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Ingestion of anthropogenic particles by wild birds from urban riparian habitats

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ABSTRACT

Plastic contamination is a recognised widespread threat to the environment, but exposure of wildlife to plastic particles has been studied mostly in marine habitats. However, plastics are mainly produced inland and carried by freshwater systems to the ocean, while also moving between aquatic and terrestrial environments. Given this, we used common bird species belonging to different dietary and foraging niches, captured in urban and sub-urban riparian areas, as indicators of exposure to anthropogenic particles, including plastics, in freshwater systems. We aimed to assess the prevalence of anthropogenic particles across different species and evaluate whether observed differences were associated with dietary preferences, foraging substrates, and urbanisation. We collected faeces from six bird species, in sixteen locations along an urbanisation gradient in Coimbra city, Portugal, during the 2024 breeding season. Anthropogenic-origin suspected particles were found in 68 out of 159 faecal samples (42.7%), and thrushes, in particular the song thrush (*Turdus philomelos*), showed the highest prevalence and abundance. Suspected particles were mainly filaments (37%) and fibres (23%), followed by fragments (21%) and pellets (15%), and most were blue (55%). There were no significant relationships between soil imperviousness and population density with the abundance of particles in the faecal samples of birds. Twenty-one percent of the successfully chemically characterised particles by micro-Fourier Transform Infrared Spectroscopy were plastic (11.5% of the suspected particles). Thrushes can be used as useful indicators of anthropogenic particle contamination in urban environments.

1. Introduction

Plastic pollution is a pervasive and increasing threat to ecosystems, constituting a global concern (Sutherland et al., 2010; Vaid et al., 2024) due to its continuous production, incorrect disposal, and persistence in the environment (Jambeck et al., 2015). While many studies have evaluated plastic contamination and its effects on aquatic systems, especially marine ecosystems (Blettler et al., 2018; Granek et al., 2020; Kanwal et al., 2025), comparatively few have done so in terrestrial (Chae and An, 2018; Richard et al., 2024) and freshwater (Ben Tanfous et al., 2026; Blettler et al., 2018; Mansfield et al., 2024) ecosystems. Most available literature regarding avifauna focuses on marine birds, and their exposure and ingestion of plastics in coastal and pelagic ecosystems. Terrestrial birds' interactions with plastic have been mostly reported regarding their use as alternative nesting material (Girão et al., 2024; Jagiello et al. 2019, 2022, 2023). Relatively few studies have evaluated the ingestion of plastics by terrestrial birds (Elias et al., 2026; Wang et al., 2021 and references therein), and those that have done so focused mainly in raptors (Elias and Corbin, 2025) and some waterfowl (Heim et al., 2025; Holland et al., 2016), with passerines being less studied (Zeng et al., 2025). Among the available studies in terrestrial birds, several resulted from examination of birds that were in recovery centres (Carlin et al., 2020; Zhao et al., 2016) and might have entered due to problems derived from plastic ingestion (e.g. emaciation due to

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obstruction of digestive tract) which could overestimate the prevalence or intensity of microplastic loads.

Recent research highlights birds from the *Turdus* genus, such as the Eurasian blackbird (*Turdus merula*) and the song thrush (*Turdus philomelos*) as important microplastic (MP, plastic particles less than 5 mm (Bessa et al., 2019)) pollution sentinels, because of their strong ground-foraging behaviour and widespread presence across many landscapes (Deoniziak et al., 2022; Tarricone et al., 2024). In the study by Deoniziak et al. (2022), 100% of the analysed blackbird and song thrush specimens from Poland were found to contain microplastics in their gut, mostly fibres and films under 1 mm in size. Insectivorous birds have also been found to ingest microplastics, probably due to contamination of their prey, and suggesting trophic transfer from insects (Hoang and Mitten, 2022). This indicates widespread exposure, even in relatively non-urbanised areas and that common songbirds could help monitor environmental contamination.

Rivers and streams constitute an important connection between terrestrial environments (that act as a source of major plastic contamination) and the ocean (a major sink; Lebreton et al., 2017; Zeng et al., 2025), thus it is important to evaluate the exposure of wildlife inhabiting these ecosystems to plastic pollution, as they can act as indicators and natural environmental samplers. Cities, which are continuously increasing due to human population growth (Sanderson et al., 2018; Steffen et al., 2007) are important sources of several contaminants, including plastics. Main sources of microplastic pollution into freshwater systems are considered to be direct sewage effluents, discharge from wastewater treatment plants, leakage from landfills, and plastic production sites (Eerkes-Medrano et al., 2015). Small streams within cities are the primary interface between land, where plastic is used and discarded into the environment, and drainage networks. To fully understand the existence and abundance of microplastics in the ocean, we need to understand their transportation pathways and land-based sources (Talbot and Chang, 2022); therefore, assessing and characterising the contamination by plastics in small streams is essential, since they are a widespread form of drainage network that connects urban runoff to rivers and oceans. Besides that, it was highlighted that microplastic concentrations in small streams are as large as in larger systems (Dikareva and Simon, 2019). Wildlife inhabiting these environments is likely vulnerable to threats related to plastic contamination.

