Research Article

Anticoagulant Exposure and Notoedric Mange in Bobcats and Mountain Lions in Urban Southern California

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ABSTRACT Humans introduce many toxicants into the environment, the long-term and indirect effects of which are generally unknown. We investigated exposure to anticoagulant rodenticides and evaluated the association between notoedric mange, an ectoparasitic disease, and anticoagulant exposure in bobcats (*Lynx rufus*) and mountain lions (*Puma concolor*) in a fragmented urban landscape in southern California, USA. Beginning in 2002, an epizootic of notoedric mange, a disease previously reported only as isolated cases in wild felids, in 2 years reduced the annual survival rate of bobcats from 0.77 (5-yr average) to 0.28. Anticoagulants were present in 35 of 39 (90%) bobcats we tested, multiple compounds were present in 27 of these 35 (77%), and total toxicant load was positively associated with the use of developed areas by radiocollared animals. Mange-associated mortality in bobcats showed a strong association with anticoagulant exposure, as 19 of 19 (100%) bobcats that died with severe mange were also exposed to the toxicants, and for bobcats with anticoagulant residues >0.05 ppm, the association with mange was highly significant ($\chi^2 = 10.36$, $P = 0.001$). We speculate that concomitant elevated levels of rodenticide exposure may have increased the susceptibility of bobcats to advanced mange disease. Bobcats were locally extirpated from some isolated habitat patches and have been slow to recover. In 2004, 2 adult mountain lions died directly from anticoagulant toxicity, and both animals also had infestations of notoedric mange, although not as advanced as in the emaciated bobcats that died with severe disease. Two other mountain lions that died in intraspecific fights also exhibited exposure to 2–4 different anticoagulants. These results show that the effects of secondary poisoning on predators can be widespread, reach even the highest-level carnivores, and have both direct and possibly indirect effects on mortality. Further research is needed to investigate the lethal and sub-lethal effects of anticoagulants and other toxicants on wildlife in terrestrial environments. (JOURNAL OF WILDLIFE MANAGEMENT 71(6):1874–1884; 2007)

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The conversion of land for urban or agricultural uses has obvious impacts on natural populations by eliminating, fragmenting, and altering habitat. However, human activity, including the introduction of toxicants into the environment, can have other unintended and more cryptic consequences for wildlife populations. Determining the nature and extent of these effects can be difficult, particularly if multiple stressors are involved. In recent years, laboratory and artificial pond experiments on aquatic amphibians have revealed that anthropogenic stressors can interact with natural ones to have a much greater influence on survival, growth, and population persistence than either factor in isolation (Kiesecker et al. 2001, Kiesecker 2002, Relyea 2003). However, there have been few similar demonstrations in terrestrial systems or in more natural field situations (e.g., Gervais and Anthony 2003).

Anticoagulant rodenticides are widely used in both urban and agricultural settings to control rodent populations. There are 6 anticoagulant rodenticides registered by the Environmental Protection Agency for control of rats and mice in and around buildings. They are often formulated as grain-based food baits, typically pellets, although other formulations are used, and all are sold over-the-counter and are therefore available to the general public. Warfarin, chlorophacinone, and diphacinone were developed earlier and are referred to as first-generation anticoagulants. They generally require multiple feeding by the target species and are less toxic to birds. They are also more readily metabolized and are much less persistent in the body. The other 3 anticoagulants, brodifacoum, bromadiolone, and difethialone, are commonly referred to as second-generation anticoagulants. They exhibit very high toxicity to birds and mammals, can provide a lethal dose in a single feeding, and can remain in body tissues for long periods (months) because they are highly persistent and are not readily metabolized (Eason et al. 2002, Erickson and Urban 2004, Berny et al. 2006).

