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Anthropogenic debris as nest material in three swift species: New insights into the interactions of atmospheric pollution with wildlife

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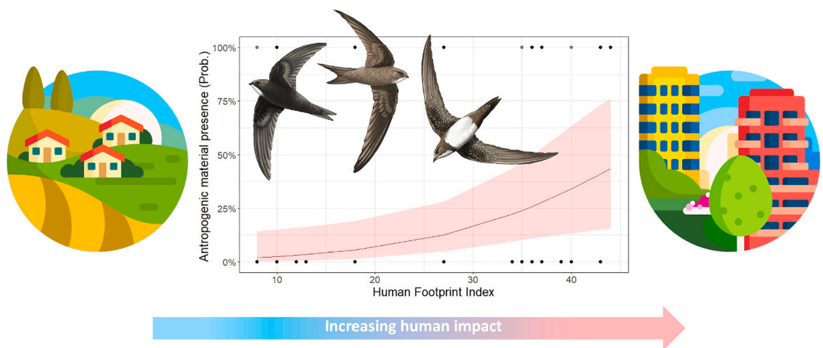
H I G H L I G H T S

- We assess the addition of anthropogenic materials in nests of three swift species.
- We found plastic in the 36.5 % of the nests evaluated, with differences among species.
- The probability of finding plastic in the nests increases at higher human footprint.
- Our results suggest a direct interaction between atmospheric plastic and wildlife.
- This is the first study to demonstrate contamination by anthropogenic materials in swifts' nests.

G R A P H I C A L A B S T R A C T



A R T I C L E I N F O

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A B S T R A C T

Plastic pollution has become a global concern, affecting many species around the world. While well-documented for marine ecosystems, the impact of plastic pollution on terrestrial ecosystems is comparatively limited. In fact, only recently have some studies begun to explore the occurrence, pathways, and impacts of plastic in the atmosphere and on terrestrial species. Here, we assess the presence of synthetic material in nests of three swift species breeding in the Western Palearctic: the common swift (*Apus apus*), the pallid swift (*Apus pallidus*), and the alpine swift (*Tachymarptis melba*). Using data from 487 nests spanning 25 colonies and seven European countries, we show that 36.5 % of the examined nests contained anthropogenic materials, mainly plastic debris. Notably, Pallid swifts' nests, with 85 % of the total nests examined with plastic, rank among birds with the highest plastic content in nests. We also demonstrate that the probability of finding plastic in the nest increased substantially with the human footprint of the landscape. Last, we recorded four cases of swifts entangled in their own nest, a low proportion compared to other species studied previously. Our study provides compelling evidence that plastic pollution may also be considered a concern for other terrestrial species, particularly for birds with highly aerial lifestyles, such as other swifts. The correlation with the human footprint suggests that areas with higher human activity contribute more significantly. Moreover, the entanglement cases, although low, indicate a threat to bird health and welfare. To our knowledge, our study is the first to report a direct interaction between floating plastic debris in the atmosphere and any species. Understanding this interaction is key, not only due to the lack of research on the topic, but also because it highlights that plastic pollution is a multifaceted environmental issue affecting various ecosystem categories, and the broader implications of atmospheric plastic circulation on wildlife and ecosystems health.

1. Introduction

Plastic pollution is a global concern, reaching all the oceans and seas, rivers and lakes, as well as terrestrial areas (Rhodes, 2018; MacLeod et al., 2021; Luna et al., 2024). Studies on plastic pollution in marine ecosystems have garnered public and scientific attention in recent decades, yet few studies offer field evidence on the sources, pathways, circulation, and impacts of plastic in soil, atmosphere and freshwater systems (Bucci et al., 2020; Hurley et al., 2020; Aeschlimann et al., 2022). In the atmosphere, plastic fragments show varying sizes, dispersing from their origin to greater distances influenced by the actions of wind and air currents, which play a crucial role in the global circulation of plastic (Allen et al., 2020; Zhang et al., 2020). Atmospheric transport of plastic by wind has favored its arrival in mountain glaciers and other high-altitude and remote ecosystems (Zhang et al., 2021 in the Tibetan Plateau; Cabrera et al., 2022 in Andean glaciers). The recirculation of plastics in the atmosphere can be especially common in cities, ranked among the main source of plastic pollution to different ecosystems (Xu et al., 2020; He et al., 2024), where mismanaged waste and plastics originating from landfills can be resuspended by dust emissions and wind (Zhang et al., 2020; Brahney et al., 2020; Brahney et al., 2021). For example, previous studies on atmospheric plastic in urban areas have revealed that the atmospheric deposition detected in London is nearly 20 times higher than in more remote and less disturbed areas such as the French Pyrenees (Wright et al., 2020). Furthermore, atmospheric fallout of microplastics has been also measured in cities as Paris, France (29 to 280 particles/m^2/day; Dris et al., 2016) and Dongguan, China (175 to 313 particles/m^2/day; Cai et al., 2017) with alarming outcomes. The presence of plastic in the atmosphere can have widespread consequences: first, the pollution of remote areas with the subsequent ingestion of microplastic by more species than previously expected (Blettler and Mitchell, 2021; moreover, microorganisms can adhere to plastic particles to travel long distances, thus potentially spreading pathogens, as confirmed in aquatic environments (Junaid et al., 2022); last, plastic debris floating in the atmosphere interact with solar radiation, releasing greenhouse gases that affect climate change processes (VishnuRadhan et al., 2021).

