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Animal mortality and illegal poison bait use in Greece

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Abstract The present study describes the use of poison baits against so-called pest species in Greece and explores various aspects of this illegal practice. Data were collected from 2000 to 2016, and a total of 1015 poisoning incidents in rural areas causing the death of 3248 animals were examined. In 58.7% of investigated cases, the motives remained unknown; in the remaining cases, human-wildlife conflicts and retaliatory actions among stakeholders (e.g., hunters vs. livestock breeders) were found to be the main reasons for poison bait use. The target animals for these actions were mainly mammalian carnivores, and stray canids, all of which were blamed for livestock and game losses. Avian scavengers were the wildlife species most affected by secondary poisoning (30% of the wildlife fatalities), whereas shepherd dogs accounted for 66.4% of domestic animal losses. Toxicological analyses showed that a wide range of chemical substances were used, mostly legal or banned pesticides (e.g., carbamates, organophosphates, and organochlorines) and potassium cyanide. Furthermore, the widespread trafficking of black marketed insecticides was also recorded, with methomyl (in powder form) and carbofuran being most common. The majority of poisoning events (72%) took place outside protected areas, while in approximately 73.4% of them, no official reporting to the competent authorities was made. Overall, the study highlights the significant impact of illegal poison bait use on wildlife in Greece and addresses its extreme socioeconomic complexity. The need for an integrated national anti-poison strategy is discussed.

Keywords Wildlife mortality · Pesticides · Poison baits · Greece

Introduction

The illegal use of poison baits for the extermination of vermin or pest species, i.e., those species that conflict with human activities by causing damages to crop and

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livestock (Howard 1962), has long been common practice in many parts of rural Europe (Graham et al. 2005; Giorgi and Mengozzi 2011) and is currently considered one of the most widespread method of predator extermination worldwide (Woodroffe et al. 2005; Lozano et al. 2010; Mateo-Tomás et al. 2012; Márquez et al. 2013). Wildlife persecution and poisoning are now prohibited in Europe by the "Habitats" and "Birds" directives (92/43/EEC, 2009/147/EC), as well as by the Bern Convention on the Conservation of European Wildlife and Natural Habitats, although selective lethal control methods are permitted on condition that the target species are not put at long-term risk.

In Greece, the use of poison baits against pests has been a long-established practice, dating back to the early 1900s. Predator control was officially initiated in 1924 (under National Law 3077/1924), and the first case of legal poison use (strychnine) against mammalian carnivores was recorded in 1927. Over the course of the previous century, the systematic use of poison baits (initially strychnine and later on potassium cyanide) in anti-predator campaigns, which were carried out by the forestry services, was intensified. According to state reports, 75 jackals (*Canis aureus*) were poisoned on the island of Samos in 1931, while 5108 wolves (*Canis lupus*) and jackals were eradicated nationwide from 1933 to 1937. From 1939 onwards, annual circulars issued by the Ministry of Agriculture regulated anti-predator campaigns via trapping and the use of strychnine baits, the latter being intensively and almost exclusively applied against wolves from 1950 to 1970. Government authorities legally poisoned 52,000 foxes (*Vulpes vulpes*) from 1974 to 1988 (Ministry of Agriculture pers. com.), and 4439 wolves were shot by hunters and stockbreeders from 1974 to 1979 (Papageorgiou et al. 1994). During that period, the wolf, the jackal, the fox, the pine marten (*Martes foina*), the hooded crow (*Corvus corone*), the jackdaw (*Corvus monedula*), the magpie (*Pica pica*), the jay (*Garrulus glandarius*), the starling (*Sturnus vulgaris*), and the house sparrow (*Passer domesticus*) were all proclaimed pests under National Laws (e.g., 86/1969, 177/1975) and regulatory texts of the Greek Forest Code, while a bounty system also existed for some of them. In 1981, strychnine gave way to potassium cyanide (KCN), used mainly against foxes. This compound causes suffocation following consumption and was believed to mitigate secondary poisoning of scavengers due to the volatile nature of its transformed substance (HCN) once digested. Overall, these anti-predator operations were organized and executed by the forestry services and involved placing poison baits in the field, leaving them overnight and collecting carcasses and unconsumed baits early the next morning. Thus, thousands of mammalian species (mainly foxes) were legally exterminated by the use of poison baits. However, as strychnine is by no means selective, and highly persistent in carcasses (i.e., bones, marrow, and certain internal organs such as the liver and kidneys), secondary poisoning of non-target species was indiscriminate. The most common victims were diurnal birds of prey, sheepdogs, domestic and wild cats (*Felix sylvestris*), badgers (*Meles meles*), weasels (*Mustela nivalis*), corvids, and gulls. Among the avian group, vultures, as obligate scavengers, were most susceptible to secondary poisoning and were killed en masse due to their social foraging behavior, quite often over a single poisoned carcass (e.g., wolf-kill). Consequently, during roughly the same period (1955–1975), a gradual decline of avian scavengers was detected in the mainland, culminating in the late 1980s with the total collapse of vulture populations in central Greece (Handrinos 1985; Skartsi et al. 2008; Legakis and Maragou 2009; Saravia et al. 2016; Vasilakis et al. 2016). Predator control by poison baits was officially banned in 1993, when the Supreme Court of Greece ruled that data on the population status of target species were inadequate, and their persecution could not be justified (Council of State Decision No. 366/1993). The actual extinction of vulture and large eagle species in many parts of the mainland coincided in space and time with the comeback of the wolf in the 1990s (Iliopoulos 2000), as its conservation status had been upgraded (to "strictly protected" south of the 39th parallel under the "Habitats" directive) (Korbeti and Politis 2012; Skartsi et al. 2014). Not surprisingly, the last viable vulture populations remained on Crete, where large mammalian carnivores are absent and no anti-predator campaign has ever been carried out (Xirouchakis et al. 2001; Xirouchakis 2004).

Despite the Supreme Court's ban, the use of poison baits in Greece has continuously unabated over the past two decades (Antoniou et al. 1996; Toutoudaki et al. 2006) while potassium cyanide is again used but illegally (Vavylis et al. 2016; Kret 2018). Given that cases of wildlife poisoning are difficult to detect and are often not reported the true nature and intensity of this illegal activity and its current impact on the status of wildlife in Greece is largely unknown. At the European level, one serious aspect of illegal poison use is the absence of centralized agencies to monitor the practice and evaluate its impact on domestic and wild fauna. Although relevant national networks set up specifically for this purpose are a step in the right direction (Lamargeue et al. 1999), there is still a lack of authorized institutions that could act as reference points for all EU member states, such as those designated for anthropozoonoses and infectious wildlife diseases (Mörner et al. 2002, Cleaveland et al. 2006, Halliday et al. 2007, Daszak 2008). Reports of poisoning generally refer to mass wildlife deaths or the secondary poisoning of endangered species, which receive extensive publicity, in contrast to common cases of intentional or secondary poisoning of shepherd dogs, companion animals or wildlife, which go largely undetected (Vyas 1999; Mineau 2005; Pavocovic and Susic 2005; Hernández and Margalida 2008; Guitart et al. 2010; Lane 2013; Ogada 2014).

