Research Article

Recreational Shooting of Prairie Dogs: A Portal for Lead Entering Wildlife Food Chains

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ABSTRACT Although lead shot has been banned for waterfowl hunting in North America, some predators continue to exhibit elevated lead burdens, which has been attributed to ingesting metallic lead from other projectiles. Few studies have investigated residual lead fragments in hunted upland animals. Therefore, specific portals for lead entering wildlife food chains remain largely unknown. Prairie dogs (*Cynomys* spp.) are shot for recreation with minimal regulation in western North America. Because recreational shooters mostly use expanding bullets and rarely remove or bury carcasses, shot prairie dogs could make lead accessible to predators and scavengers. To determine whether and to what degree shot prairie dogs carry lead fragments, we analyzed carcasses shot by recreational shooters with 2 bullet types. Bullet type influenced the probability of bullet fragments being retained in carcasses; 87% of prairie dogs shot with expanding bullets contained bullet fragments, whereas 7% of carcasses shot with non-expanding bullets did. The amount of bullet fragments per carcass also differed between bullet types; carcasses shot with expanding bullets contained a mean of 228.4 mg of the lead-containing bullet core and 74.4 mg of the copper-alloy jacket, whereas carcasses shot with non-expanding bullets averaged only 19.8 mg of the core and 23.2 mg of the jacket. Lead fragments in carcasses shot with expanding bullets were small in size; 73% of all lead mass in each carcass was from fragments that weighed <25 mg each, small enough to be easily ingested and absorbed by secondary consumers. The amount of lead in a single prairie dog carcass shot with an expanding bullet is potentially sufficient to acutely poison scavengers or predators. Therefore, shot prairie dogs may provide an important portal for lead entering wildlife food chains and may pose risks to raptors and carnivores. Managers should consider measures, such as using non-expanding or lead-free ammunition, to reduce the likelihood of lead consumption and poisoning in upland wildlife. (JOURNAL OF WILDLIFE MANAGEMENT 71(1):103–108; 2007)

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The potential of ingested elemental lead to kill or sicken free-ranging vertebrates, particularly birds, is well documented. Lead is not physiologically valuable to vertebrates at any dose or concentration (Pain 1995). Waterfowl (Grinnell 1894, Wetmore 1919), upland game birds (Calvert 1876), and raptors (Locke et al. 1969, Jacobson et al. 1977) have been shown to ingest lead from various human sources (Pain 1995), particularly spent shotgun pellets (Kendall et al. 1996). Following documentation of widespread lead shot ingestion and poisoning in waterfowl and their predators, the use of lead shot for waterfowl hunting was banned in the United States in 1991 (Anderson 1992) and Canada in 1997 (Clark and Scheuhammer 2003). However, these bans have not eliminated lead exposure in wildlife; lead levels in eagles remain elevated (Kramer and Redig 1997). Further, raptors not typically associated with aquatic food chains are poisoned from ingesting lead: rough-legged hawks (*Buteo lagopus*; Craig et al. 1990), prairie falcons (*Falco mexicanus*; Benson et al. 1974), red-tailed hawks (*Buteo jamaicensis*; Sikarskie 1977), golden eagles (*Aquila chrysaetos*; Wayland et al. 2003), and California condors (*Gymnogyps californianus*; Janssen et al. 1986). Lead poisoning among raptors appears to come primarily from ingestion of metallic lead from ammunition used in hunting (Clark and Scheuhammer 2003). Secondary intoxication appears not to be important; tissues from animals that have ingested lead shot contain insufficient lead to cause symptoms in predators that consume them (Redig et al. 1980, Pattee and Hennes 1983). Thus, continued lead poisoning among carnivores and raptors appears to result mostly from ingestion of lead fragments in hunted vertebrate carcasses.

