Biodiversity and Conservation
https://doi.org/10.1007/s10531-023-02707-7

ORIGINAL RESEARCH

Citizen science and diet analysis shed light on dog-wildlife interactions in Italy

Davide Sogliani[1,2] · Emiliano Mori[3,4] · Sandro Lovari[5,6] · Lorenzo Lazzeri[5] · Alice Longoni[7] · Karol Tabarelli De Fatis[8] · Patrizia Sabatini[5] · Matteo Riccardo Di Nicola[9,10] · Danilo Russo[4,11]

Received: 20 April 2023 / Revised: 16 August 2023 / Accepted: 31 August 2023

Abstract

Domestic dogs *Canis familiaris* may cause a range of impacts on wildlife through predation, competition, pathogen transmission, harassment and hybridisation with wolves and other wild canids, yet such effects are less known than those of other domestic species.
In this work, we have combined citizen science data and information collected by scientists on the potential impact of free-ranging dogs on wildlife in Italy. Citizen science data, obtained through online surveys on social networks, consisted of pictures of wildlife killed or harassed by dogs from 2002 to 2022. Additional records were collected from articles in newspapers. We also provide the results of a diet analysis from domestic dog scats, collected in the countryside in central Italy in 1998–1999, for which we assessed prey selection by comparing consumption with availability. The citizen science survey provided 589 records: dogs attacked and killed 95 species, mostly mammals and birds, including small game species. Among species of conservation concern, dogs attacked/killed *Mustela putorius* and *Hystrix cristata*, both included in Annex IV of the Habitats Directive, and the Italian endemic *Lepus corsicanus* and *Passer italiae*. Over 90% of the attacks were caused by unleashed dogs in the presence of their owner in urban and periurban areas. The 148 dog scats analysed contained 30 prey species, mainly mammals, which made the staple of the dog diet, followed by amorphous material, most likely pet food. Remains of domestic sheep were frequent in the diet, as were hares *Lepus europaeus* and roe deer *Capreolus capreolus* among wild mammals. Wild boar *Sus scrofa* ranked first among the selected prey species, followed by hares, whereas roe deer and grey partridges *Perdix perdix* were negatively selected. The mitigation of the impact of domestic carnivores on wildlife strongly requires awareness raising to promote responsible pet ownership and strict avoidance of dogs' free-ranging behaviour, especially where encounters with wildlife are most likely.

Keywords *Canis familiaris* · Citizen science · Free-ranging domestic species · Prey selection · Wildlife harassment · Wildlife conservation

---

Communicated by Ricardo Correia.

Davide Sogliani and Emiliano Mori have contributed equally to this work.

Extended author information available on the last page of the article

Published online: 20 September 2023

Introduction

Since AD 1500, biological invasions and feralization of domestic species have been identified as one of the drivers of wild species extinctions and they acted as the sole causal factor in ca. one-fifth of them (Bellard et al. 2016). There is an ever-growing concern about the spread of introduced and domestic species and the ecological, economic and social implications of this currently overpowering process (Pyšek et al. 2020). Therefore, much work has been done or is ongoing to prevent invasions, eradicate invaders or mitigate their impact (Hulme 2006; Pyšek et al. 2020).

Besides biological, ecological, economical and logistic constraints, people's attitudes and social values play a highly important role in managing biological invaders (Shackleton et al. 2019; Sogliani et al. 2021). Aspects such as species charisma (Jarić et al. 2020; Gargioni et al. 2021; Sogliani et al. 2021) may interfere with crucial post-invasion practices such as eradication, range containment and numerical control (McGeoch et al. 2016). Even when their wild counterpart is native, free-ranging domesticated animals from those with an owner to feral ones are regarded as a distinct group of potentially invasive species or subspecies (Essl et al. 2018). They can spread diseases or interbreed with wild species and cause uncontrolled gene flow into wild populations (Randi 2008; Gering et al. 2019; Moroni et al. 2022). They can also cause serious problems for farming and livestock management (Young et al. 2011). There is overwhelming evidence that domestic cats, from owned pets to feral cats, are a major threat to global biodiversity owing to predation, fear effects, competition, disease transmission and hybridization (Loss et al. 2013; Woolley et al. 2019; Mori et al. 2019; Trouwborst et al. 2020; Oedin et al. 2021; Salinas–Ramos et al. 2021; Loss et al. 2022). Such strong evidence is nonetheless denied or belittled by many cat owners and lovers. They fiercely oppose indoor confinement (Crowley et al. 2020)—the most obvious solution to this problem (Linklater et al. 2019)—and play a role in impairing the application of already existing legal obligations, for instance, on the removal of feral and other unowned cats, and restriction of outdoor access to owned cats (Trouwborst et al. 2020).

Domestic dogs *Canis familiaris* (sensu Gentry et al. 2004) are, undoubtedly, as charismatic as cats (Jarić et al. 2020), and have conquered privileged positions in many human societies (Serpell 2016). They have been faithful companions to humans since prehistoric times. Dog domestication may be as old as 15,000–25,000 years (Wang et al. 2016; Bergström et al. 2020) and such still-debated history (Mech and Janssens 2022) has intrigued generations of scientists, including Charles Darwin (Darwin 1868). Dogs are ecologically flexible, occupy a broad range of niches and can be found on all continents, except for Antarctica.

Domestic dogs bring many precious emotional and functional benefits to humans (Serpell 2016; Range and Marshall–Pescini 2022). When it comes to their relationships with wildlife, however, it appears clear that the presence of dogs also brings about adverse consequences. This is especially true for free-ranging dogs (i.e., those free to move in a certain area, including owned ones, both controlled and unrestrained), stray (i.e., unowned dogs mostly fed by humans), and feral (i.e., dogs naturalised and able to get food independently from humans: Boitani et al. 2006). There is mounting evidence that the presence of free-ranging dogs may constitute a significant conservation issue via predation, harassment, competition, hybridization or disease transmission (e.g., Hughes and McDonald 2013; Newsome et al. 2015; Orozco et al. 2022). Dog numbers exacerbate the impact—in 2018, over 470 million dogs were kept as pets globally (https://www.statista.com/statistics/10443

86/dog-and-cat-pet-population-worldwide/ accessed on 19.04.2023) - and such figures boost when stray and feral individuals are considered. The high numbers of free-ranging dogs worldwide are continuously fuelled by unrestricted-owned dogs and those abandoned (https://www.woah.org/en/home/ accessed on 19.04.2023). Overall, the global population of domestic dogs is ca. one billion strong and is steadily growing (Gompper 2014). In addition, the great majority of these dogs is uncontrolled (Smith et al. 2019).

When dog-wildlife conflicts arise, people are called to choose between the two, but the main outcome is the people's tendency to favour dogs over wildlife, neglecting their detrimental implications for biodiversity (Genovesi 2000; Allen 2018). As with domestic cats, practices such as controlling the number of free-ranging dogs or adopting appropriate restrictions to minimise the impact of owned dogs, depend crucially on public support, which is in turn strongly influenced by people's attitudes (ethics, belief, religion and culture) as well as by the specific dog-related risk existing in each area (Smith et al. 2022). In Italy, Genovesi (2000) revealed a noteworthy perspective: over 50% of the Italian population did not perceive unrestricted dogs as a problem whatsoever. Furthermore, a mere 3.8% of Italians viewed direct killing as an acceptable alternative to confining dogs, such as keeping them in kennels. This underscores a significant aspect of public sentiment in the country.

Collecting information on the effects of domestic dogs on wildlife is paramount to understanding their impact on wildlife populations and identifying strategies that aim at managing and reducing the conflict (Young et al. 2011). Besides, people's involvement is vital to bridge the gap between the directions that conservation biologists give, and public perceptions and expectations. In this context, the active involvement of people in collecting information on the effects of dogs on wildlife is an invaluable asset to raising public awareness and fostering people's support. Citizen science has already emerged as an interesting tool for the early detection and management of biological invasions and makes it possible to cover large areas at lower costs than traditional data collection methods (Encarnação et al. 2021; Sogliani et al. 2021).

In our work, we combined citizen science data with observations made by scientists and dietary analysis of domestic dogs in a sample area of rural central Italy to assess the effects of this domestic carnivore on wildlife.