Secondary anticoagulant poisoning of nontarget animals has been well-documented in a wide range of birds and mammals (Eason and Spurr 1995; Stone et al. 1999, 2002;

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Hosea 2000; Eason et al. 2002) including owls (Mendenhall and Pank 1980), buzzards (Berny et al. 1997), coyotes (*Canis latrans*; Riley et al. 2003), feral cats (*Felis catus*; Alterio 1996), mountain lions (*Puma concolor*; Littrell 1988), otters (*Lutra lutra*), endangered European mink (*Mustela lutreola*), and polecats (*Mustela putorius*; Fournier-Chambrillon et al. 2004). However, the vast majority of this poisoning undoubtedly remains undetected for several reasons. Most importantly, testing for the presence of anticoagulants requires necropsy and analysis of liver tissue (using high-performance liquid chromatography [HPLC]). Unless an animal is being tracked through radiotelemetry, finding deceased animals in a nondecomposed state is rarely possible in the field (Wobeser 2006). Another problem is that many animals do not exhibit any outward signs of poisoning, so toxicants go undetected without specific testing (e.g., McDonald et al. 1998).

When testing is done, anticoagulant occurrence is often high. Shore et al. (1996) found that 31% of polecats tested in Britain had anticoagulants present, Hosea (2000) found that 70% of the mammals (including coyotes and bobcats [*Lynx rufus*]) tested in California, USA, had been exposed to anticoagulants, and anticoagulants were detected in 49% of the raptors tested in New York, USA, from 1998 to 2001, including in 81% of the great horned owls (*Bubo viriginianus;* Stone et al. 2002). Although some predators die directly from anticoagulant toxicity, many others do not. For example, 86% of the raptors exposed to anticoagulants in New York did not show evidence of death from direct toxicity. However, according to Stone et al. (2002:37), "the impact of anticoagulant exposure must extend well beyond those cases in which acute lethal hemorrhage is the proximal cause of death." Little is known about what constitutes a lethal dose for wildlife species, what the sub-lethal, chronic effects may be, or what kinds of interactions may occur between anticoagulants and other factors.

We investigated the association between anticoagulants and the natural stressor of disease, specifically notoedric mange. Mange is not an uncommon disease in carnivore populations, but most reports of population-level effects are from sarcoptic mange infestation, often in canids (Pence and Ueckermann 2002). Notoedric mange has generally only been reported as isolated cases in wild felids (e.g., Pence et al. 1995, Ryser-Degiorgis et al. 2002) including both bobcats (Penner and Parke 1953, Pence et al. 1982) and captive Florida panthers (*Puma concolor coryi*; Maehr et al. 1995), although there are reports of epizootics in coatis (*Nasua narica*; Valenzuela et al. 2000) and in a feral cat population in Florida, USA (Foley 1991). The mite, *Notoedres cati*, occurs as a treatable ear parasite in domestic cats and may be more common in veterinary practices in Southern California (Brooks 2000), although it occurs in urban areas throughout the United States (K. Kwochka, DVM Pharmaceuticals, personal communication). Mange cases may become severe and result in dehydration, emaciation, and eventually death (Pence and Ueckermann 2002). However, by itself, the occurrence of mange mites, including *Sarcoptes*, on a healthy animal would not be considered fatal but can develop into lethal disease when other factors are also present (Samuel 1981). Consequently, the prevalence of mange increases in times of increased environmental stress such as drought or winter or in animals under social or nutritional stress (Pence and Ueckermann 2002).

Following results from previous research about the occurrence of antiocoagulant toxicity in coyotes (Riley et al. 2003) and more recent observations of mange-associated mortality in bobcats, we began investigating anticoagulant exposure and the potential for interactive effects of this exposure in bobcats and mountain lions. Specifically, we measured the frequency and amount of anticoagulant exposure and notoedric mange incidence in both species, and we assessed the potential association between anticoagulant exposure and susceptibility to severe mange infestation. We also evaluated the degree to which anticoagulant exposure was related to the use of development by radiocollared bobcats and the impact of the mange epizootic on the local bobcat population.