Over much of their temperate grassland range, prairie dogs (*Cynomys* spp.), colonial sciurids of North America, are subjected to unregulated human shooting (Pauli 2005). Not hunted for meat or skin, prairie dogs are used as targets by recreational shooters typically employing high-velocity rifles effective at ≤500 m. With such a weapon, and lacking state or federal regulations limiting animal harvest, a single shooter may kill scores of prairie dogs from one colony in a single session (>170 prairie dogs in one instance [Vosburgh and Irby 1998]). In recent years, recreational shooters have reported killing >2 million black-tailed prairie dogs (*Cynomys ludovicianus*) per year from 3 states combined (Reeve and Vosburgh 2005). Because shooters typically do not retrieve or bury shot prairie dogs, the carcasses are available to predators and scavengers. Unpublished accounts suggest that rates of removal, and presumably ingestion, of these carcasses by scavengers are high. Typically, recreational shooters use expanding bullets, which fragment on impact (Nunamaker and Berg 1985). Therefore, recreational shooting of prairie dogs may present a widespread source of lead to raptors and carnivores within the geographic range of prairie dogs.

To better understand the potential of shot prairie dogs to be a portal for lead entering wildlife food chains, we conducted detailed analyses of carcasses of prairie dogs that had been shot by recreational shooters. Our objectives were 3-fold: 1) to determine whether recreationally shot prairie dog carcasses contained substantive amounts of lead; 2) to assess whether the bullet type (expanding vs. non-expand-

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ing) used by shooters influenced the retention of bullet parts in the carcass; and 3) to quantify the number, size, and mass of bullet fragments in prairie dog carcasses and the surface area of lead exposed to the gut of a consumer of these carcasses.

STUDY AREA

We conducted this study while investigating the population biology of black-tailed prairie dogs around Thunder Basin National Grassland (105°13′N, 43°42′W), Wyoming, USA, in summers 2003–2004. Thunder Basin National Grassland encompassed >230,000 ha of federal land within a mixture of public and private lands in northeastern Wyoming. The region was characterized by mixed-grass prairie and sage-brush steppe habitat. Because of the large number of black-tailed prairie dog colonies in the region, Thunder Basin National Grassland was subjected to intense recreational shooting.

METHODS

Field Methods

Black-tailed prairie dogs were shot opportunistically with a .223 caliber rifle (M77; Sturm, Ruger and Co., Inc., Southport, CT) by volunteer shooters at 3 colonies located on private land. To determine whether the type of bullet influenced lead burdens in carcasses, we used 2 different bullet types: 1) 55-grain (nominal) non-expanding full metal jacketed bullets (Eldorado Cartridge Corp., Boulder City, NV), in which the bullet core, except for its base, is encased in a copper jacket; and 2) 55-grain (nominal) expanding soft-pointed bullets (Black Hills Ammunition, Rapid City, SD), in which the tip of the lead bullet core is exposed. To mimic typical shooting events, we shot prairie dogs at distances of 20–200 m. After each shooting session, we collected and froze carcasses until we processed them in the laboratory.

Laboratory Methods

We radiographed each animal laterally and then scanned radiographs into the computer program ImageJ (Rasband 2004), which counted the number of bullet fragments in each carcass and measured the projected surface area of each fragment from the radiograph. Because we were unable to distinguish material from the bullet core (about 98% lead, 2% antimony) from the bullet jacket (about 90% copper, 10% zinc) in radiographs and digitized images, we extracted all bullet fragments from a random sample of 10 carcasses shot with expanding bullets that retained bullet fragments. Only 2 carcasses shot with non-expanding bullets contained visible metallic fragments; we extracted fragments from both of them.

To extract bullet fragments, we boiled each carcass in a pressure cooker for 6–8 hours. We poured off the supernatant and added 35.0 g of protease bleach to dissolve remaining soft tissue, which we diluted with 3.5 L of purified water and let digest at 20° C for 48 hours. We again discarded the supernatant and removed and inspected all bones for bullet fragments. We extracted large bullet fragments manually, identified them as either core or jacket, and weighed them to the nearest 0.1 mg on a digital balance. We collectively rinsed small, unidentifiable particles (<1 mg) and set them aside for quantitative analysis. We used flame atomic absorption spectrometry (AAS) to estimate the mass of lead and copper, and we used inductively coupled plasma mass spectrometry (ICP-MS) to estimate the amount of secondary elements, antimony and zinc, in the unidentifiable fragments.

