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RESEARCH ARTICLE

Terrestrial mammals of the Americas and their interactions with plastic waste

Félix Ayala[1,2] · Martín Zeta-Flores[3] · Sonia Ramos-Baldárrago[4] · Juan Tume-Ruiz[5] · Antia Rangel-Vega[5] · Eddy Reyes[5] · Edgardo Quinde[5] · Gabriel Enrique De-la-Torre[6] · Leticia Lajo-Salazar[7] · Susana Cárdenas-Alayza[1,8]

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Abstract

Plastics have brought many benefits to society, but their mismanagement has turned them into a serious environmental problem. Today, the effects of plastic waste on wildlife are becoming increasingly evident. Since studies on plastic pollution have focused on species in marine ecosystems, here we review current knowledge on interactions between terrestrial mammals and plastic waste in the countries of the Americas, which is a global hotspot of mammalian biodiversity and in turn has, among its member countries, nations with high per capita generations of plastic waste globally. We identified 46 scientific articles documenting plastic ingestion in 37 species and four species that used plastic waste for nest or burrow construction. Of the 46 investigations, seven focused on plastic contamination, while the others reported on the presence of plastics in wildlife, even though this was not the primary focus of the research. However, these publications lack analytical methods commonly used in plastic studies, and only one study applied a standardized methodology for plastic detection. Therefore, in general, plastic pollution research on terrestrial mammals is limited. We extend several recommendations such as designing methodologies that are adapted to terrestrial mammals for the identification of plastics in fecal matter or gastrointestinal contents, carrying out species-specific analyzes on the impacts of plastics in nests or burrows, and giving further attention to this understudied issue and taxa.

Keywords Interaction plastic biota · Nest · Burrows · Macroplastic · Microplastic · Single-use plastics

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✉ Félix Ayala
viridisechura@gmail.com

1 Centro para la Sostenibilidad Ambiental, Universidad Peruana Cayetano Heredia, Lima, Peru

2 Subgerencia de Salud y Medio Ambiente, Municipalidad Provincial de Sechura, Piura, Peru

3 Facultad de Ingeniería de Minas, Universidad Nacional de Piura, Piura, Peru

4 Instituto Científico Michael Owen Dillon, Arequipa, Peru

5 Facultad de Ingeniería Pesquera, Universidad Nacional de Piura, Piura, Peru

6 Grupo de Investigación de Biodiversidad, Medio Ambiente y Sociedad, Universidad San Ignacio de Loyola, Lima, Peru

7 División de Mastozoología, Centro de Ornitología y Biodiversidad (CORBIDI), Lima, Peru

8 Departamento de Ciencias Biológicas y Fisiológicas, Facultad de Ciencias y Filosofía, Universidad Peruana Cayetano Heredia, Lima, Peru

Introduction

Commercially available plastics (synthetic polymers) are widely available and designed in different shapes, sizes, and weights, and tend to be of low cost and massive production (Thompson et al. 2009). They are utilized in multiple industries such as food packaging, medicine, agriculture, and household daily use items (Rivera et al. 2005; Thompson et al. 2009; Hajibabaei et al. 2018; Osman 2022). Improper management of these materials, as well as their use and disposal, has turned them into waste, and they can now be found in soils, air, and water (Welle and Franz 2018; Xu et al. 2020; Xie et al. 2022). It has been estimated that the amount of plastic waste that will be generated in the year 2060 will rise to 265 million metric tons (Lebreton and Andrady 2019). In addition to causing visual pollution, plastic waste causes alterations in biogeochemical cycles and environmental matrices (Sanz-Lázaro et al. 2021; Wang et al. 2021). Plastic wastes are classified according to their size into megaplastics (> 1 m), macroplastics (2.5 cm–1 m), mesoplastics (5 mm–2.5 cm), microplastics (1 - 5,000 μm), and nanoplastics (< 1 μm) (Lippiatt et al. 2013). Their residues are persistent pollutants to degradation, remaining for extended periods of time and potentially affecting biota (van Bijsterveldt et al. 2021; Azevedo-Santos et al. 2021). Given their ubiquity, a diverse suite of organisms interacts with plastic waste in their daily lives (e.g., nesting material), can become entangled, and/or ingest plastic (Jagiello et al. 2019; Kühn and van Franeker 2020; Ayala et al. 2022a).

Plastic pollution is currently considered a major problem and a "global change driver" that has gathered significant public attention (Malizia and Monmany-Garzia 2019). Research has heavily focused on marine environments, while terrestrial ecosystems are being less studied (Malizia and Monmany-Garzia 2019; Bucci et al. 2020; He et al. 2020; Al Malki et al. 2021; Blettler and Mitchell 2021; Nessi et al. 2022; Thrift et al. 2022). In the marine environment, at least 56% of mammal species have been reported to ingest plastic and 69% are affected by entanglements (Kühn and van Franeker 2020). However, to our knowledge, effects on terrestrial mammals are scarce. There are no known studies that collect information on different groups of mammals such as the work of Kühn and Van Franeker (2020) for marine species. However, there are reports collecting specific cases of ruminants (Priyanka and Dey 2018), rodents (Yong et al. 2020; Zolotova et al. 2022), and carnivores in agricultural areas ingesting plastics (Jankowiak et al. 2016).