In order to better understand this conservation problem, a National Anti-poison Task Force was established in 2012 in Greece, aiming to bring about institutional changes that would eradicate the deliberate and secondary poisoning of wildlife and domestic animals and publicize the extent of the problem at the local and national level (Ntemiri and Saravia 2016). The aim of the present study was to identify the drivers of the illegal use of poison baits in agricultural areas of Greece, the substances used, and path exposure. Furthermore, we investigated the stakeholders' motives for this problem and its intensity in relation to wildlife population declines. By understanding the extent and true nature of this illegal practice, we ultimately aim at formulating administrative recommendations for reporting, monitoring, and tackling the abuse of agrochemicals and their trade; our long-term goal is to alleviate the environmental impact of their illegal use in poison baits.

Materials and methods

Data collection and sample analysis

Data on the illegal use of poison baits in 2000–2016 was collated from numerous sources: (a) records kept by state authorities and official agents, e.g., forestry services, regional directorates of veterinary agencies, and the management bodies of protected areas; (b) unpublished data of non-governmental conservation organizations and wildlife rehabilitation centers; (c) information of hunting associations; (d) personal communications with various stakeholders (e.g., forestry services, municipal agencies, veterinarians, and land users who were also asked for the motives of poison use); and (e) information provided by the Anti-poison Canine Teams (i.e., dogs specially trained to detect poison baits and carcasses) that were established in 2014 (Kret et al. 2015; Kret et al. 2016; Vavylis et al. 2016a, 2016b). Poisoning incidents were listed by species affected, bait type, and chemical compounds used. A poisoning incident was regarded as such when one of the following indications or evidence were recorded: (1) the recovery of a moribund animal with clinical signs of poisoning or the recovery of an animal of normal weight lacking coordination and/or response to veterinary treatment (e.g., provision of electrolytes, corticosteroid medication); (2) the discovery of a poison-laced bait in the vicinity of a dead animal; and (3) the results of toxicological analysis of baits or tissue samples (ca. 50 g of liver, stomach, and/or intestine) taken from fresh carcasses or frozen (− 20 °C) organs of suspected poisoning victims (Whitfield et al. 2003; Hernández and Margalida 2009). Toxicological analyses in tissues focused primarily on key wildlife species (e.g., brown bears *Ursus arctos*, wolves, and accipitrid raptors) and on the detection and identification of carbamates and organophosphates by performing gas chromatography-mass spectrometry (Sparkman et al. 2011), as these chemical substances are the base of many insecticides and pesticides commonly used in poison baits. Domestic animals were less frequently sampled and analyzed due to budgetary constraints. (4) Carcasses collected in the field: these were treated as confirmed cases of wildlife poisoning following a visual inspection for external signs of poisoning or via post-mortem examination (including X-rays), once other likely causes of death such as disease, electrocution, and shooting had been excluded (Woodford 1999; Newton 2001). Proof of poisoning was considered the condition of the carcass (e.g., healthy-looking animals with no apparent injuries) in combination with an atypical postural appearance (e.g., rigid talons in birds, body stiffness, rictus grin, blood from orifices caused by convulsions in mammals) or the finding of bait remains on the claws or in the mouth (Ritchie et al. 1994, Bodega Zugasti 2014, Stahler et al. 2006, Kelly et al. 2014).

Statistical analysis

Based on the wildlife taxa recorded, individual animals were grouped and analyzed in guilds defined as: (a) large (and medium) carnivores, i.e., brown bears, wolves, jackals, and foxes; (b) small carnivores, i.e., badgers, beech martens, and weasels; and (c) raptors, including all facultative and obligatory scavengers, i.e., vultures, eagles, harriers, and buzzards, as well as corvids. Domestic animals were grouped into two broad categories, namely: (a) ungulates/livestock and (b) canids and felids. In an effort to evaluate the relative importance of different case parameters (e.g., poison substance, poison type, target species, etc.), the proportionate mortality was calculated as the percentage of animals dying of poisoning among all cases examined. This measure was estimated for the entire sample and for each species separately. The dependency between causes of poisoning and comparison of proportions was analyzed by applying *G* tests in contingency tables (Zar 1999). Non-parametric analysis of variance and Spearman rank correlation were carried out to test intergroup differences and the relationship between variables (Sokal and Rohlf 1995). The distribution pattern of poison bait use and its spatial intensity was predicted by applying regression kriging. As the exact coordinates of the poisoning events were not available, the number of dead animals (count data) was assigned to the centroid (i.e., geometric center) of the municipalities' administrative polygons representing the most detailed georeferenced record available per poisoning event in the database. A number of (predictor) variables known to influence the predation risk of free-ranging livestock and the distribution of baits were selected (Table 1) and transformed to raster maps with identical projection, extent, and pixel size (1×1 km). In addition, these maps were converted to the same binary scale by normalization and a principal component analysis (PCA) was performed by using the variance correlation matrix so as to reduce any multicollinearity effect. A stepwise multiple regression analysis was run between count data and the eigenvalues of the transformed components, followed by kriging and a variogram analysis for the spatial interpolation of regression errors (Neter et al. 1996; Hengl et al. 2007; Hengl 2009). A final poisoning incidents map was produced by combining the predicted distribution of the regression model with the spatially interpolated residuals. All statistical analyses were tested at a 0.05 level of significance, performed in R 3.2.1 (R Core Team 2015) with the aid of relevant libraries, i.e., "MASS" and "epitools" (Venables and Ripley 2002; Aragon et al. 2017). Raw spatial data were initially obtained from the open databases maintained by the Greek National Statistical Authority (http://www.statistics.gr/el/statistics/-/publication/SPK11/2000), and then an entire raster map-list was created, elaborated, and analyzed using Quantum and SAGA open source GIS software (QGIS development team 2015; Conrad et al. 2015).

Results

Poisoning events and species affected

Overall, 1015 poisoning incidents were recorded during the study period, resulting in the death of 3248 animals. These comprised 976 wild animals (430 birds, 443 mammals, 4 reptiles, 42 species in total) and 2364 domesticated individuals (10 species). The mean number of animals found dead per poisoning event was 2.2 (range = 1–51), and the number of cases correlated positively with the number of the individuals found poisoned ($r_s = 0.94$, $P < 0.001$). Excluding insects and unidentified species, domestic animals suffered 60% of total losses due to poisoning. Among wildlife, carrion-eating birds were worst affected by poison baits (33.5% of the cases) with a total of 293 individuals retrieved poisoned (i.e. 30% of the wildlife and 68% of the avifauna). Griffon vultures (*Gyps fulvus*) and foxes were the wild species most frequently poisoned, accounting for 17.1 and 29.4% of the wildlife fatalities respectively (Fig. 1). Other significant wildlife to suffer severe population losses were the Egyptian (*Neophron percnopterus*) and the cinereous vultures (*Aegypius monachus*), with mass poisoning incidents, the Golden eagle (*Aquila chrysaetos*), the wolf, and the brown bear (Fig. 1). From the domestic animals, dogs accounted for 66.4% of losses, while it should be noted that 28.8% of cases involved livestock (e.g., poultry, caprine, porcine). For instance, during the study period (2012), ca. 17 breeding pairs in the largest mainland colony of the species in Greece (Nestos straits, NE Greece) were decimated in a mass poisoning incident on a presumed wolf-kill, i.e., two horses which had been shot dead, skinned, and deliberately laced with carbofuran. However, only two griffons were collected in the vicinity of this crime scene along with four golden eagles (the total breeding population in the area) and one common buzzard (*Buteo buteo*) (Jerrentrup and Efthimiou 2006; Ntemiri and Saravia 2016). Furthermore, 10 cinereous and 17 Egyptian vultures were fatally poisoned in 7 and 12 incidents, respectively, with one individual of the

