

SUPPLEMENTARY MATERIAL

Unraveling Plastic Pollution in Protected Terrestrial Raptors Using Regurgitated Pellets

Chloe Wayman ¹, Francisca Fernández-Piñas ^{2,3}, Irene López-Márquez ⁴, Rocío Fernández-Valeriano ⁴, Juan José Iglesias-Lebrija ⁴, Fernando González-González ^{4,5}, Roberto Rosal ¹ and Miguel González-Pleiter ^{2,3,*}

- ¹ Department of Chemical Engineering, Universidad de Alcalá, 28871 Alcalá de Henares, Madrid, Spain; c.wayman@uah.es (C.W.); roberto.rosal@uah.es (R.R.)
- ² Department of Biology, Faculty of Science, Universidad Autónoma de Madrid, 28049 Madrid, Spain; francisca.pina@uam.es
- ³ Centro de Investigación en Biodiversidad y Cambio Global (CIBC-UAM), Universidad Autónoma de Madrid, 28049 Madrid, Spain
- ⁴ Group of Rehabilitation of the Autochthonous Fauna and Their Habitat (GREFA), Wildlife Hospital, 28220 Majadahonda, Madrid, Spain; irene@grefa.org (I.L.-M.); rocio@grefa.org (R.F.-V.); jji Iglesias@grefa.org (J.J.I.-L.); fgonzalez@grefa.org (F.G.-G.)
- ⁵ Departmental Section of Pharmacology and Toxicology, Faculty of Veterinary Science, University Complutense of Madrid, 28020 Madrid, Spain

* Correspondence: mig.gonzalez@uam.es

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Table S1. Information on the sampling sites where regurgitated pellets of each protected terrestrial raptor species were collected between 2022 and 2023. The criteria used to classify the areas were based on the fact that areas located at a distance > 10 km to a city that has > 15.000 inhabitants were categorized as rural. Areas not meeting these criteria were designated as urban.

Species	Location	Rural/ Urban	Protected Zone
Barn Owl	Punta Entina, Almería	Rural	Yes

Barn Owl	Punta Entina, Almería	Rural	Yes
Barn Owl	Punta Entina, Almería	Rural	Yes
Barn Owl	Punta Entina, Almería	Rural	Yes
Barn Owl	Roquetas del Mar, Almería	Urbano	No
Barn Owl	Roquetas del Mar, Almería	Urbano	No
Barn Owl	Roquetas del Mar, Almería	Urbano	No
Bonelli's Eagle	Albox, Almería	Rural	No
Bonelli's Eagle	Albox, Almería	Rural	No
Bonelli's Eagle	Alcaudete, Jaén	Rural	No
Bonelli's Eagle	Alcaudete, Jaén	Rural	No
Bonelli's Eagle	Barranco de las Palomas, Granada	Rural	No
Bonelli's Eagle	Cóbdar, Paraje de los Molinos, Almería	Rural	No
Bonelli's Eagle	Taberno, Paraje Sierra Madroños, Almería	Rural	No
Bonelli's Eagle	Taberno, Paraje Sierra Madroños, Almería	Rural	No
Bonelli's Eagle	Olvera, Paraje Peñón de Montestier, Cádiz	Rural	No
Bonelli's Eagle	Encinas Reales, Córdoba	Rural	No
Bonelli's Eagle	Encinas Reales, Córdoba	Rural	No
Bonelli's Eagle	Paraje Cerro Negro, Granada	Rural	No
Bonelli's Eagle	Paraje Cerro Negro, Granada	Rural	No
Bonelli's Eagle	Pegalajar, Jaén	Rural	Yes
Bonelli's Eagle	Pegalajar, Jaén	Rural	Yes
Bonelli's Eagle	Pegalajar, Jaén	Rural	Yes
Bonelli's Eagle	Iznalloz, Granada	Rural	Yes
Bonelli's Eagle	S'Avall, Santanyí, Mallorca	Rural	Yes
Bonelli's Eagle	Huércal-Overa, Almería	Urbano	No
Bonelli's Eagle	Pizarra, Málaga	Urbano	No
Bonelli's Eagle	Zarzalejo, Madrid	Urbano	No
Bonelli's Eagle	Zarzalejo, Madrid	Urbano	No
Bonelli's Eagle	Porreras, Sa Bastida, Baleares	Urbano	Yes
Bonelli's Eagle	Porreras, Sa Bastida, Baleares	Urbano	Yes
Bonelli's Eagle	Porreras, Sa Bastida, Baleares	Urbano	Yes
Bonelli's Eagle	Huercal-Overa, Almería	Urbano	Yes
Bonelli's Eagle	San Martín de Valdeiglesias, Picadas, Madrid	Urbano	Yes
Cinereous Vulture	Hoyo de Pintares, Ávila	Rural	Yes
Cinereous Vulture	Cebreros, Camino de la Dehesa de Villalba, Ávila	Rural	Yes
Cinereous Vulture	Cebreros, Camino de la Dehesa de Villalba, Ávila	Rural	Yes
Cinereous Vulture	Cebreros, Camino de la Dehesa de Villalba, Ávila	Rural	Yes
Cinereous Vulture	Cebreros, Camino de la Dehesa de Villalba, Ávila	Rural	Yes
Cinereous Vulture	Huerta de Arriba, Burgos	Rural	Yes