In recent years, many impacts related to plastic pollution have been confirmed in seabirds, often resulting from the ingestion of naturally-occurring debris (Codina-García et al., 2013; Baak et al., 2020; Charlton-Howard et al., 2023) as well as entanglement in fishing nets and other synthetic materials, usually with negative consequences for both individuals and populations (Votier et al., 2011; Costa et al., 2020). In inland ecosystems, the ingestion of plastics by birds or its presence in nests has been less studied, although it has been recorded for different species that usually exploit dumps and human waste, like the white stork (*Ciconia ciconia*; Jagiello et al., 2018), the black kite (*Milvus migrans*; Canal et al., 2016) or the Andean condor (*Vultur gryphus*; Gamarra-

Toledo et al., 2023). Plastic debris have also been detected in nests of hornbirds (*Phacellodomus ruber*) breeding in trees of river floodplain wetlands (Blettler et al., 2020) and nests of gull-billed terns (*Gelochelidon nilotica*) and black-winged stilts (*Himantopus himantopus*) in inland saline lakes (Luna et al., 2022). Furthermore, some studies have documented the occasional entanglement in synthetic materials used in the nests of terrestrial birds, sometimes resulting in injuries or death. For example, Restani (2023) showed that in ospreys (*Pandion haliaetus*), 44.2 % of nests examined contained twine and 3.4 % of nestlings were entangled.

Swifts (Apodidae) have an eminently aerial life. They spend most of their time aloft (Åkesson et al., 2012; Liechti et al., 2013), using their beaks and feet to collect nest materials suspended in the air while flying at high and low altitudes (Lack, 1956; Henningsson et al., 2009; Hedenström et al., 2016). Thus, swifts are potential candidates to use atmospheric plastic debris and other anthropogenic debris carried by the wind as nest material. To date, however, there have been no comprehensive studies investigating the presence of synthetic materials in swift nests (see Chmielewski, 2021 for anecdotal evidence of plastic string causing the death of a common swift (*Apus apus*) nesting in Poland). Here, using data from 25 nesting colonies monitored by scientific and nature conservation organizations throughout the Western Palearctic, we assess the presence of synthetic material in 487 nests of three swift species (*Apus apus*, *Apus pallidus*, *Tachymarptis melba*) breeding either in nest boxes or natural nests. Our goals are threefold: 1) to explore the presence of plastic or other anthropogenic materials in swift nests and characterize the extent of their use; 2) to report on possible damage and mortality of nestlings and adults due to entanglement; 3) to analyze the relationship between the human footprint and anthropogenic materials accumulation by the swifts. Given their highly aerial lifestyle and based on previous findings (Chmielewski, 2021), we expect that the three species of swifts would use synthetic debris as nest material. We also predict that the use of synthetic debris would increase with human pressure in the landscape, which would be exacerbated under future scenarios of global plastic waste generation.

2. Material and methods

2.1. Study species and area

Swifts (Fam: Apodidae) have wings and bodies adapted for fast flight while maximizing flight efficiency (Lentink et al., 2007; Muijres et al., 2012). Some species spend most of their time flying, landing only to breed, so they typically engage in continuous flights for several months outside their breeding seasons (Liechti et al., 2013; Hedenström et al., 2016; Hedenström et al., 2019). Our study focuses on three species. The common swift (*Apus apus*) and the pallid swift (*Apus pallidus*), two migrant species that breed in the Palearctic and whose populations spend the boreal winter in West Africa, the Congo basin and even further south, although it is possible that eastern European populations overwinter in eastern Africa using the eastern Mediterranean route (Åkesson et al., 2012; Finlayson et al., 2021; Hufkens et al., 2023). Moreover, the alpine swift (*Tachymarptis melba*), is a trans-Saharan migrant that coincides with the other two species in their wintering areas of West Africa, although individuals migrating along the east-Mediterranean route can also spend the winter in East Africa (Meier et al., 2020). In the Palearctic, swifts are cavity nesters, using trees, cliffs and rock cavities (Thibault et al., 2020), roofs and crevices of buildings (Corrales et al., 2013), as well as other human-made constructions like bridges (Wellbrock et al., 2022) and nest boxes (Schaub et al., 2016). These species typically collect the nest materials while flying, that usually consist in items suspended in the air, including feathers and plant material such as hay and seeds (Chantler, 2010; Bermejo et al., 2012). The two *Apus* species included in our study are common breeders in the Mediterranean basin. While the pallid swifts is restricted to this area and the Middle East (Hedenström et al., 2019), the common swifts is also widespread in Central and North Europe (Åkesson et al., 2020) and extends its range to Central Asia and China (Zhao et al., 2022). In the Palearctic area, the alpine swift breeds around the Mediterranean Sea and the Middle East, breeding also in lowlands around 450 m a. s. l.,in the Alps are less numerous and they breed almost only in cliffs (Meier et al., 2018; Humann-Guilleminot et al., 2021).