In this study, we evaluated plastic exposure via ingestion in common wild birds inhabiting different urban and sub-urban streams in Coimbra, Portugal. These streams differed in their level of urbanisation assessed through the degree of soil imperviousness and population density around the sampling sites. Additionally, we assessed the prevalence of anthropogenic particles across different species to evaluate whether observed differences were associated with dietary preferences and foraging substrates. All these traits may affect if and how much plastics are ingested by birds (Elias and Corbin, 2025), and given the relatively low amount of information on plastic ingestion in terrestrial ecosystems, especially for passerine birds, it is important to evaluate a diverse array of species using the same habitat to understand the species ecological characteristics that might influence their microplastic loading, and the potential sources of contamination (Elias and Corbin, 2025). We predict that there will be a positive relationship between the degree of urbanisation and the prevalence and intensity of anthropogenic particles in the faeces of birds (Klein et al., 2015) although local-scale factors related to the stream characteristics and the integrity of the ecosystem may be especially relevant in comparison with large-scale processes in determining microplastic pollution in small streams (Dikareva and Simon, 2019). We also predict that the anthropogenic particles prevalence and load will be different among bird species, and that the birds foraging habits will affect microplastic exposure, with omnivorous ground dwelling birds such as thrushes (Deoniziak et al., 2022) being more exposed to plastic contamination than species from other foraging guilds (Baum et al., 2026; Moreira et al., 2026).

2. Methods

2.1. Sample collection

During June and July 2024, we captured birds using mist nets in 16 streams in the city of Coimbra, Portugal (Fig. 1). Mist nets were deployed before sunrise and were operated during approximately 5 h without any luring. We collected samples from several bird species representing different ecological characteristics: i) thrushes (*T. merula* and *T. philomelos*) were included because of their reported potential as indicators of terrestrial microplastic pollution (Deoniziak et al., 2022), ii) European robins (*Erithacus rubecula*), Eurasian blackcaps (*Sylvia atricapilla*) and house sparrows (*Passer domesticus*) given their ubiquity and their different foraging strategies and diets (Cramp and Simmons, 1977; Wilman et al., 2014); and iii) the kingfisher (*Alcedo atthis*) as a bioindicator of freshwater environments (Wu et al., 2020). These bird species represent two orders within the class Aves and, therefore, different phylogenetical proximity: Passeriformes, and Coraciiformes - represented by the kingfisher. Together, these species provide an opportunity to investigate microplastic exposure across birds occupying different ecological niches. Captured birds belonging to these target species were removed from the mist nests and placed individually inside a paper bag, which was then placed inside a white cotton bag. We purposefully used bags made of white cotton, a natural material, to decrease the probability of any particles that could contaminate the faeces, to be confused with anthropogenic materials, especially synthetics and plastic. The birds remained there for at least 10 min and were then carefully removed from the bags, which were visually inspected for the presence of faeces inside. Faeces were collected with tweezers, previously cleaned with ethanol-soaked cotton and air-dried, into a microtube and refrigerated until arriving at the laboratory, where they were stored at −80°C. Moreover, birds were ringed and measured, including their body mass, with a Pesola to the nearest 0.1g, and their wing (to the nearest 0.5 mm) and tarsus length (to the nearest 0.1 mm).

Each sampled stream was characterised according to its human population density and soil impervious surface area. Public databases were used to obtain population density (Eurostat, 2023) and imperviousness density (EEA, 2020) across a circular buffer zone of 500 m radius (geodesic distance) around each sampling site. Spatial data were projected to ETRS 1989 LAEA (Lambert Azimuthal Equal-Area) projection, to ensure accurate calculations of area and distance. Population density (population/km^2) within each buffer zone was derived as the weighted mean within each buffer, the weighting based on the proportion of each local administrative unit's area that intersected the buffer. Imperviousness density was extracted to each buffer as the weighted average of the raster data using the raster cells area as the weight using the "*exactextractr*" package (in R version 0.10.0, Baston, 2024).

2.2. Faecal sample treatment and anthropogenic particle analysis

Faeces were thawed and weighed to the nearest 0.0001g. Then, they were hydrated with (1:1) filtered distilled water, and organic material was digested by adding three times the volume of 10% KOH to the glass container, which was covered with a Petri dish and was placed on an agitator for 24 h following (Bessa et al., 2019). After digestion, filtration was performed through a microfiber glass filter disk of 1.2 μm pore (Branchia, Labbox). After filtration, the filter was placed on a Petri dish and dried in a drying oven at 30°C.

Visual analysis of the filters was conducted under a stereomicroscope equipped with a camera. Anthropogenic origin suspected particles were measured and categorized according to size as large microparticles (LMPP, 5 mm to 1 mm) and small microparticles (SMPP, 1 mm to 1 μm; Galgani et al., 2023). Particles were classified in relation to their shape as fragments, fibres, filaments, microbeads, pellets, and rubber according to Bessa et al., (2019). No film or sponge/rubber-like particles were detected. The colour classification included blue, green, black, purple,