Cinereous Vulture	Villavelayo, La Rioja	Rural	Yes
Lesser Kestrel	La Fuente de San Esteban, Salamanca	Rural	No
Lesser Kestrel	Campo Lugar, Cáceres	Rural	No
Lesser Kestrel	Villalpando, Zamora	Rural	No
Lesser Kestrel	Guareña, Badajoz	Rural	Yes
Lesser Kestrel	Trujillo, Cáceres	Rural	Yes
Lesser Kestrel	Arganda del Rey, Madrid	Urbano	No
Lesser Kestrel	Arganda del Rey, Madrid	Urbano	No
Lesser Kestrel	Arganda del Rey, Madrid	Urbano	No
Lesser Kestrel	Arganda del Rey, Madrid	Urbano	No
Lesser Kestrel	Arganda del Rey, Madrid	Urbano	No
Lesser Kestrel	Villares de la Reina, Salamanca	Urbano	No
Lesser Kestrel	Perales del Rio, Madrid	Urbano	Yes
Lesser Kestrel	Perales del Rio, Madrid	Urbano	Yes
Little Owl	Punta Entina, Almería	Rural	Yes
Little Owl	Punta Entina, Almería	Rural	Yes
Little Owl	Punta Entina, Almería	Rural	Yes
Little Owl	Punta Entina, Almería	Rural	Yes
Little Owl	Punta Entina, Almería	Rural	Yes
Little Owl	Punta Entina, Almería	Rural	Yes
Little Owl	Punta Entina, Almería	Rural	Yes
Little Owl	Punta Entina, Almería	Rural	Yes
Little Owl	Roquetas del Mar, Almería	Urbano	No
Red Kite	Casa de Campo, Madrid	Urbano	No
Red Kite	Casa de Campo, Madrid	Urbano	No
Red Kite	Majadahonda, Madrid	Urbano	No
Red Kite	Majadahonda, Madrid,	Urbano	No
Red Kite	Majadahonda, Madrid	Urbano	No
Red Kite	Majadahonda, Madrid	Urbano	No
Red Kite	El Molar, Madrid	Rural	No

Table S2. Species characteristics and traits.

Species	Habitat & Altitude	Diet & Feeding Behavior	Average Weight	References
Lesser Kestrel	Open grasslands, agricultural areas, lowlands. Often, they	Primarily feeds on insects like grasshoppers and	150-200g	(Anderson, Kok, and Erasmus 1999; Donazar et al. 1993; Negro, De