Materials and methods

Citizen science survey

We conducted a citizen science survey to collect a representative sample of pictures of wild vertebrate species killed or harassed by domestic dogs. Particularly, we surveyed social networks (Facebook and Instagram) and submitted enquiries to specific groups dealing with dogs and/or wild species, following Mori et al. (2019). We requested participants to provide photographs depicting instances of animal species being killed or harassed by dogs, primarily focusing on their own pets, during the period spanning 2002 to 2022. Additionally, we sought the geographical coordinates of the specific location where each event took place, and the annual trend of these occurrences can be found in Supplementary Material 1. In this process, participants were specifically encouraged to recall events dating back to 2002 and were required to provide photographic evidence as validation of their interactions with wildlife.

According to Italian laws, photographs, sensitive data, and coordinates of owners' houses are subject to licences/restrictions [National Law 633/1941 and following integrations, DL 196/2003; General Data Protection Regulation - EU Regulation 2016/679] and are not herewith disclosed, as agreed with participants.

Dog victims were identified to species level from photographs or confirmed evidence by Italian experts in zoology and wildlife rescue centres. When species identification was not possible or no photographic evidence was provided, the information was discarded. The dataset used for analyses is provided in Supplementary Material 2. The database includes the specific identity of the prey, the attack location, year and month, the global and national IUCN threat categories (Rondinini et al. 2022), age category (adult or juveniles), dog condition (i.e., confined, leashed, unleashed, free-ranging or, specifically, stray/feral dogs), type of harm made to wildlife (killed, injured or harassed), wildlife's physiological stage (i.e., hibernation or reproduction: cf. Supplementary Material 2). The *Z*-test was used to compare percentages of occurrence in our dataset (Sokal and Rohlf 2012).

Further data collection

We conducted searches through newspapers, magazines, web news, and television for news on domestic dog attacks on wildlife that occurred between 2002 and 2022. We used the google search engine to screen the web and gather relevant articles and TV news, as well as print versions of newspapers and magazines when available. Search terms included all possible combinations of these words (in Italian): "dog", "*Canis familiaris*", "interaction", "wild species" and "wildlife". We kept only photos and videos where dogs were clearly seen interacting with wildlife, between 2002 and 2022. All available videos were stored in our dataset, including, whenever possible, the date, location, and identification of the prey species.

Diet analysis

To provide a picture of which wildlife species fall prey to domestic dogs, we concentrated our dietary analysis on rural and hunting properties of the province of Siena (43° 10' N, 11° 30' E; central Italy), as also in an area interspersed with fallows and small woods. The study area was characterised by a Mediterranean climate, with warm, dry summers and relatively mild temperatures year-round. Average monthly temperatures were always below 25 °C in summer and above 0 °C in winter. The monthly average rainfall was ca. 60 mm, with a peak in autumn (October and November). Snowfall was a very rare (1–2 days per year) event (Lovari et al. 2013, 2017). About 67% of the area was characterised by cereals, sunflowers, lucerne, and 4% fallows. Deciduous forest (*Quercus cerris L.*, *Q. pubescens* Willd., *Ostrya carpinifolia* Scop. and *Fraxinus ornus L.*) and shrubland (*Spartium junceum L.*, *Prunus spinosa L.*, *Ligustrum vulgare L.*, *Crataegus monogina* Jacq., *Cornus sanguinea L.*, *Rosa canina L.* and *Rubus* spp.) covered 11% and 6% of the territory, respectively.

Some groups composed of 3.4 ± 1.7 free-ranging dogs were recorded through visual observations, although, in 45% of cases ($n = 151$), dogs were solitary. We considered all these dogs as "free-ranging", without discriminating between owned and stray/feral, as it was not possible to determine whether scats were laid by one of the two categories. Dog scats were collected monthly from July 1998 through June 1999, along 40×1 km transects evenly distributed across the study area, for a total of approx. 40 km in length. Scats were collected throughout the four seasons. Transects were selected at least 50 m away from dirt roads and paths, to decrease the possibility to collect scats of leashed dogs.

When collecting scats in our study area, the misidentification of domestic dog scats as those of wolves *Canis lupus* was not a concern due to the wolf's rarity in those years (Lovari et al. 2013, 2017). Scats from red foxes (*Vulpes vulpes*) were common. Field identification can occasionally be incorrect, even with experienced observers (Monterroso et al. 2019). However, fox scats have a distinct smell and other features which usually make them easy to detect, allowing us to exclude them and uncertain cases from our analyses (Sogliani and Mori 2019).

In the field, we used specific features such as size, texture, shape, content, and smell to identify scats (Jędrzejewski and Jędrzejewska 1992). Only clearly identified dog scats were collected, and any scats with uncertain identification were discarded. We followed established protocols for analysing wild carnivore diets (Kruuk and Parish 1981; Teerink 1991; Sogliani and Mori 2019).

In the laboratory, we took precautions to process dog scats. They were dried at 80 °C for over 3 h to minimize the risk of zoonotic transmission and inactivate parasites (Ferretti et al. 2021). The undigested materials (such as hairs, bones, and plant matter) were separated using a 1–3 mm mesh sieve and tweezers in hot water. These materials were then kept dry in labelled Eppendorf tubes (Sogliani and Mori 2019; Ferretti et al. 2021).

For hair analysis, we evaluated general colour by sight and examined the cuticle, medulla, and cortex on glass slides under a microscope at magnifications of 100 × − 400× (Teerink 1991; Paolucci and Bon 2022). Microstructures were analysed following Teerink (2004) and compared with specific atlases and a local reference collection at the Department of Life Sciences, University of Siena, which included also plant matter, small mammal and reptile jaws, and bird beaks (Teerink 1991; Paolucci and Bon 2022).

We calculated absolute (AF: number of occurrences of each food, when present/total number of scats × 100) and relative (RF: number of occurrences of each food when present/total number of occurrences of all food items × 100) frequencies of occurrence of each prey species in the diet (Lucherini et al. 1995; Sogliani and Mori 2019). For each sample, the estimated-by-eye relative volume of food ingested (estimated volume of each category/ total number of scats × 100) was scored on a seven-point scale (absent, < 6, 6–25, 26–50, 51–75, 76–95, > 95%: Kruuk and Parish 1981; Kruuk 1989). Relative frequencies and volumes were then plotted in a diagram (Kruuk 1989). We refrained from using formulas to calculate consumed biomasses due to the potential misleading factors that may impact this calculation (Chakrabarti et al. 2016; Lumetsberger et al. 2017). In fact, Khan et al. (2018) stated that it is impossible to assess (i) whether a young/subadult/male/female has been consumed (body mass significantly varies across distinct age classes and sexes of prey species, especially polygynous mammals); (ii) whether a carnivore scavenged from a carcass previously partially consumed by other carnivores or from its own kill; (iii) whether it fed alone or with conspecifics, such as members of the same pack.

Food items were categorised as follows: (1) small mammals (Rodentia and *Eulipotyphla*); (2) European brown hare *Lepus europaeus*; (3) roe deer *Capreolus capreolus*; (4) wild boar *Sus scrofa*; (5) domestic sheep *Ovis aries*; (6) other mammals (crested porcupine *Hystrix cristata*, domestic cat *Felis catus*); (7) birds (Galliformes - especially the grey partridge - Passeriformes, undetermined eggs); (8) plant matter (fruits of *Malus sylvestris* (L.) Mill., *Pyrus pyraster* (L.) Burgsd. *Rosa canina* L., *Prunus domestica*, *Prunus spinosa* L., *Vitis vinifera* L., seeds and grasses); (9) amorphous material (e.g. pet food); (10) Reptilia; (11) Invertebrates, and (12) undetermined. To determine prey selection, we compared prey use vs. local prey availability. This was done only for game species, for which availability data were known through the evaluation of the Kilometric Abundance Index (KAI) obtained from both night and daytime counts (Siena Provincial Administration - Wildlife Office, pers. comm.). Then, prey selection was assessed through Johnson (1980)'s ranking method: each prey species was ranked according to its frequency in the dog diet (i.e., the "use", with rank 1 = the most abundant prey). The same ranking criterion was used for the local abundance of each prey (the "availability"). We calculated the difference between use and availability ranking to obtain a preference scale for each prey. All analyses were performed with the R ver. 4.1.2 software (R Core Team 2013). In statistical tests, significance was set at $p < 0.05$ (Sokal and Rohlf 2012).

