 2021). From those, 28 families and 206 species depend on Brazilian continental and marine aquatic environments (Pacheco et al., 2021). These species occupy all Brazilian biomes, including freshwater systems such as the Amazon Basin and the Pantanal, which are among the world's largest tropical wetlands (Fraser and Keddy, 2005). Brazil has a large latitudinal gradient, from 5°N to 34°S, with a 3.5 million km^2 Exclusive Economic Zone and ~7500 km long coastline. In addition, Brazil has four oceanic islands or archipelagos (i.e. those out of the continental shelf), up to 1200 km from the coast, where 12 seabird species breed (Mancini et al., 2016). Several of these species are threatened nationally (Ministério do Meio Ambiente, 2022), while migratory seabirds are threatened globally (Dias et al., 2019). Due to the environmental heterogeneity, massive freshwater systems, extensive coastal region, and wide latitudinal gradient, the Brazilian territory offers a variety of ecological opportunities for species with distinct environmental requirements. In addition, as signatory of the Convention on Biodiversity (CBD), Convention on Migratory Species (CMS), the Agreement for the Conservation of Albatross and Petrels (ACAP), part of the Western Hemisphere Shorebird Reserve Network, among other international agreements, Brazil had committed to preserve waterbirds and their habitats. Finally, due to recent initiatives towards a global legal responsibility aiming to solve the huge concerns on plastic pollution (Simon et al., 2021), and despite an unfavourable national political scenario regarding environmental issues (Menezes and Barbosa-Jr., 2021; Pelicice and Castello, 2021), it is timely to address the effects of plastic pollution on waterbirds and provide support based on the best available information.

Plastic pollution is widespread in Brazilian aquatic environments and has been reported in rivers (Andrade et al., 2019), estuaries (Ivar do Sul and Costa, 2013), beaches (Andrades et al., 2020), continental shelf (Lacerda et al., 2020), and oceanic islands (Monteiro et al., 2018). Contributing to this are the 50 million people living in coastal regions (Instituto Brasileiro de Geografia e Estatística, 2011); the proximity of Brazil's southern region to the South Atlantic garbage patch (van Sebille et al., 2012, 2015); and the transport of plastics into aquatic areas via large freshwater systems such as the Amazon, São Francisco and La Plata rivers (Molleri et al., 2010; Möller et al., 2008). So persistent is this, that there are records of plastic material cemented with biogenic and siliciclastic material, forming sedimentary rocks in beaches (Fernandino et al., 2020) and oceanic islands (Santos et al., 2022), and microplastics recorded in lakes and rivers (Gerolin et al., 2020; Bertoldi et al., 2021), demonstrating that pollution has been present in marine and freshwater systems for decades.

In this study, we reviewed the evidence of interactions between waterbirds, both continental and marine, and plastics in order to provide a country-wise perspective and the development of studies on the topic. We identified knowledge gaps in habitat representativeness, among taxonomic groups, and regarding the information reported by the studies. We proposed future studies assessing which species would be useful sentinels, highlight possible adjustments in current monitoring programs with non-invasive sampling opportunities, and discuss systematization and standards that future studies should have, aiming toward a more accurate and comprehensive understanding of waterbirds' interactions with plastics in Brazil. This synthesis thus supports the prioritisation of field efforts and research funding, and contributes to society and decision-makers for the development of conservation actions and public policies.

2. Methods

All searches, screening, and data summarisation were done by one reviewer (NWD), apart from CAPES and BDTD database searches, which were carried out by GTN (see acronyms definition below). We do not consider this review fully systematic, nor automatized, but an exhaustive effort to gather as much as possible information available to date on the subject. As such, every study that could be a source of information was fully screened.

2.1. Data sources

As a first attempt to collate all possible data, we gathered published (research articles and book chapters) and grey literature (here defined as academic documents, such as Honours, Masters, and Doctoral theses). For this, we used a mix of 'systematic' and 'active' search methods.

We used advanced search on Google Scholar for scientific literature and academic documents. Given that Google Scholar returns ~95% of the same findings from Web of Science and Scopus databases, returns unpublished reports and grey literature, and non-English documents (Martín-Martín et al., 2018), we assumed it as our main source. In addition, we used advanced search in the governmental platform 'Portal de Periódicos da CAPES' (hereafter CAPES; https://www.periodicos.capes.gov.br) which searches for Brazilian literature, including research articles, conference abstracts and grey literature; also, we used the 'Biblioteca Digital Brasileira de Teses e Dissertações' (BDTD; https://bdtd.ibict.br), an online, open library which looks specifically for Masters and Doctoral theses from Brazil.

Honours theses are usually not in indexed databases (such as CAPES and BDTD), so we made an effort to actively search for them in university repositories. For this, first, we looked into online curriculum vitae (CV) of key Brazilian waterbird researchers, searching after supervisions and theses markings (from undergraduate and graduate students), as well as research papers of possible contribution to the topic. Brazil has an official, federal CV platform 'Plataforma Lattes' (https://lattes.cnpq.br), which was scanned for finding such information (Supplementary material, Table S1).

2.2. Search strategy

First, all searches were carried out using English keywords and their Portuguese translation, respectively, as below. Mandatory words are before the underlined conditioning "AND". We did not specify limits of dates, and we did not include conference abstracts neither bycatch reports (e.g. Cardoso et al., 2011). All searches were carried out in May and July 2020.

- Brazil AND plastic AND birds* <u>AND</u> waterbirds OR seabirds OR "aquatic birds" OR debris OR "anthropogenic debris" OR litter OR ingestion OR entanglement OR "stomach content" OR diet OR nest.
- Brasil AND plástico AND aves <u>AND</u> "aves aquáticas" OR "aves marinhas" OR "aves costeiras" OR debris OR lixo OR "lixo marinho" OR ingestão OR enredamento OR "conteúdo estomacal" OR dieta OR ninho.

Here, we define 'waterbirds' (as waterbirds and seabirds) following both Ramsar Convention (Article 1.2) and Votier and Sherley (2017) (taxonomy follows Pacheco et al. (2021) throughout our text and files), and 'interaction' as plastic ingestion, entanglement, or nest incorporation (Battisti et al., 2019). Bearing these definitions, the Google Scholar searches returned ~224,000 results from English, and ~23,200 from Portuguese keywords, respectively, which were manually screened twice (in May and July 2020) until the 2,000th title (20 records per label, until the 100th label, ordered by 'relevance').

Eligibility criteria were loose, as we admitted a whole spectrum of possible terms in the titles that could potentially mention plastic interactions with waterbirds, such as studies on natural history, breeding biology/phenology description, biodiversity assessments, distribution, and diet—besides the ones clearly mentioning plastics in the title. From the selected documents, we added up documents returned from CAPES (BDTD had zero new documents, therefore, from herein we omit it) and CV checking. We then went through all documents gathered and searched for backwards citations (literature cited by them) and repeated this step for every new study in our list. We contacted librarians and colleagues to get hold of copies not available on the internet, trying to cover as many references as possible.

Therefore, we consider that the review was exhaustive in terms of research articles and grey literature, and that any study that eventually escaped our thorough search would not affect the general patterns, trends and gaps identified, as well as the main conclusions. Considering the whole searching process, this review covers literature up to December 2021.

2.3. Data gathered and analysis

Answers to the following questions were collated from each document:

1. Is there a temporal trend in the number of studies?
2. Is there any bias related to environment/region in the reported cases?
3. Are all taxonomic groups equally represented?
4. What was the main purpose of studies reporting interactions between waterbirds and plastic?
5. What is the most reported type of interaction?
6. Which quantitative parameters are being used by researchers to describe interactions?
7 How many studies address microplastic (sensu Provencher et al., 2017, i.e. <5 mm) in comparison with macroplastics?

Documents were characterised individually (book chapters were treated as independent pieces), and answers to these questions were summarised in order to quantify them. We also had computed the periods in which studies had collected samples; if from alive or dead animals; total sample size; and from the ones that report plastic ingestion, which methods researchers used to assess it; and which quali-quantitative metrics they have used. For grey literature, we also noted if results regarding the plastic interaction were fully, partially, or not published—if fully published, we only used information from the research article(s); if partially, we included both grey and published documents.

All data were processed and analysed in R 4.2.0 (R Core Team, 2021), using packages 'tidyverse' 1.3.1 (Wickham et al., 2019), 'sf' 1.0–8 (Pebesma, 2018), 'mgcv' 1.8–40 (Wood, 2017), 'rnaturalearth' 0.1.0 (South, 2017), 'RColorBrewer' 1.1–3 (Neuwirth, 2014), 'patchwork' 1.1.1 (Pedersen, 2020), and 'ggspatial' 1.1.6 (Dunnington, 2021). We pooled together published and grey literature information, unless stated, and undertook descriptive and graphical analyses. To evaluate if there is an increasing trend on the number of studies by year, we ran a generalised additive model with mgcv::gam(), based on a Poisson error distribution, with number of publications as the response variable and year (as numeric) as the explanatory variable, using a cubic spline.

A list of all documents and the associated metadata and data, along with the R code used for analysis is available in Daudt (2022). A collection of all digitised documents can be requested for the first author.