STUDY AREA

Our study was conducted in the coastal mountain ranges north and west of the city of Los Angeles in southern California, including the Santa Monica Mountains, Simi Hills, and Santa Susana Mountains (Fig. 1). The area had a Mediterranean climate with cool, wet winters and hot, dry summers. Predominant habitat types included mixed chaparral, coastal sage scrub, oak woodland and savanna, riparian areas, and introduced annual grasslands. Human land-uses included commercial development, low- to high-density residential development, golf courses, landscaped areas in parks and adjacent to office buildings, agricultural land, and a 120-ha landfill. An 8–10-lane freeway (United States Route 101), 2 4–6-lane freeways (State Routes 23 and 118), and numerous secondary roads intersected our study area (Fig. 1). For bobcats, we focused on the southern Simi Hills area, including habitat fragments, and the portions of the Santa Monica Mountains immediately across the 101 freeway (see bobcat study area, Fig. 1). For mountain lions, our study area included all of the Santa Monica Mountains, Simi Hills, and Santa Susana Mountains.

METHODS

Bobcat and Mountain Lion Capture and Radiotracking

We captured bobcats using foothold traps and snares (1996–1998) and cage traps (2000–2004) and captured mountain lions using foot-snares, cage-traps, and hound-capture. We chemically immobilized all animals with ketamine hydrochloride and xylazine hydrochloride in a 5:1 ratio, and then weighed, measured, and marked them with ear-tags. We fitted adult bobcats with very high frequency (VHF) radiotransmitters (Telonics Inc., Mesa, AZ; Telemetry Solutions, Concord, CA; Advanced Telemetry Systems, Isanti, MN). We fitted mountain lions with combination VHF and Global Positioning System (GPS) collars (Tele-