Results

Citizen science survey

From 2002 to 2022, we gathered 589 instances of domestic dog attacks on wildlife (n = 585) and domestic species (n = 4) from 162 locations across Italy (see Fig. 1a and b), involving 95 species. We showed a rise in data over the years, aligning with the escalating upload of pictures on social networks, with a decline in 2020 and 2021 (see Supplementary Material 1). Domestic animals like *Felis catus* and *Gallus gallus* were excluded from the analysis and can be found in Supplementary Material 2.

Most (95.75%) events ended with the death of the attacked individual, while in 2.89% of cases, this was wounded but survived the attack. The remaining 1.36% were not physically harmed yet they were disturbed in sensitive phases of their life cycle such as nesting, provision of parental care or when feeding. Amongst the killed individuals, three (belonging to *Sciurus carolinensis, Hystrix cristata* and *Sus scrofa*, one for each species) were also eaten by the dog, in all cases a free-ranging dog (Fig. 2).

Most attacks by dogs were directed to adults (68.50%) rather than to juveniles (also including fawns, cubs and nestlings/fledglings: *Z*-test, $p < 0.0001$).

At least 450 attacks (77.00%) were caused by free-ranging dogs and 133 (23.00%) by dogs that were either confined or on a leash. Eight individuals belonging to 6 species (*Columba livia domestica, Pica pica, Larus michahellis, Vipera aspis, Podarcis muralis*, and *Tarentola mauritanica*) were also attacked and killed by dogs on a leash (1.20%). Most events (69.50%) occurred in the warm months (March–August: Fig. 3).

The most frequently attacked wildlife were mammals (53.48%), followed by birds (33.28%), reptiles (12.22%), and amphibians (1.02%). The most frequently killed species was the roe deer *Capreolus capreolus* (10.86% of RF), but *Erinaceus europaeus* (9.00%), *Myocastor coypus* (5.26%), *Lepus europaeus* (4.07%) and *Turdus merula* (3.56%) were also killed in some cases (Fig. 4; Supplementary Material 2 for the whole list).

Most attacked wild vertebrates belonged to species classified as "least concern" (LC) both globally (91.68%) and in the national red list (69.15%). According to the global red list, some species are "not evaluated" due to recent taxonomy splitting (*Natrix helvetica*). Other species are globally classified as "data deficient" (*Sorex antinorii*, *Zamenis lineatus*), "near threatened" (*Oryctolagus cuniculus, Alectoris rufa, Testudo hermanni* and *Elaphe quatuorlineata*) or "vulnerable" (*Lepus corsicanus*, *Passer italiae, Testudo graeca* and *Rana latastei*) (Fig. 5; Supplementary Material 2).

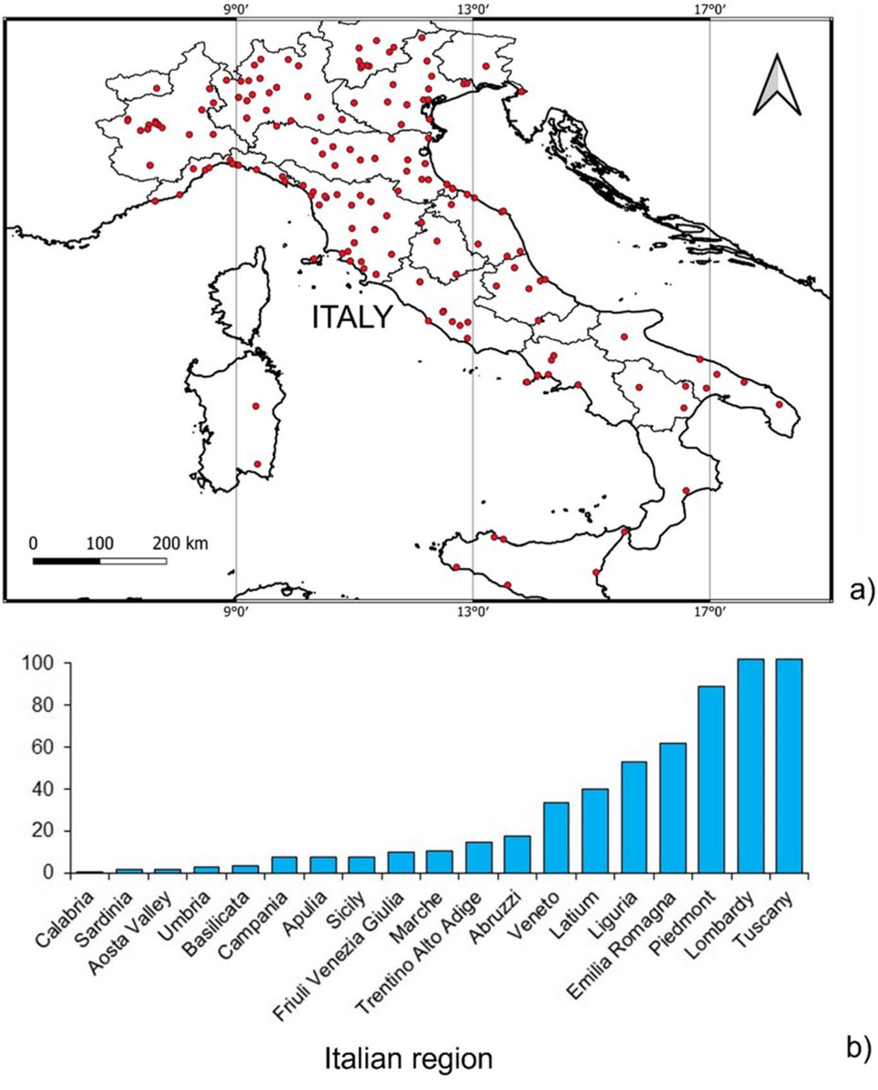

Fig. 1 Locations of documented dog attacks on wildlife and domestic animals in Italy between 2002 and 2022, and the Italian regions where these incidents occurred

Also, the endemic sub-species of Apennine brown bear *Ursus arctos marsicanus* is listed under the "brown bear" specific name in the global red list, thus being considered as "Least Concern", but it is assessed as "Critically endangered" in the national red list.

Furthermore, the sample included eight endemic or near-endemic Italian species, i.e., *Lepus corsicanus, Ursus arctos marsicanus, Sorex antinori, Passer italiae*, *Zamenis lineatus*, *Podarcis siculus, Ichthyosaura alpestris apuana* and *Rana latastei*. Of these, *Passer italiae, Rana latastei*, and *Lepus corsicanus* are classified as "vulnerable" by the Italian red list, together with other more widespread species, i.e., *Bufo bufo*, *Chloris chloris* and *Passer montanus.* Apart from the above-mentioned critically endangered Apennine

Fig. 2 Wildlife killed or wounded by dogs in Italy: **a**-**b** *Hystrix cristata*, showing evident signs of consumption; **c** *Streptopelia decaocto*; **d** *Meles meles*; **e** *Mustela putorius* and **f** *Capreolus capreolus*

brown bear, the only "endangered" species according to the Italian red list were the Kentish plover *Charadrius alexandrinus*, a small shorebird nesting on beaches, with ten killings by domestic dogs (Supplementary Material 2), and Hermann's tortoise *Testudo hermanni*. A total of 99 individuals (16.92%), encompassing 13 species (refer to Supplementary Material 2), were identified as non-native to the Italian territory.

Diet of free-ranging domestic dogs

We identified 30 prey taxa in 148 dog scats, 18% of which were detected only once (Table 1).