3. Results

In total, 304 selected documents were fully screened; from those, 96 reported some interaction between waterbirds and plastics (Supplementary material, Literature review). We found 62 published and 34 grey literature studies with information on plastics and waterbirds in Brazil, up to December 2021. From the grey literature, only 8 (23.5%) were fully published, the remaining not (73.5%) or only partially (3%) published. From herein, we excluded from Results those eight grey documents that had their information regarding waterbirds-plastic interactions fully published and a book chapter that has the same results published in a peer-reviewed journal (Colabuono and Vooren, 2006; Colabuono and Vooren, 2007), totalling 87 documents at the end. Four studies were published in 2022, up to May, although they were not included in the analyses (Azevedo-Santos et al., 2022; Costa et al., 2022; Nascimento et al., 2022; Robuck et al., 2022). Noteworthy, Azevedo-Santos et al. (2022) reported on a duck (Anseriformes) entangled in a ghost fishing net.

More than half of the studies were written in Portuguese (n = 45), including 20 published. The oldest document is Bege and Pauli (1989), who reported the use of plastic in nests by magnificent frigatebirds (*Fregata magnificens*), during 1981–1989 fieldwork. The first evidence of plastic ingestion by waterbirds in Brazil is from an Honours thesis (Zarzur, 1995), which analysed stomach contents of Procellariiformes collected between 1982 and 1995, in south Brazil demonstrating a severe problem dating back at least to early 1980s. The GAM model showed that the number of publications is slightly increasing towards recent years ($R^2_{adj} = 0.10$, $\chi^2 = 5.74$, $p = 0.016$; Fig. 1).

Studies were highly biased towards the marine environment (78%), while 10% were in estuarine or mangrove habitats. Only five studies (7%) were in freshwater environments. Nevertheless, the vast majority of them are concentrated in coastal areas (Fig. 2). The orders Procellariiformes, Charadriiformes and Sphenisciformes, and the families Procellariidae, Spheniscidae, Laridae were the most numerously studied, primarily from marine or coastal environments (Fig. 3). Strikingly, entire speciose orders and families, typically from inland aquatic environments, were not sampled at all—such as Anseriformes (but see Azevedo-Santos et al., 2022). The ten most-studied species feed primarily on the marine environment, and the interaction most reported was plastic ingestion (Table 1).

Studies focusing on diet aspects made up most of the interaction reports, followed by studies focusing on plastic interactions and breeding aspects (Fig. 4). Together, studies that did not primarily focused on plastic interactions summed up to 79% of the information collated, indicating plastic interactions as a secondary objective or an 'accidental' outcome of most studies. Plastic ingestion was the most reported type of interaction (n = 58; 67%), followed by the use of plastic as nest material (n = 17; 19%) and entanglement (n = 7; 8%).

Researchers used mainly descriptive metrics, with half reporting the frequency of occurrence and a third reporting the number of plastic items encountered (Supplementary material, Table S2). However, one third of the studies only mentioned the occurrence of plastic and did not quantify it (Supplementary material, Table S2). Robust statistical analysis was barely used (Tavares et al., 2016; Petry and Benemann, 2017; Tavares et al., 2017). Only nine studies reported the size of items, and four of those reported microplastics (Carlos et al., 2004; Colabuono et al., 2010; Rossi et al., 2019; Vanstreels et al., 2021). Additionally, although the authors did not report plastic sizes, Tavares et al. (2017) analysed particles larger than 1 mm, which likely included microplastics.

4. Discussion

We synthesized published and grey literature about interactions between waterbirds and plastics in Brazil and demonstrated substantial geographic and taxonomic gaps, in addition to low systematization of sampling efforts and poor plastic documentation (descriptive and physicochemical). From 206 waterbird species occurring in Brazil, only 32% had at least one specimen investigated. However, even for the analysed species, little information is available, and 16 were reported as they did not interact with plastics (although their sample sizes ranged

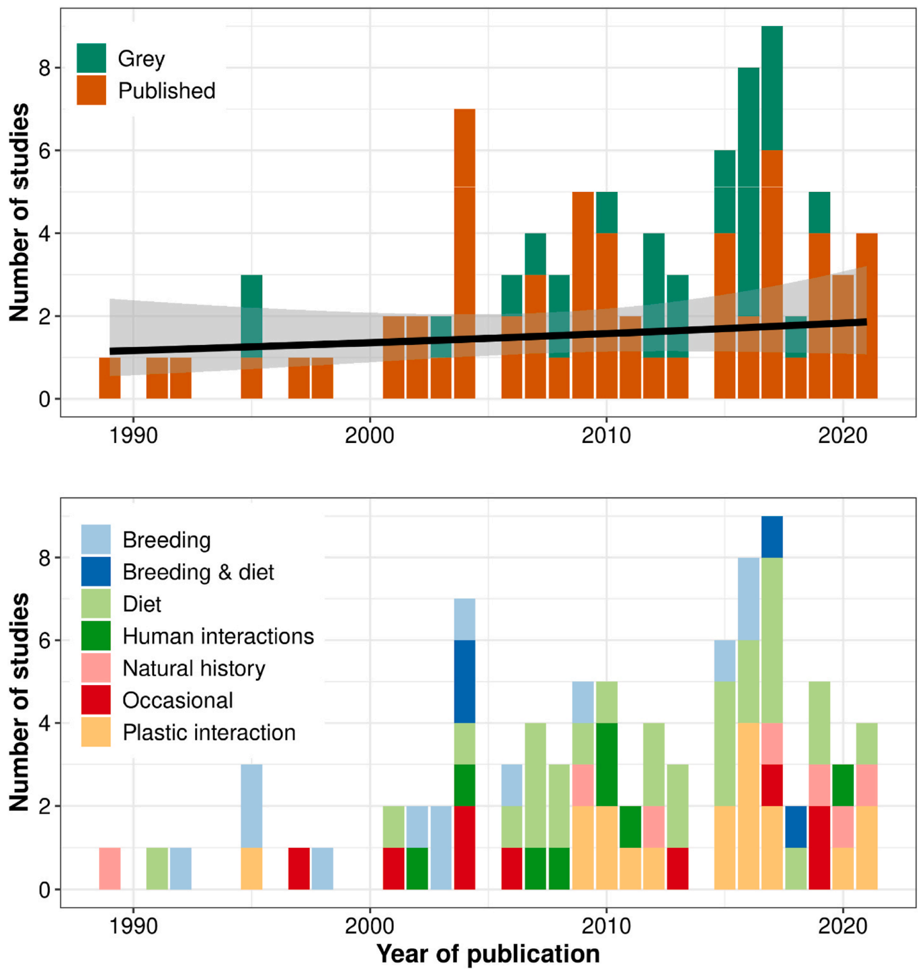

Fig. 1. Temporal trends in number of studies about interactions between waterbirds and plastics in Brazil, up to December 2021, by (top panel) type of document (published, grey literature) and (bottom panel) study aim. The top panel also shows GAM's fitted smoother. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

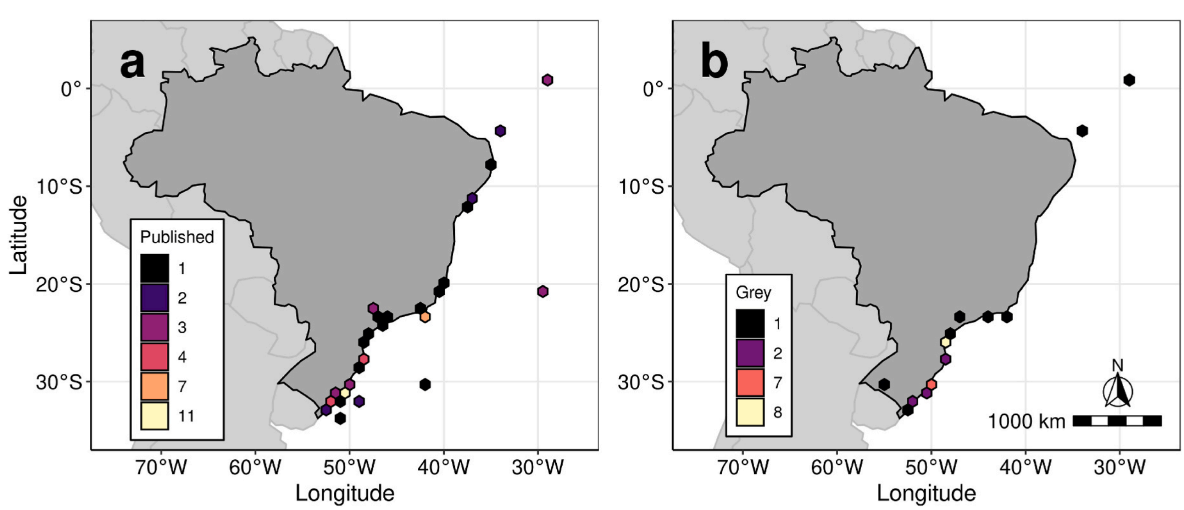

Fig. 2. Geographical bias in sampling and number of studies about interactions between waterbirds and plastics in Brazil, up to December 2021. Panels show (a) published literature and (b) grey literature (unpublished).

between 1 and 3 individuals). Additionally, most reports were opportunistic, resulting from diet studies, in which plastics were reported in stomach contents. In these cases, the description of the plastic is superficial, without the use of standard metrics or techniques to characterize polymers. While useful, studies without standard metrics limit our interpretation about plastic interactions and environmental contamination, making it difficult to infer how representative these samples are. Finally, the lack of a growth trend in the number of