We prepared samples for AAS and ICP-MS using standard procedures (Schmitt et al. 1988, Krueger and Duguay 1989, Tam and Yao 1999). Briefly, we dissolved each sample in 10 mL of HNO_3 and heated each in a water bath (65° C) for 24 hours. We centrifuged samples and diluted the supernatant with 50 ml of ultrapure water. We diluted a 0.5-mL aliquot to 10 mL with ultrapure water. We analyzed diluted samples with AAS for copper and lead and with ICP-MS for zinc and antimony, again following standard procedures. For quality assurance, we employed one blank of diluted HNO_3 and one control, which was from a prairie dog carcass that did not contain any bullet fragments but went through the entire extraction process.

For each of the 12 carcasses, we estimated core and jacket masses by combining the mass estimate of lead from AAS with the mass estimate of antimony from ICP-MS and similarly combining the mass estimates of copper with those of zinc. To estimate the total amount of core and jacket material in each carcass, we combined the masses of large fragments of core and jacket to those of small fragments estimated from ICP-MS and AAS. These values were compared with those for unfired bullets, which we also separated into jacket and core and weighed on a digital balance.

Statistical Analyses

We compared the proportion of carcasses with bullet fragments between expanding and non-expanding bullets with the Fisher exact test. For carcasses shot with expanding bullets for which we measured radiographic attributes and extracted mass of the bullet core and jacket ($n = 10$), we fitted a series of simple linear regression models predicting the mass of core material, jacket material, and total bullet material from 2 predictor variables: 1) the number of bullet fragments in the radiograph and 2) the total projected surface area of the fragments in the radiograph. We employed each predictor variable separately because predictor variables were highly collinear (all $r^2 > 0.95$) and combining them for multiple linear regression analyses did not improve the overall predictive power of the models. We simplified all models by forcing the regression through the origin (no surface area or particles equated with zero mass). We selected the models with the highest correlation coefficients and predicted the mass of core material, jacket material, and total bullet material for carcasses shot with expanding bullets from which we did not extract bullet fragments.

We combined estimates for the amount of core, jacket, and total bullet material in prairie dogs shot with expanding bullets using a weighted mean ($\bar{x}_w$) because variances associated with these measured (weighed) and predicted values differed. We calculated the weighted mean for each bullet fragment type with the equation $\bar{x}_w = w_m\bar{x}_m + w_p\bar{x}_p$, where w_m and w_p are the weighting factors applied to the measured ($\bar{x}_m$) and predicted ($\bar{x}_p$) mean mass of core, jacket, and total bullet material. We calculated weighting factors (Neter et al. 1990, Lipsey and Wilson 2001) from the variances of measured (V_m) and predicted (V_p) values using the following equations:

$$w_m = \frac{\frac{1}{V_m}}{\frac{1}{V_m} + \frac{1}{V_p}} \text{ and } w_p = \frac{\frac{1}{V_p}}{\frac{1}{V_m} + \frac{1}{V_p}}.$$

Similarly, we generated a combined standard deviation for the mass of metals from measured and predicted samples as $SD(\bar{x}_w) = \sqrt{w_m^2 V_m + w_p^2 V_p}$.

RESULTS

Radiographs revealed that the presence–absence of bullet fragments in carcasses differed between bullet types ($P < 0.0001$, Fisher exact test); only 2 of 29 (7%) prairie dogs shot with non-expanding bullets contained bullet fragments, whereas the majority, 26 of 30 (87%), of prairie dogs shot with expanding bullets held fragments (see Fig. 1 for example). The 2 carcasses with fragments of non-expanding bullet each contained a small amount of both components, averaging 19.8 mg of core material (98% of which was lead) and 23.2 mg of jacket material, or approximately 1.2% ($\bar{x}_m = 43.0$ mg) of the original mass of the bullet (Table 1).

All 10 randomly selected carcasses with expanding bullet fragments contained core and jacket material in much larger quantities; carcasses averaged 235.7 mg of core material (98% of which was lead) and 82.1 mg of jacket material (Table 1). In total, carcasses retained 317.8 mg of bullet fragments, 9.0% of the original expanding bullet. The individual fragments of core material in carcasses shot with expanding bullets were predominantly small; 73.1 ± 9.3% of all core material was from fragments that weighed <25 mg each (Fig. 2). Metal concentrations in our blank and control were below detection thresholds.