Given the ubiquitous presence of plastics on land, we believe that interactions between terrestrial mammal species and plastic debris are not well documented (Blettler et al. 2018). In the Americas, there are several countries with high per capita plastic waste generation capacity (e.g., United States, Brazil, Mexico, and Argentina) (Law et al. 2020). In addition, this continent is home to 17% of described mammals and 26.5% of threatened species (Mammal Diversity Database 2022). In this regard, we reviewed the current status of wild terrestrial mammals reported in the Americas in relation to their interaction with plastic pollution. Our objective was to provide an overview of current knowledge on plastic-terrestrial mammal interactions in the Americas, discuss positive or negative impacts, identify knowledge gaps and deficiencies, and, finally, extend recommendations for future researchers toward required studies on the fauna of terrestrial ecosystems in the Americas.

Materials and methods

Scopus and Google Scholar were used from September to November 13, 2022 to search for published literature on interactions in wild mammals involving 1) plastic ingestion, 2) entanglement, and 3) plastic waste used in nests and/or burrows. The search was carried out by a search of relevant keywords such as “Plastic and terrestrial mammals,” “Chiroptera and plastic waste,” “Cingulates and plastic waste,” “Dasyuromorphia and plastic waste,” “Dermoptera and plastic waste,” “Didelphimorphia and plastic waste,” “Eulipotyphla and plastic waste,” “Lagomorpha and plastic waste”, “Paucituberculata and plastic waste,” “Anteaters and plastic waste,” “Primate and plastic waste,” “Rodentia and plastic waste,” “Carnivora and plastic waste,” and “Artiodactyla and plastic waste.” A search was also performed with common names for different species (e.g., bats and plastic waste, monkeys, and plastic waste). In addition, with the identified scientific articles, we filled a database answering the following queries: 1) What type of interaction is most reported? 2) What are the methodologies for plastic detection? 3) What are the most common plastics? For this purpose, theses, reports, conference proceedings, preprints, original articles, and short notes were considered. Documents were also found by consulting the references of previously located articles. Documents were retrieved in English, Spanish, and Portuguese. A PRISMA flow chart according to Moher et al. (2009) was used to represent the information search stages (Fig. 1). If details were available, the reported plastics were sorted by size following Lippiatt et al. (2013).

Results

Identified research spans from 1977 to 2022. A total of 46 documents were identified and divided into 38 original research articles, 5 theses, two conference proceedings, and one preprint paper (Supplementary Table 1). The Journal of Zoology had the most studies on American mammal interactions with plastic waste with 15% ($n = 3$). This was followed by Journal of Mammalogy, Mammalian Biology, Mastozoología Neotropical, Notas Sobre Mamíferos, Science of the Total Environment, and Urban Ecosytems with 4% (i.e., two publications per journal) (Fig. 2). Information on institutions where theses, conference proceedings, and preprints were produced is provided in Supplementary Material.

Records were compiled for the following families and number of species (in brackets): Phylostomidae (17), Canidae (6), Embalonuridae (4), Procyonidae (3), Didelphidae (2), Felidae (2), Sciuridae (2), Ursidae (2), Mormophidae (2), and Octodontidae (1) (see Table 1). Research was most abundant in Brazil and the United States, where there were 16 and 10 papers, respectively (Fig. 3).

What type of interaction is the most reported?

The information collected allowed us to group interactions into two main categories: 1) ingestion of plastics and 2) plastic waste used in burrows or nests. No terrestrial mammals were reported with entanglements. We found 37 species that