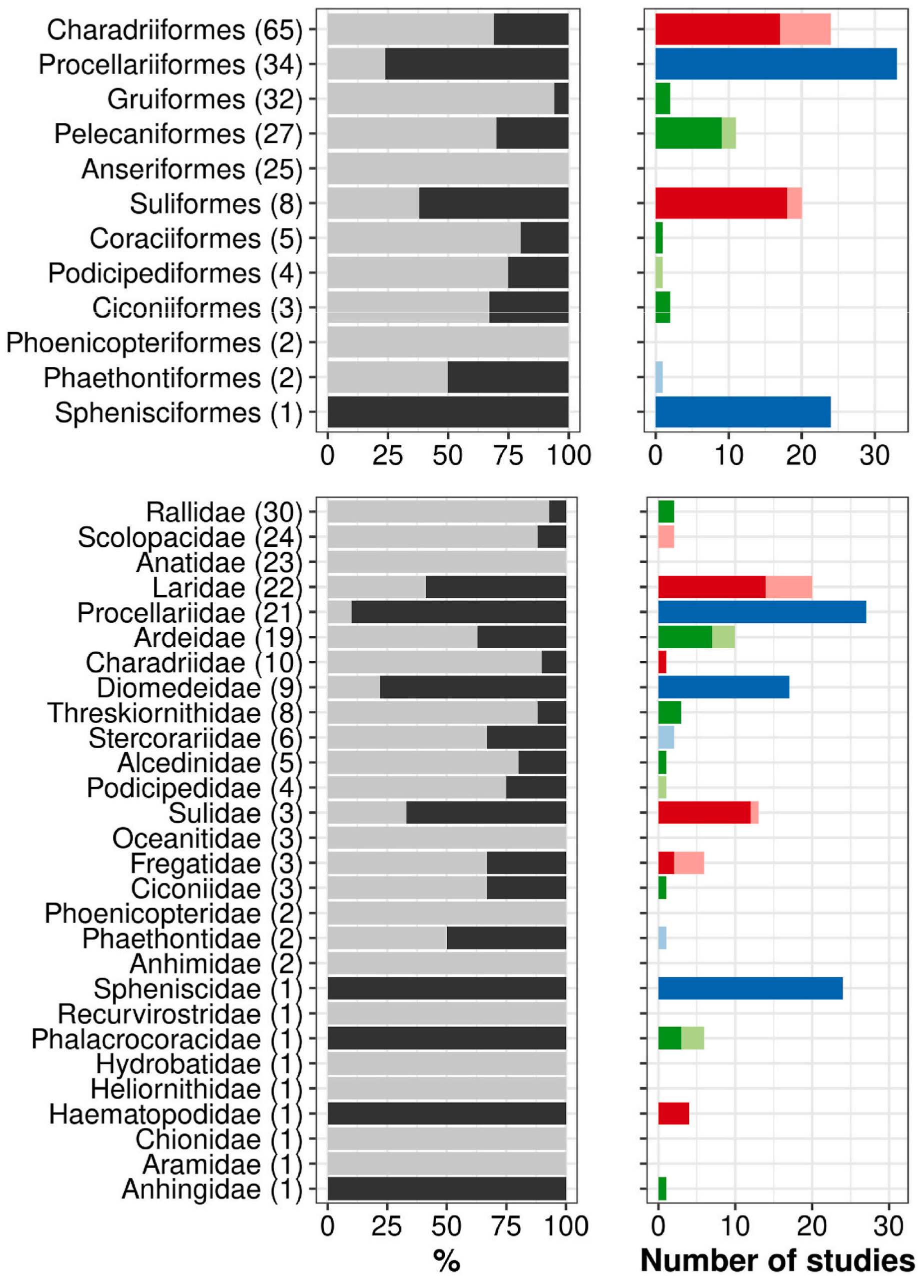

Fig. 3. Taxonomic bias in sampling and number of studies about interactions between waterbirds and plastics in Brazil, up to December 2021. The top panels show biases at the Order level and the bottom panels at the Family level (both ordered by the most species-richness taxa, in parenthesis). On the left, the percentage of species, within that taxa, with at least one specimen/individual analysed (dark grey) or not analysed (light grey); on the right, the number of publications by taxa, with red representing coastal, blue marine, and green continental species (darker colours means that studies recorded waterbird-plastic interaction, whereas light colours no interaction was recorded). Published and grey literature pooled. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

publications about this topic does not follow the global pattern observed for studies with birds (Battisti et al., 2019) or targeting aquatic ecosystems (Kasavan et al., 2021), suggesting that plastic contamination of waterbirds in Brazil is likely underestimated. Such shortcomings in the evaluation of waterbird-plastic interactions reveals opportunities for future studies in Brazil, and we provide recommendations to optimise research efforts.

The inclusion of grey literature and documents written in Portuguese contributed substantially to synthesize information presented herein. Other review efforts to understand plastic interactions within countries and regions included non-published reports as well as documents in non-English languages as part of their literature review (Provencher et al., 2015; O'Hanlon et al., 2017; Battisti et al., 2019). However, these documents were under-represented. For instance, Battisti et al. (2019), which is the biggest attempt to review bird-plastic interactions to date, had only 3 out of 171 documents written in languages other than English. By contrast, the number of peer-reviewed publications and book chapters written in Portuguese in the present study stood out. These were mostly published in Neotropical or Brazilian journals, and Brazilian-edited books. For some species, such as the masked booby (*Sula dactylatra*) (Schulz-Neto, 1998; Mariano and Targino, 2012) and the blue petrel (*Halobaena caerulea*) (Fonseca et al., 2001), documents in Portuguese were the only source of information regarding plastic interactions. As such, despite interactions being recorded since the 1980s in Brazil, most records were not included in global syntheses (e.g. Li et al., 2016; Battisti et al., 2019; Kasavan et al., 2021). The inclusion of non-English documents in syntheses has been acknowledged in other fields as critical for a complete understanding of the topic (Konno et al., 2020; Amano et al., 2021; Nuñez and Amano, 2021). For countries that English is not its native language(s), including native language(s) documents will likely increase the numbers of studies gathered and therefore the amount of information, as demonstrated in our study. Thus, we highly encourage this practice when reviewing plastic pollution impacts, especially at broad scales which will likely encompass regions where English is not the native language.

Brazilian studies were mostly carried out in coastal regions in

Table 1
Summary of the number of studies, sample size and frequency of occurrence, by type of interaction, for the ten most-studied species reporting on waterbird-plastic interactions in Brazil, up to December 2021. Note that all species are seabirds and are ordered by the descending total number of studies by species. Year (range) presents the oldest and the newest sampling dates and does not mean necessarily continuity of sampling during this period. n.i. = not informed.

Species	Interaction[a]	Studies	Studies with plastics (%)	Year (range)	Sample size (total)	Sample size (range)	Frequency of occurrence (mean ± SD)	Frequency of occurrence (range)
Spheniscus magellanicus	ingestion	22	100	1987–2021	1978	9–470	35.6 ± 24.1	2–87
	entanglement	3	100	1999–2010	15,031	1–14875	34.2 ± 57	0.05–100
Puffinus puffinus	ingestion[b]	15	80	1982–2021	260	1–52	35.9 ± 24.1	0–85.7
	entanglement	1	0	1999–2010	295	295	0	0
Procellaria aequinoctialis	ingestion	14	100	1982–2021	330	1–114	55.9 ± 23.4	25–100
	entanglement	1	100	1999–2010	256	256	1.2	1.2
Ardenna gravis	ingestion	12	100	1982–2016	377	1–121	81.9 ± 14.5	56.3–100
	entanglement	1	100	1999–2010	428	428	0.2	0.23
Thalassarche chlororhynchos	ingestion	11	81.8	1982–2021	115	1–27	26.3 ± 31	0–100
	entanglement	2	100	1999–2010	250	80–170	1.2 ± 0	1.2–1.2
Sula leucogaster	nest[c]	9	44.4	1984–2016	1177	31–288	20.2 ± 24.4	0–61
	ingestion	4	75	2006–2021	203	12–126	13.2 ± 13.5	0–30
Thalassarche melanophris	ingestion	11	100	1982–2016	283	2–59	31.4 ± 31.2	6–100
	entanglement	1	100	1999–2010	207	207	1.9	1.9
Calonectris borealis	ingestion	9	88.9	1982–2021	391	1–185	57.3 ± 34.9	0–100
	entanglement	1	0	1999–2010	349	349	0	0
Larus dominicanus[d]	ingestion	7	42.9	1994–2021	400	2–212	10.5 ± 19.2	0–50
	nest	2	50	1992–1999	107	107	0.4 ± 0.6	0–0.9
	entanglement	1	100	1999–2010	n.i.	n.i.	n.i.	n.i.
Ardenna grisea	ingestion	7	85.7	1982–2013	64	1–27	53.8 ± 30.6	0–100
	entanglement	1	0	1999–2010	142	142	0	0

[a] All studies reporting entanglement in these species are based on beach surveys and external carcass/individual evaluation.
[b] Sick (1997) did not provide information regarding sample size and frequency of occurrence.
[c] Schulz-Neto (1998); Krul (2004); Coelho et al. (2004); Barbosa-Filho and Vooren (2009) did not report sample size and/or frequency of occurrence; Kohlrausch's (2003) data was considered two separate studies for the summary, given different location of colonies.
[d] For nests, Krul (2004) did not report sample size but also did not report plastics on the nests; also, we assumed that the occurrence reported in Soares and Schiefler (1995) happened once, and calculated frequency of occurrence accordingly. For entanglement, Scherer et al. (2011) did not report sample size, however they report on one individual entangled in a fishing net.