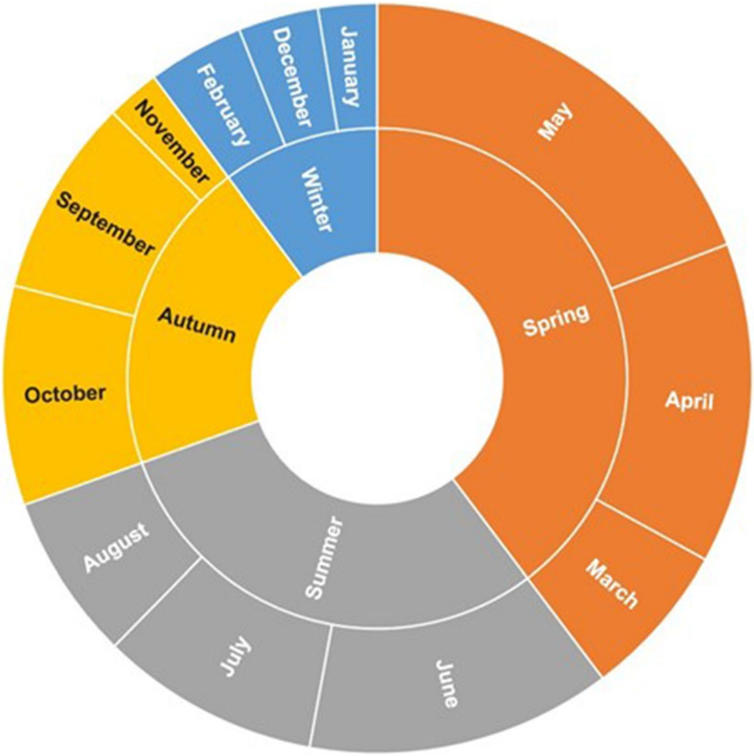

Fig. 3 Seasonal and monthly distribution of attacks on wildlife by dogs in Italy in 2002–2022

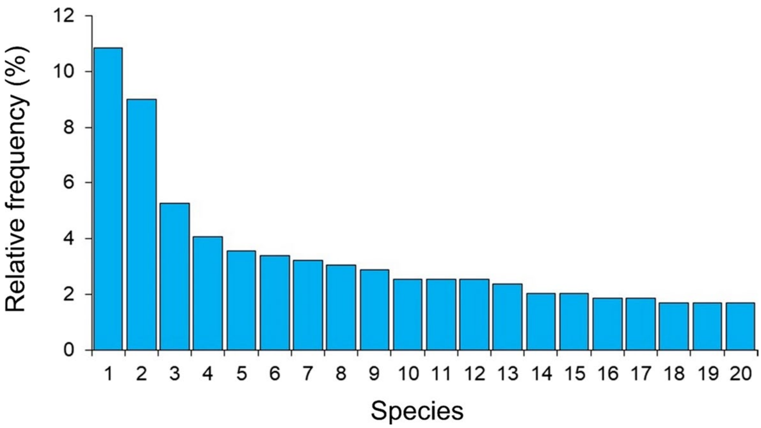

Fig. 4 Relative frequency (%) of the 20 species most frequently attacked by domestic dogs in 2002–2022 in Italy. Species: (**1**) *Capreolus capreolus*; (**2**) *Erinaceus europaeus*; (**3**) *Myocastor coypus*; (**4**) *Lepus europaeus*; (**5**) *Turdus merula*; (**6**) *Columba livia domestica*; (**7**) *Sylvilagus floridanus*; (**8**) *Podarcis muralis*; (**9**) *Fulica atra*; (**10**) *Phasianus colchicus*; (**11**) *Sciurus carolinensis*; (**12**) *Streptopelia decaocto*; (**13**) *Hierophis viridiflavus*; (**14**) *Gallinula chloropus*; (**15**) *Natrix helvetica*; (**16**) *Hystrix cristata*; (**17**) *Talpa europaea*; (**18**) *Charadrius alexandrinus*; (**19**) *Sus scrofa*; (**20**) *Vulpes vulpes*

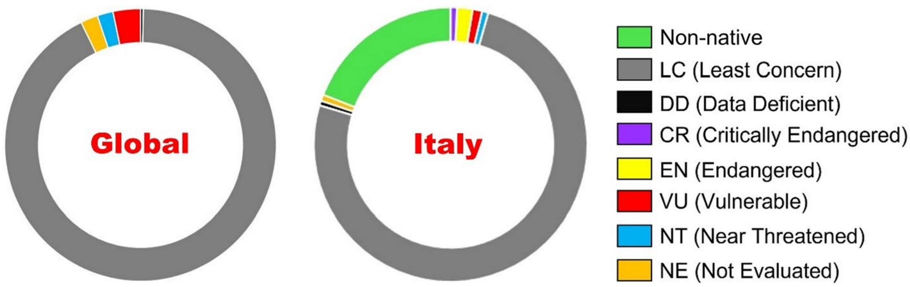

Fig. 5 Threat categories of individual vertebrates attacked by domestic dogs in Italy, based on their classification in the IUCN global and Italian red lists

Table 1 Occurrences, absolute frequency (AF %) and relative volume when present (RV %) of prey items in dog scats collected in a rural area of central Italy (Siena province)

Prey	N° occurrences	AF (%)	RV (%)
Invertebrates	**19**	**12.8**	**1.7**
Coleoptera	15	10.1	0.8
Orthoptera	7	4.7	0.6
Larvae (unidentified)	4	2.7	0.3
Myriapoda	1	0.7	< 0.05
Mollusca	2	1.4	< 0.05
Mammals	**82**	**55.4**	**56.6**
Small mammals	13	8.8	6.2
Lepus europaeus	10	6.8	6.5
Capreolus capreolus	10	6.8	6.2
Sus scrofa	7	4.7	4.5
Hystrix cristata	4	2.7	2.4
Ovis aries	33	22.3	21.1
Felis catus	3	2.0	1.5
Unidentified	2	1.4	1.3
Birds	**8**	**5.4**	**3.8**
Galliformes	6	4.1	3.4
Passeriformes	1	0.7	0.1
Eggs	1	0.7	0.3
Reptiles	**3**	**2.0**	**1.5**
Plants	**45**	**30.4**	**6.3**
Fruits	20	13.5	3.4
Poaceae (seeds)	45	30.4	2.9
Grasses	2	1.4	< 0.05
Amorphous material	**77**	**52.0**	**37.3**

Bold refers to food macrocategories

The animal component, mainly mammals, made the dogs' diet staple (RF = 44.9%, RV = 56.6%), followed by amorphous material (RF = 30.9%, RV = 37.3%), presumably food of human origin, e.g., pet food. The plant component occurred frequently but at a low volume (RF = 24.1%, RV = 6.3%).

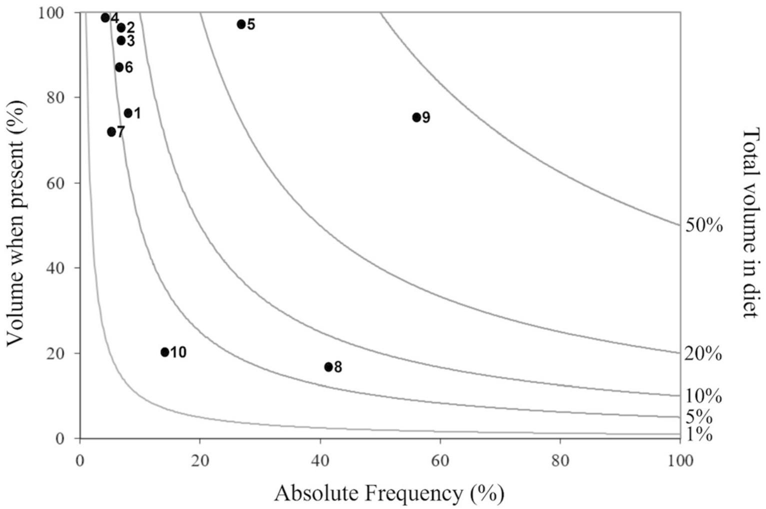

Fig. 6 Diet of dogs in a rural area of central Italy: absolute frequency plotted versus volume of each food category, when present. Isopleths connect points of the same total volume in diet: (**1**) small mammals; (**2**) *Lepus europaeus*; (**3**) *Capreolus capreolus*; (**4**) *Sus scrofa*; (**5**) *Ovis aries*; (**6**) other mammals; (**7**) birds; (**8**) plants; (**9**) amorphous material; (**10**) other

Table 2 Food item selection by domestic dogs in a rural area of central Italy and availability and use ranks. Selection index: = prey used proportionally to its availability; − prey avoided; + prey selected; KAI Kilometric Abundance Index

	Lepus europaeus	*Capreolus capreolus*	*Sus scrofa*	*Perdix perdix*
KAI	4.93	4.03	0.02	2.50
Availability	2.0	1.0	4.0	3.0
Use	2.0	3.0	1.0	4.0
Selection Index	=	−	+	−

The amorphous material was the most important category, being present in 77/148 scats, with a volumetric value of up to 37.2% when present, almost accounting for the totality of the scat volume (98% in 54 samples: Fig. 6). Another particularly abundant food component was the domestic sheep. Hares and roe deer featured among the most frequently consumed wild mammals. Bird consumption was limited and mostly concentrated on Galliformes, i.e., on the grey partridge. Among plant material, the most common fruits in the diet volume were blackthorns and plums (Fig. 6).