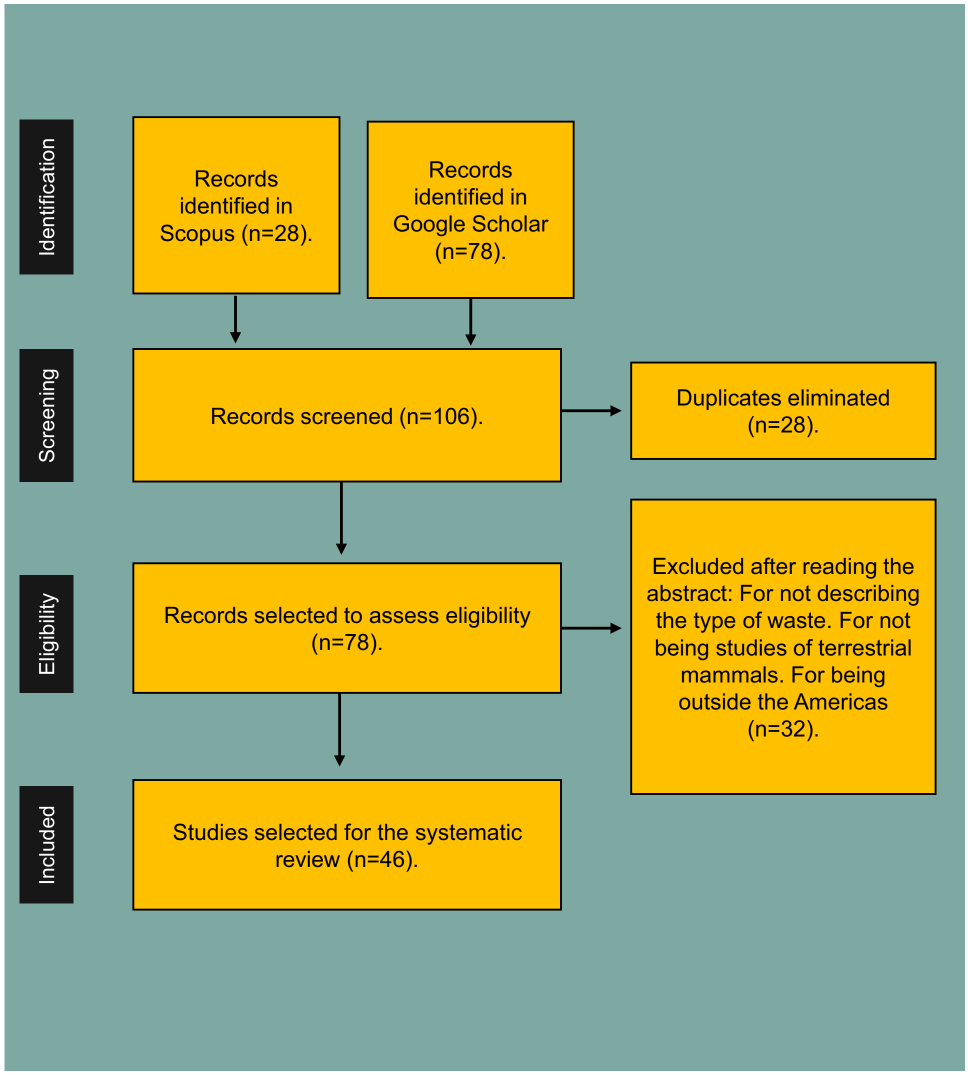

Fig. 1 PRISMA flowchart showing the protocol for locating and selecting papers

ingested plastics, with *Canis latrans* being the most reported species with 13 studies and *Nasua nasua* in second place with six studies. This was followed by *Cerdocyon thous* and *Chrysocyon brachyurus* with four studies each (see Table 1 for details). On the other hand, in the category of nest and/or burrow debris, only four species were reported. These were *Spalacopus cyanus*, *Simosciurus nebouxii*, *Sciurus carolinensis*, and *Didelphis albiventris* with one record for each species (Table 1).

What are the methodologies for plastic detection?

Most of the records are incidental, and their objectives were not focused on the identification of plastic residues. Only 15% (n = 7) of the studies provided details about plastics and discussed their presence in the samples (Supplementary Table 1). Because of this, it was not possible to develop more detailed statistical analyses. Three studies described and discussed the presence of plastics in the diet of *T. ornatus*, *Puma concolor*, and *Cerdocyon thous*, but standardized methodologies or analytical analyses were not employed (Cáceres-Martínez et al. 2015; Bartolucci et al. 2020; Bocchiglieri et al. 2021). Three articles described the presence of plastics in burrows and/or nests in *D. albiventris*, *S. nebouxii*, and *S. carolinensis* (Blettler and Mitchell 2021; Ayala et al. 2022b; Ammendolia et al. 2022). Finally, only one study on the presence of microplastics in 23 bat species used standardized methodologies but lacked analytical methods to confirm the polymeric composition of the suspected plastics (Correia et al. 2022).

What are the most common plastics?

The studies evidenced plastic film, nylon, cigarettes, disposable cups, and disposable masks associated with the Covid-19 pandemic (Supplementary Table 1). However, since the study of plastics was not the main research objective, in most studies, only descriptions of the presence of plastics are available