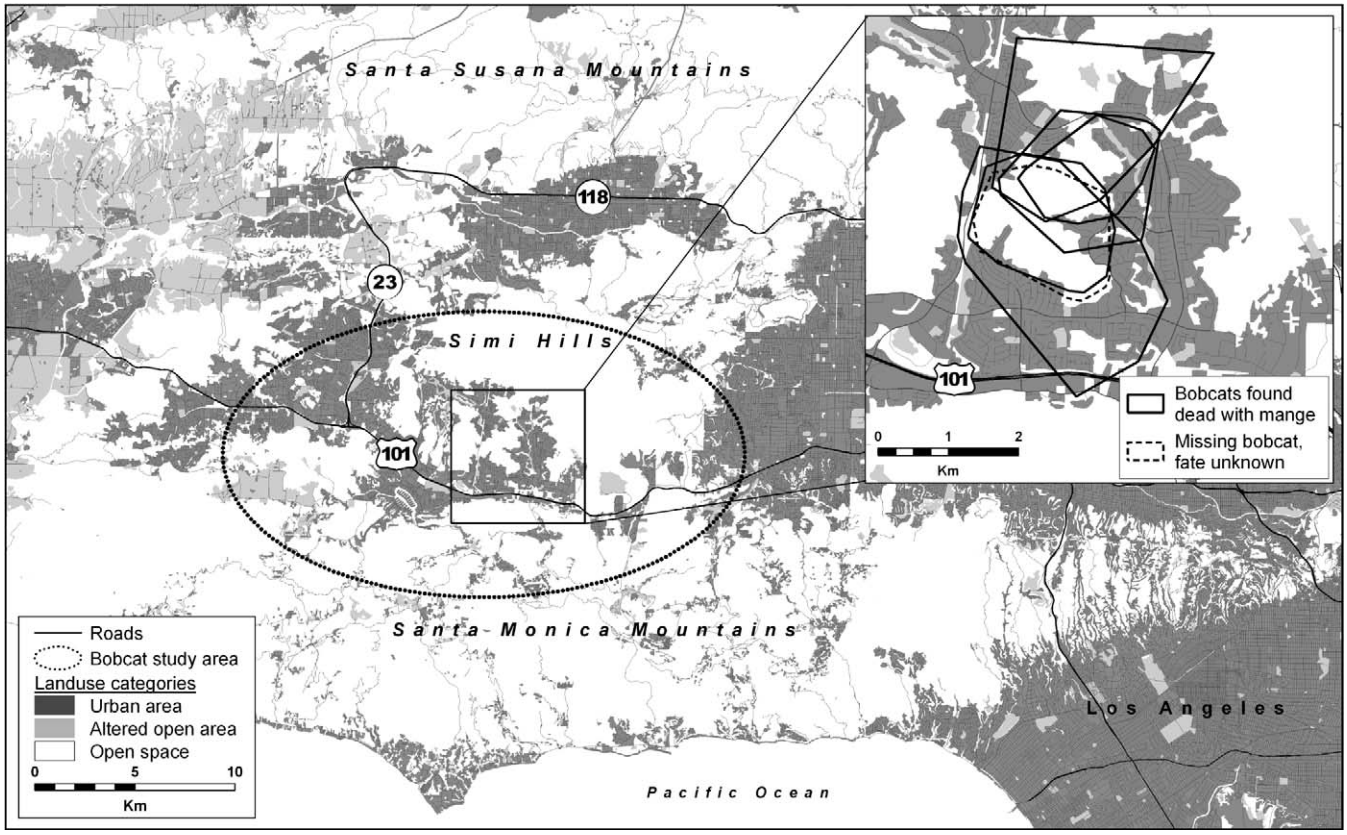

Figure 1. Study area for bobcats and mountain lions near Los Angeles, California, USA, 1996–2006. Inset: home ranges (95% min. convex polygons) of 6 bobcats in an isolated habitat patch in Westlake Village, California. Five of 6 radiocollared bobcats in this patch died of mange between March 2002 and March 2003, and contact was lost with the sixth animal. Based on trapping and scat surveys, little or no evidence of bobcat activity has been seen in this patch since.

vilt, Lindesberg, Sweden). All radiocollars were equipped with mortality sensors. We obtained the necessary permits for animal capture and handling.

We located bobcats by ground telemetry using triangulation (3 compass azimuths obtained within 15 min) 2–5 times per week throughout the 24-hour cycle. Locations used for home range analysis were separated by >12 hours. We tested radiotelemetry accuracy using test collars (see Riley et al. 2003) and it averaged 42.4 m (SD = 50.2). We calculated 95% minimum convex polygon home ranges using the home range extension in the program ArcView. We calculated bobcat survival rates with the techniques of Heisey and Fuller (1985) using the program MICROMORT.

We calculated the urban association (the relative amt of potential interaction with human development) of bobcats by determining the percentage of developed land and the percentage of altered land (areas that are not natural habitat, but are potentially more conducive to wildlife use than developed areas) present in the home range (see also Riley et al. 2003). Developed land included commercial areas and residential areas with ≥1 house per 0.4 ha. Altered land included golf courses, landscaped areas such as office or city parks, a landfill, small strips or patches of habitat, and low-density (≤1 house/2 ha) residential areas. We define unnatural area as developed areas plus altered areas.

We radiotracked mountain lions 2–3 times per week by VHF ground telemetry, and we obtained 100–150 GPS collar locations each month by remote download. Potential mountain lion prey kill-sites were identified by examining each month's GPS locations for clusters of locations (Anderson and Lindzey 2003) encompassing a period of 24 hours or more. Potential kill sites were investigated and prey remains were identified to species, age, and sex, when possible.

Bobcat Distribution and Relative Abundance

We collected scat on established transects each month. Over multiple years, changes in the numbers of scat collected over time allowed us to monitor changes in bobcat distribution and relative abundance. Transects were cleared in March 2001, and then all bobcat scat was collected each month through December 2004, except for 3 months in 2002. We identified bobcat scat by size and shape (Murie 1954). Verification of species identification of bobcat scat in the same region using faecal genotyping revealed approximately 90% accuracy using field characteristics (Kohn et al. 1999, Fedriani et al. 2000), although for examining trends over time, consistency of technique is most important.