Table 1 Predictor variables used in regression kriging for interpolation the spatial use of poison baits in Greece during 2000–2016

Predictor variable	Description	Association to poison bait use
Temperature M	Mean annual temperature	Depredation related to the presence of free-ranging livestock
Temperature S	Temperature seasonality	Areas with transhumant and seasonally moving livestock
Temperature C	Temperature of the coldest quarter	Activity and hunger levels of mammalian carnivores
Rainfall	Annual precipitation (mm)	Existence of suitable rangeland
Altitude	Elevation of the terrain a.s.l. (m)	Upland pastures used as rangelands/remote areas with low density of perpetrators
Slope	Slope of the terrain (%)	Ruggedness of the terrain impedes livestock guarding and poison bait use
Valley depth	Low areas in the terrain/index of relief magnitude	Winter pastures with high livestock density
Population	Density of inhabitants	Human wildlife conflicts/high population of stray canids and felids
Land use	Habitat suitability index (0 = water bodies, 1 = forests, 2 = scrubland, 3 = cultivations, 4 = pastures)	Habitat types used as rangelands
Livestock D	Density of domestic ungulates (animals/km^2)	Human wildlife conflicts
Livestock N	Number of domestic ungulates	High predation risk by mammalian carnivores
Sheep and goat	Sheep and goat numbers	High predation risk by mammalian carnivores

Data account to the municipality where poisoning incidents took place

latter species being poisoned twice (both prior to and following its rescue, rehabilitation, and release).

Temporal and spatial distribution of poisoning incidents

During the study period (2000–2016), three peaks in the number of poisoning events were observed, in 2006–2007, 2013, and 2016, respectively (Fig. 2). On average, 59 ± 24.2 (median = 56) poisoning incidents were registered annually (range = 26–121). The use of poison baits proved to be a year-round practice, although seasonal variation intensifying in autumn was noted. In particular, poisoning incidents exhibited a rather bimodal pattern, peaking in winter, i.e., January ($n = 77$) and March ($n = 60$), dropping till late spring and building up steadily with a peak in September ($n = 108$) and decreasing thereafter (Fig. 3). Excluding exceptional figures relating to the destruction of a bee-swarm and a poultry farm, the highest number of poisoning incidents was recorded on the island of Crete (34.6%, $n = 349$ of cases), followed by the regions of north (16.3%, $n = 165$) and central Greece (15.8%, $n = 160$). On average, 17 ± 10 animals (range = 6–44, median = 15.9) died annually in each region examined and significant regional differences were found in the mean number of poisoning events ($\bar{x} = 7 \pm 5$, range = 2–20, median = 5.6) or animals found dead ($\bar{x} = 14 \pm 10$, range = 3–35, median = 12.9) over the years (Kruskal-Wallis, $H_2 = 50$, $P < 0.001$; $H_2 = 39.1$, $P < 0.001$). The majority of poisoning incidents and poisoned animals were recorded in the island of Crete and northwest mainland regions with regard to wild birds and mammalian carnivores, respectively (G test, $P < 0.0001$, Fig. 4). Taking into account the surface area of each region, Crete showed the highest density of poisoned wild birds (0.16 individuals/km^2/year), small carnivores (0.02 individuals/km^2/year), and livestock (0.2 individuals/km^2/year), while Epirus was the mainland region with the highest density of large carnivores found poisoned (0.08 individuals/km^2/year). It is noteworthy that 27.9% of known poisoning incidents occurred within protected areas such as National Parks or NATURA 2000 sites.

Large and small carnivores were mostly poisoned in northwest continental Greece and the island of Crete, respectively. On the other hand, domestic canids were poisoned countrywide, while domestic felid poisoning exhibited a more variable geographical pattern (Fig. 5). Overall, on a spatial scale, large mammalian carnivores and canids seem to suffer the greatest impact of poison bait use (Fig. 5a, c), though when we examined the study period in 4-year stages, the latter group emerged as that increasingly affected over the last decade (G test, $G = 71.4$, $P < 0.001$). In the regression kriging procedure, the variogram of residuals was of exponential form

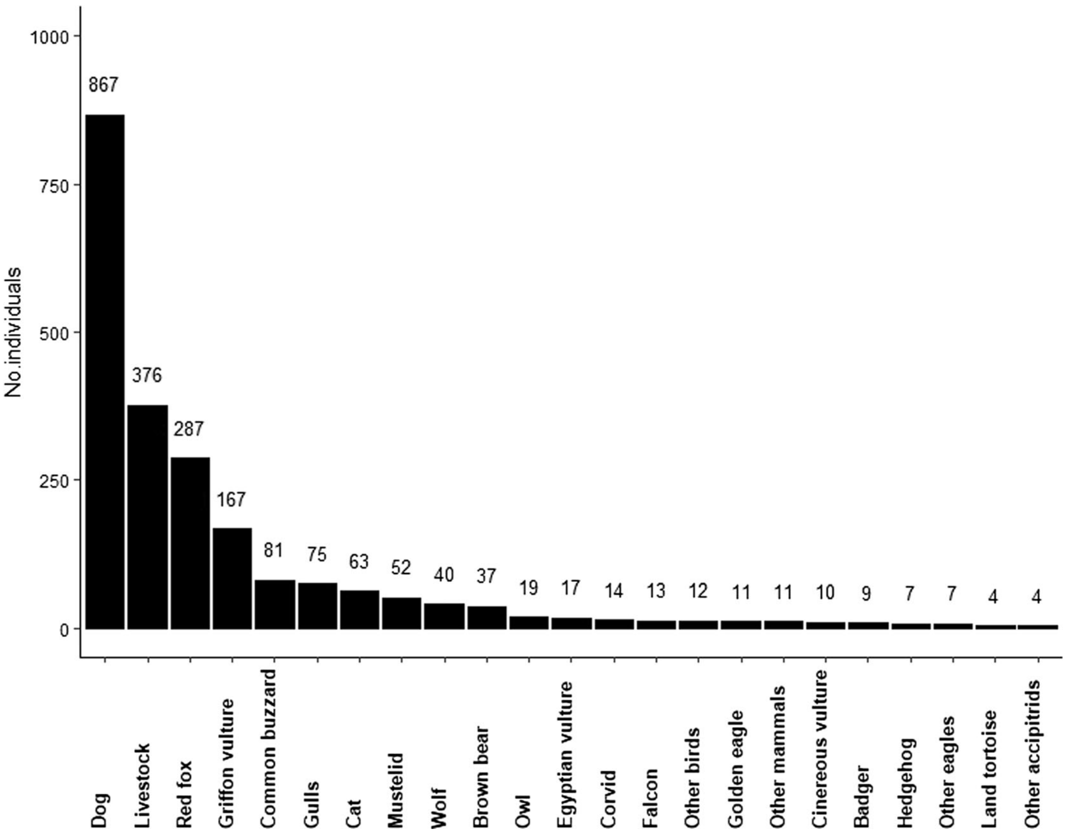

Fig. 1 Number of individuals per species found dead due to consumption of poison baits in Greece during 2000–2016