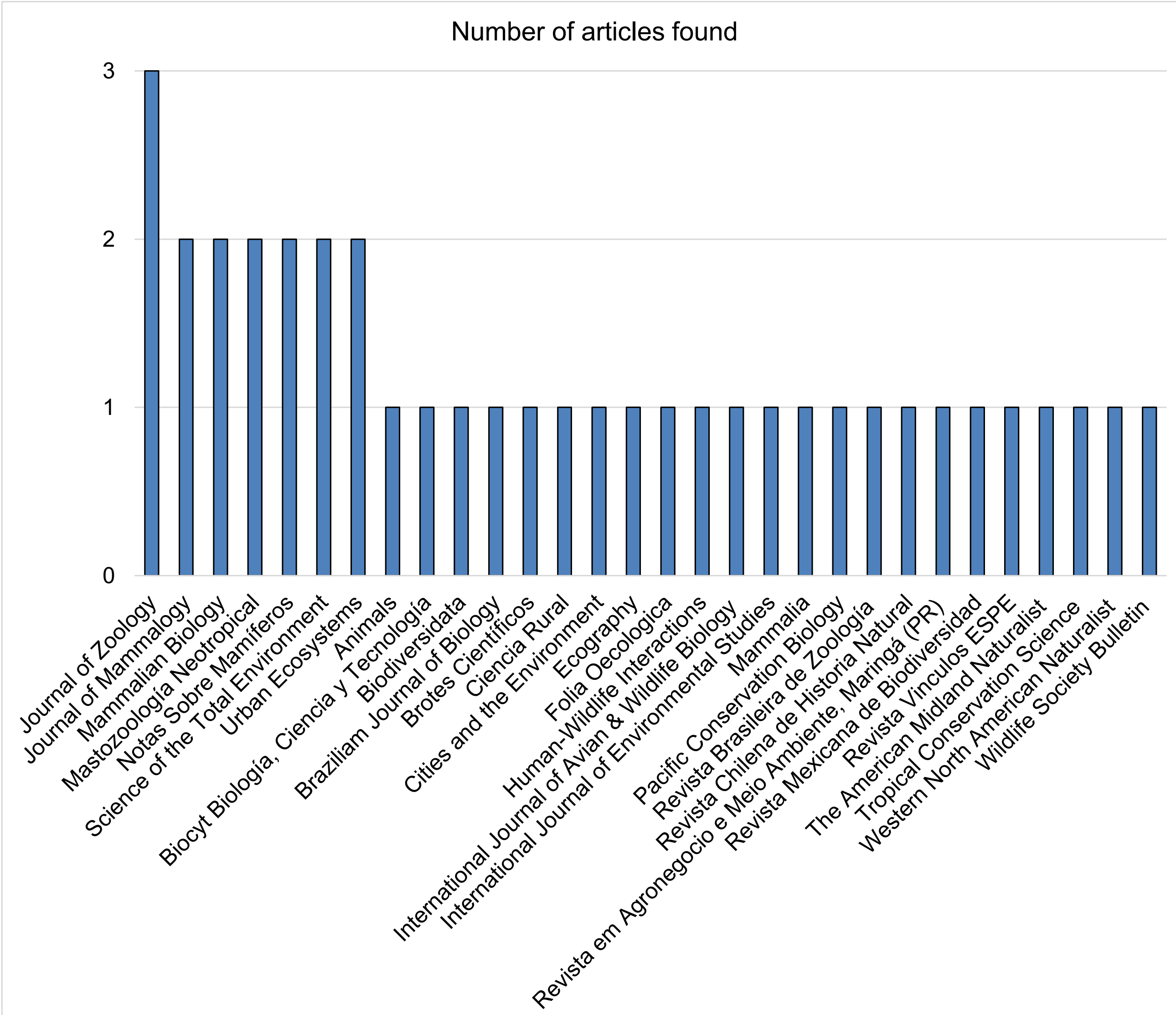

Fig. 2 Journals from which the documents were retrieved. Additional information in the supplementary material

(e.g., Campos 2009; Tirelli et al. 2019). In seven studies, it was possible to determine plastics size when photographs with scales in the figures or size reference of animals was presented. Of these, the identification of macroplastics was possible in six and that of microplastics in one article (supplementary Table 1).

The type of interaction with plastic waste was evaluated for each taxon (Fig. 4). However, since these data are not representative as details are not included in all the publications evaluated, caution is advised.

Discussion

Our review shows that in the Americas, research on interactions with plastic debris in terrestrial mammal is scarce, and that reports were conducted in only 9/35 countries throughout the range. These results do not necessarily mean that this phenomenon does not occur in the other countries of the Americas, but rather that publication efforts to highlight this problem are low. Currently, a large amount of studies focuses on marine environments, while terrestrial ecologists

Table 1 List of species that have interacted with plastic waste in the Americas. Symbol (x) shows records, while symbol (-) indicates no report

Family	Species	Conservation status	Interaction		Reference
			Ingestion	Nest/burrowing	
Canidae	*Canis latrans*	Least concern	x	-	MacCracken 1982, Manning 2007, Morey et al.2007, Lukasik et al. 2008, Grigione et al. 2011, Lukasik et al. 2011, Larson et al. 2015, Murray et al. 2015, Santana and Armstrong 2017, Espinosa-Graciano and García-Collazo 2017, Cypher et al. 2018, Krug 2020, Peterson et al. 2021
	Cerdocyon thous	Least concern	x	-	Montanelli 2001, Cirignoli et al. 2011, Tirelli et al. 2019, Bocchiglieri et al. 2021
	Chrysocyon brachyurus	Near threatened	x	-	Aragona et al., 2001, Silva et al. 2003, Massara et al. 2012, Aximoff et al. 2020
	Lycalopex griseus	Least concern	x	-	Zúñiga et al. 2022
	Lycalopex culpaeus	Least concern	x	-	Beltrán-Ortiz et al. 2017, Jarrín-Porras et al. 2020
	Lycalopex gymnocercus	Least concern	x	-	Birochio 2008, Monteiro et al. 2015
	Lycalopex sp		x	-	García et al. 2018, Fuenzalida et al. 2020
Didelphidae	*Lutreolina crassicaudata*	Least concern	x	-	Facure et al. 2011
	Didelphis albiventris	Least concern	-	x	Blettler and Mitchell 2021
Embalonuridae	*Rhynchonycteris naso*	Least concern	x		Correia et al. 2022
	Saccopteryx bilineata	Least concern	x		Correia et al. 2022
	Saccopteryx leptura	Least concern	x		Correia et al. 2022
	Peropteryx trinitatis	Data deficient	x		Correia et al. 2022
Felidae	*Puma concolor*	Least concern	x	-	Núñez et al. 2000, Gheler-Costa et al. 2018, Bartolucci et al. 2020
	Leopardus tigrinus	Vulnerable	x	-	Campos 2009
Octodontidae	*Spalacopus cyanus*	Least concern		x	Begall and Gallardo 2000
Procyonidae	*Procyon lotor*	Least concern	x	-	Hoffmann and Gottschang 1977
	Nasua Nasua	Least concern	x	-	Montanelli 2001, Alves-Costa et al., 2004, Ferreira et al. 2013, Ambrosio Ferreira 2017, Rodrigues et al. 2021, Rodrigues et al. 2022
	Nasuella olivacea	Near threatened	x	-	Cáceres-Martínez et al. 2015
Sciuridae	*Sciurus carolinensis*	Least concern	-	x	Ammendolia et al. 2022
	Simosciurus nebouxii	Least concern	-	x	Ayala et al. 2022a
Ursidae	*Ursus arctos*	Least concern	x	-	Smith and Lindsey 1989
	Tremarctos ornatus	Vulnerable	x	-	Cáceres-Martínez et al. 2015
Mormophidae	*Pteronotus gymnonotus*	Least concern	x	-	Correia et al. 2022
	Pteronotus rubiginosus	Least concern	x	-	Correia et al. 2022
	Pteronotus sp		x	-	Correia et al. 2022