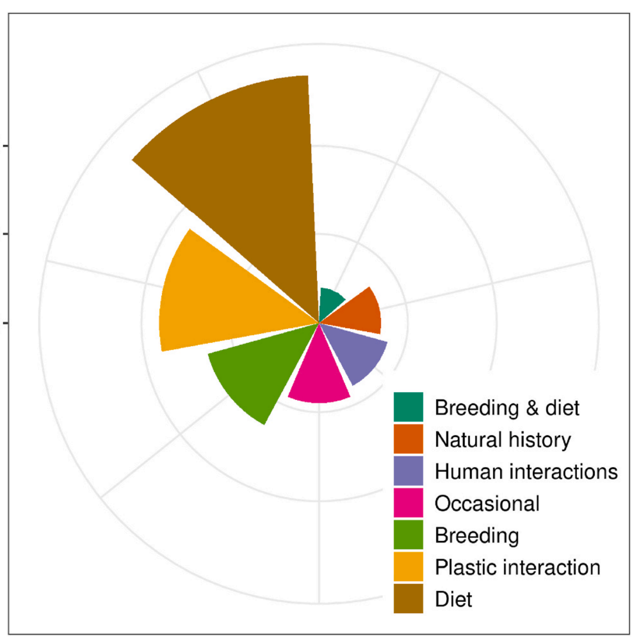

Fig. 4. Primarily aim of studies reporting on waterbird-plastic interactions in Brazil, up to December 2021. Published and grey literature pooled. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

southern Brazil, which also made the taxonomic representativeness biased. South Brazil is an important foraging area for migratory Procellariiformes, Sphenisciformes and Charadriiformes, which are also frequently found dead in beach surveys (Tavares et al., 2021). Long-term beach surveys have been carried out by different institutions for decades in this region (e.g. Colabuono et al., 2009; Petry and Benemann, 2017), prompting studies sampling albatrosses, petrels and penguin carcasses since the 1980s (e.g. Zarzur, 1995). As a result, most of the current knowledge on plastic contamination in Brazil is strongly based on beach stranded avian carcasses. Beach monitoring programs have been carried out along most of the Brazilian coastline (e.g. Mariani et al., 2019; Tavares et al., 2021; Prado et al., in press), and synchronised samples obtained from beached carcasses could help fill some of the geographic and taxonomic gaps presented in this study. In addition, a recent government program began monitoring seabird colonies located on Brazilian oceanic islands which could also contribute filling gaps about specific groups, such as Suliformes and Phaethontiformes, through the inclusion of non-invasive sampling in the protocols (e.g. faeces, regurgitated material, and nest materials). In this way, the coverage of information on plastic contamination in seabirds and shorebirds would expand in geography and taxonomy by adjusting current protocols in existing monitoring programs.

Major freshwater systems and their biomes, such as the Amazon and Pantanal, did not have a single study reporting waterbirds interacting with plastics. Surprisingly, the identification of pollution (plastic, inorganic, or organic contamination) was not among the research gaps highlighted for the Pantanal (Frota et al., 2020; Fernández-Arellano et al., 2021). The lack of waterbird studies in the Amazon Basin is also noteworthy, considering its vast area, about half the Brazilian territory. Nevertheless, it seems that the scarcity of information on waterbirds-plastic interactions in freshwater ecosystems in Brazil is due to the lack of studies rather than the absence of environmental pollution or contamination, as plastics were reported in many wetlands and continental rivers (Giarrizzo et al., 2019; Gerolin et al., 2020; Faria et al., 2021). For example, plastic consumption by fishes in the Amazon was widespread (Andrade et al., 2019; Ribeiro-Brasil et al., 2020), as in streams of south and southeast Brazil (Garcia et al., 2020; Urbanski et al., 2020). Fishes could be a source of plastic contamination for waterbirds, as they can indirectly ingest plastic from foraging activities (e.g. Jawad et al., 2021). Environmental contamination and the risk of secondary ingestion via trophic interactions with fish suggest that interactions with plastics are likely under reported in continental waterbirds. Waterbirds plastic ingestion is not unprecedented as reported elsewhere (Gil-Delgado et al., 2017; Reynolds and Ryan, 2018). Rivers represent the main plastic routes from the continent to the ocean and Brazil is ranked 7th country in annual plastic flow to the ocean through continental runoffs (Meijer et al., 2021).

In general, plastic contamination in waterbirds has been reported through studies designed with other primary objectives, especially those aimed at dietary analysis. The consequences are twofold. Firstly, as the study aim is not on reporting plastic interactions, rarely, if so, this result will be highlighted in the title, abstract or keywords of the study, thus not being easily 'findable' for synthesis and reviews—which may be worsen if the document is written in Portuguese (or any other non-English language). This could be very prejudicial as systematic review approaches usually include screening records based on title and abstract only. Secondly, plastics have been reported in a non-systematic or even informal way, so that none of the studies reported the standard metrics proposed by Provencher et al. (2017) (but see Vanstreels et al., 2021). A review on interactions of seabirds with marine plastics in the northeast Atlantic Ocean found only 37% of the studies focused on reporting the interactions and most failed in reporting the basic metrics (O'Hanlon et al., 2017). On the other hand, Baak et al. (2020) found that 61% of the documents analysed in a similar review for the circumpolar Arctic had focused on reporting plastic interactions with seabirds; even though, many studies did not report some of the basic metrics. In this context, a crucial step to increase robustness of analysis and inferences on waterbirds interacting with plastics is embrace the standard metrics proposed, such as frequency of occurrence, mean (with standard deviation or standard error), median and range for mass of ingested plastics per individual, and all plastics reported by category (Provencher et al., 2017).

4.1. Recommendations

(1) Identify and use sentinel species

Identification and use of sentinel species is an approach used worldwide, which allows to understand patterns of contamination for different taxa, regions/biomes, and across time. Mobility, home range, population structure, foraging site fidelity, and dietary aspects are important information for defining indicator species. For example, brown boobies (*Sula leucogaster*) occur along most of the Brazilian coast (5°N–28°S) with marked genetic (Nunes and Bugoni, 2018), morphological (Nunes et al., 2017) and dietary (Souza, 2021) differences among breeding sites, suggesting adaptation and dependency to local conditions. In this context, monitoring plastic contamination in distinct brown booby colonies could provide information on local environmental pollution along the Brazilian coast. Likewise, this rationale could be applied to other waterbird species with known movement and wide spatial distribution patterns, such as Neotropic cormorants (*Nannopterum brasilianum*), which, in addition to nests for checking could also provide regurgitated pellets in roosting places throughout the year, in both inland and coastal regions (Barquete et al., 2008). Similarly, species frequently stranded on the beach in several regions are good candidates as sentinels, such as great shearwater (*Ardenna gravis*) (Robuck et al., 2022). Seabirds have been used as sentinels of environmental contamination in the northern Atlantic Ocean for a long time (van Franeker et al., 2011; Nehring et al., 2017), a model that could be applied for waterbirds occurring in different Brazilian biomes. Thus, future studies should look for choosing sentinel species, benefiting from previous ecological knowledge at the population level to understand variations of plastic contamination in space and time, and then the delimitation of standard minimum protocol for long-term monitoring.

(2) Adjust monitoring programs in place to understand waterbird-plastic interactions

An excellent opportunity to implement systematic assessment of plastic contamination in waterbirds is the monitoring programs already in place in Brazil. Large monitoring programs in Brazil are mainly dedicated to assessment of oil contamination (beach surveys) or to breeding/demographic aspects in colonies. These protocols could be complemented for systematically monitoring plastic contamination, as they ease access to biological samples with the logistics and facilities already in place. Beach surveys could be used as a mean to collect and sample carcasses to access plastic ingestion across a large geographic area (e.g. Trevail et al., 2015), by many resident and migratory species. Likewise, breeding/demographic assessment programs could collect data regarding plastics used as nest materials through collection and/or photographic methods (Costa et al., 2022), and from faeces and regurgitated material for understanding ingestion. Additionally, these programs could incorporate data from beach clean-ups and plastics in the surrounding areas (e.g. marshes) and use it as a proxy for the availability of plastics for birds to interact with (e.g. Tavares et al., 2019; van de Crommenacker et al., 2021; Weitzel et al., 2021). Such protocols should also include reports/publications using standard metrics proposed by Provencher et al. (2017), to facilitate and make it useful for future meta-analysis. Besides, these protocols should account for different size classes of plastics as well, as environmental pollution by microplastics (1 μm–5 mm size) and nanoplastics (particles size <1 μm) is a growing issue worldwide. The knowledge gap on waterbird contamination by micro and nanoplastics needs to be urgently filled in Brazil, and monitoring programs could be a way to achieve it.

(3) Multidisciplinary teams targeting a comprehensive analysis of plastic pollution

Another important gap to be filled refers to polymers identification and characterization, implying the use of refined techniques for the physicochemical characterization of plastic items. The classification of particles according to shape, size, color, and chemical composition are crucial to allow inferences about sources and pathways of contamination. However, it does require study techniques (e.g. scanning electron microscopy for physical characterization, and Raman/μ-Raman analysis or Fourier-transform infrared for chemical characterization; Tirkey and Upadhyay, 2021) and control methods which may not be easily accessed and performed by professionals dedicated to biological sampling (i.e. mostly biologists and veterinarians). Thus, it is important to develop studies by multidisciplinary teams composed by professionals and laboratories with complementary skills and facilities from Biological, Veterinary, Chemistry, and Engineering Sciences. This will ensure an end-to-end scientific rigor assessing plastic contamination of waterbirds.