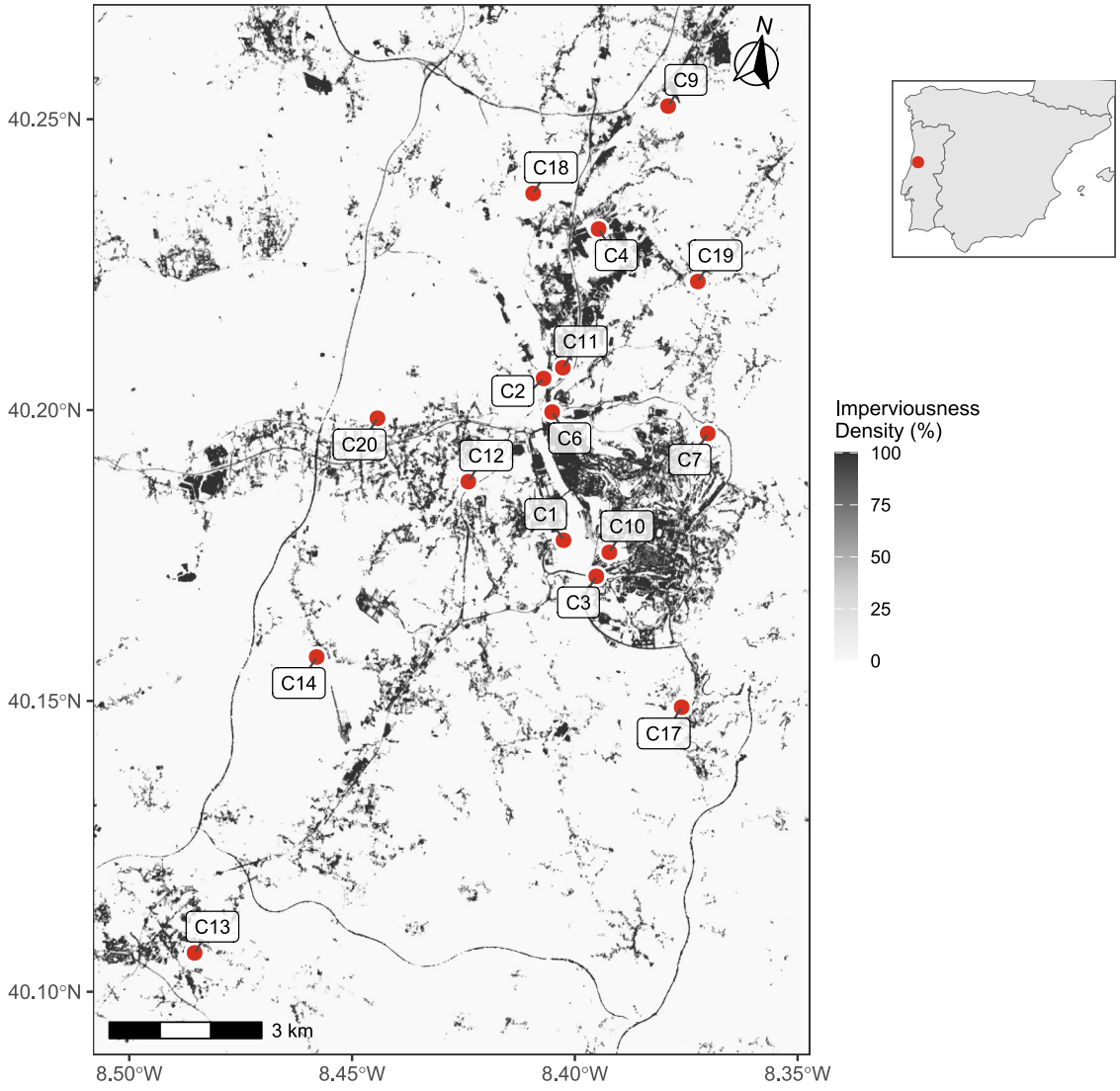


Fig. 1. Sampling locations of wild birds in Coimbra, Portugal, urban and sub-urban riparian areas. Copernicus Imperviousness Density layer is included as the background. Sampling sites are plotted in red. For further details please see the Methods section. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

transparent, white, yellow, red, orange, and brown. The suspected particles were counted and photographed.

A subset of the suspected particles detected was then isolated for analysis through micro-Fourier Transform Infrared Spectroscopy (μFTIR), in the mid-IR range (800–4000 cm $^{-1}$), at the vibrational spectroscopy laboratory of the Molecular Physical-Chemistry, LAQV/Requimte @ University of Coimbra (Portugal). Particles representing different types and colours, illustrating the diversity found in the samples, were considered for μFTIR analysis. However, particles ≥ 100 μm were preferentially analysed due to methodological constraints related to manual sample manipulation (i.e. manual transfer to the μFTIR instrument), because smaller particles could not always be reliably manipulated and transferred without risk of loss or contamination (minimum particle size analysed was 140 μm). Because of these technical constraints, this characterisation means to represent an illustrative qualitative screening of a variety of the largest suspected-anthropogenic particles found, rather than an estimation of the percentage of plastic particles in the parent population of samples. The acquisitions were performed using a Bruker Hyperion 2000 microscope (Bruker Optik, GmbH, Ettlingen, Germany), in either transmittance or reflectance mode depending on the type of sample, with a 15× Cassegrain objective and condenser, coupled to a Bruker Optics Vertex 70 FTIR spectrometer (Bruker Optik GmBH, Ettlingen, Germany). A liquid nitrogen-cooled wideband mercury cadmium telluride (MCT) detector and a Ge and KBr substrate beamsplitter were used. The entire system was purged by CO_2-free dry air. For each sample, the observation was delimited by a knife-edge aperture adjusted to the sample size. Each spectrum corresponds to the average of 128 scans (for both sample and background) at 4 cm^{-1} resolution. Pre-processing of the spectra was performed with the Bruker OPUS Spectroscopy Software (8.1 version) (baseline correction) and OriginPro 9.1 software (normalization relative to the most intense band).