have overlooked this type of pollution in terrestrial fauna (Malizia and Monmany-Garzia 2019; Bucci et al. 2020; He et al. 2020; Blettler and Mitchell 2021; Nessi et al. 2022; Thrift et al. 2022). Interestingly, reports noted the ingestion of "garbage" or "debris" by terrestrial mammals (Mattson et al. 1991; Dobey et al. 2005), but the term "plastic waste" was not mentioned in those papers. However, it is likely that these animals also ingested plastic. We recommend that future diet studies employ the terminology "plastic waste" ingestion and not overlook such details in determining interactions with other mammalian species.

The species that ingested the most plastics were *C. latrans* and *N. nasua*. In the case of *C. latrans*, these species are opportunistic predators and approach human settlements. Foraging behaviors in close proximity to urban areas for these species include inspecting garbage cans or ingesting food scraps in plastic containers, which increases the likelihood of plastic ingestion (Morey et al. 2007; Larson et al. 2015; Santana and Armstrong 2017; Krug 2020). *N. nasua* are omnivores and have a varied diet that includes fruits, vertebrates, and invertebrates, and opportunistically take advantage of anthropogenic foods in areas where people

Table 1 (continued)

Phylostomidae	*Carollia brevicauda*	Least concern	x	-	Correia et al. 2022
	Carollia perspicillata	Least concern	x	-	Correia et al. 2022
	Lonchorhina aurita	Least concern	x	-	Correia et al. 2022
	Lophostoma silvicola	Not included	x	-	Correia et al. 2022
	Phyllostomus discolor	Least concern	x	-	Correia et al. 2022
	Phyllostomus elongatus	Least concern	x	-	Correia et al. 2022
	Phyllostomus hastatus	Least concern	x	-	Correia et al. 2022
	Tonatia bidens	Data deficient	x	-	Correia et al. 2022
	Rhinophylla fischerae	Least concern	x	-	Correia et al. 2022
	Artibeus lituratus	Least concern	x	-	Correia et al. 2022
	Artibeus gnomus	Least concern	x	-	Correia et al. 2022
	Artibeus obscurus	Least concern	x	-	Correia et al. 2022
	Artibeus cinereus	Least concern	x	-	Correia et al. 2022
	Sturnira lilium	Least concern	x	-	Correia et al. 2022
	Sturnira tildae	Least concern	x	-	Correia et al. 2022
	Uroderma bilobatum	Least concern	x	-	Correia et al. 2022
	Uroderma magnirostrum	Least concern	x	-	Correia et al. 2022

congregate (Ferreira et al. 2013). This species has been observed to ingest plastic wrappers with food debris (Montanelli 2001), a probable reason why plastics are found in fecal samples (Alves-Costa et al. 2004; Ferreira et al. 2013; Ambrosio Ferreira 2017; Rodrigues et al. 2021, 2022). However, elements such as metals, glass, threads, latex, and paper have also been recorded, suggesting sustained foraging on human waste residues (Rodrigues et al. 2022). The specific effects of plastic ingestion on coatis are so far unknown but should be studied further (Rodrigues et al. 2022).