In this study, we encompass the broadest range possible within the Western Palearctic, incorporating various regions where the study species breed. Specifically, our study includes colonies spanning from Sweden, representing the northern limit, to Türkiye and Spain in the south. In total, we account for a total of 487 nests spanning 25 colonies and seven European countries. (Table 1 and Fig. 1 to see details).

2.2. Anthropogenic materials in swift nests

For this study we collaborated with organizations dedicated to the conservation and study of swifts. First, we contacted naturalists and scientists who monitor swift colonies, both in nest boxes and in building cavities and cliffs, with access to observe the contents of the nests. We sent a protocol to potential participants, indicating the procedure to collect data. Thus, each collaborator was invited to provide information on the exact location of the colony, the species breeding in the colony, the total number of nests analyzed and the number of them containing visible anthropogenic debris. When possible, they were also asked to report the percentage of the nest covered with synthetic material, as a proxy of quantity and distribution of those debris in the nests. Thus, we suggested to classify the nests in five categories: 0 (no anthropogenic materials), $<$ 25 % of the surface covered by anthropogenic materials, 25–50 %, 50–75 % and $>$ 75 %. In this sense, the collaborators conducted a thorough visual inspection of each nest. This involved carefully examining all parts of the nest for any signs of synthetic materials. The inspection was done in situ after removal during cleaning of the nest boxes and while working in the monitoring of the nests, in the case of those colonies located in cliffs and similar but human-made habitats (i.e. walls of Seville). They held the nests in their hands, allowing them to manipulate and closely examine all parts of each nest. This hands-on approach enabled investigators to better differentiate between natural materials and synthetic ones by assessing texture, flexibility, and other physical properties. Considering that we are working for macroplastics, no other analyses are mandatory, as visual inspection is enough to determine the nature of the materials found. Moreover, they were asked to report if there were adults and/or chicks entangled, whether alive or dead. Lastly, we gathered information about the use of the same nests by other bird species, to discard the possibility that species other than swifts could be placing synthetic debris in the nests. To avoid any disturbance during the breeding season, all nests were examined in the subsequent non-breeding season, i.e. after swifts left for their wintering areas.

2.3. Human influence in the landscape

To examine the impact of human influence on the probability of finding plastic debris as nest material, we used the Human Footprint index (hereafter HFP; Venter et al., 2016) as a proxy for humanization of the landscape around the breeding colonies. The HFP is a global map of the cumulative human pressure on the environment in 2009. This layer measures the human pressure using eight variables, including built-up environments, population density, electric power infrastructure, crop lands, pasture lands, roads, railways, and navigable waterway, at a spatial resolution of ~1 km using the Mollweide projection (equal pixel size). We extracted the value for each colony with the *extract* function of the R package ́raster' (Hijmans and van Etten, 2012).

We conducted logistic regression analyses to investigate the relationship between the occurrence of anthropogenic materials in nests of three swift species and the human footprint (HFP). Each nest was considered as a non-independent sample, as they belong to the same colony. Therefore, we fitted a mixed model logistic regression, with the

Table 1
Summary of the areas, colonies and species included in this study, the number of nests analyzed, the year, and the Human Footprint (HFP) associated to every colony.