The spectra were compared with an online database (Cowger et al., 2025) and using Spectragryph (ver. 1.2, https://www.effemm2.de/spectragryph/), by comparison with the spectral library database BASEMAN developed by Primpke et al. (2018) for identification. A percentage match ≥70% was considered and accepted in accordance with the highest agreement value. Particles were categorized by plastic and polymer type, natural (when spectra only matched natural items (e.g., chitin or hemp/cellulose without obvious dye), anthropogenic with natural base (had a match with natural fibres but were visibly identified as a dyed fibre), unknown (where a match was unsuccessful for natural

and synthetic items), or contamination from collection materials (matched spectra retrieved from cellulose bags used to keep the birds during ringing procedures Sherlock et al. (2022).

2.3. Quality assurance and quality control (QA/QC)

Quality and control measures were taken: throughout the laboratory work, gloves, cotton lab coats, and metal instruments were consistently used when handling samples. All surfaces and instruments were cleaned beforehand with ethanol. For every group of 15–20 samples, a control filter was included and accompanied the entire process of extraction, digestion, and drying. Additionally, another control filter was used within the same sample group during visual observation of microplastics under magnification at the stereomicroscope.

Suspected particles observed in samples were considered contaminants and excluded from further analyses when they: (a) were loosely deposited on the filter surface rather than embedded within or adhered to the filtered material, (b) displayed intense and uniform colouring, (c) showed no visible signs of environmental weathering, abrasion, fraying, or deformation which are commonly observed in particles exposed to environmental and biological processes (Zhang et al., 2026; Prabhu et al., 2024), and/or (d) had similar morphology, colour, and size to particles recorded in laboratory blank controls or identified as originating from the paper bags used for sample collection (in this specific work).

2.4. Statistical analyses

For each species, we computed the frequency of occurrence of anthropogenic particles, i.e., the proportion of individuals with anthropogenic debris in their faeces (hereafter called prevalence), and the mean particle abundance in faeces (mean number of particles per faecal sample, including those that did not contain suspected particles).

The probability of detecting a suspected particle was related to faeces weight using a logistic regression. Also, the number of suspected particles was related to faeces weight using a linear regression; only faeces where at least one suspected particle was detected were used in this analysis. The probability of occurrence of suspected particles in the faeces of different bird species, bird genera, dietary groups, and groups of birds foraging in different substrates was compared using a Fisher's Exact test. The abundance of suspected particles was compared between bird species, dietary groups, and foraging substrate using a Kruskal-Wallis test followed by Wilcoxon post hoc comparisons. The size of suspected particles was compared between species with a Kruskal-Wallis test. The abundance of different particle types and colours was also compared between species, dietary groups, and foraging substrates with Kruskal-Wallis tests followed by Wilcoxon post hoc comparisons.

The abundance of suspected particles in the faeces of wild birds was related to the degree of imperviousness around the sampling area, and with its human population density, using GLMs fitted with Poisson distributions. Statistical analyses were performed in JMP Student Edition 18.2.2, and graphs for data visualization were performed using RAWGraphs (Mauri et al., 2017). The map of the sampling sites in Fig. 1 was built in R (ggplot2/sf/terra).

3. Results

We collected faeces from 159 individual birds from six species (6 kingfishers, 26 European robins, 41 House sparrows, 46 Eurasian blackcaps, 30 Eurasian blackbirds and 10 song thrushes). Mean faeces weight was 0.088 ± 0.009g. Faeces weight was not related to either the probability of containing a suspected particle ($\chi^2_{1,153} = 0.04$, $p = 0.84$) nor with the number of particles detected ($F_{1,65} = 0.27$, $P = 0.60$). Suspected particles of anthropogenic origin were found in 68 out of 159 faecal samples (42.7%; Table 1; Sup. Mat 1.). There were no significant differences between bird species in the probability of excreting suspected particles (Fisher exact test two-sided: $p = 0.08$), but if we compare thrushes (genus *Turdus* sp.) with the other species analysed, thrushes showed a significantly higher prevalence of suspected particles than other genera ($\chi^2_{1,\ 156} = 5.33$, $p = 0.02$). Bird species differed significantly in the number of suspected particles per faecal sample (Kruskal-Wallis $\chi^2 = 17.53$, $p = 0.004$). Non-parametric paired comparisons (Wilcoxon method) showed that the song thrush had significantly higher number of particles than all the other species ($2.19 < Z < 3.69$; $0.03 < p < 0.0002$). Also, the blackcap had a significantly lower abundance of particles than the blackbird ($Z = 2.15$, $p = 0.03$; Fig. 2a).

Although omnivorous birds that feed on the ground and understorey tended to have a higher frequency of occurrence of suspected particles in their faeces (51.7 and 81%, Table 1), there were no overall significant differences between different dietary groups neither in terms of prevalence (Fisher exact test two-sided: $p = 0.59$), nor abundance (KW $\chi^2_{2,156} = 1.82$, $p = 0.40$). However, birds that foraged exclusively on the ground presented more suspected particles than the those foraging in the ground/understorey and mid-high levels of the canopy (KW $\chi^2_{3,155} = 10.93$, $p = 0.01$), in spite of no significant differences in the prevalence of suspected particles in their faeces (Fisher exact test two-sided: $p = 0.095$).

Mean particle size was 0.56 ± 0.75 mm, and 76% of the particles were ≤ 1 mm, and, therefore, were considered small microplastics. The size of the particles (maximum length) did not differ significantly between species ($\chi^2_{5,116} = 5.4$, $p = 0.37$, Fig. 2b).