Regression models developed from carcasses for which bullet mass was measured exhibited a strong relationship between attributes in the radiographs and mass of fragments in the carcasses (Fig. 3; t-tests for all slope parameters had df $= 10$, $t > 6.0$, and $P < 0.005$). The total surface area of fragments in radiographs was the best predictor of the mass of core material (Fig. 3a), whereas the number of fragments in radiographs was the best predictor of the mass of jacket material (Fig. 3b) and total bullet material (Fig. 3c). The averages of predicted values from the regression equations ($\bar{x}_p$) were similar to those directly measured: 225.1 mg of core material, 73.5 mg of jacket material, and 256.2 mg of total bullet material.

Combining the measured values with predicted values in a weighted mean ($\bar{x}_w$) revealed that 8.3% (228.4 mg) of the core, 9.1% (74.4 mg) of the jacket, and 7.5% (265.4 mg) of

Figure 1. Lateral radiograph of a black-tailed prairie dog carcass (no. 1688) shot with an expanding bullet from a .223 caliber rifle, Thunder Basin, Wyoming, USA, 2004. Bullet fragments (white) are distributed through much of the carcass. In this carcass, 28.3% (774.5 mg) of the bullet core and 55.0% (449.1 mg) of the jacket was retained. We show a United States penny (diameter = 1.90 cm) for scale.

the total bullet remained behind in prairie dogs shot with expanding bullets (Table 1). There was, however, high variation in the amount of bullet core in those carcasses (range: 5.1–774.5 mg). Nevertheless, considering only carcasses that contained fragments, prairie dogs shot with expanding bullets averaged >11 times more bullet core than those shot with non-expanding bullets (228.4 mg/19.8 mg; Table 1).

Considering all carcasses shot with non-expanding bullets, including those containing no detectable bullet fragments, carcasses retained about 0.1% (1.4 mg) of the core, 0.2% (1.6 mg) of the jacket, and 0.1% (3.0 mg) of the total bullet (Table 2). By contrast, the recomputed weighted mean ($\bar{x}_w$), incorporating the 4 of 30 carcasses of animals shot with expanding bullets that did not contain detectable bullet fragments, revealed that 7.5% (206.0 mg) of the core, 8.8%

Table 1. Mean mass and standard deviation of bullet components (jacket, core, and total bullet) recovered from and predicted to be in black-tailed prairie dog carcasses shot with non-expanding and expanding bullets, Thunder Basin, Wyoming, USA, 2004. We provide the mean mass of each component for unfired bullets, bullet fragments measured directly from shot prairie dogs, bullet fragments predicted from a regression equation, and the combined mean. We show values only for carcasses that contained detectable bullet fragments (2 of 29 for non-expanding bullets and 26 of 30 for expanding bullets).

	Non-expanding bullet (mg)							Expanding bullet (mg)						
		Jacket		Core		Total bullet			Jacket		Core		Total bullet	
	n	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	*n*	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Unfired	5	1,059.4	14.5	2,494.6	2.7	3,554.0	15.4	5.0	816.0	3.0	2,742.4	3.2	3,558.4	4.0
Measured[a]														
>1 mg	2	23.2	8.9	19.8	20.2	43.0	29.1	10.0	80.8	136.3	149.8	179.1	230.7	229.0
<1 mg	2	0.0	0.0	0.0	0.0	0.0	0.0	10.0	1.2	2.6	85.9	107.3	87.1	109.9
Total	2	23.2	8.9	19.8	20.2	43.0	29.1	10.0	82.1	138.1	235.7	281.2	317.8	383.1
Predicted	0	—[b]	—	—	—	—	—	16.0	73.5	45.9	225.1	187.5	256.2	160.1
Combined[c]	0	—	—	—	—	—	—	26.0	74.4	43.6	228.4	156.0	265.4	147.7

[a] We weighed fragments >1 mg on a digital balance; we estimated fragments <1 mg using spectrometry.
[b] Dash indicates value is incalculable.
[c] We combined measured and predicted means with a weighted equation.

(71.6 mg) of the jacket, and 7.1% (251.0 mg) of the total bullet were retained (Table 2).