(4) Create opportunities: grant allocations and outreach

Assessment and mitigation of plastic pollution may also be carried out through the allocation of resources and efforts towards research dedicated to this topic, and the awareness of society in relation to the consequences of such contamination. Research funding agencies should allocate specific calls for the assessment of environmental pollution in Brazil, which would be an opportunity to fill in the gaps regarding waterbird contamination as well. Finally, monitoring and communicating through charismatic species (e.g. González-Carman et al., 2021), such as waterbirds, can be an important tool to reach society with messages related to non-generation, reduction, reuse, recycling and treatment of solid waste. Environmentally adequate waste disposal propaganda, as disposed in the Brazilian National Policy on Solid Waste (Federal Law No. 12305/2010), could also benefit from charismatic species.

5. Conclusion

Annual global production of plastic has doubled over the past two decades and plastic waste has more than doubled over the same period, representing an upward trend in plastic consumption (Geyer et al., 2017). Mitigation measures currently in place will not be able to cope with such amount of mismanaged waste (Borrelle et al., 2020). In Brazil, large urban cities located in coastal regions (e.g. Rio de Janeiro, Santos) or along important rivers (e.g. Manaus, São Paulo) are still the main source responsible for plastic leakage into the environment (Associação Brasileira de Empresas de Limpeza, 2021), making Brazil appearing in the top rank of countries contributing to plastics into the oceans (Meijer et al., 2021). In addition, the country's coastline is exposed to pollution from the open ocean, especially from the South Atlantic Ocean (Cozar et al., 2014; Chassignet et al., 2021). Given this scenario, the trend is for plastics to continue being released into aquatic environments and consequently to remain available for interactions with waterbirds.

In this synthesis we highlight significant knowledge gaps in our understanding about waterbird-plastic interactions in Brazil. Given the country's waterbird diversity and vast area covered by aquatic environments, it is imperative that coordinated actions for the diagnosis and monitoring of these interactions are developed and put into practice. Information is not currently available for the majority of species and large regions are still without any information regarding waterbird-plastic interactions. Increasing taxonomic and geographic coverage of research efforts is essential for understanding the issue, its magnitude, and its possible conservation consequences for waterbirds. Finally, these efforts must embrace standard collection and reporting procedures to establish a country-wise baseline and enable future comparisons across space and time in Brazil and internationally.

Authors' contribution (CRediT)

Nicholas W. Daudt: Methodology; Software; Formal analysis; Visualisation; Data curation; Writing - original draft; Writing - review & editing. **Leandro Bugoni:** Conceptualisation; Methodology; Supervision; Writing - review & editing. **Guilherme T. Nunes:** Conceptualisation; Methodology; Supervision; Writing - original draft; Writing - review & editing.

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.

Data availability

Data and code are available in Daudt (2022).

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Appendix A. Supplementary data

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References

Amano, T., Berdejo-Espinola, V., Christie, A.P., Willott, K., Akasaka, M., Báldi, A., Berthinussen, A., Bertolino, S., Bladon, A.J., Chen, M., Choi, C.Y., Kharrat, M.B.D., Oliveira, L.G., Farhat, P., Golivets, M., Aranzamendi, N.H., Jantke, K., Kajzer-Bonk, J., Aytekin, M.K., Khorozyan, I., Kito, K., Konno, K., Lin, D.L., Littlewood, N., Liu, Y., Liu, Y., Loretto, M.C., Marconi, V., Martin, P.A., Morgan, W.H., Narváez-Gómez, J.P., Negret, P.J., Nourani, E., Quintero, J.M.O., Ockendon, N., Oh, R.R.Y., Petrovan, S.O., Piovezan-Borges, A.C., Pollet, I.L., Ramos, D.L., Segovia, A.L.R., Rivera-Villanueva, A.N., Rocha, R., Rouyer, M.M., Sainsbury, K.A., Schuster, R., Schwab, D., Şekercioğlu, H., Seo, H.M., Shackelford, G., Shinoda, Y., Smith, R.K., Tao, S.d., Tsai, M.s., Tyler, E.H.M., Vajna, F., Valdebenito, J.O., Vozykova, S., Waryszak, P., Zamora-Gutierrez, V., Zenni, R.D., Zhou, W., Sutherland, W.J., 2021. Tapping into non-English-language science for the conservation of global biodiversity. PLoS Biol. 19, e3001296 https://doi.org/10.1371/journal.pbio.3001296.

Andrade, M.C., Winemiller, K.O., Barbosa, P.S., Fortunati, A., Chelazzi, D., Cincinelli, A., Giarrizzo, T., 2019. First account of plastic pollution impacting freshwater fishes in the Amazon: ingestion of plastic debris by piranhas and other serrasalmids with diverse feeding habits. Environ. Pollut. 244, 766. https://doi.org/10.1016/j.envpol.2018.10.088.

Andrades, R., Pegado, T., Godoy, B.S., Reis-Filho, J.A., Nunes, J.L.S., Grillo, A.C., Machado, R.C., Santos, R.G., Dalcin, R.H., Freitas, M.O., Kuhnen, V.V., Barbosa, N. D., Adelir-Alves, J., Albuquerque, T., Bentes, B., Giarrizzo, T., 2020. Anthropogenic litter on Brazilian beaches: baseline, trends and recommendations for future approaches. Mar. Pollut. Bull. 151, 110842 https://doi.org/10.1016/j.marpolbul.2019.110842.

Associação Brasileira de Empresas de Limpeza, 2021. Panorama dos resíduos sólidos no Brasil 2020. ABRELPE, São Paulo, SP, Brazil, p. 53.

Azevedo-Santos, V.M., Brito, M.F.G., Manoel, P.S., Perroca, J.F., Rodrigues-Filho, J.L., Paschoal, L.R.P., Gonçalves, G.R.L., Wolf, M.R., Blettler, M.C.M., Andrade, M.C., Nobile, A.B., Lima, F.P., Ruocco, A.M.C., Silva, C.V., Perbiche-Neves, G., Portinho, J. L., Giarrizzo, T., Arcifa, M.S., Pelicice, F.M., 2021. Plastic pollution: a focus on freshwater biodiversity. Ambio 50, 1313–1324. https://doi.org/10.1007/s13280-020-01496-5.

Azevedo-Santos, V.M., Hughes, R.M., Pelicice, F.M., 2022. Ghost nets: a poorly known threat to Brazilian freshwater biodiversity. An. Acad. Bras. Ci. 94, e20201189 https://doi.org/10.1590/0001-3765202120201189.

Baak, J.E., Linnebjerg, J.F., Barry, T., Gavrilo, M.V., Mallory, M.L., Price, C., Provencher, J.F., 2020. Plastic ingestion by seabirds in the circumpolar Arctic: a review. Environ. Rev. 28, 506–516. https://doi.org/10.1139/er-2020-0029.

Barbosa-Filho, R.C., Vooren, C.M., 2009. Monitoramento da avifauna. In: Viana, D.L., Hazin, F.H.V., Souza, M.A.C. (Eds.), O Arquipélago de São Pedro e São Paulo: 10 anos de estação científica. SECIRM, Brasília, pp. 260–268.

Barnes, D.K.A., Walters, A., Gonçalves, L., 2010. Macroplastics at sea around Antarctica. Mar. Environ. Res. 70, 250–518. https://doi.org/10.1016/j.marenvres.2010.05.006.

Barquete, V., Bugoni, L., Vooren, C.M., 2008. Diet of Neotropic cormorant (*Phalacrocorax brasilianus*) in an estuarine environment. Mar. Biol. 153, 431–443. https://doi.org/10.1007/s00227-007-0824-8.

Battisti, C., Staffieri, E., Poeta, G., Sorace, A., Luiselli, L., Amori, G., 2019. Interactions between anthropogenic litter and birds: a global review with a 'black-list' of species. Mar. Pollut. Bull. 138, 93–114. https://doi.org/10.1016/j.marpolbul.2018.11.017.

Bege, L.A.R., Pauli, B.T., 1989. As aves nas ilhas Moleques do Sul, Santa Catarina: aspectos da ecologia, etologia e anilhamento de aves marinhas. FATMA, Florianópolis.

Bergmann, M., Gutow, L., Klages, M. (Eds.), 2015. Marine anthropogenic litter. Springer, Cham, Switzerland.

Bertoldi, C., Lara, L.Z., Mizushima, F.A.L., Martins, F.C.G., Battisti, M.A., Hinrichs, R., Fernandes, A.N., 2021. First evidence of microplastic contamination in the freshwater of Lake Guaíba, Porto Alegre, Brazil. Sci. Total Environ. 759, 143503 https://doi.org/10.1016/j.scitotenv.2020.143503.

Blettler, M.C.M., Abrial, E., Khan, F.R., Sivri, N., Espinola, L.A., 2018. Freshwater plastic pollution: recognizing research biases and identifying knowledge gaps. Water Res. 143, 416–541. https://doi.org/10.1016/j.watres.2018.06.015.

Borrelle, S.B., Ringma, J., Law, K.L., Monnahan, C.C., Lebreton, L., McGivern, A., Murphy, E., Jambeck, J., Leonard, G.H., Hilleary, M.A., Eriksen, M., Possingham, H. P., De Frond, H., Gerber, L.R., Polidoro, B., Tahir, A., Bernard, M., Mallos, N., Barnes, M., Rochman, C.M., 2020. Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. Science 369, 1515–1518. https://doi.org/10.1126/science.aba3656.550.