The wild boar ranked first among the preferred food species, followed by the European brown hare, whereas the roe deer and the grey partridge were selected against (Table 2).

Discussion

Our findings suggest that domestic dogs were responsible for attacking a diverse array of wildlife, and these attacks were prevalent throughout Italy. However, the regional variations observed are likely due to uneven participation by respondents rather than actual ecological trends. Uneven spatial distribution is a recognized limitation in citizen science (e.g., Cretois et al. 2021). Furthermore, the reduction in collected data during 2020–2021 may be attributed to lockdown restrictions stemming from the COVID-19 pandemic (refer to Supplementary Material 1).

The fact that dog attacks ended in almost all instances with the death of their victims highlights the potential danger of these events, while the very low frequency of dog consumption of the victim suggests a killing behaviour that is independent of trophic stimuli and is under separate genetic control (Shan et al. 2021). Moreover, attacks recorded as non-lethal may still have led to death, which is unknown since the victim's fate was not tracked after the event. Admission data analysis from an Australian wildlife rescue centre showed that mortality was the highest (72.7% of examined cases) in wild animals following a dog's attack (Taylor–Brown et al. 2019).

The high degree of mortality associated with dog attacks has been well-documented in previous studies, which, on the other hand, recorded no consumption of the victim, in agreement with our results (e.g., Weston et al. 2014 for a review). Furthermore, predominantly adult individuals were documented in dog-wildlife interactions, as juveniles are frequently concealed in shelter sites (e.g., dens, nests, warrens), thereby limiting access to predators and potentially exerting additional impact on wildlife populations. However, the diet analysis we present seems to tell a different story. Vertebrates were frequent food items, especially medium-sized game species, and wild boar and hares were selected positively. Game species also occurred frequently in the diet of free-ranging dogs from other European regions (Krauze–Gryz and Gryz 2014). It cannot be excluded that some of these food items were ingested by scavenging dead animals. In our study area, hunting dogs were infrequent (i.e., fewer than 10 sightings) and typically hunters did not provide their dogs with offcuts of captured game, thereby indicating a dependable selection of these food categories by free-ranging dogs.

The picture provided by our diet analysis only concerns one study area, but wildlife hunting might be significant in free-ranging dogs that are not constantly fed by humans (Krauze–Gryz and Gryz 2014). In agreement with our dietary data, dogs have been found to eat a substantial amount of wildlife in many world regions (e.g., Butler and du Toit 2002; Campos et al. 2007; Vanak and Gommper 2009; Carrasco–Román et al. 2021), but, where possible, the dominance of scavenging over predation was assessed and even considered a competitive threat for wild scavengers (Butler and du Toit 2002).

We caution that, in our scat analysis, the condition of the involved dogs was unknown. Although all scats were collected off-track and far from the dirt roads present in our study area, some scats might come from owned dogs, including hunting dogs, hence fed by humans. This would explain the not negligible presence of amorphous material (most likely, pet food). Our analyses will be replicated in the forthcoming years, given the significant increase in grey wolf numbers in our study area (Galaverni et al. 2016) and the advent of molecular techniques for dietary analyses. Additionally, sheep are presently confined in pens at night, potentially altering the impact of free-ranging dogs towards wild species. Furthermore, the population of free-ranging dogs in the study area appears to have diminished in recent years, possibly because of rural depopulation and the enhanced Italian legislation concerning responsible dog ownership and animal welfare.

The citizen observations we recorded included only a small percentage of harassment cases that did not imply physical harm to the victim. Many such instances typically go unnoticed or unreported because they are not perceived as an issue by the dog's owner or other witnesses, but they may still imply substantial adverse effects on wildlife (Weston and Stankowich 2013). This is also the reason by which we were unable to gather data on "no interaction" between dogs and wildlife. The presence of dogs may generate peaks in wildlife's "landscapes of fear" (e.g., Laundré et al. 2010), for example by temporarily or permanently excluding animals from otherwise highly suitable foraging, breeding, or resting places, or by alarming animals and interrupting their activities. If protracted, such interferences may reduce an individual's fitness and even bring about negative demographic consequences. For instance, dog walkers and unleashed dogs in British heathlands were found to cause a 17% productivity drop in a ground-nesting woodlark *Lullula arborea* breeding area (Mallord et al. 2007). As other noteworthy examples, in New Zealand one single dog preyed upon more than half of a kiwi bird population (Taborsky 1988), while in Italy uncontrolled dogs led to the annihilation of the largest Sardinian flamingo colony (Genovesi 2000).

Most attacks were conducted by free-ranging dogs, in agreement with other studies (e.g., Lafferty 2001; Mallord et al. 2007; Weston and Elgar 2005; Underhill–Day and Liley 2007; Williams et al. 2009), which remarks on the critical impact of unrestrained dogs. Despite the legal obligation existing in Italy to keep dogs leashed in urban areas and any space open to the public (Italian Ministry of Health 2022), in rural areas of Italy unrestrained owned or resident village dogs, free to roam in the countryside, are a common sight. This situation also takes place in nature reserves (pers. obs.) and is common to protected areas of other world regions (Dowling and Weston 1999; Arnberger et al. 2005; Antos et al. 2007; Arnberger and Eder 2008; Weston et al. 2009), where leaving dogs unrestrained (or in some cases, even dog access) is strictly forbidden. Despite walking dogs on a leash being the best way to control their roaming (Weston and Stankowich 2013), we found that leashed or confined dogs were also responsible for a significant share (> 20%) of attacks, some of which ended with a kill, which highlights the role of dog walkers' appropriate behaviour in preventing such events.

Dog attacks on wildlife were more prevalent during the warmer months, which could be attributed to factors such as increased dog walking or roaming during mild weather and the greater outdoor presence of citizen scientists. Temporal patterns may also emerge due to weekends, holidays, and weather conditions (Weston and Stankowich 2013). The March–August period, during which most attacks occurred, is crucial for reproduction or high activity levels in many Italian wildlife species. While this may increase the chances of dog-wildlife encounters, it also emphasises the negative effects occurring during particularly sensitive stages of wildlife's life cycles. These effects are particularly relevant for mammals and birds, which were the most commonly attacked species, but also for reptiles, which are more active in the warmer months. For example, *P. siculus* is active for 2–3 h in winter compared to 14 h in July and August (Foà et al. 1992), so it is clearly more exposed to predation in the warm months, and this pattern may hold for virtually all reptiles. The low frequency of attacked amphibians results from the specific aquatic habitat these vertebrates use, which is hard to access and therefore only sporadically explored by dogs. This also may explain why dog attacks on amphibians are scarcely represented in the scientific literature. In their reviews on dog attacks on wildlife, Doherty et al. (2017) mention three cases only, while Hughes and Macdonald (2013) considered a single study on the

Fijian ground frog (*Platymantis vitianus*)—a species characterised by prominent terrestrial habits, including nesting behaviour (Narayan et al. 2008), therefore more exposed to dogs. Toads—amphibians showing terrestrial behaviour for part of their life cycles, among the attacked species in our study—use a venom secretion that can cause serious harm and even death in dogs, a defence that may likely discourage killing and reduce its occurrence (e.g., Sakate and De Oliveira 2000).

While most dog attacks involved species whose conservation status is not of special concern according to both global and national red lists, according to our records, dogs killed individuals of two endangered species (a bird, the Kentish plover, and a reptile, the Hermann's tortoise) and, in one case, the critically endangered Apennine brown bear (*Ursus arctos marsicanus*). Attacks on small-sized species such as the first two may be recurrent in areas frequently visited by dogs and imply adverse demographic consequences, while the relative rarity of attacks on large mammals such as the above-mentioned bear should not dismiss their conservation consequences. In this special case, the overall Apennine brown bear population numbers ca. 50 individuals, cubs included (Ciucci et al. 2015), and even a single attack would take a toll on an effective population size restricted to a handful of bears (Benazzo et al. 2017). Our data, therefore, add to the already concerning picture of the impact of dogs on threatened vertebrates provided by Doherty et al. (2017).