and therefore only two variables (predictors) were finally included in the regression model, namely population density and livestock numbers, which both showed a positive association ($r = 0.14$, $P = 0.03$, $r = 0.22$, $P < 0.001$) with the number of the animals found dead. Due to unequal sampling intensity and the limited variation (7.1%) explained by the model, the final map should be regarded as indicative. Nevertheless, it did show that the highest numbers of animals found dead per poisoning event were in the rural areas of northwest and central Greece, encompassing the main mountain range (Pindos) down to the lower slopes bordering with the plains (Fig. 6).

Bait type and toxic substances used

In most of the poisoning cases evaluated (82.5%), the bait was not found, as it had either already been consumed or was very difficult to detect due to its small size and/or inconspicuousness in the field (and in incidents which has not handled by anti-poison canine teams). In the 152 cases where the poison bait was found, the most widespread type was to be a piece of meat, e.g., liver or sausage, mixed with a pesticide (54.6% of cases). For the extermination of large carnivores (mainly wolves), whole livestock carcasses were laced with various agrochemicals (16.4%). Foxes, mustelids, and stray dogs were targeted using cyanide encapsulated in paraffin or wax (13.2%). Other bait types included pure pesticide remains (1.3%) and meatballs (1.3%) or fish (1.3%) dipped in agrochemicals. Bait and tissue sampling was restricted to 245 out of 1015 poisoning events (24%), mainly due to the advanced decomposition of the carcasses or the inability to collect proper samples due to logistic constraints. Toxicological analyses of timely collected samples ($n = 100$) indicated that agrochemicals were frequently used (86.9%), comprising legally registered and distributed products as well as various agrochemicals that are banned at national and European level. In total, 13 different compounds were detected in the samples. Highly toxic carbamate insecticides were regularly identified, with methomyl being by far the most common substance used (54.2% of samples), followed by carbofuran (11%). From 2012 to 2016,

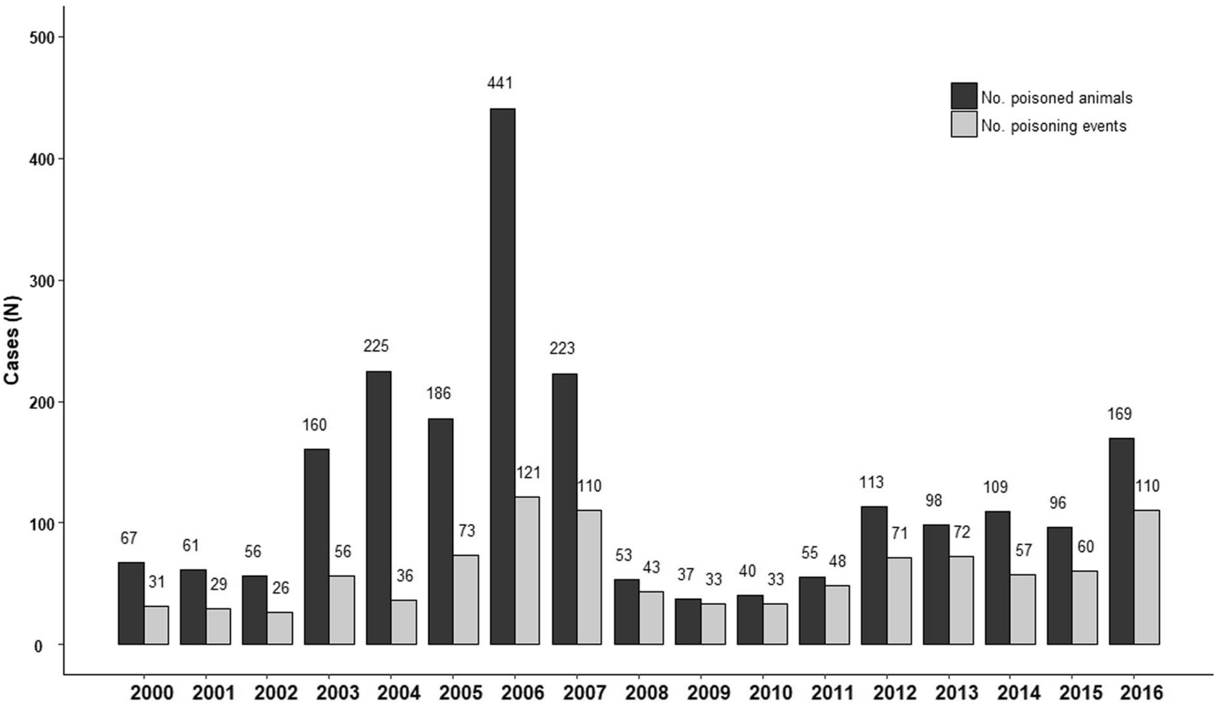

Fig. 2 Annual variation in the number of poisoning events ($n = 1009$) and poisoned animals ($n = 2189$) from validated cases in Greece during 2000–2016