Browne, M.A., Crump, P., Niven, S.J., Teuten, E., Tonkin, A., Galloway, T., Thompson, R., 2011. Accumulation of microplastic on shorelines worldwide: sources and sinks. Environ. Sci. Technol. 45, 9175–9179. https://doi.org/10.1021/es201811s.

Cardoso, L.G., Bugoni, L., Mancini, P.L., Haimovici, M., 2011. Gillnet fisheries as a major mortality factor of Magellanic penguins in wintering areas. Mar. Pollut. Bull. 62, 840–844. https://doi.org/10.1016/j.marpolbul.2011.01.033.560.

Carlos, C.J., Colabuono, F.I., Vooren, C.M., 2004. Notes on the northern royal albatross *Diomedea sanfordi* in south Brazil. Ararajuba 12, 166–167.

Chassignet, E.P., Xu, X., Zavala-Romero, O., 2021. Tracking marine litter with a global ocean model: where does it go? Where does it come from? Front. Mar. Sci. 8, 667591 https://doi.org/10.3389/fmars.2021.667.
Colabuono, F.I., Vooren, C.M., 2006. Hábitos alimentares de alguns albatrozes e petréis na região sul do Brasil. In: Neves, Tatiana S.T., Bugoni, L., Rossi-Wongtschowski, C.L. D.B. (Eds.), Aves oceânicas e suas interações com a pesca na região sul-sudeste do Brasil. Instituto Oceanográfico—USP, São Paulo, Brazil, pp. 83–102. REVIZEE - Score Sul.
Colabuono, F.I., Vooren, C.M., 2007. Diet of black-browed *Thalassarche melanophrys* and Atlantic yellow-nosed *T. chlororhynchos* albatrosses and white-chinned *Procellaria aequinoctialis* and spectacled *P. conspicillata* petrels off southern Brazil. Mar. Ornithol. 35, 9–20.
Coelho, E.P., Alves, V.S., Soares, A.B.A., Couto, G.S., Efe, M.A., Ribeiro, A.B.B., Vielliard, J., Gonzaga, L.P., 2004. O atobá-marrom (*Sula leucogaster*) na ilha de Cabo Frio, Arraial do Cabo, Rio de Janeiro, Brasil. In: Branco, J.O. (Ed.), Aves marinhas e insulares brasileiras: bioecologia e conservação. UNIVALI, Itajaí, pp. 233–254.
Colabuono, F.I., Barquete, V., Domingues, B.S., Montone, R.C., 2009. Plastic ingestion by Procellariiformes in southern Brazil. Mar. Pollut. Bull. 58, 93–96. https://doi.org/10.1016/j.marpolbul.2008.08.020.570.
Colabuono, F.I., Taniguchi, S., Montone, R.C., 2010. Polychlorinated biphenyls and organochlorine pesticides in plastics ingested by seabirds. Mar. Pollut. Bull. 60, 630–634. https://doi.org/10.1016/j.marpolbul.2010.01.018.
Collard, F., Ask, A., 2021. Plastic ingestion by Arctic fauna: a review. Sci. Total Environ. 786, 147462 https://doi.org/10.1016/j.scitotenv.2021.147462.
Costa, L.N., Nascimento, T.P.X., Esmaeili, Y.S., Mancini, P.L., 2022. Comparing photography and collection methods to sample litter in seabird nests in a coastal archipelago in the Southwest Atlantic. Mar. Pollut. Bull. 175, 113357 https://doi.org/10.1016/j.marpolbul.2022.113357.
Cózar, A., Echevarria, F., Gonzalez-Gordillo, J.I., Irigoien, X., Ubeda, B., Hernandez-Leon, S., Palma, A.T., Navarro, S., Garcia-de-Lomas, J., Ruiz, A., Fernandez-de-Puelles, M.L., Duarte, C.M., 2014. Plastic debris in the open ocean. In: Proceedings of the National Academy of Sciences of the United States of America, 111, pp. 10239–10244. https://doi.org/10.1073/pnas.1314705111.
Daudt, N.W., 2022. Data and code from: 'Plastics and waterbirds in Brazil: a review of ingestion, nest materials and entanglement reveals substantial knowledge gaps and opportunities for research' (v1.0). https://doi.org/10.5281/zenodo.7314740.
Dias, M.P., Martin, R., Pearmain, E.J., Burfield, I.J., Small, C., Phillips, R.A., Yates, O., Lascelles, B., Borboroglu, P.G., Croxall, J.P., 2019. Threats to seabirds: a global assessment. Biol. Conserv. 237, 525–537. https://doi.org/10.1016/j.biocon.2019.06.033.
Driedger, A.G.J., Dürr, H.H., Mitchell, K., van Cappellen, P., 2015. Plastic debris in the Laurentian Great Lakes: a review. J. Great Lake. Res. 41, 9–19. https://doi.org/10.1016/j.jglr.2014.12.020.
Dunnington, D., 2021. ggspatial: spatial data framework for ggplot2. https://CRAN.R-project.org/package=ggspatial. R package version 1.1.5.
Eriksen, M., Lebreton, L.C.M., Carson, H.S., Thiel, M., Moore, C.J., Borerro, 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.
Faria, Girard, P., Nardes, C.S., Moreschi, A., Christo, S.W., Ferreira Junior, A.L., Costa, M. F., 2021. Microplastics pollution in the South American pantanal. Case Stud. Chem. Environ. Eng. 3, 100088 https://doi.org/10.1016/j.cscee.2021.100088.
Fernández-Arellano, G.J., Teixido, A.L., Bernardon, B., Bueno, E.R., Ferreira, T.V., Gonçalves, S.R.A., Jesus, M., Thomas, K.P.C.S., Zucchetto, M., Piacentini, V.Q., Pinho, J.B., 2021. Knowledge gaps and biases in the Pantanal indicate future directions for ornithological research in large wetlands. Ibis 163, 784–797. https://doi.org/10.1111/ibi.12931.
Fernandino, G., Elliff, C.I., Francischini, H., Dentzien-Dias, P., 2020. Anthropoquinas: first description of plastics and other man-made materials in recently formed coastal sedimentary rocks in the southern hemisphere. Mar. Pollut. Bull. 154, 111044 https://doi.org/10.1016/j.marpolbul.2020.111044.
Fonseca, V.S.S., Petry, M.V., Fonseca, F.L.S., 2001. Ocorrência de petrel-azul (*Halobaena caerulea*) no litoral do Brasil. Ornitol. Neotrop. 12, 355–356.
Fraser, L.H., Keddy, P.A., 2005. The world's largest wetlands: ecology and conservation, first ed. Cambridge University Press.
Frota, A.V.B., Vitorino, B.D., Nunes, J.R.S., Silva, C.J., 2020. Main trends and gaps in studies for bird conservation in the Pantanal wetland. Neotrop. Biol. Conserv. 15, 427–445. https://doi.org/10.3897/neotropical.15.e52905.
Gall, S., Thompson, R., 2015. The impact of debris on marine life. Mar. Pollut. Bull. 92, 170–179. https://doi.org/10.1016/j.marpolbul.2014.12.041.
Gallitelli, L., Cesarini, G., Cera, A., Sighicelli, M., Lecce, F., Menegoni, P., Scalici, M., 2020. Transport and deposition of microplastics and mesoplastics along the river course: a case study of a small river in central Italy. Hydrology 7, 90. https://doi.org/10.3390/hydrology7040090.
Garcia, T.D., Cardozo, A.L.P., Quirino, B.A., Yofukuji, K.Y., Ganassin, M.J.M., dos Santos, N.C.L., Fugi, R., 2020. Ingestion of microplastic by fish of different feeding habits in urbanized and non-urbanized streams in southern Brazil. Water, Air, Soil Pollut. 231, 434. https://doi.org/10.1007/s11270-020-04802-9.
Gerolin, C.R., Pupim, F.N., Sawakuchi, A.O., Grohmann, C.H., Labuto, G., Semensatto, D., 2020. Microplastics in sediments from Amazon rivers, Brazil. Sci. Total Environ. 749, 141604 https://doi.org/10.1016/j.scitotenv.2020.141604.
Geyer, R., Jambeck, J.R., Law, K.L., 2017. Production, use, and fate of all plastics ever made. Sci. Adv. 3, e1700782 https://doi.org/10.1126/sciadv.1700782.
Giarrizzo, T., Andrade, M.C., Schmid, K., Winemiller, K.O., Ferreira, M., Pegado, T., Chelazzi, D., Cincinelli, A., Fearnside, P.M., 2019. Amazonia: the new frontier for plastic pollution. Front. Ecol. Environ. 17, 309–310. https://doi.org/10.1002/fee.2071.672.
Gil-Delgado, J., Guijarro, D., Gosálvez, R., López-Iborra, G., Ponz, A., Velasco, A., 2017. Presence of plastic particles in waterbirds faeces collected in Spanish lakes. Environ. Pollut. 220, 732–736. https://doi.org/10.1016/j.envpol.2016.09.054.677.
Gill, F., Donsker, D., Rasmussen, P., 2020. IOC World Bird List. https://doi.org/10.14344/IOC.ML.11.2.
González-Carman, V., Denuncio, P., Vassallo, M., Berón, M.P., Álvarez, K.C., Rodriguez-Heredia, S., 2021. Charismatic species as indicators of plastic pollution in the Río de la Plata estuarine area, SW Atlantic. Front. Mar. Sci. 8, 699100 https://doi.org/10.3389/fmars.2021.699100.
Instituto Brasileiro de Geografia e Estatística, 2011. Atlas geográfico das zonas costeiras e oceânicas do Brasil. Ministério do Planejamento, Orçamento e Gestão, Instituto Brasileiro de Geografia e Estatística–IBGE, Diretoria de Geociências, Rio de Janeiro.
Ivar do Sul, J.A., Costa, M.F., 2013. Plastic pollution risks in an estuarine conservation unit. J. Coast Res. 48–53. https://doi.org/10.2112/SI65-009.1.88539.
Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., Law, K.L., 2015. Plastic waste inputs from land into the ocean. Science 347, 768–771. https://doi.org/10.1126/science.1260352.
Jawad, L.A., Adams, N.J., Nieuwoudt, M.K., 2021. Ingestion of microplastics and mesoplastics by *Trachurus declivis* (Jenyns, 1841) retrieved from the food of the Australasian gannet *Morus serrator*: first documented report from New Zealand. Mar. Pollut. Bull. 170, 112652 https://doi.org/10.1016/j.marpolbul.2021.112652.
Kasavan, S., Yusoff, S., Rahmat Fakri, M.F., Siron, R., 2021. Plastic pollution in water ecosystems: a bibliometric analysis from 2000 to 2020. J. Clean. Prod. 313, 127946 https://doi.org/10.1016/j.jclepro.2021.127946.
Kohlrausch, A.B., 2003. Biologia reprodutiva, comportamento e ecologia de atobás (Sulidae): implicações para a evolução do dimorfismo sexual no tamanho. Ph.D. thesis. Universidade de São Paulo, São Paulo, Brazil.
Konno, K., Akasaka, M., Koshida, C., Katayama, N., Osada, N., Spake, R., Amano, T., 2020. Ignoring non-English-language studies may bias ecological meta-analyses. Ecol. Evol. 10, 6373–6384. https://doi.org/10.1002/ece3.6368.
Krul, R., 2004. Aves marinhas costeiras do Paraná. In: Branco, J.O. (Ed.), Aves marinhas e insulares brasileiras: bioecologia e conservação. UNIVALI, Itajaí, pp. 37–56.
Lacerda, A.L.F., Proietti, M.C., Secchi, E.R., Taylor, J.D., 2020. Diverse groups of fungi are associated with plastics in the surface waters of the Western South Atlantic and the Antarctic Peninsula. Mol. Ecol. 29, 1903–1918. https://doi.org/10.1111/mec.15444.
Li, W., Tse, H., Fok, L., 2016. Plastic waste in the marine environment: a review of sources, occurrence and effects. Sci. Total Environ. 566–567, 333–349. https://doi.org/10.1016/j.scitotenv.2016.05.084.
Mancini, P.L., Serafini, P.P., Bugoni, L., 2016. Breeding seabird populations in Brazilian oceanic islands: historical review, update and a call for census standardization. Rev. Bras. Ornitol. 24, 94–115. https://doi.org/10.1007/BF03544338.
Mariani, D.B., Almeida, B.J., Febrônio, A.D., Vergara-Parente, J.E., Souza, F.A., Mendonça, F.S., 2019. Causes of mortality of seabirds stranded at the northeastern coast of Brazil. Pesqui. Vet. Bras. 39, 523–529. https://doi.org/10.1590/1678-5150-pvb-5812.
Mariano, E.D.F., Targino, C.H., 2012. Ingestão de plástico pelo atobá-mascarado, *Sula dactylatra* Lesson, 1831, na Reserva Biológica do Atol das Rocas, RN, Brasil. Biotemas 25, 285–288. https://doi.org/10.5007/2175-7925.2012v25n4p285.
Martín-Martín, A., Orduna-Malea, E., Thelwall, M., Delgado López-Cózar, E., 2018. Google Scholar, Web of Science, and Scopus: a systematic comparison of citations in 252 subject categories. J. Infometr. 12, 1160–1177. https://doi.org/10.1016/j.joi.2018.09.002.
Meijer, L.J.J., Emmerik, T.v., Ent, R.v.d., Schmidt, C., Lebreton, L., 2021. More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean. Sci. Adv. 7, eaaz5803. https://doi.org/10.7291126/sciadv.aaz5803.
Menezes, R.G., Barbosa-Jr, R., 2021. Environmental governance under Bolsonaro: dismantling institutions, curtailing participation, delegitimising opposition. Z. für Vgl. Politikwiss. (ZfVP) 15, 229–247. https://doi.org/10.1007/s12286-021-00491-8.
Ministério do Meio Ambiente, 2022. Lista nacional de espécies ameaçadas de extinção. Portaria n. 148, de 7 de junho de 2022. Diário Oficial da República Federativa do Brasil, Brasília, DF. Seção 1 (108), 74.
Möller, O.O., Piola, A.R., Freitas, A.C., Campos, E.J., 2008. The effects of river discharge and seasonal winds on the shelf off southeastern South America. Cont. Shelf Res. 28, 1607–1624. https://doi.org/10.1016/j.csr.2008.03.012.
Molleri, G.S., Novo, E.M.M., Kampel, M., 2010. Space-time variability of the Amazon river plume based on satellite ocean color. Cont. Shelf Res. 30, 342–352. https://doi.org/10.1016/j.csr.2009.11.015.
Monteiro, R.C.P., Ivar do Sul, J.A., Costa, M.F., 2018. Plastic pollution in islands of the Atlantic Ocean. Environ. Pollut. 238, 103–110. https://doi.org/10.1016/j.envpol.2018.01.096.
Morritt, D., Stefanoudis, P.V., Pearce, D., Crimmen, O.A., Clark, P.F., 2014. Plastic in the Thames: a river runs through it. Mar. Pollut. Bull. 78, 196–200. https://doi.org/10.1016/j.marpolbul.2013.10.035.
Nascimento, G.D., Pereira, A., Brito, G.R.R., Kolesnikovas, C.K.M., Serafini, P.P., 2022. Prevalência e tipos de plásticos em albatrozes e petréis (Aves: Procellariiformes): recorte espacial da costa sudeste e sul do Brasil, de 2015 a 2019. Biodiv. Bras. 12, 15–24. https://doi.org/10.37002/biobrasil.v12i1.1855.
Nehring, I., Staniszewska, M., Falkowska, L., 2017. Human hair, Baltic grey seal (*Halichoerus grypus*) fur and herring gull (*Larus argentatus*) feathers as accumulators of bisphenol A and alkylphenols. Arch. Environ. Contam. Toxicol. 72, 552–561. https://doi.org/10.1007/s00244-017-0402-0.