	are found in abandoned building or farms	beetles. Also hunts small rodents and birds.		La Riva, and Bustamante 1991)
Little Owl	Farmland, semi-open country, extensively cultivated areas with scattered trees	Nocturnal hunter feeding on insects, small mammals, birds, and reptiles.	98-300g	(Apolloni et al. 2018; Van Nieuwenhuysse 2008; Goutner and Alivizatos 2003; Dunning Jr 1985)
Barn Owl	Wide range of habitats from grasslands to forests. Lowlands	Nocturnal hunter primarily preys on small mammals like rodents, also hunts birds and insects.	330-460g	(Bonvicino and Bezerra 2003; Goutner and Alivizatos 2003; Dunning Jr 1985)
Bonelli's Eagle	Varied habitats from open woodland to rocky cliffs.	Feeds primarily on medium-sized birds, and small mammals (such as rabbits)	1900-2500g	(Redondo-Gómez et al. 2022; Balbontín 2005; Carrete et al. 2002;)
Cinereous Vulture	Various habitats including forests and mountains.	Scavenger feeding on carrion, primarily large mammals.	7000-12500g	(Salvador, 2024)
Red Kite	Wooded areas, farmland, and open countryside. Lowlands.	Opportunistic feeder consuming small mammals, birds, and carrion.	800-1200g	(Mougeot, Garcia, and Viñuela 2011; Ferguson-Lees and Christie 2001)

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Table S3. Microparticles (MPs) and artificial fibers or particles (AFs) found in controls.

Species	Typology	Action taken in the affected samples
Barn Owl	Black PE	Remove black PE
Cinereous Vulture	Blue, grey, black, red cellulose	Remove blue cellulose
Bonelli's Eagle	Black cellulose	Remove black cellulose

Bonelli's Eagle	Red fiber	Remove red cellulose
Bonelli's Eagle	Black cellulose	Remove black cellulose
Bonelli's Eagle	Blue cellulose	Remove blue cellulose
Bonelli's Eagle	Blue, red cellulose	Remove red and blue cellulose
Bonelli's Eagle	Red cellulose	Remove red cellulose
Bonelli's Eagle	Blue cellulose	Remove blue cellulose
Bonelli's Eagle	Red, grey cellulose fragment	Remove grey cellulose fragment
Bonelli's Eagle	Black PET	Remove black PET
Lesser Kestrel	Black cellulose	Remove black cellulose
Lesser Kestrel	Blue cellulose	Remove blue cellulose
Lesser Kestrel	Black cellulose	Remove black cellulose
Lesser Kestrel	Black cellulose	Remove black cellulose
Lesser Kestrel	Black cellulose	Removed black cellulose
Lesser Kestrel	Black cellulose	Removed black cellulose
Lesser Kestrel	Black, brown, blue	Remove blue cellulose
Lesser Kestrel	Blue	Removed blue cellulose
Little Owl	Black and yellow cellulose	Remove black cellulose
Red Kite	Red cellulose	Remove red cellulose
Red Kite	Red cellulose	Remove red cellulose
Red Kite	Black PE	Remove black PE

Table S4. Prevalence in percentage of each type of polymer by species.

Species	Prevalence in percentage					
	ACR	PA	PET	PE	PP	PVC
Bonelli's Eagle	16%	8%	48%	27%	2%	0%
Cinereous Vulture	36%	0%	55%	9%	0%	0%
Lesser Kestrel	12%	6%	59%	24%	0%	0%

Barn Owl	14%	43%	43%	0%	0%	0%
Red Kite	13%	8%	54%	25%	0%	0%
Little Owl	0%	0%	29%	57%	0%	14%

Table S5. Size d_v (μm) of the MPs and AFs per species.

Species	Average d_v AFs	Average d_v MPs
Bonelli's Eagle	76.32	83.60
Cinereous Vulture	80.88	86.93
Lesser Kestrel	72.77	103.96
Barn Owl	73.32	122.99

Red Kite	66.83	80.28
Little Owl	71.61	131.20

Table S6. Size comparisons of the MPs and AFs per species. Kruskal-Wallis test, with a post-hoc FDR correction.