Despite the large number of domestic dogs in Italy (approximately 8.8 million in 2022: https://www.statista.com/statistics/515521/dog-population-europe-italy; Accessed on 08.08.2023), we obtained only a limited number of records from at least 500 dogs, primarily involving "least concern" species. These records represent a small portion of the human population that participated in our survey by uploading photos on social networks. Consequently, we acknowledge that most likely our dataset underestimates the actual impact of free-ranging dogs on wildlife. However, the potential effects on certain animal populations cannot be ruled out and would require systematic studies, particularly in the case of threatened species, such as the Apennine brown bear and the Kentish plover.

In summary, while we cannot conclude that dog attacks always pose a conservation concern, our findings indicate that they can be problematic, particularly when targeting small wildlife populations during critical phases of their life cycle (e.g., breeding Kentish plovers on beaches). Even minor disturbances can pose a significant threat in certain conditions. Additionally, our study did not explore other potential threats associated with dogs, such as pathogen transmission (Knobel et al. 2013; Costanzi et al. 2021), competition with wild predators for food (Lescureux and Linnell 2014), hybridization with wolves and its ecological impacts (Bassi et al. 2017), and attacks on livestock (Bergman et al. 2009) or humans (Iliopoulos et al. 2022), which may exacerbate existing conflicts between humans and wolves. Furthermore, outdoor lifestyle in dogs (and cats) enhance human risk of contracting zoonotic diseases, especially parasitic ones (for a comprehensive review: Mendoza Roldan and Otranto 2023).

Solutions are needed to mitigate dog impacts on biodiversity, including stricter enforcement of existing laws and regulations on dog restraining and abandonment prevention, a legal framework covering the risk posed by dogs to biodiversity, as well as effective awareness-raising of the public, especially dog owners. The issue has deep cultural roots since the public rarely perceives dog attacks on wildlife as a serious problem. For example, a survey of public attitudes towards different strategies of free-ranging dog management revealed that in Chile over 98% of respondents would accept killing dogs who attacked sheep more than those attacking wildlife (Villatoro et al. 2019). This feeling is by no means limited to one country, and after all, is reflected in national laws and regulations too. For instance, Italian legislation requiring dogs to be leashed in public areas or urban spaces aims to ensure "public safety", without taking into account potential effects on wildlife. However, with Italy recently taking a historic step by including the protection of the environment, biodiversity, and ecosystems in its constitution, it is high time to expand the focus to numerous aspects of civil life, including the interactions between domestic animals and wildlife, and take appropriate actions.

Supplementary information The online version contains supplementary material available at https://doi.org/10.1007/s10531-023-02707-7.

Acknowledgements We thank all citizen-scientists who provided attack data; our expert colleagues (Luca Lapini, Gentile Francesco Ficetola, Giulia Tessa, Salvatore Ferraro, Marco Brandi, Nunzio Grattini and Massimo Crema) and Wildlife Rescue Centres for providing us with some records and for their help in species identification; Maddalena Mattii and Giorgina Romeo for the diet of free-ranging domestic dogs; Roberta Latini (Abruzzo, Lazio, and Molise National Park) for the Apennine brown bear records; the Siena Provincial Administration—Wildlife Office, who provided KAIs of game and ungulate species for the scat collection area. We would also like to thank Gabriele Stanisci and Francesco Castaldo (Rifugio Miletta) for providing some of the images in Fig. 2. DS is grateful to the Ghislieri Foundation for supporting his research activity with an accommodation scholarship. We thank two anonymous reviewers for their useful comments which helped us to improve our article.

Author's contributions DS, LL, DR, and AL conceived the study; EM, DS, AL, KTDF, and MRDN collected most citizen-science data; DS and LL organised the dataset for citizen science; DS, EM, and SL analysed the data; SL and PS collected field data; LL geolocalized data; DR, DS, EM, and SL wrote the first draft. All authors read and approved the final manuscript.

Funding Open access funding provided by Consiglio Nazionale Delle Ricerche (CNR) within the CRUI-CARE Agreement. EM was funded by the National Recovery and Resilience Plan (NRRP), Mission 4 Component 2 Investment 1.4—Call for tender No. 3138 of 16 December 2021, rectified by Decree n.3175 of 18 December 2021 of Italian Ministry of University and Research funded by the European Union – NextGenerationEU; Project code CN_00000033, Concession Decree No. 1034 of 17 June 2022 adopted by the Italian Ministry of University and Research, CUP B83C22002930006, Project title "National Biodiversity Future Center—NBFC" .

Data availability Data used in this study are available in the Electronic Supplementary Materials.

Declarations

Competing interests The authors declare no competing interests.

References

Allen BL (2018) And the people's choice award goes to… dogs: a comment on home. Anim Conserv 21:283–284

Antos MJ, Ehmke GC, Tzaros CL, Weston MA (2007) Unauthorised human use of an urban coastal wetland sanctuary: current and future patterns. Lansc Urb Plan 80:173–183

Arnberger A, Eder R (2008) Assessing user interactions on shared recreational trails by long-term video monitoring. Managing Leisure 13:36–51

Arnberger A, Brandenburg C, Eder R (2005) Dog walkers as management challenge in urban forests. In: Neuhöferová P (ed) Management of urban forests around large cities. Czech University of Agriculture, Prague, Czech Republic, pp 3–5

Bassi E, Canu A, Firmo I, Mattioli L, Scandura M, Apollonio M (2017) Trophic overlap between wolves and free-ranging wolf × dog hybrids in the Apennine Mountains, Italy. Glob Ecol Conserv 9:39–49

Bellard C, Cassey P, Blackburn TM (2016) Alien species as a driver of recent extinctions. Biol Lett 12:20150623

Benazzo A, Trucchi E, Cahill JA, Maisano Delser P, Mona S, Fumagalli M, Bunnefeld L, Cornetti L, Ghirotto S, Girardi M, Ometto L et al (2017) Survival and divergence in a small group: the extraordinary genomic history of the endangered apennine brown bear stragglers. Proc Nat Ac Sci 114:9589–9597

Bergman DL, Breck SW, Bender SC (2009) Dogs gone wild: feral dog damage in the United States. Proc XIII Wildl Damage Manage Conf 13:177–183

Bergström A, Frantz L, Schmidt R, Ersmark E, Lebrasseur O, Girdland-Flink L, Lin AT, Stora J, Sjogren KG, Anthony D, Antipina E et al (2020) Origins and genetic legacy of prehistoric dogs. Science 370:557–564

Boitani L, Ciucci P, Ortolani A (2006) Behaviour and social ecology of free-ranging dogs. In: Jensen P (ed) The behavioral biology of dogs. CABI Publishing, Wallingford, U.K, pp 147–164

Butler JRA, du Toit JT (2002) Diet of free-ranging domestic dogs (*Canis familiaris*) in rural Zimbabwe: implications for wild scavengers on the periphery of wildlife reserves. Anim Conserv Forum 5:29–37

Campos CB, Esteves CF, Ferraz KMPMB, Crawshaw PG Jr, Verdade LM (2007) Diet of free-ranging cats and dogs in a suburban and rural environment, south-eastern Brazil. J Zool 273:14–20

Carrasco-Román E, Medina JP, Salgado-Miranda C, Soriano-Vargas E, Sánchez-Jasso JM (2021) Contributions on the diet of free-ranging dogs (*Canis lupus familiaris*) in the Nevado de Toluca Flora and Fauna Protection Area, Estado de México, Mexico. Rev Mex Biodiv 92:1

Chakrabarti S, Jhala YV, Dutta S, Qureshi Q, Kadivar RF, Rana VJ (2016) Adding constraints to predation through allometric relation of scats to consumption. J Anim Ecol 85:660–670

Ciucci P, Gervasi V, Boitani L, Boulanger J, Paetkau D, Prive R, Tosoni E (2015) Estimating abundance of the remnant apennine brown bear population using multiple noninvasive genetic data sources. J Mammal 96:206–220

Costanzi L, Brambilla A, Di Blasio A, Dondo A, Goria M, Masoero L, Gennero MS, Bassano B (2021) Beware of dogs! Domestic animals as a threat for wildlife conservation in Alpine protected areas. Eur J Wildl Res 67:70