Most of the anthropogenic-suspected particles were filaments (37%), followed by fibres (23%), fragments (21%), and pellets (15%; Fig. 3a). There were significant differences in the quantity of fibres between species ($\chi^2 = 16.53$, $p = 0.006$; Sup. Mat. 2): the song thrush had significantly more fibres than the house sparrow ($Z = 3.59$, $p = 0.0003$) and the blackcap ($Z = 3.02$, $p = 0.003$). The house sparrow had significantly less fibres than the blackbird ($Z = 2.16$, $p = 0.03$). Birds foraging in the ground had significantly more fibres than birds foraging in both mid-high levels of the canopy ($Z = -2.24$, $p = 0.03$) and in the ground-understorey ($Z = -8.38$, $p = 0.02$). There were no significant differences in contamination by filaments, fragments, or pellets between species, dietary groups, and foraging behaviours (all $p > 0.05$).

Particles were mostly blue (55%; Fig. 3b). With respect to colour distribution among species, transparent particles were more frequently found in blackbirds ($p = 0.02$), but this was due to only one individual having 7 transparent filaments. Birds foraging on the ground had significantly higher number of particles from other colours (rather than

Table 1
Prevalence and mean abundance (±SD) of anthropogenic origin suspected particles in faeces from wild birds captured in urban riparian areas in relation to bird species, diet and foraging substrates. Each faecal sample corresponds to an individual bird.

Bird species	Diet	Foraging substrate	Prevalence (%)	Samples with particles/analysed	Mean particle abundance (mean ± SD)
Kingfisher	Fish	Water	33.3	2/6	0.34 ± 0.52
European robin	Omnivore	Ground/understorey	50.0	13/26	0.73 ± 0.83
House sparrow	Granivorous	Ground/understorey	36.6	15/41	0.66 ± 1.26
Eurasian blackcap	Omnivore	Mid-high canopy	32.6	15/46	0.35 ± 0.53
Eurasian blackbird	Omnivore	Ground	51.7	15/29	0.97 ± 1.57
Song thrush	Omnivore	Ground	80.0	8/10	2.9 ± 2.96
Total			42.7	68/159	0.77 ± 1.38