Comparison	dv AF Value	dv MP Value
Barn Owl - Cinereous Vulture	0.262	0.244
Barn Owl - Bonelli's Eagle	0.154	0.314
Cinereous Vulture - Bonelli's Eagle	0.388	0.334
Barn Owl - Lesser Kestrel	0.178	0.133

Cinereous Vulture - Lesser Kestrel	0.411	0.307
Bonelli's Eagle - Lesser Kestrel	0.481	0.128
Barn Owl - Little Owl	0.375	0.325
Cinereous Vulture - Little Owl	0.167	0.391
Bonelli's Eagle - Little Owl	0.082	0.475
Lessser Kestrel - Little Owl	0.101	0.219
Barn Owl - Red Kite	0.268	0.466
Cinereous Vulture - Red Kite	0.080	0.143
Bonelli's Eagle - Red Kite	0.017	0.174
Lesser Kestrel - Red Kite	0.029	0.044
Little Owl - Red Kite	0.401	0.236

Table S7. Polymers densities.

Polymer	Density (g/cm³)
Acrylic (ACR)	1.18
Polyamide (PA)	1.07
Polyester (PET)	1.39
Polyethylene (PE)	0.95
Polypropylene (PP)	0.91

Polyvinylchloride (PVC)	1.38
Cellulose	1.50

Table S8. The concentrations of MPs and AFs per regurgitated pellets.

Species	Total MP/pellet	Total AF/pellet
Lesser Kestrel (N=13)	0.85 ± 0.46	2.60 ± 0.81
Bonelli's Eagle (N=27)	2.74 ± 0.78	7.60 ± 1.21
Cinereous Vulture (N=7)	3.90 ± 1.56	4.27 ± 1.23
Red Kite (N=7)	4.21 ± 0.95	4.12 ± 1.74

Little Owl (N=8)	1.59 ± 0.54	0.88 ± 0.48
Barn Owl (N=7)	2.17 ± 0.70	7.90 ± 3.97

Table S9. Results of Permutation test (n=1000) of multiple comparisons between species for the Total Contaminant per pellet, with a post-hoc FDR correction.

Comparisons Between Species	MP/pellet FDR p value	AF/pellet FDR p value
Little Owl and Red Kite	0.033	0.080
Little Owl and Barn Owl	0.509	0.076

Little Owl and Cinereous Vulture	0.193	0.024
Little Owl and Lesser Kestrel	0.358	0.122
Little Owl and Bonelli's Eagle	0.512	<0.001
Red Kite and Barn Owl	0.107	0.498
Red Kite and Cinereous Vulture	0.868	0.943
Red Kite and Lesser Kestrel	0.014	0.392
Red Kite and Bonelli's Eagle	0.382	0.17
Barn Owl and Cinereous Vulture	0.343	0.490
Barn Owl and Lesser Kestrel	0.180	0.134
Barn Owl and Bonelli's Eagle	0.892	0.860
Cinereous Vulture and Lesser Kestrel	0.046	0.240
Cinereous Vulture and Bonelli's Eagle	0.512	0.172
Lesser Kestrel and Bonelli's Eagle	0.080	0.002

Table S10. Comparison between different areas (categorized as non-protected urban, protected urban, non-protected rural, and protected rural areas). Kruskal-Wallis test, with post-hoc FDR corrections.

Comparison	MP P-Value	AF P-Value
Non-protected rural vs Protected rural	0.48	0.09
Non-protected rural vs Non-protected urban	0.56	0.29

Non-protected rural vs Protected urban	0.65	0.47
Protected rural vs Non-protected urban	0.17	0.49
Protected rural vs Protected urban	0.31	0.55
Non-protected urban vs Protected urban	0.99	0.93

Table S11. Comparison between different species per areas (categorized as non-protected urban, protected urban, non-protected rural, and protected rural areas). Kruskal-Wallis test, with post-hoc FDR corrections.