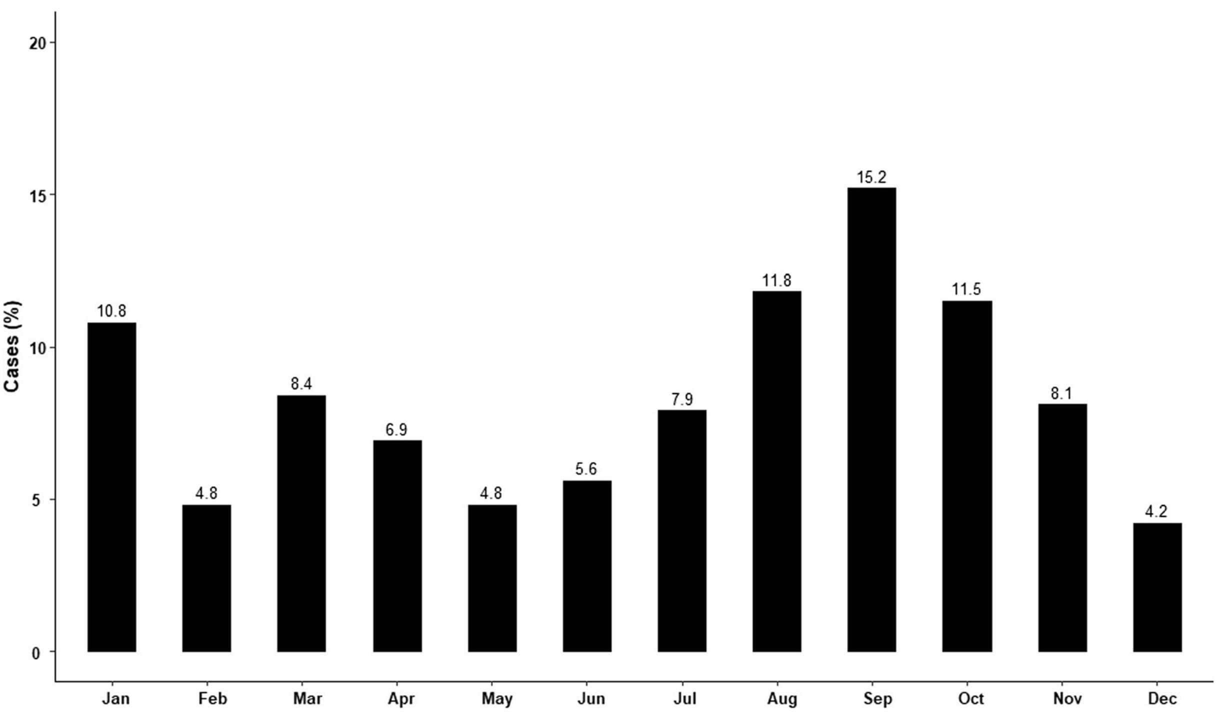

Fig. 3 Seasonal variation in the number of poisoning events ($n = 712$) in Greece (2000–2016)

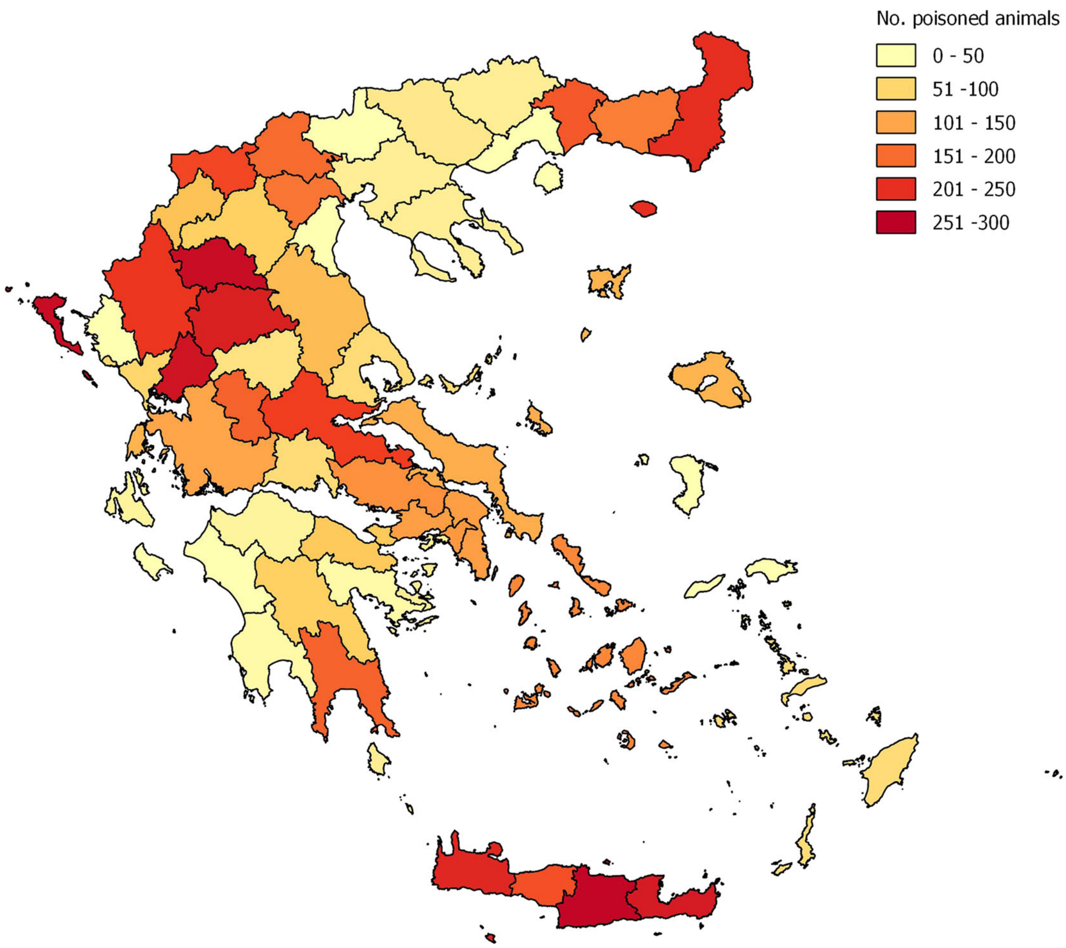

Fig. 4 Spatial distribution of animals found poisoned in Greece (2000–2016). (*Data presented per prefecture*)

when poisoning incidents were recorded more systematically, these two substances resulted in the confirmed death of at least 29 animals, including two Egyptian vultures, six griffon vultures, four golden eagles, and two common buzzards. Other toxicants involved in poisoning incidents included pesticides of the organophosphate group (13.6% of samples), i.e., fenthion (5.5%), methamidophos (3.9%), malathion (1.1%) and methyl-parathion (1.1%), phorate (1%), and chlorpyrifos (1%), as well as organochlorines (5% of samples), i.e., endosulfan (3%), endrin-aldehyde (1%), and heptachlor (1%). Furthermore, sulfur was identified in one case, while potassium cyanide wax capsules were detected (often mixed with palatable components) in 15% of the samples. The latter bait type caused the death of 52 animals, including 36 foxes and 16 domestic dogs, in samples collected during 2012–2016. Between the current and past decade, a significant difference was noted in the use of the most common compounds of poison baits, namely a decrease in the use of methomyl (73 vs. 31.8%) and an increase in the use of potassium cyanide (5 vs. 27.3%) and carbofuran (0 vs. 25%) (G test, $G = 33.7$, $P < 0.001$).

Motives for poison bait use

Overall in 73.4% of the poisoning events, no official reporting to the competent authorities was made. Besides for the incidents investigated ($n = 286$), the motive for the poison bait use was not determined in 58.7% of them. Available testimony came largely from land users (e.g., farmers and hunters). This pointed to bait use following actual or anticipated crop production; livestock losses due to predators, e.g., beehives destroyed by bears; game or livestock predated by wolves and foxes; or even the mere presence of wolves in areas with free-ranging livestock. However, in those cases where the motives were confirmed ($n = 118$), the most