Species of the family Canidae such as *C. thous* and *C. brachyurus* presented four records of plastic ingestion per species, although information regarding polymer composition or types of plastics is scarce in these studies. For example, for *C. thous,* only in two studies it was possible to identify plastics in fecal samples as plastic films (Cirignoli et al. 2011; Bocchiglieri et al. 2021). The other studies present only one description (Montanelli 2001; Tirelli et al. 2019). On the other hand, in *C. brachyurus*, the samples presented a plastic film (Aximoff et al. 2020). The other studies lack details (Aragona et al. 2001; Silva et al. 2003; Massara et al. 2012). Because the objectives of these investigations do not focus on the identification of plastics, it is likely that smaller plastics such as microplastics have gone unnoticed. In other studies focused on solid waste in canid fecal samples, the incidence in the samples was low; however, these studies were on arctic foxes (*Vulpes lagopus*), a species that inhabits sparsely anthropized areas and inspects waste when natural food is scarce (Hallanger et al. 2022; Technau et al. 2022). The information available in the Americas does not allow us to determine whether plastics present in fecal samples are determined by their feeding grounds linked to urban areas given the paucity of data. However, in pachyderms, up to 32% of the fecal samples analyzed had plastics associated with human-modified habitats where plastic waste was improperly dumped (Katlam et al. 2022).

The only species that had standardized analyses for the detection of plastics (microplastics) were bats. Microfibers smaller than 5 mm were detected in the digestive and respiratory tracts of Brazilian species (Correia et al. 2022). Currently, to our knowledge, only microplastics have been examined in UK bats (Arnold et al. 2022). The hypothesis is that microplastics reach bats through their diet and through suspended microplastics during foraging (Arnold et al. 2022; Correia et al. 2022). The technique of Correia et al. 2022 was the only one in the ingestion category that applied cervical dislocation. The other studies in this category detected plastic debris in feces. However, in this group, microplastics have also been detected through fecal analysis. so they are proposed as biomonitors of plastic contamination (Arnold et al. 2022). Other studies on terrestrial mammals have seen an effective use of mammalian waste organic matter for the detection of plastic particles (Gallitelli et al. 2022; Thrift et al. 2022; Toto et al. 2023). This implies its applicability to future studies on plastic waste pollution in terrestrial mammals.