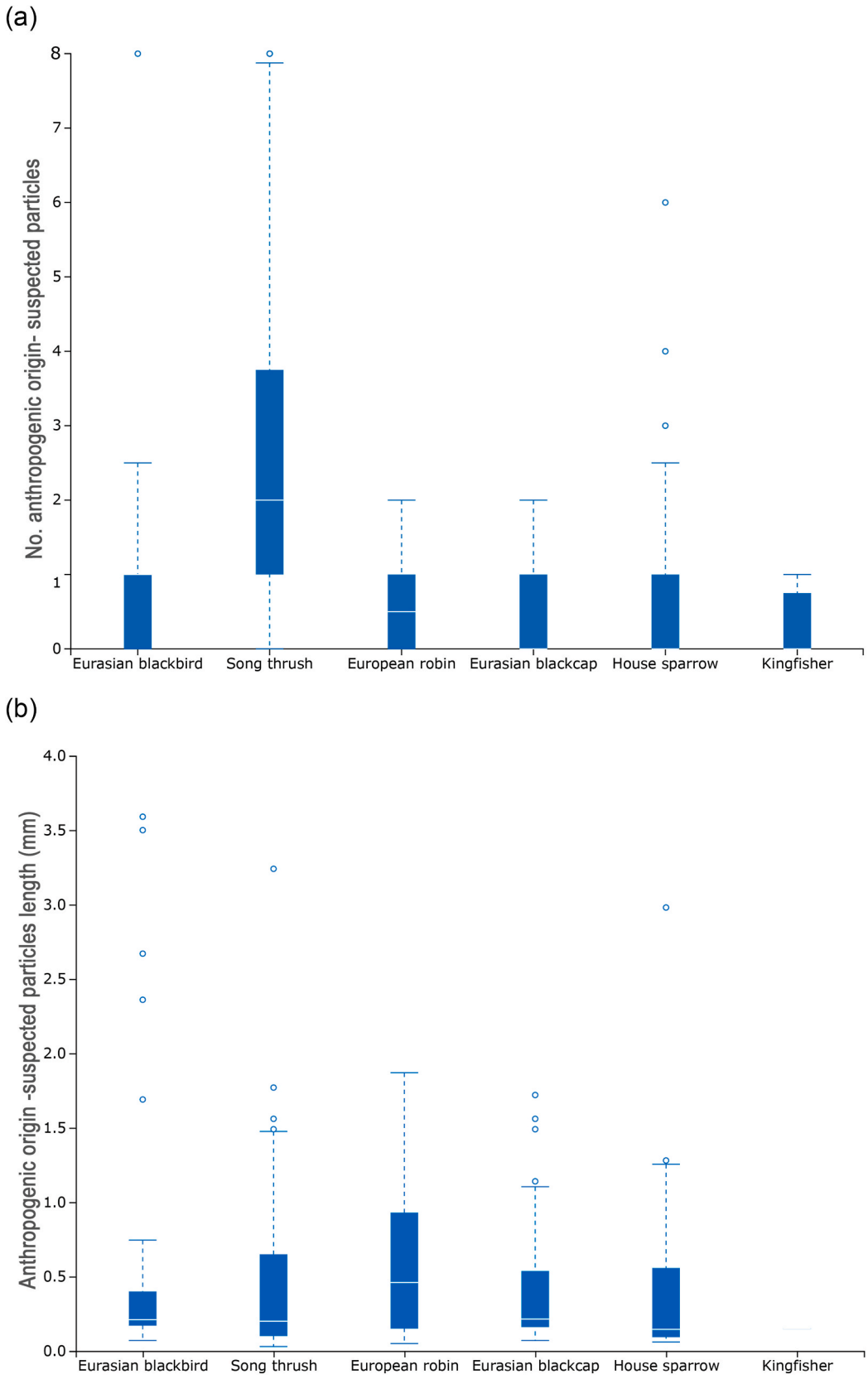


Fig. 2. Mean number of suspected anthropogenic particles (a) and particle length (mm; b) in faecal samples of common species of birds captured in urban and sub-urban stream riparian areas around Coimbra, Portugal. The lowest and highest values are presented (whiskers = 1.5 x interquartile range), along with the lower quartile, median and upper quartile (box) and outliers. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

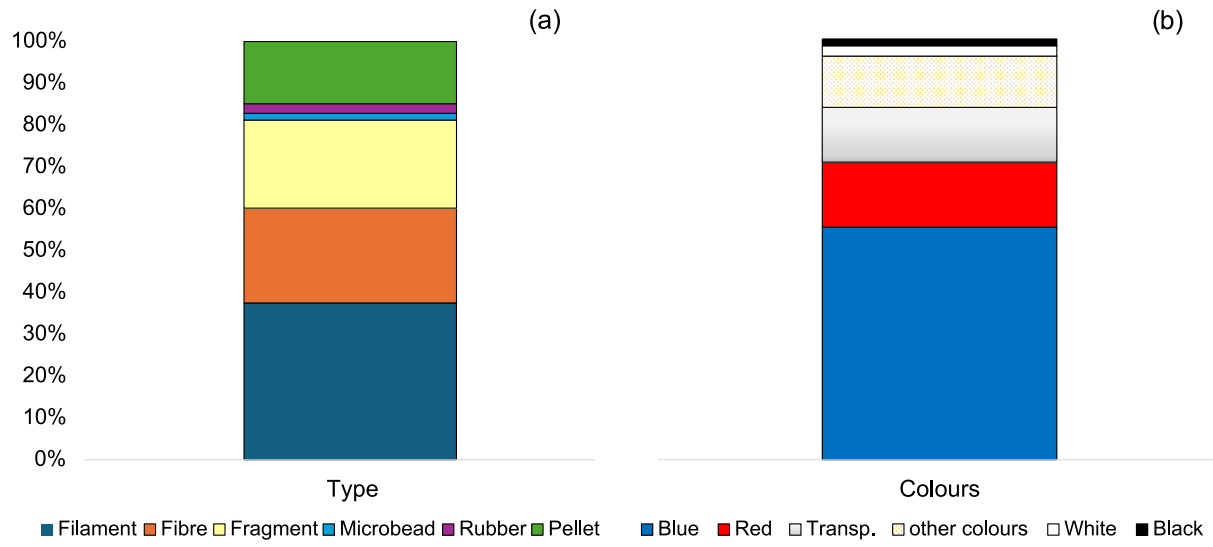


Fig. 3. Type (a) and colour (b) of suspected anthropogenic particles found in the faeces of common wild birds captured in urban stream riparian areas in Coimbra, Portugal.

blue, transparent, black and red) than birds foraging at mid-high levels of the canopy ($Z = -2.5$, $p = 0.014$).

There were no significant relationships between the abundance of particles in the faecal samples of birds and imperviousness ($F_{1, 156} = 0.15$, $p = 0.70$), and human population density ($F_{1,156} = 0.0006$, $p = 0.98$) around the streams.

3.1. Micro-Fourier Transform Infrared Spectroscopy characterisation of selected suspected anthropogenic particles of large size

Nineteen percent of the suspected particles that were not ruled out visually as contamination (i.e. 26 out of 134) were isolated and analysed through μFTIR. From these, 14 particles (53.8%) were successfully identified according to their chemical composition: three of the 14 successfully identified particles (21.4%) were confirmed to be plastic – one polyacrylonitrile fibre from a blackbird, one polypropylene fibre from a house sparrow, and one PET fibre from a robin (Sup. Mat 3). The remaining particles were natural fibres (e.g. animal fur, fibre flax, brood comb) that were anthropogenically altered in terms of colour (n = 4, 28.6%), natural materials (chitin, fur and brood comb, n = 4, 28.6%), and possible contamination from collection material (bags where the birds were held, n = 3, 21.4%).

4. Discussion

In this study, we evaluated the occurrence of anthropogenic particles, including plastics, in the faeces of 5 passerine bird species and the kingfisher, which were captured in the riparian zones of urban and suburban streams. The present study focused on common bird species associated with such habitats and differing in size, diet and foraging substrate. We found an overall prevalence of 42.7% without significant differences between bird species, although thrushes (genus *Turdus*) showed a significantly higher prevalence of suspected particles than other genera analysed.