Species	Country	Location	Colony	Year	n° Nest	HFP
Apus apus	Spain	Badajoz	Badajoz Centro	2022	11	36
Apus apus	Spain	Badajoz	Edif. Biología UEx	2022	5	35
Apus apus	Germany	Berlin	Berlin	2022	7	34
Apus apus	Spain	Coria del Río	Calle Blas Infante	2022	3	36
Apus apus	Switzerland	Fribourg	MHNF	2022	30	40
Apus apus	Czech Republic	Jihlava	Jihlava	21/22	23	44
Apus apus	Switzerland	Laufen	Laufen carpentry	2022	28	37
Apus apus	Switzerland	Laufen	M27	2022	7	39
Apus apus	Switzerland	Meltingen	church Meltingen	2022	29	12
Apus apus	Sweden	Södermanland	Tovetorp	2022	18	8
Apus apus	Germany	Wischhafen	Praxis	2021	14	18
Apus apus	Switzerland	Zullwil	church Oberkirch	2022	59	13
Apus apus	Switzerland	Zwingen	castle Zwingen	2022	13	36
Apus apus	Switzerland	Zwingen	chapelle castle	2022	7	36
Apus pallidus	Spain	Coria del Río	Calle Chapista	2020	4	37
Apus pallidus	Spain	Jerez de la Frontera	Jerez de la Frontera	2022	13	40
Apus pallidus	Spain	San Juan Aznalfarache	Calle Virgen Rosario	2020	3	37
Apus pallidus	Spain	Sevilla	Muralla Sevilla	2023	13	47
Apus pallidus	Spain	Sevilla	Avda Padre García Tejero	2020	2	37
Apus pallidus	Spain	Valencia	Alba	2022	5	46
Apus pallidus	Portugal	Vila Nova de Famalicão	Camara Municipal	2022	10	46
Apus pallidus	Spain	Zaragoza	Parque Bomberos	2022	66	47
Tachymarptis melba	Türkiye	Adrasan, Antalya	Pırasalı island	2022	50	10
Tachymarptis melba	Switzerland	Lenzburg	Hühnerwadelhaus	2022	40	43
Tachymarptis melba	Switzerland	Seengen	Reformierte Kirche	2022	27	27