Species	Group_Rural-No	Group_Rural-Yes	MP_pvalue	AF_pvalue
Bonelli's Eagle	Non-protected rural	Protected rural	0.16	0.16
Bonelli's Eagle	Non-protected rural	Non-protected urban	0.50	0.62

Bonelli's Eagle	Non-protected rural	Protected urban	0.31	0.69
Bonelli's Eagle	Protected rural	Non-protected urban	0.12	0.11
Bonelli's Eagle	Protected rural	Protected urban	0.46	0.14
Bonelli's Eagle	Non-protected urban	Protected urban	0.33	1.00
Lesser Kestrel	Non-protected rural	Protected rural	0.11	0.80
Lesser Kestrel	Non-protected rural	Non-protected urban	0.09	1.00
Lesser Kestrel	Non-protected rural	Protected urban	0.50	0.51
Lesser Kestrel	Protected rural	Non-protected urban	0.88	0.33
Lesser Kestrel	Protected rural	Protected urban	0.14	0.80
Lesser Kestrel	Non-protected urban	Protected urban	0.16	0.14
Red Kite	Non-protected rural	Non-protected urban	0.33	0.67

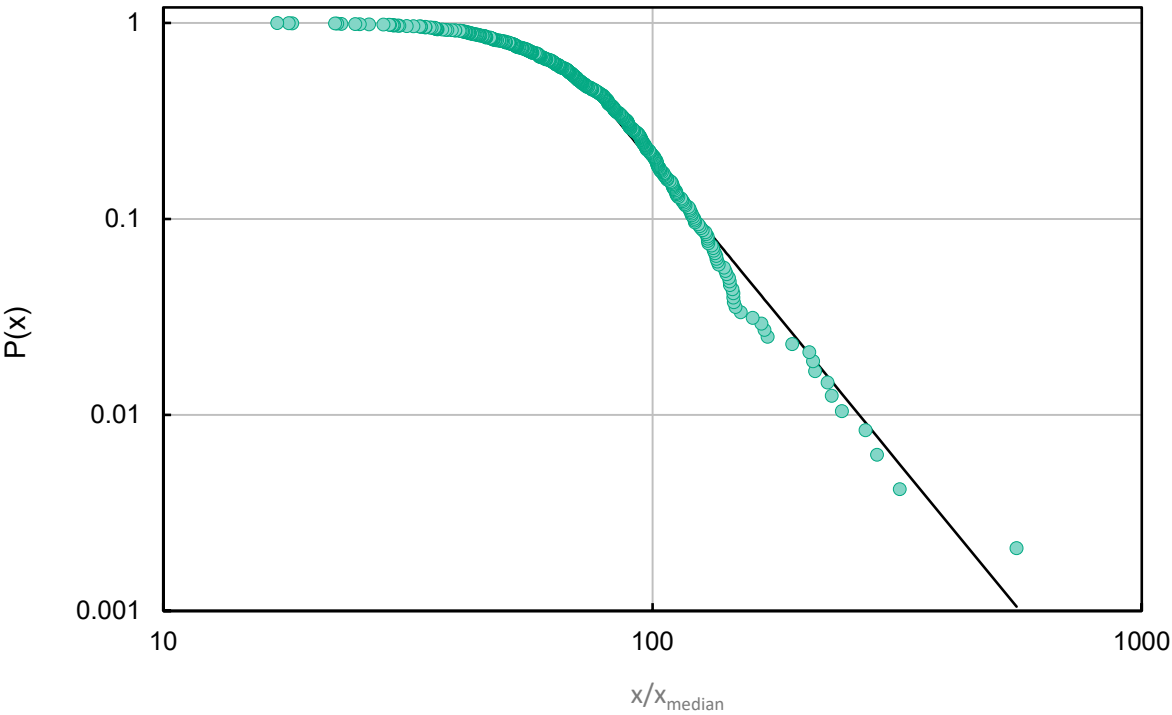


Figure S1. Particle size distributions as CFD, $P(\text{size} > x)$.