The prevalence and abundance of suspected anthropogenic particles per faecal sample of birds in our study area was lower than that found in birds of coastal and marine environments: prevalence of 60%, and a mean number of 1.36 particles per faecal sample was found in waders, charadriiforms including gulls, and *Sterna albifrons*, in mudflats, lagoons and open seas in the Portuguese south coast (Veríssimo et al., 2025). A study in inland Canada focused on raptors, scavengers (including gulls) and herbivores (e.g., swans and goose) showed, through necropsy, that only 5.3% of the birds contained anthropogenic particles (>2 mm) in their guts, and that 44.4% out of the 54 individuals analysed had faecal precursor samples containing microparticles, with a mean abundance of 1.5 particles per sample, which is more similar to our results in terms of prevalence, but not abundance (Schutten et al., 2024). The waterbirds sampled by Veríssimo et al. (2025) and Schutten et al. (2024) were generally larger than the species sampled in this study, and size could influence exposure to anthropogenic particles through the size of the bird's beak and gape, and the size of the food items that they may be able to ingest. However, within the range of bird sizes in our study, we do not have reasons to suspect these biases because the size of the faecal sample did not affect the probability of containing suspected anthropogenic particles, or their number (see also Zeng et al., 2025).

Generalist species with a varied diet could be more exposed to anthropogenic particles and microplastics through a greater number of potential pathways while foraging, in contrast to specialist species (Caldwell et al., 2020; Carlin et al., 2020). However, a study on the dipper *Cinclus cinclus,* which has a highly specialized feeding niche, relying almost exclusively on freshwater aquatic invertebrate prey, showed a plastic prevalence of 45% in faecal samples (D'Souza et al., 2020), and an intensity of contamination in faeces of 8 ± 2 particles/g dw. In tree swallows (*Tachycineta bicolor*), that also feed on a freshwater aquatic-based diet – i.e., on adult stages of aquatic insects such as dragonflies and damselflies (McCarty and Winkler, 1999), nestling faecal sacs had 90% prevalence of microparticles and a mean loading between 5.9 and 8.7 particles/faecal sac (Sherlock et al., 2022). In general, foraging habitat and surrounding land use is a main determinant of MPs exposure in wildlife because plastic contamination is associated with highly focalised sources: e.g. the proximity to a local road, a garbage dump or a human settlement (Teampanpong and Duengkae, 2024). In a study conducted in China, the presence of rare polymers, including silicone and acrylates, resulting from the decomposition of electronic waste, was found in wild animals from the area of an abandoned e-waste recycling site (Zheng et al., 2023). There, kingfishers, a specialist species that feeds on small freshwater fish, had a mean of 191 particles per individual, in the digestive tracts of a total of 23 individuals sampled. In our study, although the sample size for kingfishers was small and may not be representative, they showed a

relatively low prevalence and number of particles in the faeces compared to the other sampled species, but, even so, the values were higher than those in the regurgitates of the kingfishers from the Ticino river in Italy in a targeted species study: microplastic prevalence of 7.5% and mean abundance of 0.09 plastics per pellet from 133 kingfishers (Winkler et al., 2020).

In our study, thrushes, as representatives of terrestrial omnivorous and ground foraging birds, showed a much higher prevalence of anthropogenic particles than the insectivorous foraging gleaning birds such as robins and blackcaps. This agrees with Baum et al. (2026) reporting ground-foraging omnivores such as the Great-tailed Grackle *Quiscalus mexicanus* exhibiting the highest ingestion mean rate (5.92 MPs per bird), while foliage-gleaning insectivores like the Nashville warbler *Leiothlypis ruficapilla* had the lowest (0.42 MPs per bird). In Apulia, Italy, hunted song thrushes had a prevalence of MP of 71.4% in their guts, and a mean number of 5.43 particles per bird in their gastrointestinal tract (Tarricone et al., 2024). Hoang and Mitten (2022) also found that the hermit thrush *Catharus guttatus* had the highest MP load in the gut when compared with other 4 migratory passerines in north America. In polish rural and urban areas, Deoniziak et al. (2022) found thrushes with 100% MP prevalence in their gastrointestinal tracts with a mean intensity of 31.56 ± 32.5 MP per individual. In terrestrial ecosystems, trophic transfer from ground-dwelling invertebrates may increase MP exposure as demonstrated in chickens (*Gallus gallus domesticus*), which had higher MP load (129.8 ± 82.3 particles g−1), than earthworms (14.8 ± 28.8 particles g−1) and soil (Huerta Lwanga et al., 2017). Deoniziak et al. (2022) also found that song thrushes were more exposed to MP than blackbirds, and suggested that this could be related with song thrushes foraging more in open areas with lower vegetation cover usually associated with agricultural environments. In our study we cannot discuss about the difference between blackbirds and song thrushes because our sample size for the song thrush (n = 10) was small. An inter-relationship between the characteristics of the study areas and the foraging strategies used by species in each study area should be important to explain plastic prevalence.