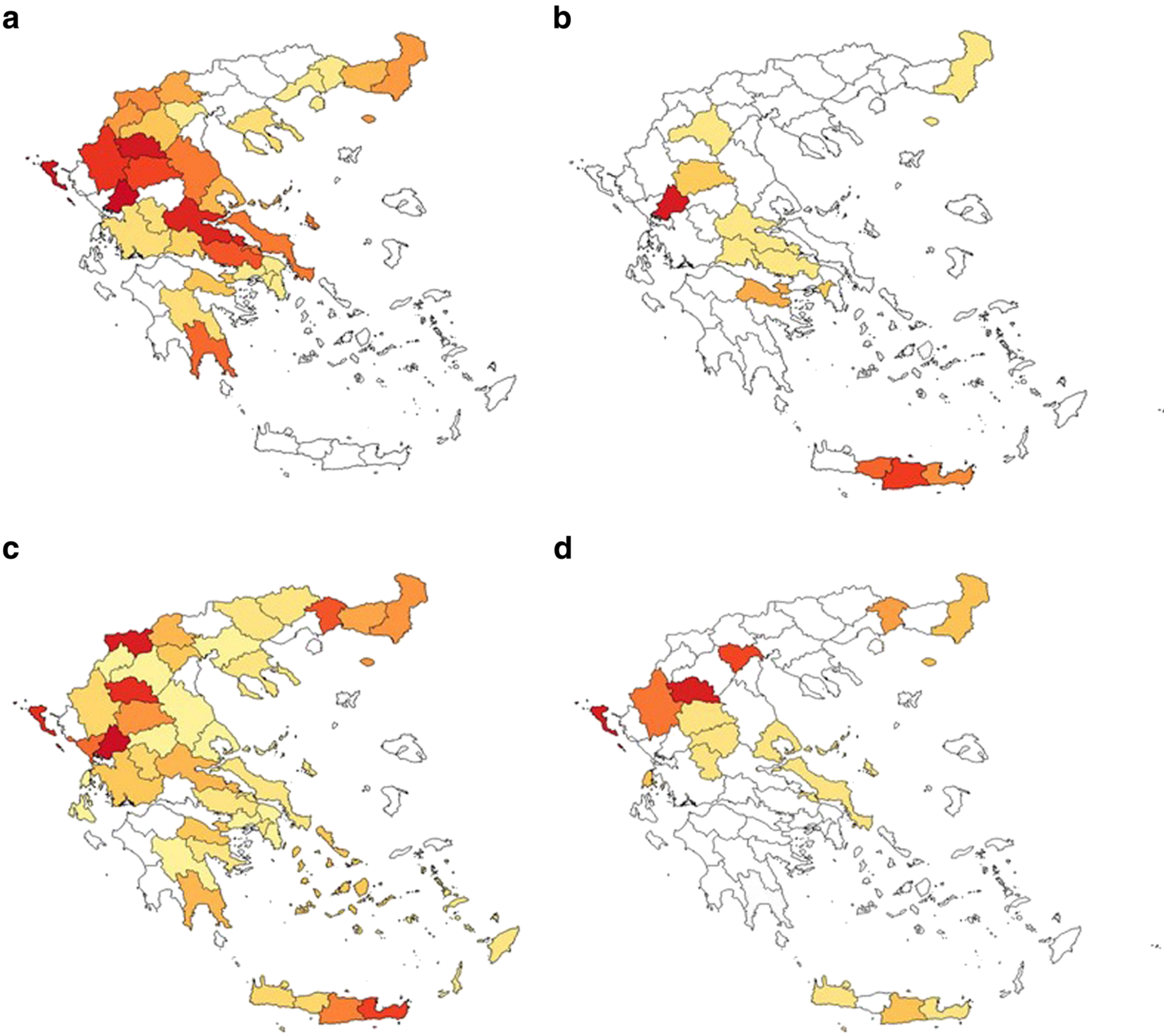

Fig. 5 Distribution of mammalian predators. **a** large carnivores, **b** small carnivores, **c** domestic canids, and **d** domestic felids, found poisoned in the different prefectures of Greece (2000–2016). (*Color shading for number of poisoned animals as in* Fig. 4)

common reason for the use of poison baits was disputes between land users and retaliation acts (i.e., bait use by hunters targeting sheepdogs, for fear that they might predate on hunting dogs, and the deliberate poisoning of shepherd and hunting dogs or livestock among neighboring stockbreeders over land property and grazing rights), which accounted for 56.1% of the incidents investigated (Fig. 7). The second major motive for poison bait use was livestock predation primarily by wolves and beehive destruction by bears or game protection against foxes (15.4%). Farmers also put down poison baits against small predators (e.g., badgers and martens) that cause damage to their crops (12.3%) or to control stray dogs near settlements in rural areas (12.7%).

Discussion

This study represents an attempt to assess and quantify the use of poison baits in Greece, based on data collected and validated in a systematic manner. In addition, the common protocol for data collection and handling reported above proved to be an important tool for the integrated recording of poisoning incidents. The study achieved sample data collection from several state agencies and non-governmental organizations actively concerned with this issue. Quantitative data are difficult to acquire and assess via reporting, as deaths may go undetected if they occur long after exposure or at a great distance from the original site (i.e., Mineau et al. 1999;

Fig. 6 Regression kriging spatially interpolated poison bait use map of the number of poisoned wildlife and livestock in Greece (2000–2016)

Hernández and Margalida 2009). Similarly, in the present study, the true number of animals poisoned remains largely unknown. Official recording of poisoning cases has been rather infrequent and carcass retrieval extremely difficult. For example, in the poisoning incident that exterminated the largest griffon vulture colony in the mainland, only two vultures were found dead out of a total population of 30–40 birds (Jerrentrup and Efthimiou 2006). The bias of true mortality due to poison baits was greatly substantiated by the findings of the anti-poison canine teams. In fact, during their annual patrols in mainland regions with suspected heavy bait use (e.g., areas with high wolf densities), the animals found dead were 30–50% more than those initially suspected and reported as poisoned by stakeholders (Ntemiri and Saravia 2016). Therefore, the number of incidents currently recorded represents only a small percentage of wildlife poisoning. It should be noted that the peak in bait use in 2005–2007 was probably a product of the elevated reporting frequency brought about by assessment with questionnaires implemented by the "Antidoto" project (2007). Likewise, the high number of poisoning incidents recorded on the island of Crete and some mainland regions (e.g., eastern Macedonia and Thrace) should be attributed to better and more systematic long-term monitoring and the findings of the anti-poison canine teams, rather than to any actual increase in bait use (Skartsi et al. 2008; Kret et al. 2015; Ntemiri and Saravia 2016; Vavylis et al. 2016a, 2016b). Similarly, the incidents inside Special Protection Areas (SPAs) noted over time were mainly due to patrols carried out by the anti-poison canine teams close to Egyptian vulture territories, all of which are located within SPAs (Ntemiri and Saravia 2016). In addition, there are certain areas (e.g., central Greece) where poisoning reports had been scarce, but the recovery and expansion of the wolf are nevertheless known to have provoked an escalation of bait use during the last decades (Iliopoulos et al. 2009). In most cases, the impact of bait use on wildlife emerges indirectly in the regional crash of avian scavengers, with vultures being the first species that disappear (Handrinos 1985, (Hallmann 1985, Xirouchakis et al. 2001, Iliopoulos et al. 2009, Xirouchakis and Tsiakiris 2009, Skartsi et al. 2010).

In general, deliberate poisoning impacted three main animal groups: (a) raptors, (b) foxes, and (c) domestic canids (i.e., shepherd, hunting, and stray dogs). Vulture species and facultative scavenges such as golden eagles and buzzards were the worst affected by bait use, which was only to be expected given their foraging behavior.