DISCUSSION

Depending on bullet type, prairie dogs shot by recreational shooters contained variable but potentially substantive amounts of metallic lead. Of carcasses shot with expanding bullets, 87% contained detectable metallic lead, whereas only 7% carcasses shot with non-expanding bullets did. The carcasses shot with expanding bullets that contained bullet fragments detectable with radiography held large quantities of lead. Non-expanding bullets, by contrast, tended to pass through prairie dogs, leaving small or undetectable amounts of lead. This lead likely originated from the unjacketed base of the non-expanding bullets. In all, considering the bullet-

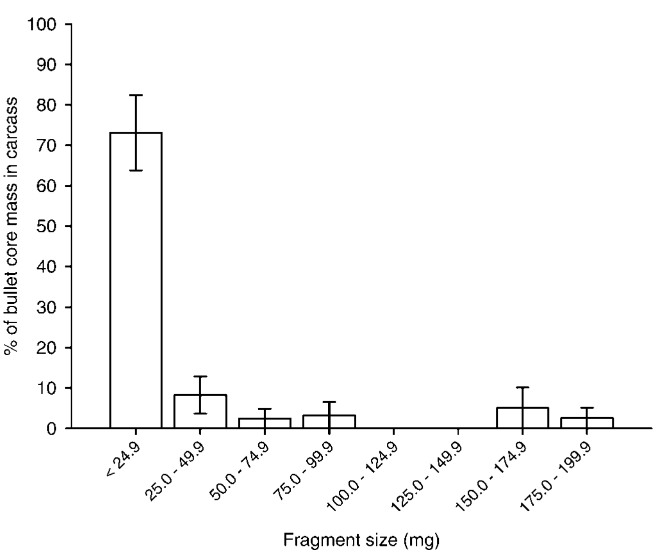

Figure 2. Histogram depicting the relative amount of different-sized bullet core fragments in prairie dogs shot with expanding bullets from a .223 caliber rifle (±1 SD), Thunder Basin, Wyoming, USA, 2004. The majority, 73.1%, of all bullet core fragments in carcasses were from the smallest fragment size, with each fragment weighing <24.9 mg.

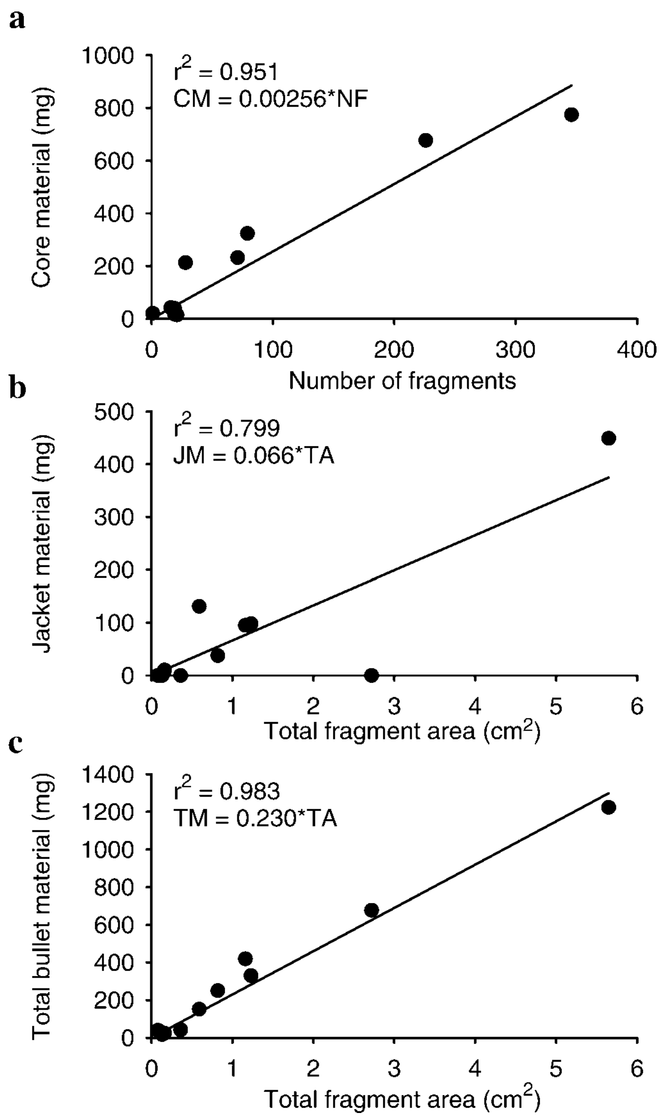

Figure 3. Regression models predicting the mass of (a) core material (CM), (b) jacket material (JM), and (c) total bullet material (TM) in prairie dog carcasses shot with .223 caliber expanding bullets from the number of bullet fragments (NF) and total surface area (TA) of bullet fragments in the radiographs of the carcasses, Thunder Basin, Wyoming, USA, 2004. We used these models to predict the mass of each bullet component for carcasses from which we had not extracted fragments.