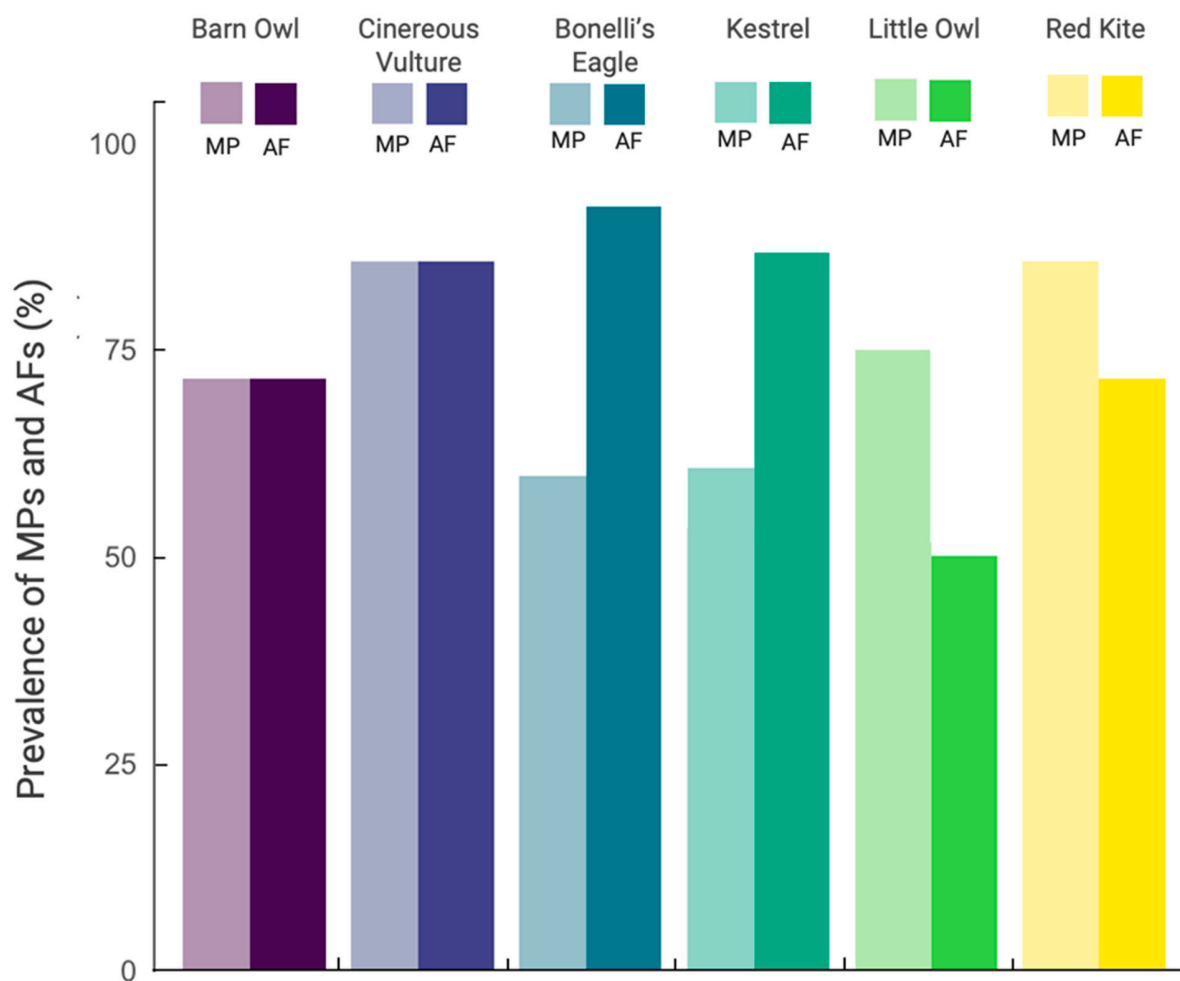


Figure S2. Prevalence of anthropogenic pollution defined as the number of pellets per species containing at least one particle (MPs or AFs) divided by the total number of pellets analyzed per species.

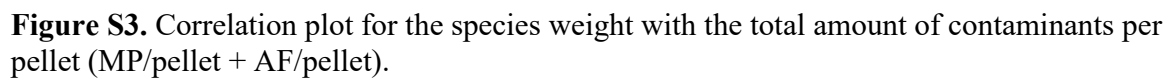


Figure S3. Correlation plot for the species weight with the total amount of contaminants per pellet (MP/pellet + AF/pellet).