Cretois B, Simmonds EG, Linnell JD, van Moorter B, Rolandsen CM, Solberg EJ, Strand O, Gundersen V, Roer O, Rød JK (2021) Identifying and correcting spatial bias in opportunistic citizen science data for wild ungulates in Norway. Ecol Evol 11:15191–15204

Crowley SL, Cecchetti M, McDonald RA (2020) Diverse perspectives of cat owners indicate barriers to and opportunities for managing cat predation of wildlife. Front Ecol Environm 18:544–549

Darwin C (1868) The variation of animals and plants under domestication. Murray Editions, London, UK

Doherty TS, Dickman CR, Glen AS, Newsome TM, Nimmo DG, Ritchie EG, Vanak AT, Wirsing AJ (2017) The global impacts of domestic dogs on threatened vertebrates. Biol Conserv 210:56–59

Dowling B, Weston MA (1999) Managing the hooded plover in a high-use recreational environment. Bird Conserv Intern 9:255–270

Encarnação J, Teodósio MA, Morais P (2021) Citizen science and biological invasions: a review. Front Environm Sci 8:602980

Essl F, Bacher S, Genovesi P, Hulme PE, Jeschke JM, Katsanevakis S, Kowarik I, Kühn I, Pyšek P, Rabitsch W, Schindler S, van Kleunen M, Wilson JRU, Richardson DM (2018) Which taxa are alien? Criteria, applications, and uncertainties. Bioscience 68:496–509

Ferretti F, Pacini G, Belardi I, ten Cate B, Sensi M, Oliveira R, Rossa M, Burrini L, Lovari S (2021) Recolonizing wolves and opportunistic foxes: interference or facilitation? Biol J Linn Soc 132:196–210

Foà A, Tosini G, Avery R (1992) Seasonal and diel cycles of activity in the ruin lizard, *Podarcis sicula*. Herpetol J 2:86–89

Galaverni M, Caniglia R, Fabbri E, Milanesi P, Randi E (2016) One, no one, or one hundred thousand: how many wolves are there currently in Italy? Mammal Res 61:13–24

Gargioni C, Monaco A, Ficetola GF, Lazzeri L, Mori E (2021) From the Andes to the Apennines: rise and fall of a free-ranging population of feral llamas. Animals 11:857

Genovesi P (2000) Impact of free ranging dogs on wildlife in Italy. Proc Vertebr Pest Conf 19:19

Gentry A, Clutton-Brock J, Groves CP (2004) The naming of wild animal species and their domestic relatives. J Archaeol Sci 31:645–651

Gering E, Incorvaia D, Henriksen R, Wright D, Getty T (2019) Maladaptation in feral and domesticated animals. Evol Appl 12:1274–1286

Gompper ME (2014) Free-ranging dogs and wildlife conservation. Oxford University Press, Oxford, UK
Hughes J, MacDonald DW (2013) A review of the interactions between free-roaming domestic dogs and wildlife. Biol Conserv 157:341–351
Hulme PE (2006) Beyond control: wider implications for the management of biological invasions. J Appl Ecol 43:835–847
Iliopoulos Y, Astaras C, Chatzimichail E (2022) Dogs, not wolves, most likely to have caused the death of a british tourist in northern Greece. Nat Conserv 50:115–143
Italian Ministry of Health (Ministero della Salute) (2022) Ordinanza 08 agosto 2022. Proroga dell'ordinanza contingibile e urgente 6 agosto 2013, e successive modificazioni, concernente la tutela dell'incolumità pubblica dall'aggressione dei cani. (22A05160). G.U. Serie Generale, n. 212 del 10 settembre 2022. Accessed on 06.04.2023
Jarić I, Courchamp F, Correia RA, Crowley SL, Essl F, Fischer A, Gonzalez-Moreno P, Kalinkat G, Lambin X, Lenzner B, Meinard Y et al (2020) The role of species charisma in biological invasions. Front Ecol Environm 18:345–353
Jędrzejewski W, Jędrzejewska B (1992) Foraging and diet of the red fox Vulpes vulpes in relation to variable food resources in Bialowieza National Park, Poland. Ecogr 15:212–220
Johnson DH (1980) The comparison of usage and availability measurements for evaluating resource preference. Ecol 61:65–71
Khan U, Lovari S, Ali Shah S, Ferretti F (2018) Predator, prey and humans in a mountainous area: loss of biological diversity leads to trouble. Biodiv Conserv 27:2795–2813
Knobel DL, Butler JR, Lembo T, Critchlow R, Gompper ME (2013) Dogs, disease, and wildlife. In: Gompper ME (ed) Free-ranging Dogs and Wildlife Conservation. Oxford Academic Press, Oxford, UK, pp 144–169
Krauze-Gryz D, Gryz J (2014) Free-ranging domestic dogs (*Canis familiaris*) in Central Poland: density, penetration range and diet composition. Pol J Ecol 62:183–193
Kruuk H (1989) The social badger: ecology and behaviour of group living carnivore (*Meles meles*). Oxford University Press, Oxford, UK
Kruuk H, Parish T (1981) Feeding specialization of the european badger *Meles meles* in Scotland. J Anim Ecol 50:773–788
Lafferty KD (2001) Disturbance to wintering western snowy plovers. Biol Conserv 101:315–325
Laundré JW, Hernández L, Ripple WJ (2010) The landscape of fear: ecological implications of being afraid. Open Ecol J 3:1–7
Lescureux N, Linnell JD (2014) Warring brothers: the complex interactions between wolves (*Canis lupus*) and dogs (*Canis familiaris*) in a conservation context. Biol Conserv 171:232–245
Linklater WL, Farnworth MJ, van Heezik Y, Stafford KJ, MacDonald EA (2019) Prioritizing cat-owner behaviors for a campaign to reduce wildlife depredation. Conserv Sci Practice 1:e29
Loss SR, Will T, Marra PP (2013) The impact of free-ranging domestic cats on wildlife of the United States. Nat Comm 4:1–8
Loss SR, Boughton B, Cady SM, Londe DW, McKinney C, O'Connell TJ, Riggs GJ, Robertson EP (2022) Review and synthesis of the global literature on domestic cat impacts on wildlife. J Anim Ecol 91:1361–1372
Lovari S, Sforzi A, Mori E (2013) Habitat richness affects home range size in a monogamous large rodent. Behav Processes 99:42–46
Lovari S, Serrao G, Mori E (2017) Woodland features determining home range size of roe deer. Behav Processes 140:115–120
Lucherini M, Lovari S, Crema G (1995) Habitat use and ranging behaviour of the red fox (*Vulpes vulpes*) in a Mediterranean rural area: is shelter availability a key factor? J Zool 237:577–591
Lumetsberger T, Ghoddousi A, Appel A, Khorozyan I, Waltert M, Kiffner C (2017) Re-evaluating models for estimating prey consumption by leopards. J Zool 302:201–210
Mallord JW, Dolman PM, Brown AF, Sutherland WJ (2007) Linking recreational disturbance to population size in a ground-nesting passerine. J Appl Ecol 44:185–195
McGeoch MA, Genovesi P, Bellingham PJ, Costello MJ, McGrannachan C, Sheppard A (2016) Prioritizing species, pathways, and sites to achieve conservation targets for biological invasion. Biol Invasions 18:299–314
Mech LD, Janssens LA (2022) An assessment of current wolf *Canis lupus* domestication hypotheses based on wolf ecology and behaviour. Mammal Rev 52:304–314
Mendoza Roldan JA, Otranto D (2023) Zoonotic parasites associated with predation by dogs and cats. Parasites & Vectors 16:55

Monterroso P, Godinho R, Oliveira T, Ferreras P, Kelly MJ, Morin DJ, Waits LP, Alves PC, Mills LS (2019) Feeding ecological knowledge: the underutilised power of faecal DNA approaches for carnivore diet analysis. Mammal Rev 49:97–112

Mori E, Menchetti M, Camporesi A, Cavigioli L, Tabarelli De Fatis K, Girardello M (2019) License to kill? Domestic cats affect a wide range of native fauna in a highly biodiverse Mediterranean country. Front Ecol Evol 7:477

Moroni B, Brambilla A, Rossi L, Meneguz PG, Bassano B, Tizzani P (2022) Hybridization between Alpine ibex and domestic goat in the alps: a sporadic and localized phenomenon? Animals 12:751