Table 2. Mean mass and standard deviation of bullet components (jacket, core, and total bullet) for all prairie dog carcasses shot with non-expanding and expanding bullets, including those that contained no bullet fragments, Thunder Basin, Wyoming, USA, 2004.

		Jacket (mg)		Core (mg)		Total bullet (mg)	
Bullet type	***n***	$\bar{x}$	**SD**	$\bar{x}$	**SD**	$\bar{x}$	**SD**
Non-expanding	29	1.6	6.2	1.4	6.4	3.0	12.4
Expanding	30	71.6	44.1	206.0	150.2	251.0	149.3

type differences in presence of fragments in carcasses, the expanding bullets used in our study left nearly 150 times as much metallic lead in prairie dog carcasses as did non-expanding bullets. Further, bullet fragments in carcasses shot with expanding bullets were mostly very small; >70% of the retained bullet core mass, 98% of it lead, was in particles <25 mg in weight. This small fragment size increases the surface area of metallic lead and its uptake in animals that consume the fragments, relative to larger particles, such as typical shotgun pellets (Barltrop and Meek 1979).

Prairie dogs are commonly preyed upon or scavenged by many birds and mammals. At least 10 species of mammals and 9 species of raptors, including the black-footed ferret (*Mustela nigripes*) and bald eagle (*Haliaeetus leucocephalus*), have been reported predating or scavenging prairie dogs (Hillman 1968, Hoogland 2003). Raptors in particular are susceptible to lead poisoning; as little as 180 mg of metallic lead powder can kill nestling raptors (Hoffman et al. 1985) and only 2 g of lead shot is sufficient to kill adult eagles (Pattee et al. 1981). We found that 47% of prairie dogs shot with expanding bullets contained >180 mg of elemental lead, enough to be acutely lethal to nestling raptors and, depending on the absorption rate of the bullet fragments, an amount potentially sufficient to be acutely lethal to adult raptors as well. Of course, for both birds and mammals, a wide range of sublethal toxic effects are also possible from smaller quantities of lead, which could alter population processes such as survival and reproduction (Pain 1995).

In general, pellets from shotgun ammunition are large enough for scavengers to detect and avoid while feeding (Stendell 1980) and when incidentally ingested, raptors often regurgitate pellets before being completely digested (Platt 1976, Pattee et al. 1981). These mechanisms may reduce ingestion and assimilation of lead shot in prey or carrion. However, we found that >70% of lead was in fragment sizes likely too small (<25 mg) to be avoided during ingestion and perhaps too small to be egested through regurgitation of indigestible material. These small bullet core fragments each weighed <25 mg, which is about 0.1× the size of a no. 4 lead pellet. Small lead fragments are readily absorbed in the gastrointestinal tract (Barltrop and Meek 1979). Therefore, recreational shooting using expanding lead alloy bullets may present a particularly important portal for the entry of lead into wildlife food chains.

MANAGEMENT IMPLICATIONS

Our results suggest that recreational shooting of prairie dogs contributes to the problem of lead intoxication in wildlife food chains that include prairie dogs. Indeed, some features of recreational shooting, including the killing of large numbers of animals, not removing carcasses from the field, and using expanding bullets, is in contrast to traditional forms of hunting and may present potentially dangerous amounts and particle sizes of metallic lead to scavengers and predators of prairie dogs. Recreational shooting of black-tailed prairie dogs occurs with minimal regulation, yet appears to provide a readily available source of lead to scavenging vertebrates. Few agencies regulate recreational shooting intensity and duration, and none currently regulate the type of ammunition that can be used. Managers should consider measures, such as using non-expanding or lead-free ammunition, to reduce the likelihood of lead poisoning in scavenging raptors and carnivores.

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