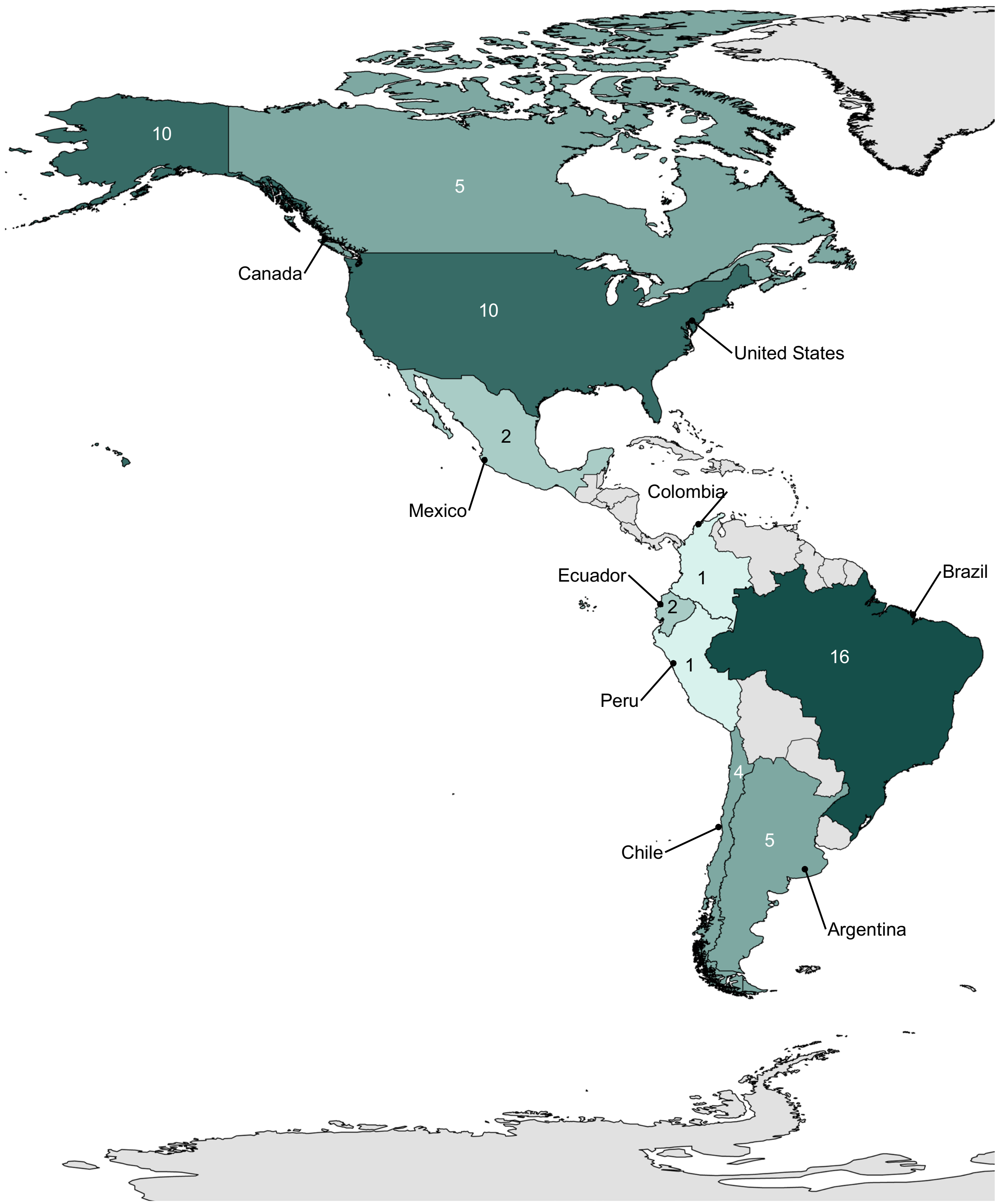

Fig. 3 Number of registrations in the countries of the Americas

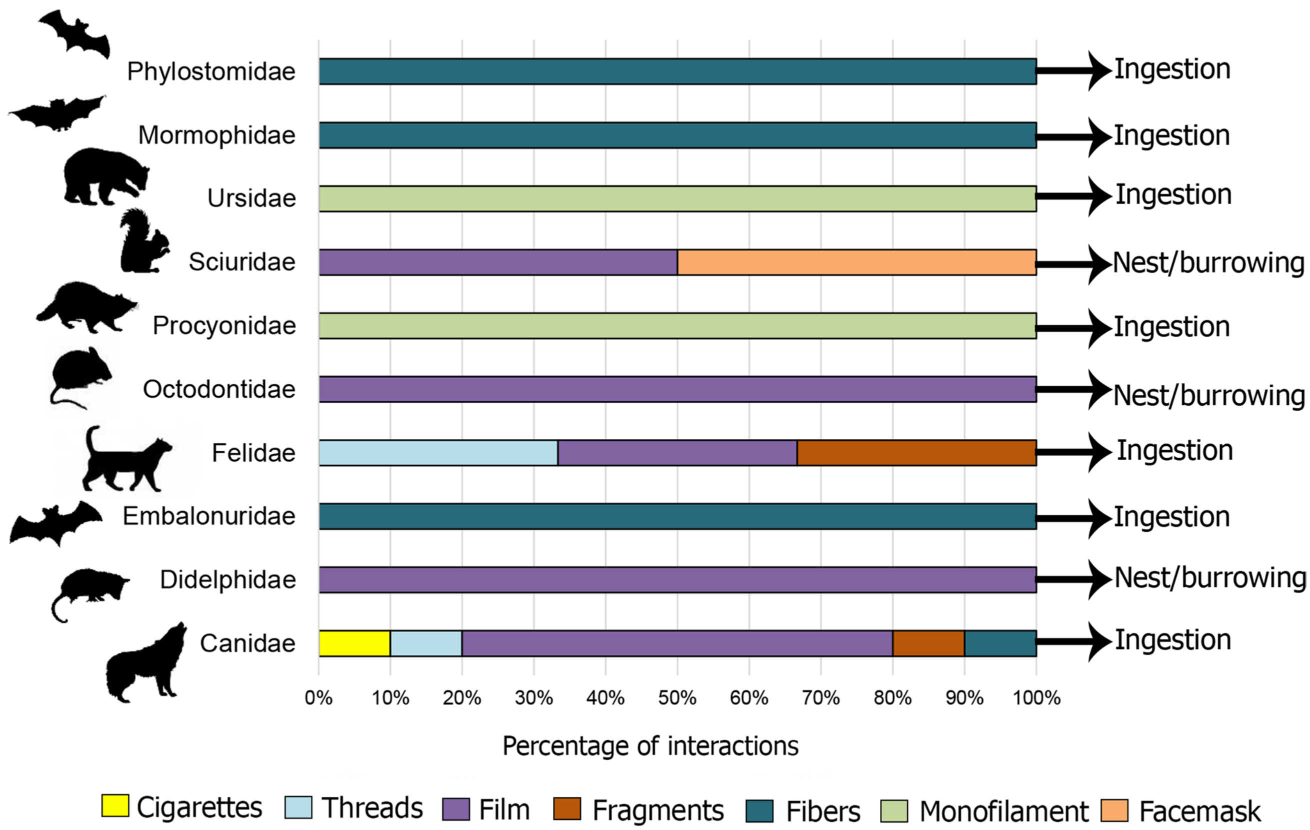

Fig. 4 Types of waste with which mammals interacted

In ruminants such as Artiodactyla, ingested plastic is trapped in the rumen and does not reach the feces, which can lead to death and can only be detected by necropsy (Kumar and Dhar 2013). However, in our search, plastic ingestion was not reported through necropsies. Considering that this type of contamination in specific cases can be detected by post-mortem evaluation, studies on dead animals could help to reveal the types of plastics consumed. In camels, plastic bezoars (i.e., clumps of bags, ropes, and other plastic materials) have been detected in the stomachs of at least 300 individuals (Eriksen et al. 2021).