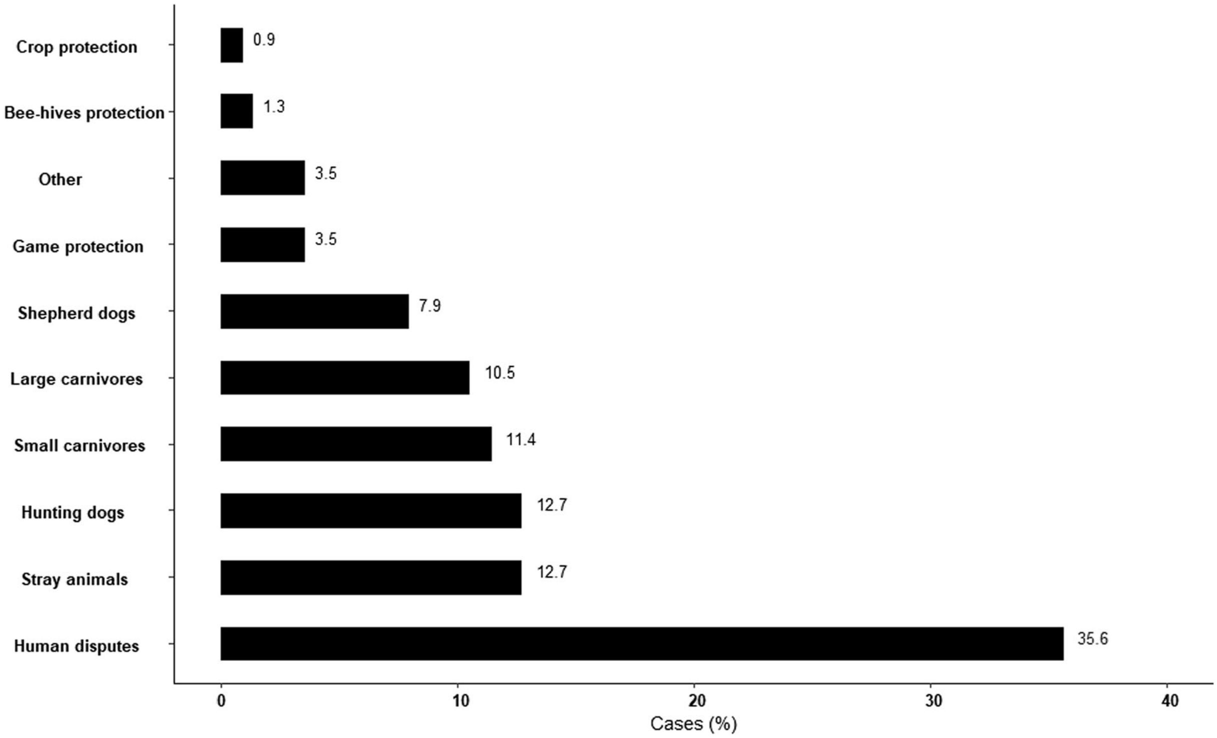

Fig. 7 Motivation of poison bait use ($n = 118$) in Greece (2000–2016)

Among birds of prey, adult mortality due to secondary poisoning is the primary cause of population decline (Newton 1979, Tewes et al. 2004, Botha et al. 2017), and this has been most pronounced in mainland vulture populations (Xirouchakis and Tsiakiris 2009). In fact, considering the current status of the aforementioned species in Greece (Legakis and Maragou 2009), the toll of poisoned individuals corresponds to a loss of circa one breeding territory per year, which is extremely high for species such as vultures, with slow maturation periods, low fecundities, and demands for high adult survival rates to sustain their population (Newton 1998; Meretsky et al. 2000). In the case of vultures, taking into consideration that some poisoning might have taken place during the chick rearing period, the impact of baits on population was certainly augmented by consequent nest failures (Skartsi et al. 2008). The same applies to the brown bear. The high number of poisoned individuals is rather alarming, and deliberate or secondary poisoning is apparently a primary mortality factor putting the species at risk (ca. 2 individuals/year or 1% population loss). On the other hand, the high frequency of poisonings involving shepherd and hunting dogs reveals that retaliatory acts are significant drivers of bait use. Besides stray dogs are of increasing significance as countryside pests in several areas, whether as competitors or substitutes for wild predators.

The temporal pattern of bait use reveals that this practice constitutes a common predator control measure throughout the year. Nevertheless, its seasonal variation is more strongly associated with hunting seasonal activities and the local abundance of game species than with crop and livestock protection. Most poisoning incidents occur in September, coinciding with the opening of the shooting season, i.e., late August-mid September and the movement of nomadic livestock. Similarly, bait use peaks in March specifically after to the end of the hunting season (i.e., February), when illegal anti-predator control campaigns are implemented by illegal hunters targeting foxes. The fox is considered to be a significant small-game predator and held responsible for the local decrease in hare populations. Furthermore, it distracts hunting dogs from the desired quarry during their training (lasting ca. 6 months outside the shooting season). The main driving force for bait use has been found to be intense conflicts between hunters and stockbreeders. The former group seeks to eliminate sheepdogs that may harm their hunting dogs in the field, while the latter aims to discourage hunters from using their grazing land for hunting or dog training.

In spatial terms, the low variation contained in the explanatory variables in regression kriging should be attributed to the high variability of the count data. Furthermore, the selected predictor variables showed low discriminative ability, due to the broad spatial distribution of the poisoning events, which took place in practically all landscape types across the country. The poison bait use map produced for this study should thus be viewed with great caution, though it can still be used as an approximation of reality and at the very least provides full coverage of how intense the problem is in geographical terms. Besides, the two predictors entered into the regression model proved highly significant, showing that poison baits were mostly set in areas with high pastoral activity which attract carnivores, as well as in populated areas with elevated numbers of stray animals. This highlights the need to construct a good predictive map in the future, taking human behavior patterns rather than environmental variables into account. In any case, the majority of poisoned animals were recovered in northwest and central Greece, in regions largely coinciding with the core areas of large mammalian carnivore distribution in Greece (Legakis and Maragou 2009). In this context, it is noteworthy that the earliest outbreak of illegal bait use in continental Greece was provoked by the recovery of the wolf, which was regarded as the key carnivore species in combating wildlife poisoning (Sakoulis 2000). Besides, documented raptor decline and the significant depredation of livestock (2700 cattle and 21,000 sheep and goats from 1989 to 1991) spatially coincided with wolf distribution range and expansion (Handrinos 1985; Papageorgiou et al. 1994; Xirouchakis et al. 2001; Iliopoulos et al. 2009; Kaczensky et al. 2012; Stoynov et al. 2014). Quite unexpectedly, out of a total population of 600 wolves nationwide (Legakis and Maragou 2009), only 15 individuals (< 1%) were eliminated by poison baits during the study period. This figure might be an underestimation, as poisoned animals exhibit altered behavior and may die from other causes, e.g., traffic accidents, but it certainly does not corroborate the use of poison baits as an efficient wolf control method. The present study further revealed that the main reasons for illegal poison bait use are conflicts among stakeholders and the control of stray dogs, which have been seen to cause livestock losses surpassing those attributed to wolves when compared to past decades. In 2015–2016, livestock predation by stray dogs in Heraklion prefecture (Crete) accounted for 46.8 and 54.8% of the countrywide reimbursements paid out by the national rural compensation regime (Hellenic Organization of Agricultural Compensations 2015, 2016, personal communication).