Thrushes, especially the song thrush, ingested significantly more fibres, which is in accordance with studies from Poland (Deoniziak et al., 2022), and, in general, in most terrestrial birds (Baum et al., 2026; Mansfield et al., 2024), including the high mountain river dependent dipper (D'Souza et al., 2020). Fibres were also the most detected particles in waterbirds in the study by Veríssimo et al. (2025) and in seabirds (Matos et al., 2023). Particle size showed no significant differences between bird species examined in our study, although these tend to prey on different-sized items. This supports that exposure does not occur only via trophic transfer but also by direct ingestion (e.g., as a mistaken food item), via inhalation, or ingestion of water (Baum et al., 2026). In our study, ground foraging birds, i.e., thrushes, tended to have particles with a wider variety of colours (other than white, transparent, black, and red) than the other bird species. This contrasts with the finding by Deoniziak et al. (2022) where thrushes mainly had transparent fibres, similar to reports for other terrestrial birds (Moreira et al., 2026), in comparison to seabirds where blue and black predominate (Carrasco et al., 2025, and references therein). Overall, the lack of a predominant colour of the particles found in the samples from thrushes suggests that mistaking synthetic particles by food items is not the main route of exposure for thrushes in our study, making the exposure more likely caused by inhalation in this genus (Tokunaga et al., 2023), when foraging on the ground. Anthropogenic fibres, with both natural and synthetic composition, make up the majority of anthropogenic particles in the atmospheric compartment (Edo et al., 2023; Wright et al., 2020). This is related to their high global production (from textile, construction) and to the fact that they are highly prone to atmospheric dispersion and deposition given their lightness (Xiao et al., 2023). This is probably why it is the most ubiquitous form of MP pollution across avian taxa in marine, freshwater, and terrestrial ecosystems (Sarlin et al., 2025, and references therein), and across species with different diets and foraging habitats.

We found no relationships between anthropogenic particles in the birds' faeces and either imperviousness or human population density in the surrounding areas of the urban streams. In contrast, D'Souza et al. (2020) showed that the concentration of plastic particles in the faeces and regurgitates of dippers increased with urban land cover. The prevalence and quantity of plastics in waterbirds from urban areas were found to be higher than generally reported in other studies on freshwater bird species (Heim et al., 2025). Also, Wayman et al. (2024) found that the abundance of microplastics and fibres from anthropogenic origin was higher in city-dwelling raptors than in the surrounding areas. This positive relationship between exposure and anthropization has also been found in barn owls *Tyto alba* (Pietrelli et al., 2024).

Regarding the chemical composition of the suspected particles, processed cellulose and PET/polyester were reported to be commonly found in terrestrial biota studies (Carlin et al., 2020), and, therefore, suggested to be ubiquitous in terrestrial food webs (Sherlock et al., 2022). Two of the plastic particles chemically identified in our study were PP and PET, that may originate from textiles including nonwovens (e.g. for diapers and sanitary products in the case of PP), but also packaging and ropes/yarns fabrication. We also found a polyacrylonitrile (PAN) fibre in the faeces of a blackbird. This is a synthetic, semicrystalline organic polymer resin, used to produce large variety of products including fibres for textiles. Additionally, we identified natural fibres (fur/wool and fibre flax) anthropogenically modified in terms of colour. Unfortunately, the fact that we analysed particles excreted in faeces, that were already deteriorated from chemical and physical processes in the gut, greatly reduced the success of unequivocal chemical characterization, which is limited to the availability of reference spectra for aged and degraded materials. The relatively low % of particles identified as plastic is likely an underestimation.

The results from our study confirm that filaments and fibres of blue colour are the most abundant particles that birds are exposed to, also in freshwater terrestrial environments. Further it supports that thrushes can be used as useful indicators of anthropogenic contamination in urban environments including in riparian zones, due to their relatively high exposure, which is likely caused by their foraging habits in the ground. The highly localised point sources of plastic contamination render it difficult to relate urbanisation indices with plastic particle exposure in wildlife, and requires a sampling strategy and a habitat characterisation that takes this into account. Accordingly, Elias et al. (2026) also reported that MP loads in terrestrial birds were more influenced by fine-scale local variation on individuals rather than their ecological traits. A limitation of our study is that each location was sampled only once, and repeating the sampling of common resident bird species would provide a more robust assessment of spatial heterogeneity of microplastic contamination. Faecal anthropogenic particle loads provide a snapshot of environmental exposure, but represents a useful non-invasive proxy. Results are comparable to GI analysis (Elias et al., 2026), and previous studies have reported a strong agreement between the characteristics of microplastic particles ingested by organisms and those of the plastic debris in the vicinity where individuals were collected (Gouin, 2020). We cannot exclude the possibility that the birds may have been exposed elsewhere, but our sampling was performed in spring/early summer, during the breeding season, when these birds are mostly territorial. Future studies should evaluate the availability of anthropogenic particles in the habitat, including the water, soil, air and vegetation compartments (Adediran et al., 2026) to pinpoint sources of plastic contamination, and sampling of organisms at different trophic levels would help to understand the role of trophic transfer in exposure levels. Notheless, this study provides basic information about anthropogenic particle ingestion in a bird community, including for some new species that have never been evaluated for this type of exposure. Increasing this knowledge for new wild species, over wider geographic areas and over time, will constitute a valuable database to evaluate contamination trends, and to direct conservation and remediation

initiatives.

CRediT authorship contribution statement

Marisa Cota: Writing – review & editing, Investigation. **Diana Matos:** Writing – original draft, Methodology. **Marcos Rocha Dias:** Writing – review & editing, Investigation. **Janine Pereira da Silva:** Writing – review & editing, Investigation, Formal analysis. **Ana Luísa C. Brandão:** Writing – review & editing, Validation, Methodology, Data curation. **Luís A.E. Batista de Carvalho:** Writing – review & editing, Validation, Resources, Funding acquisition. **Maria Paula M. Marques:** Writing – review & editing, Resources, Funding acquisition. **Jaime Albino Ramos:** Writing – review & editing, Investigation. **Maria João Feio:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization. **Ana Cláudia Norte:** Writing – original draft, Supervision, Investigation, Formal analysis, Data curation, Conceptualization.

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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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envres.2026.126084.

Data availability

Data is available as Suplemental Material

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