Furthermore, four species were recorded with residues in burrows or nests. Two species were native to South America (*D. albiventris* and *S. nebouxii*), one species was native to North America (*S. carolinensis*), and one species was endemic specifically to Chile (*Spalacopus cyanus*). In three of these species, details on the use of plastics have been provided (Blettler and Mitchell 2021; Ayala et al. 2022b; Ammendolia et al. 2022). Only one of these studies mentions plastics in burrows (Begall and Gallardo 2000). The family Sciuridae is the only one with more than one study on plastics in nests (Ayala et al. 2022b; Ammendolia et al. 2022). The use of plastic waste in nests or burrows is a recently reported problem, and it is unknown whether plastic use may have short or long-term harm to mammal survivorship (Mohan and Singh 2018; Ayala et al. 2022b). Single-use plastic bags were the predominant materials in the nests of the two South American mammal species (*D. albiventris* and *S. nebouxii*) (Blettler and Mitchell 2021; Ayala et al. 2022b). In birds, it has been hypothesized that plastic bags in nests could cause embryo mortality by increasing temperature (Blettler et al. 2020). Thus, in mammals, the use of plastics could also be preferred by species if these materials for structural or providing cushioning in nests, making them more comfortable. However, preference of plastic types by species, location, and plastic waste availability (e.g., mapping distance to dumping sites) would help understanding if increased use is related to material preference or resource availability. In addition, new waste materials such as Covid-19-associated face masks have recently been incorporated into squirrel nests (Ammendolia et al. 2022). Finally, plastics may have endocrine-disrupting chemicals such as bisphenol-A (BPA), associated with reproductive damage in humans (Kawa et al. 2021) and induction of carcinogenesis, as reported in animal models (Ma et al. 2019). In addition, larger plastics can degrade into microplastics and be ingested (Thrift et al. 2022) and reach the bloodstream (Leslie et al. 2022). Therefore, it is necessary to assess the toxicological impact of plastics on terrestrial mammals according to plastic types and species to understand the level of this problem for wildlife health.

We expected to find American land mammals in the entanglement category, but this has not been identified in the studies consulted. This is striking given the high incidence of entanglements in marine ecosystems (Battisti and Gippoliti 2018; Jepsen and de Bruyn 2019; Donnelly-Greenan et al. 2019; Høiberg et al. 2022; Rodríguez et al. 2022; Battisti et al. 2023). However, bears with plastic feeders around their necks have been observed in social networks (MyFWC 2021). Social networks are good tools for detecting plastic pollution in wildlife (Ayala et al. 2023). Future studies using iEcology (Jarić et al. 2020) could further address this problem in terrestrial mammals.

Citizen science was also used to identify wildlife interacting with plastic waste (Blettler and Mitchell 2021). Although the study identified mostly continental birds, there were two mammal species that made use of plastic: one was *D. albiventris* using plastic bags in burrows and the other species was *Thylamy ssp.* inside a bottle apparently using it as a shelter (Blettler and Mitchell 2021). The latter species was not considered in our review because it did not fall into the categories of ingestion or nest waste. Citizen science has also recently been employed in the study of microplastics in fecal samples of small mammals in the UK (Thrift et al. 2022). In addition, one study used social media to collect records of different animal groups that had interacted with Covid-19-associated debris (Ammendolia et al. 2022). In the aforementioned study, we did not consider a record of *Ursus arctos horribilis* because it was in a different category than in our review.

Among the species identified with interactions, we were able to identify two species listed as vulnerable (*Tremarctosornatus* and *Leopardus tigrinus*) under IUCN Red List of Threatened Species (Table 1). However, we cannot confirm the potential effects of plastic on these endangered species given the limited information available. Future reports should include as much information as possible to assess level of potential damage by plastic waste (gastrointestinal perforation or obstruction, entanglement). Also, analysis of the plastics by spectroscopic methods (e.g., FTIR spectroscopy) will allow researchers to understand the possible sources of contamination and propose management measures based on this information.

Conclusions and future directions

From our study, we conclude that the incidence potential detrimental effects of plastic waste on terrestrial mammals in the Americas are currently unknown. Although some occasional records of wildlife ingesting plastics and using single-use plastic bags to build nests or burrows, records remain scarce. In the case of plastic waste in nests and/or burrows, not much has been studied and some of the key questions that remain include: Does the use of plastics help maintain an adequate temperature in low-temperature conditions? Does the use of plastics prevent conflicts with conspecifics or help avoid predators? Is there a preference for the choice of certain plastic materials in nests? What will be the toxicological effects of the use of plastics in nests? Does the choice of plastics occur mainly because of the scarcity of natural resources or high availability of plastic material? As these research efforts develop, future studies should aim to identify plastics and standardize detection protocols to be able to compare across taxa to 1) understand the magnitude of this problem, 2) pinpoint sources of contamination, and 3) recommend management actions (Zantis et al. 2021).

Interaction with plastics is a widely reported problem in marine ecosystems but has been documented in only a few countries in the Americas with terrestrial ecosystems albeit the existence of an established scientific research community. Thus, terrestrial researchers should also focus their attention on the impact of plastic waste, as this is where the greatest plastic loads occur (Jambeck et al. 2015). The study of plastic waste in terrestrial environments lands on at least five of the United Nations Sustainable Development Goals (Malizia and Monmany-Garzia 2019), making it an important topic on the global agenda that needs to be better addressed. Finally, given the increase of human settlements in previously undeveloped areas, we predict that terrestrial mammal interactions with plastic waste will increase in the near future, reason why efforts to adequately address this issue calls for prompt research and management actions in terrestrial ecosystems.

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Declarations

Conflict of interest The authors declare no competing interests.

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