Neuwirth, E., 2014. RColorBrewer: ColorBrewer palettes. URL: https://CRAN.R-project.org/package=RColorBrewer. R package version 1.1-2.

Nunes, G.T., Bugoni, L., 2018. Local adaptation drives population isolation in a tropical seabird. J. Biogeogr. 45, 332–341. https://doi.org/10.1111/jbi.13142.

Nunes, G.T., Mancini, P.L., Bugoni, L., 2017. When Bergmann's rule fails: evidences of environmental selection pressures shaping phenotypic diversification in a widespread seabird. Ecography 40, 365–375. https://doi.org/10.1111/ecog.02209.

Nuñez, M.A., Amano, T., 2021. Monolingual searches can limit and bias results in global literature reviews. Nat. Ecol. Evol. 5, 264. https://doi.org/10.1038/s41559-020-01369-w, 264.

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.

Pacheco, J.F., Silveira, L.F., Aleixo, A., Agne, C.E., Bencke, G.A., Bravo, G.A., Brito, G.R.R., Cohn-Haft, M., Maurício, G.N., Naka, L.N., Olmos, F., Posso, S.R., Lees, A.C., Figueiredo, L.F.A., Carrano, E., Guedes, R.C., Cesari, E., Franz, I., Schunck, F., Piacentini, V.Q., 2021. Annotated checklist of the birds of Brazil by the Brazilian Ornithological Records Committee—second edition. Ornithol. Res. 29, 94–105. https://doi.org/10.1007/s43388-021-00058-x.

Pebesma, E., 2018. Simple features for R: standardized support for spatial vector data. R Journal 10, 439–446. https://doi.org/10.32614/RJ-2018-009.674.

Pedersen, T.L., 2020. patchwork: the composer of plots. URL: https://CRAN.R-project.org/package=patchwork. R package version 1.1.1.

Pelicice, F.M., Castello, L., 2021. A political tsunami hits Amazon conservation. Aquat. Conserv. Mar. Freshw. Ecosyst. 31, 1221–1229. https://doi.org/10.1002/aqc.3565.

Petry, M.V., Benemann, V.R., 2017. Ingestion of marine debris by the white-chinned petrel (*Procellaria aequinoctialis*): is it increasing over time off southern Brazil? Mar. Pollut. Bull. 117, 131–135. https://doi.org/10.1016/j.marpolbul.2017.01.073.

Phillips, R.A., Waluda, C.M., 2020. Albatrosses and petrels at South Georgia as sentinels of marine debris input from vessels in the southwest Atlantic Ocean. Environ. Int. 136, 105443 https://doi.org/10.1016/j.envint.2019.105443.

Prado, J.H., Daudt, N.W., Perez, M.S., Castilho, P.V., Monteiro, D.S., (in press). Intensive and wide-ranging beach surveys uncover temporal and spatial stranding patterns of marine megafauna. ICES J. Mar. Sci., doi:10.1093/icesjms/fsac119.

Provencher, J.F., Bond, A.L., Mallory, M.L., 2015. Marine birds and plastic debris in Canada: a national synthesis and a way forward. Environ. Rev. 23, 1–13. https://doi.org/10.1139/er-2014-0039.