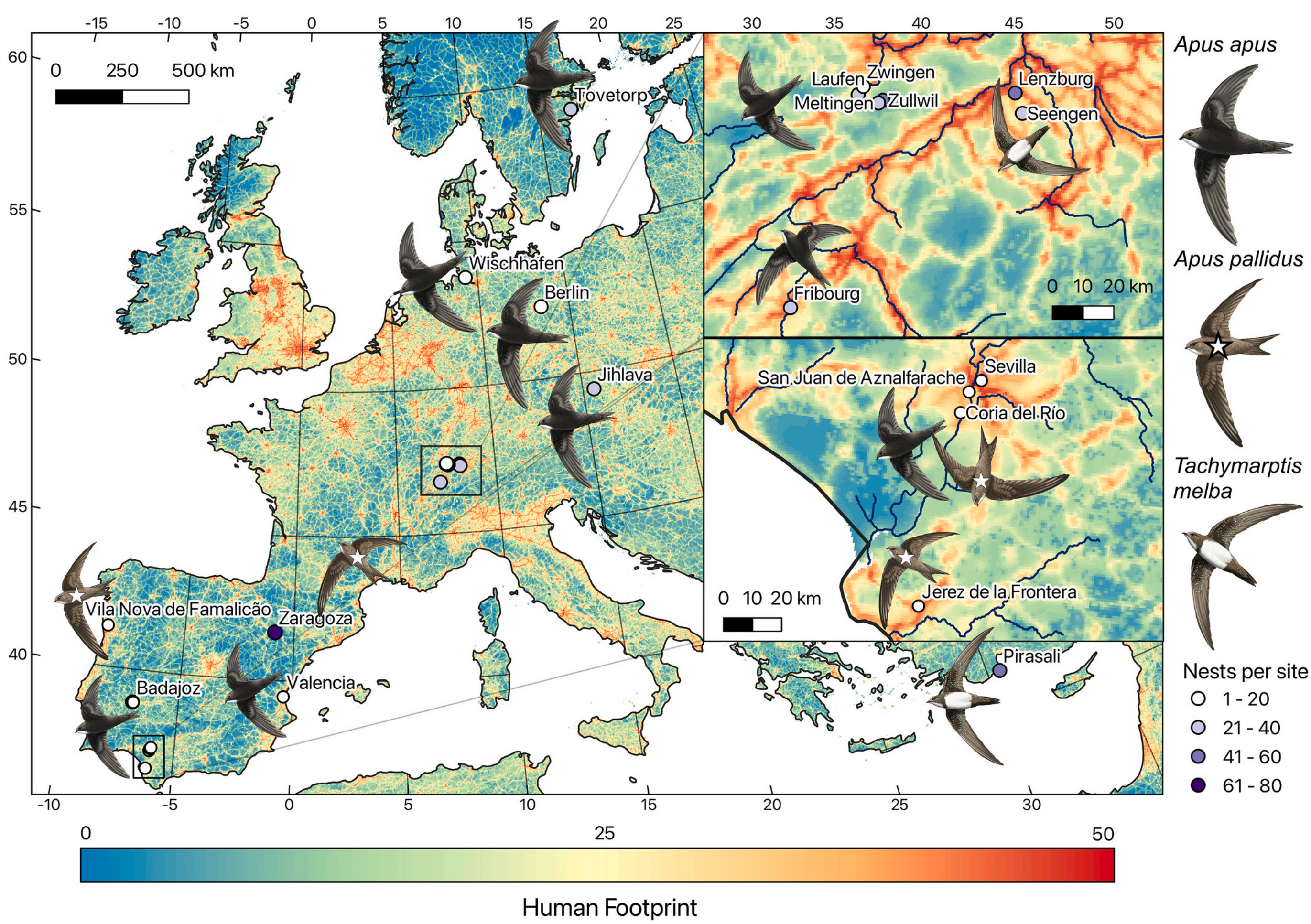

Fig. 1. Study area and distribution of the different locations surveyed and the three swift species included. Colored dots indicate colony size (nest per site) and Human Footprint is represented with a color gradient from blue (lowest influence) to red (highest influence). Pictures of the swifts by Alex Mascarell. Squares in the right side amplify the regions of Southern Spain (bottom) and Switzerland (top).

function *glmer* from the package lme4 (Bates et al., 2015) using colony as the random factor for the nest samples. We consider the colony to be affecting the intercept variances in the mixed model because we know that nests are not independent. However, we expect the same effect (slope) for all of them. For the analyses, we excluded the pallid swift data because of the low variance obtained in the HFP index, as our data mostly cover urban colonies, and nests from less humanized areas are not sufficiently represented for this species. Then, we performed a model selection process using an Akaike's Information Criterion (AIC) framework, choosing the model with the lowest AICc (AIC adjusted for small sample size) as the best supported model. We considered two models to be statistically different in their performance when ΔAICc >2. In cases where two models have similar performance, we will follow the conservative rule of selecting the more parsimonious model. For the selected model, we calculated the odd ratios, confidence intervals and *p*-values, including the random effect variance (σ_i^2), the random intercept for the colony (τ_{00}) and the Intraclass Correlation Coefficient (ICC) using the function *plot_model* from package performance (Lüdecke et al., 2021). To describe the model performance, we used the marginal and the conditional R^2 of the model, using *plot_model* from package performance (Lüdecke et al., 2021). For further disclosure of the data, we also carried a multinomial analysis, in which we analyzed the relationship between the HFP and the percentage of the nest covered by synthetic debris. These models were discarded because the small sample size produce no convergent models. All analyses have been done in the R 4.3.1. environment (R Core Team, 2021).

3. Results

We found anthropogenic materials in 178 of the 487 nests analyzed (36.55 %). The items detected were identified as plastic debris in the 97 % of the cases, either alone or mixed with other anthropogenic materials as paper-like fragments (Fig. 2). When considering species separately, the occurrence of anthropogenic materials in the nests of the pallid swifts was 85.34 % (99 nests of 116 analyzed), thus having the highest occurrence among the species included in the study, followed by the alpine swift, with 29.91 % (35 nests of 117 analyzed), and finally the common swift, with 17.32 % (44 nests of 254 analyzed). Regarding the surface of the nests covered by anthropogenic materials, including only those with confirmed occurrence of human-made debris, we found that the 65.73 % of the nests had <25 % of its surface covered, the 17.42 % of the nests showed a 25 % and 50 %, the 14.04 % between 50 % -75 % and only 5 nests had more than the 75 % of the surface covered, representing the 2.81 % of the nests of the total (see SP1 SP2, and SP3for further details). To classify by species, we found that from the total considered in the study the half of the nests of pallid swifts had at least 25 % of its surface covered by anthropogenic materials, while this situation occurred in the 29.06 % and 9.84 % of the alpine and common swift respectively (SP1,SP2 and SP3for further details). We also recorded four cases of entanglement during the fieldwork: one common swift in Badajoz (Fig. 2B and C to see a detailed picture), another one from Laufen (Switzerland), and two pallid swifts that were found alive and rescued, one in Vila Nova de Famaliçao (Portugal) and the other one in a nest in Valencia (Spain).

Moreover, in our study, most of co-authors confirm that another species could not have been responsible for placing the anthropogenic materials in the nests, either because they are continuously monitored, because the plastics were stuck to the nest with saliva, as swifts do, or directly because the nests are removed during the non-breeding period, so other species cannot use them throughout the year.