Narayan E, Christi K, Morley C (2008) Ecology and reproduction of the endangered fijian ground frog *Platymantis vitianus*–Fiji Islands. S Pac J Nat Appl Sci 26:28–32

Newsome TM, Dellinger JA, Pavey CR, Ripple WJ, Shores CR, Wirsing AJ, Dickman CR (2015) The ecological effects of providing resource subsidies to predators. Global Ecol Biogeogr 24:1–11

Oedin M, Brescia F, Millon A, Murphy BP, Palmas P, Woinarski JC, Vidal E (2021) Cats *Felis catus* as a threat to bats worldwide: a review of the evidence. Mammal Rev 51:323–337

Orozco L, López-Pérez AM, Zarza H, Suzán G, List R (2022) Dog demography and husbandry practices facilitate dog-wildlife conflict in a suburban-forest interface. Urb Ecosyst 25:1725–1734

Paolucci P, Bon M (2022) Mammiferi terrestri d'Italia. Riconoscimento, ecologia e tricologia. WBA Handbooks 11, WBA Project Ed., Verona, Italy

Pyšek P, Hulme PE, Simberloff D, Bacher S, Blackburn TM, Carlton JT, Dawson W, Essl F, Foxcroft LC, Genovesi P, Jeschke JM et al (2020) Scientists' warning on invasive alien species. Biol Rev 95:1511–1534

R Core Team (2013) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/. Accessed on 15 Mar 2023

Randi E (2008) Detecting hybridization between wild species and their domesticated relatives. Mol Ecol 17:285–293

Range F, Marshall-Pescini S (2022) Comparing wolves and dogs: current status and implications for human 'self-domestication'. Trends Cogn Sci 26:337–349

Rondinini C, Battistoni A, Teofili C (2022) Lista Rossa IUCN dei Vertebrati Italiani. Comitato Italiano IUCN e Ministero dell'Ambiente e della Sicurezza Energetica (Editions), Roma, Italy

Sakate M, De Oliveira PL (2000) Toad envenoming in dogs: effects and treatment. J Ven Anim Toxins 6:52–62

Salinas-Ramos VB, Mori E, Bosso L, Ancillotto L, Russo D (2021) Zoonotic risk: one more good reason why cats should be kept away from bats. Pathogens 10:304

Serpell J (2016) The domestic dog: its evolution, behavior and interactions with people. Cambridge University Press, Cambridge, UK

Shackleton RT, Larson BM, Novoa A, Richardson DM, Kull CA (2019) The human and social dimensions of invasion science and management. J Environm Manage 229:1–9

Shan S, Xu F, Brenig B (2021) Genome-wide association studies reveal neurological genes for dog herding, predation, temperament, and trainability traits. Front Vet Sci 8:693290

Smith LM, Hartmann S, Munteanu A, Dalla Villa P, Quinnell RJ, Collins LM (2019) The effectiveness of dog population management: a systematic review. Animals 9:1020

Smith LM, Quinnell R, Munteanu A, Hartmann S, Dalla Villa P, Collins L (2022) Attitudes towards free-roaming dogs and dog ownership practices in Bulgaria, Italy, and Ukraine. PLoS ONE 17:e0252368

Sogliani D, Mori E (2019) The Fox and the cat: sometimes they do not agree. Mammal Biol 95:150–154

Sogliani D, Cerri J, Turetta R, Crema M, Corsini M, Mori E (2021) Feral rabbit populations in a peri-urban area: insights about invasion dynamics and potential management strategies. Eur J Wildl Res 67:1–9

Sokal RR, Rohlf FJ (2012) Biometry, third ed. W.H. Freeman and Company, New York, USA

Taborsky M (1988) Kiwis and dog predation: observations in Waitangi State Forest. Notornis 35:197–202

Taylor-Brown A, Booth R, Gillett A, Mealy E, Ogbourne SM, Polkinghorne A, Conroy GC (2019) The impact of human activities on australian wildlife. PLoS ONE 14:e0206958

Teerink BJ (1991) Hair of West-European Mammals. Cambridge University Press, Cambridge, UK

Teerink BJ (2004) Hair of west european mammals: atlas and identification key. Cambridge University Press, Cambridge, UK

Trouwborst A, McCormack PC, Martínez Camacho E (2020) Domestic cats and their impacts on biodiversity: a blind spot in the application of nature conservation law. People and Nature 2:235–250

Underhill-Day JC, Liley D (2007) Visitor patterns on southern heaths: a review of visitor access patterns to heathlands in the UK and the relevance to Annex I bird species. Ibis 149:112–119

Vanak AT, Gompper ME (2009) Dietary niche separation between sympatric free-ranging domestic dogs and indian foxes in central India. J Mammal 90:1058–1065

Villatoro FJ, Naughton-Treves L, Sepúlveda MA, Stowhas P, Mardones FO, Silva-Rodrìgues EA (2019) When free-ranging dogs threaten wildlife: public attitudes toward management strategies in southern Chile. J Environm Manage 229:67–75

Wang GD, Zhai W, Yang HC, Wang LU, Zhong LI, Liu YH, Fan RX, Yin TT, Zhu CL, Poyarkov AD, Irwin DM et al (2016) Out of southern East Asia: the natural history of domestic dogs across the world. Cell Res 26:21–33

Weston MA, Elgar MA (2005) Disturbance to brood-rearing hooded plover *Thinornis rubricollis*: responses and consequences. Bird Cons Intern 15:193–209

Weston MA, Stankowich T (2013) Dogs as agents of disturbance. In: Gompper ME (ed) Free-ranging Dogs and Wildlife Conservation. Oxford Academic Press, Oxford, UK, pp 94–113

Weston M, Antos MJ, Glover HK (2009) Birds, buffers and bicycles: a review and case study of wetland buffers. Vic Nat 126:79–86

Weston MA, Fitzsimons JA, Wescott G, Miller KK, Ekanayake KB, Schneider T (2014) Bark in the park: a review of domestic dogs in parks. Environm Manage 54:373–382

Williams KJ, Weston MA, Henry S, Maguire GS (2009) Birds and beaches, dogs and leashes: dog owner's sense of obligation to leash dogs on beaches in Victoria, Australia. Hum Dim Wildl 14:89–101

Woolley LA, Geyle HM, Murphy BP, Legge SM, Palmer R, Dickman CR, Augusteyn J, Comer S, Doherty TS, Eager C, Edwards G et al (2019) Introduced cats *Felis catus* eating a continental fauna: inventory and traits of australian mammal species killed. Mammal Rev 49:354–368

Young JK, Olson KA, Reading RP, Amgalanbaatar S, Berger J (2011) Is wildlife going to the dogs? Impacts of feral and free-roaming dogs on wildlife populations. BioSci 61:125–132

Authors and Affiliations

Davide Sogliani[1,2] · Emiliano Mori[3,4] · Sandro Lovari[5,6] · Lorenzo Lazzeri[5] · Alice Longoni[7] · Karol Tabarelli De Fatis[8] · Patrizia Sabatini[5] · Matteo Riccardo Di Nicola[9,10] · Danilo Russo[4,11]

✉ Emiliano Mori
emiliano.mori@cnr.it

1 Department of Biology and Biotechnology, University of Pavia, Via A. Ferrata 9, 27100 Pavia, Italy

2 Collegio Ca' della Paglia, Fondazione Ghislieri, 27100 Pavia, Italy

3 CNR-IRET, Via Madonna del Piano 10, 50019 Sesto Fiorentino, Florence, Italy

4 National Biodiversity Future Center, 90133 Palermo, Italy

5 Department of Life Sciences, University of Siena, Via P.A. Mattioli 4, 53100 Siena, Italy

6 Museo di Storia Naturale della Maremma, Strada Corsini 5, 58100 Grosseto, Italy

7 Independent Researcher, Venaria Reale, Corso Matteotti 35, 10078 Torino, Italy

8 MUSE – Museo delle Scienze, Corso del Lavoro e della Scienza 3, 38121 Trento, Italy

9 Unit of Dermatology, IRCCS San Raffaele Hospital, Via Olgettina 60, Milan 20132, Italy

10 Asociación Herpetológica Española, Apartado de Correos 191, 28911 Leganés, Madrid, Spain

11 Laboratory of Animal Ecology and Evolution (AnEcoEvo), Dipartimento di Agraria, Università degli Studi di Napoli Federico II, Via Università 100, 80055 Portici (Napoli), Italy