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. Anal. Methods 9, 1454–1469. https://doi.org/10.1039/C6AY02419J.

R Core Team, 2021. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: https://www.R-project.org/.

Reynolds, C., Ryan, P.G., 2018. Micro-plastic ingestion by waterbirds from contaminated wetlands in South Africa. Mar. Pollut. Bull. 126, 330–333. https://doi.org/10.1016/j.marpolbul.2017.11.021.

Ribeiro-Brasil, D.R.G, Torres, N.R., Picanço, A.B., Sousa, D.S., Ribeiro, V.S., Brasil, L.S., Montag, L.F.A., 2020. Contamination of stream fish by plastic waste in the Brazilian Amazon. Environ. Pollut. 266, 115241 https://doi.org/10.1016/j.envpol.2020.115241.

Robuck, A.R., Hudak, C.A., Agvent, L., Emery, G., Ryan, P.G., Perold, V., Powers, K.D., Pedersen, J., Thompson, M.A., Suca, J.J., Moore, M.J., Harms, C.A., Bugoni, L., Shield, G., Glass, T., Wiley, D.N., Lohmann, R., 2022. Birds of a feather eat plastic together: high levels of plastic ingestion in great shearwater adults and juveniles across their annual migratory cycle. Front. Mar. Sci. 8, 719721 https://doi.org/10.3389/fmars.2021.719721.

Rossi, L.C., Scherer, A.L., Petry, M.V., 2019. First record of debris ingestion by the shorebird American oystercatcher (*Haematopus palliatus*) on the southern coast of Brazil. Mar. Pollut. Bull. 138, 235–240. https://doi.org/10.1016/j.marpolbul.2018.11.051.

Santos, F.A., Diório, G.R., Guedes, C.C.F., Fernandino, G., Giannini, P.C.F., Angulo, R.J., Souza, M.C., César-Oliveira, M.A.F., Oliveira, A.R.S., 2022. Plastic debris forms: rock analogues emerging from marine pollution. Mar. Pollut. Bull. 182, 114031 https://doi.org/10.1016/j.marpolbul.2022.114031.

Scherer, J.F.M., Scherer, A.L., Petry, M.V., 2011. Ocorrência de carcaças de aves marinhas no litoral do Rio Grande do Sul, Brasil. Rev. Bras. Ornitol. 19, 505–513.

Schmidt, C., Krauth, T., Wagner, S., 2017. Export of plastic debris by rivers into the sea. Environ. Sci. Technol. 51, 12246–12253. https://doi.org/10.1021/acs.est.7b02368.

Schulz-Neto, A., 1998. Aspectos biológicos da avifauna marinha na Reserva Biológica do Atol das Rocas, Rio Grande do Norte, Brasil. Hornero 15, 17–28.

Sick, H., 1997. Ornitologia brasileira. Nova Fronteira, Rio de Janeiro.

Sigler, M., 2014. The effects of plastic pollution on aquatic wildlife: current situations and future solutions. Water, Air, Soil Pollut. 225, 2184. https://doi.org/10.1007/s11270-014-2184-6.

Simon, N., Raubenheimer, K., Urho, N., Unger, S., Azoulay, D., Farrelly, T., Sousa, J., van Asselt, H., Carlini, G., Sekomo, C., Schulte, M.L., Busch, P.O., Wienrich, N., Weiand, L., 2021. A binding global agreement to address the life cycle of plastics. Science 373, 43–47. https://doi.org/10.1126/science.abi9010.

Soares, M., Schiefler, A.F., 1995. Reprodução de *Larus dominicanus* (Aves, Laridae), na Ilhota da Galheta, SC, Brasil. Arq. Biol. Tecnol. 38, 313–316.

South, A., 2017. rnaturalearth: world map data from natural Earth. URL: https://CRAN.R-project.org/package=rnaturalearth. R package version 0.1.0.

Souza, J.J., 2021. Padrões biogeográficos da dieta de *Sula leucogaster* (Suliformes: Sulidae) no Brasil. B.Sc. (Hons). Universidade Federal do Rio Grande do Sul. Imbé, Brazil.

Tanaka, K., Watanuki, Y., Takada, H., Ishizuka, M., Yamashita, R., Kazama, M., Hiki, N., Kashiwada, F., Mizukawa, K., Mizukawa, H., Hyrenbach, D., Hester, M., Ikenaka, Y., Nakayama, S.M., 2020. *In vivo* accumulation of plastic-derived chemicals into seabird tissues. Curr. Biol. 30, 723–728. https://doi.org/10.1016/j.cub.2019.12.037.891.

Tavares, D.C., Costa, L.L., Rangel, D.F., Moura, J.F., Zalmon, I.R., Siciliano, S., 2016. Nests of the brown booby (*Sula leucogaster*) as a potential indicator of tropical ocean pollution by marine debris. Ecol. Indicat. 70, 10–14. https://doi.org/10.1016/j.ecolind.2016.06.005.

Tavares, D.C., 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.2017.04.012.895.

Tavares, D.C., Moura, J.F., Merico, A., 2019. Anthropogenic debris accumulated in nests of seabirds in an uninhabited island in West Africa. Biol. Conserv. 236, 586–592. https://doi.org/10.1016/j.biocon.2019.05.043.

Tavares, M., Alvares, D., Borges-Martins, M., 2021. Spatiotemporal patterns of carrion biomass of marine tetrapods at the ocean-land interface on the southern Brazilian coastline. Mar. Ecol. Prog. Ser. 672, 57–72. https://doi.org/10.3354/meps13812.

Tirkey, A., Upadhyay, L.S.B., 2021. Microplastics: an overview on separation, identification and characterization of microplastics. Mar. Pollut. Bull. 170, 112604 https://doi.org/10.1016/j.marpolbul.2021.112604.

Trevail, A.M., Gabrielsen, G.W., Kühn, S., van Franeker, J.A., 2015. Elevated levels of ingested plastic in a high Arctic seabird, the northern fulmar (*Fulmarus glacialis*). Polar Biol. 38, 975–981. https://doi.org/10.1007/s00300-015-1657-4.

Urbanski, B.Q., Denadai, A.C., Azevedo-Santos, V.M., Nogueira, M.G., 2020. First record of plastic ingestion by an important commercial native fish (*Prochilodus lineatus*) in the middle Tietê River basin, south-east Brazil. Biota Neotrop. 20, e20201005 https://doi.org/10.1590/1676-0611-BN-2020-1005.

van de Crommenacker, J., Soares, J.H., Larose, C.S., Feare, C.J., 2021. Importation of plastic fragments into a seabird colony: accident or design, threat or benign? Bird. Conserv. Int. https://doi.org/10.1017/S0959270921000538.

van Franeker, J.A., Blaize, C., Danielsen, J., Fairclough, K., Gollan, J., Guse, N., Hansen, P.L., Heubeck, M., Jensen, J.K., Le Guillou, G., Olsen, B., Olsen, K.O., Pedersen, J., Stienen, E.W.M., Turner, D.M., 2011. Monitoring plastic ingestion by the northern fulmar *Fulmarus glacialis* in the North Sea. Environ. Pollut. 159, 2609–2615. https://doi.org/10.1016/j.envpol.2011.06.008.

van Sebille, E., England, M.H., Froyland, G., 2012. Origin, dynamics and evolution of ocean garbage patches from observed surface drifters. Environ. Res. Lett. 7, 044040 https://doi.org/10.1088/1748-9326/7/4/044040.

van Sebille, E., Wilcox, C., Lebreton, L., Maximenko, N., Hardesty, B.D., van Franeker, J.A., 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.

Vanstreels, R.E.T., Gallo, L., Serafini, P.P., Santos, A.P., Egert, L., Uhart, M.M., 2021. Ingestion of plastics and other debris by coastal and pelagic birds along the coast of Espírito Santo, eastern Brazil. Mar. Pollut. Bull. 173, 113046 https://doi.org/10.1016/j.marpolbul.2021.113046.

Votier, S.C., Sherley, R.B., 2017. Seabirds. Curr. Biol. 27, R448–R450. https://doi.org/10.1016/j.cub.2017.01.042.

Weitzel, S.L., Feura, J.M., Rush, S.A., Iglay, R.B., Woodrey, M.S., 2021. Availability and assessment of microplastic ingestion by marsh birds in Mississippi Gulf Coast tidal marshes. Mar. Pollut. Bull. 166, 112187 https://doi.org/10.1016/j.marpolbul.2021.112187.

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L.D., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T.L., Miller, E., Bache, S.M., Müller, K., Ooms, J., Robinson, D., Seidel, D.P., Spinu, V., Takahashi, K., Vaughan, D., Wilke, C., Woo, K., Yutani, H., 2019. Welcome to the tidyverse. J. Open Source Softw. 4, 1686. https://doi.org/10.21105/joss.01686.

Wilcox, C., van Sebille, E., Hardesty, B.D., 2015. Threat of plastic pollution to seabirds is global, pervasive, and increasing. Proc. Natl. Acad. Sci. U.S.A. 112, 11899–11904. https://doi.org/10.1073/pnas.1502108112.

Wood, S., 2017. Generalized additive models: an Introduction with R, 2 ed. Chapman and Hall/CRC.

Zarzur, S., 1995. Alimentação e ingestão de plásticos nos Procellariiformes (albatrozes e petréis) encontrados na Praia do Cassino, Rio Grande, RS. B.Sc. (Hons). Universidade Federal do Rio Grande, Rio Grande, Brazil.