We found evidence of the relationship between the presence of anthropogenic materials and the degree of human disturbance around the nest. Thus, the model selected includes HFP as the best explanatory variable for the presence of anthropogenic material in the nest, not

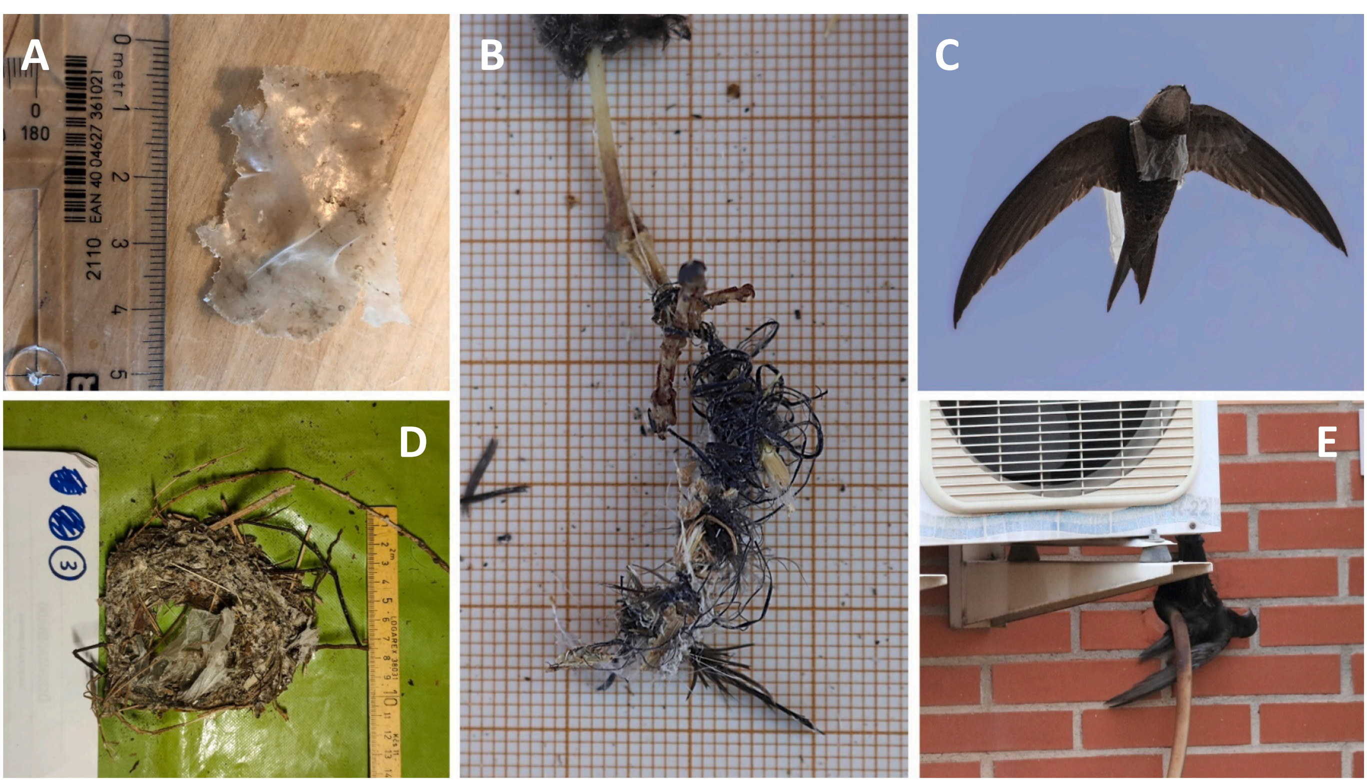

Fig. 2. A: Synthetic debris found in a common swift nest; Cecilia Kullberg (Tovetorp, Sweden) B: Chick with the leg entangled in synthetic fibers; José A. Masero & Jorge S. Gutiérrez (Badajoz, Spain). C: Common swift with a large plastic piece attached, photographed in flight; Daniel Cañadas Navarro (Jaén). D: Nest with large plastic pieces; Aleš Toman (Jihlava, Czech Republic). E: Common swift alive but entangled in synthetic fibers in its own nest (Juan Pérez). The photos C and E were taken out of the study, and those individuals are not included among our data, but reflect some of the potential impacts associated to plastic debris.

founding statistical difference between species (Table 2; SP4, 5, 6 and 7 to see details about the models 2 and 3 respectively). Our model shows a strong positive correlation between the presence of anthropogenic materials and the HFP (odds Ratio = 1.10, CI = 1.02–1.20, $P = 0.014$; Table 3). The considerable difference between the conditional and marginal R^2 values highlights a substantial nest dependency among colonies, which underscores the importance of employing mixed models for these analyses (Marginal $R^2 = 0.22$, conditional $R^2 = 0.60$; Table 3).

This significant positive correlation exhibits an exponential pattern, where the strength of the correlation intensifies with higher values of HFP (Human Footprint Index) (Fig. 3). At lower HFP values, the probability of finding anthropogenic material in the nests increases only slightly. However, this probability accelerates at greater humanization of the landscape. According to our model, the probability of encountering anthropogenic materials escalates from approximately 0 % in less disturbed ecosystems to about 43 % in highly anthropized environments (when the HFP index value reaches 44).

Table 3
The disclosed parameters estimates for the best generalized linear mixed model for which σ_i^2 is the random effect variance, $\tau_{00\ Name\_colony}$ is the random intercept for the colony, ICC is the Intraclass Correlation Coefficient, N_{Name_colony} is the number of colonies used, and Marginal R^2 (without the random effects) / Conditional R^2 (total model) explains the goodness of the fit of the model.