It has been suggested that bait type and toxicant used determine the relevant impact on wildlife (Hernádez & Margalida 2008). In the present case, it was found that bait type was dependent on the species targeted. Small baits were normally used against small carnivores, with KCN wax baits primarily targeting primarily foxes, mustelids, and stray dogs, which are regarded as serious game predators. On the other hand, pesticides poured over whole carcasses usually make use of ungulates predated by wolf packs, aiming to take advantage of the carnivore’s habit of returning to scavenge on old kills (Stahler et al. 2006; Mech and Boitani 2010). One might suppose that whole carcasses would be more destructive to wildlife than poisoned meatballs or KCN wax baits (Hernádez & Margalida 2008, Carrete et al. 2009). However, this would mainly apply to colonial bird species that forage gregariously, such as griffon vultures (Mundy et al. 1992; Roxburgh and McDougall 2012; Campbell 2015). Territorial raptors that feed on small- or medium-sized carcasses might be more susceptible to poisoning by the excessive and indiscriminate use of small baits (Antor 1999; Xirouchakis et al. 1999; Xirouchakis et al. 2001; Hernández and Margalida 2009; Skartsi et al. 2010).

The chemical substances most frequently used in baits were highly toxic anticholinesterase insecticides, i.e., carbamates and organophosphates, some of which are forbidden in Greece and throughout the EU. For instance, methomyl and carbofuran, which accounted for 65.9% of poisoning incidents, have been banned in the country since 2008, although the former agent was reapproved in liquid form in 2013 (Ntemiri and Saravia 2016). Similarly, 75% of the phytosanitary products detected in toxicological analyses have been withdrawn from the market since 2008. Even though it is illegal, the use of potassium cyanide has increased alarmingly compared to the last decade (Vavylis et al. 2016b, Kret 2018). Perpetrators still have easy access to toxic substances, whether as active ingredients of a wide range of approved agrochemicals, or as illegal products still available on the black market. According to European Crop Protection Association (ECPA) data, 10% of the pesticides in the EU are trafficked (European Commission 2015). It is worth mentioning that since 2012, when a law (4036/2012) on the disposal of agrochemicals was implemented, the Greek authorities have handled more than 160 cases of trafficking in illegal formulations (Ministry of Agriculture/ Division of Plant Protection Products, personal communication). In addition, many of these illegal substances were not correctly disposed after 2012 and are still held by farmers.

To conclude, the illegal use of poison baits was found to be a widespread practice in the Greek countryside, constituting the leading cause of non-natural mortality for many endangered species, as in other Mediterranean and Balkan countries (Pavokovic & Susic 2002, Sánchez 2004, Berny 2007, Hernández and Margalida 2008, Mateo-Tomás et al. 2012). The illegal use of various agrochemical substances has become even more common since the official ban on strychnine and potassium cyanide in anti-predator campaigns (Iliopoulos 2000). The results of the present study suggest that as they are non-selective, illegal baits have a tremendous effect on biodiversity, particularly for large mammalian carnivores and avian scavengers, which are most susceptible to poisoning on account of their feeding habits. Compared to previous years and data available for Greece, the study confirms the ongoing impact of toxicants of the carbamate and organophosphate group for the deliberate or accidental killing of livestock, working and companion animals and wild species, and a downward trend in organochloride contaminants in wildlife (Antoniou et al. 1998; Zantopoulos et al. 1999; Antoniou et al. 2005; Hela et al. 2006; Goutner et al. 2011). In particular, methomyl and carbofuran have been used uninterruptedly over the past two decades, primarily against mammalian predators, most likely due to their high toxicity and acute poisoning effects. While potassium cyanide is increasingly used in wax baits, strychnine appears to be in decline, most probably because it has been banned in Greece since 1984 and stocks are now depleted. In addition, analysis of the incidents recorded showed that the main cause of poison bait use was vengeance acts between land users, revealing that the illegal use of poison baits is primarily a complex socioeconomic issue and should be viewed and dealt with accordingly.

Conservation measures

The National Anti-Poison Task Force has succeeded to some extent to mobilize the authorities and prioritize the issue of bait use and to upgrade it on the political agenda of the competent Ministries. To combat the unaccountable illegal trade in agrochemical products, obligatory prescription was introduced in 2014 (Law 4235/2014) and finally came into force under a Joint Ministerial Decree on 2017 (Official Gazette 2724/B/03.08.2017). This development is expected to contribute to agrochemical trafficking control, as well as to risk management, by discouraging perpetrators from using such products in poison baits and possibly facilitating the investigation of poisoning incidents. Nevertheless, poison bait use is still expected to be practiced for the protection of livestock from predators. Although there is an official system of financial compensation, this has proved dysfunctional and complicated (e.g., reimbursement is only available if four caprine are lost per predator attack, and crop damages by wild boars are only compensated for in Ramsar wetlands). Among other improvements, this system needs to be upgraded and updated by adding species (e.g., avian predators) and fully compensating individual animal losses. In this context, controlling the stray dog population would be crucial. Pet legislation has tried to combat dog abandonment by micro-chipping, the creation of an internet database for micro-chipped animals and their owners, and the imposition of strict sanctions (e.g., prison sentences, penalty payments of up to 15,000 Euros, and administrative fines of up to 30,000 Euros per animal). So far, micro-chipping has been incomplete, however, leaving local authorities to enforce relevant laws and any amendments concerning stray animal such as their collection, vaccination, sterilization, tagging, relocation, hosting, and adoption. In the same context, proper tools and alternative livestock protective measures should also be developed, such as electric fencing for livestock or the provision of properly trained guard dog breeds which can reduce livestock losses and consequently poison bait use (Iliopoulos et al. 2009; Karamanlidis et al. 2011; Skartsi et al. 2014).

Public awareness campaigns on the detrimental effect of poisons on biodiversity, public health, and economic activities in the countryside are also necessary. These campaigns should target all land users and must be broadcasted nationwide on all mass media clarifying that poison use is a punishable criminal offense. Land users must also be constantly informed by state agencies of the important role played by top predators in maintaining ecosystems in good health. Scavenger birds of prey, the collateral victims of poison, should be specifically referenced, as they are highly vulnerable to primary and secondary poisoning (e.g., anticoagulant or chronic organochlorine exposure). These birds perform an extremely important ecological and socio-economic service by removing sources of contamination and disease transmission from the countryside

(Prakash et al. 2003; De Vault et al. 2016). There is an urgent need for a national action plan that will include targeted measures for the prevention of poison use, while also providing for the active participation of state authorities, judges, prosecutors, and land users. Law enforcement and the establishment of a clear legal framework laying out responsibilities per authority should be further prioritized, and all relevant authorities including the judiciary should receive appropriate training. These tasks could be integrated into the EU Action Plan compiled under the terms of the European Network against Environmental Crime (ENEC) (Faure et al. 2016).

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