Fixed effects			
Predictors	Odds Ratios	CI	p
(Intercept)	0.01	0.00–0.13	0.001
HFP	1.10	1.02–1.20	0.014
Random Effects			
σ_i^2	3.29		
$\tau_{00\ Name\_colony}$	3.08		
ICC	0.48		
N_{Name_colony}	18		
Observations	371		
Marginal R^2 / Conditional R^2	0.22 / 0.60		

4. Discussion

Using data from 487 swift nests spanning 25 colonies and seven European countries, we show that, as predicted, the use of anthropogenic debris, mostly plastic, as nest material increases with human transformation of the landscape. While our study provides important insights into the interaction between plastic debris and birds, the identification of plastic materials was primarily visual, which may lead to an occasional misclassification, so further analyses in laboratory conditions could improve the accuracy of the plastics identification. To our knowledge, this is the first study that investigates the widespread use of plastic debris across swifts colonies (Battisti et al., 2019; Jagiello et al., 2019). Furthermore, this is the first study to assess the direct interaction between atmospheric plastic and any species, given the strictly aerial lifestyle of swifts.

Interestingly, we found a higher proportion of plastic debris in nests of pallid swifts than in those of the other two species, probably because most of the pallid swifts colonies in our study are located in urbanized areas, while common and alpine swift colonies were represented in both less disturbed but also humanized landscapes. Specifically, 85.34 % of the pallid swift nests included plastic or other anthropogenic debris, ranking among the birds with highest proportion of nests with plastic across terrestrial and marine ecosystems (examples of birds with >80 % nests with plastics: *Phalacrocorax aristotelis:* Thompson et al., 2020*;* *Milvus migrans* and *Milvus milvus*: Zduniak et al., 2021; *Pandion haliaetus*: Rodríguez et al., 2023). The observed trend of a heightened probability of anthropogenic material presence correlating with an increased human footprint in the landscape appears to be a pattern consistent with findings in other species: *Cyanistes caeruleus* and *Parus major* (Hanmer et al., 2017), *Columbina talpacoti*, *Thamnophilus doliatus*, *Turdus amaurochalinus*, *Coryphospingus cucullatus*, and *Zonotrichia capensis* (Batisteli et al., 2019) and *Ciconia ciconia* (Jagiello et al., 2023), since urban and agricultural areas accumulate higher quantities of human debris that other terrestrial ecosystems (Plastics Europe, 2018; Zhang et al., 2020). In recent years more researchers are alarming about the growing occurrence of plastic and other human debris and the resulting threats for birds inhabiting rural and urban habitats (Richard et al., 2021; Haaksma, 2022; Espinoza et al., 2024). Regarding this, we only found four individuals entangled with plastic, a lower prevalence than that reported for other birds; (Ryan, 2018; Ayala et al., 2023). This may be due to the type of material used for swifts, mostly floating plastic films and wraps (personal observation of the authors). On the contrary, most of the studies that report massive entanglement of individuals highlight the use of ropes, nets and twines related to human activities (Votier et al., 2011; Townsend and Barker, 2014; Restani, 2023). Although we are confident species other than swifts (e.g. starlings *Sturnus* spp., sparrows *Passer* spp.; jackdaws *Coloeus monedula*) did not utilize the nests in most the colonies studied here, the hypothetical presence of other species could increase the total amount of anthropogenic material in the nests. Furthermore, cross-pollution may occur and materials disposed by other species according to their specific preferences, such as fibers, could exacerbate the risk of entanglement for both adults and chicks. Finally, although non probably it is not impossible to consider the additional incorporation of plastics by the effects of the wind or other ways not related to the action of swifts or other occupants of the nests.

In conclusion, this study contributes to advance the previous knowledge of plastic pollution (anthropogenic materials by extension) in birds, showing a previously overlooked interaction of those synthetic materials floating in the atmosphere with eminently aerial species as swifts. Further research is needed to assess the presence of plastic in nests of more swift species, particularly in countries with higher levels of plastic pollution, such as those in Southeast Asia (Blettler et al., 2018). Future studies could also contribute to elucidate whether swifts obtain benefits by using synthetic materials (e.g. thermal insulation), and to explore sublethal negative impacts (Suárez-Rodríguez et al., 2017). Furthermore, colonies with higher prevalence of synthetic ropes or twines could carry an increased risk of entanglement for individuals. Moreover, regarding potential impacts, swifts build their characteristic nests by using their sticky saliva to glue the nesting material they collect in flight. The use of this technique to bind together pieces of waste plastic that were previously circulating could potentially contaminate

Table 2
Model selection table for generalized linear mixed models of anthropogenic material found in nests as a function of species and human foot print index. For the five models tested we show the LogLink, the value of the maximized log-likelihood function, df, the number of parameters in the model, AICc, Akaike's Information Criterion adjusted for small sample size, ΔAICc, the scaled value of AICc, and weight, the Akaike weight. Models are presented with their estimates and, for the categorical variables, a (+) symbol if they are included.

Model	(Intercept)	HFP	Species	HFP:Species	Df	logLik	AICc	ΔAICc	Weight
1	−4.62	0.10			3	−141.64	289.34	0.00	0.43
2	−5.08	0.11	+		4	−140.95	290.02	0.68	0.31
3	−5.60	0.12	+	+	5	−140.71	291.58	2.24	0.14
4	−1.75	NA			2	−144.27	292.57	3.23	0.09
5	−1.93	NA	+		3	−144.03	294.13	4.79	0.04

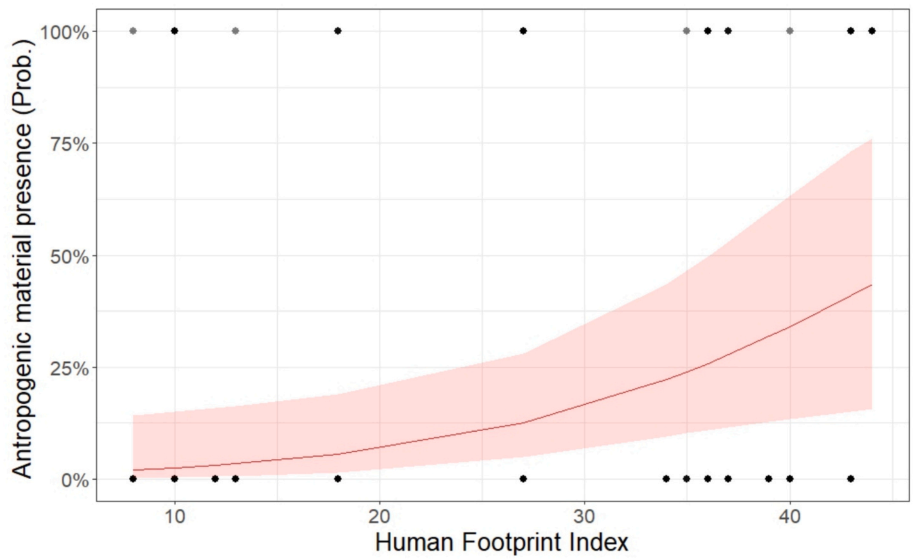

Fig. 3. Predicted probability of anthropogenic material presence in relation to the human foot print. Red line shows the mean prediction while the red margins show the confidence interval for the model prediction. Dots show the sample values, where the color intensity indicates the number of sample points overlapping.

adult birds with microorganisms and introduce leached products that may act as endocrine disruptors into their bodies (Silva et al., 2019; Meng et al., 2021; Ormsby et al., 2023). Likewise, it would be interesting to assess the interaction of plastic with swifts through their diet by analyzing feces (a non-invasive and easily reproducible approach that could be used across the breeding range) since they could be ingesting synthetic materials while catching aerial invertebrates. Finally, we encourage researchers, conservationists and politicians to improve the available knowledge on the problem of plastic pollution in less studied environments and its associated species.

CRediT authorship contribution statement

Álvaro Luna: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Elena Moreno:** Writing – review & editing, Data curation, Conceptualization. **José Antonio Pinzolas:** Writing – review & editing, Data curation. **Santiago Oliver:** Writing – review & editing, Data curation. **Susanna Meyer:** Writing – review & editing, Data curation. **Olaf Brodermann:** Writing – review & editing, Data curation. **Carlos Merino:** Writing – review & editing, Data curation. **Hakan Karaardıç:** Writing – review & editing, Data curation. **Luis P. da Silva:** Writing – review & editing, Data curation. **Caroline Chatton:** Writing – review & editing, Data curation. **Jacques Laesser:** Writing – review & editing, Data curation. **Christoph M. Meier:** Writing – review & editing, Data curation. **Jorge S. Gutiérrez:** Writing – review & editing, Data curation. **José A. Masero:** Writing – review & editing, Data curation. **Juán Pérez:** Writing – review & editing, Data curation. **Cecilia Kullberg:** Writing – review & editing, Data curation. **Álvaro Pérez-Gómez:** Writing – review & editing, Data curation. **Fernando Mateos-González:** Writing – review & editing, Data curation. **Ulrich Tigges:** Writing – review & editing, Data curation. **Bernardo Toledo:** Writing – review & editing, Formal analysis, Data curation, Writing – original draft. **Armand Rausell-Moreno:** Data curation, Formal analysis, 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 will be made available on request.

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Appendix A. Supplementary data

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