Necropsy and Diagnostic Analysis

When we detected mortality signals, we immediately located the carcasses of radiocollared animals. We determined cause

of death by necropsy and, when possible, by using associated ancillary tests including routine histology, bacteriology, virus isolation, and toxicology. We transported the first 4 bobcats that showed indications of mange to the California Animal Health and Food Safety Laboratory (CAHFS) San Bernardino Branch, where full necropsies were performed. We treated skin scrapings from these animals with 10% potassium hydroxide and examined them microscopically for mites, and we examined mites as whole mounts in glycerin. We identified future cases of mange in bobcats by visual examination and by the distinctive pattern of disease progress for notoedric mange. We performed a field necropsy on the first mountain lion that died, an adult female. We transferred her liver, head, and pelt and the complete carcasses of the other 3 mountain lions, an adult male, an adult female, and a yearling female, to CAHFS for examination. We also obtained skin scrapings and mites from the 2 mange-infested mountain lions, which we processed as described for the bobcats.

Anticoagulant Testing

We collected liver samples from radiocollared bobcats that died and were recovered intact. We also collected livers from unmarked bobcat carcasses encountered in the field and from 2 bobcats collected by the City of Los Angeles. We froze all liver samples at −20° C and shipped them to the CAHFS laboratory (Davis Branch), where they were tested for the presence of 7 anticoagulants: warfarin, bromadialone, coumachlor, brodifacoum, diphacinone, chlorophacinone, and difethialone. We also collected blood samples from 3 bobcats that were afflicted with mange when live-captured. For 2 of these animals, we measured prothrombin time of blood samples to determine anticoagulant presence. These samples were analyzed by Idexx Veterinary Services (San Bernardino, CA). Normal prothrombin time was considered to be 7.0–12.7 seconds, based on values for domestic cats. The third animal was B108, a female bobcat that also had an early stage case of mange and was kept at the California Wildlife Center for rehabilitation (see Results). Partial thromboplastin time was determined for this bobcat (Idexx Veterinary Services). Between 10 seconds and 28 seconds was considered normal partial thromboplastin time, again based on values for domestic cats.

We analyzed liver samples using a previously published method for the analysis of anticoagulant rodenticides in serum (Palazoglu et al. 1998) modified for tissue analysis. We acidified 5-g liver samples with acetic acid and homogenized them with 5% ethanol in ethyl acetate. We cleaned up the samples using gel-permeation chromatography (GPC). We then exchanged the GPC eluent to methanol and reduced the volume of methanol to 0.5 mL. We analyzed the methanol extracts by HPLC using diode-array and fluorescence detectors in series. Identification was by comparison with diode-array and fluorescence spectra from known standards. In cases in which diode-array and fluorescence spectra were ambiguous, we performed qualitative confirmation analysis using liquid chromatography–mass spectrometry. We performed quantification by comparison of analyte response in samples with that of known standards. Minimum detectable levels were 0.05 ppm for warfarin, bromadiolone, and coumachlor, 0.01 ppm for brodifacoum, and 0.25 ppm for diphacinone, chlorphacinone, and difethialone.

Statistical Analyses

We measured the association between severe notoedric mange and anticoagulant exposure using a chi-square test. We assessed the relationship between mange and urban association of radiocollared bobcats with nonparametric Mann–Whitney *U* tests, measured the relationship between the total concentration of anticoagulants (ppm) and urban association with simple linear regression, and compared the total concentration of anticoagulants between mange-infected and uninfected bobcats with a 2-sample *t*-test. We report statistical results with a *P*-value of ≤ 0.10. We performed statistical tests with the program SYSTAT (SPSS Inc., Chicago, IL).

RESULTS

We tested the livers from 39 bobcats, including animals with and without mange and that died both before and after the mange epizootic. Anticoagulant toxicants were present in 35 of 39 (90%) bobcat livers, and 27 of these 35 (77%) revealed exposure to ≥ 2 compounds. We detected brodifacoum in 31 of the liver samples at levels ranging up to 0.56 ppm, bromadialone in 25 livers at levels up to 0.82 ppm, diphacinone in 12 livers up to 0.58 ppm, and difethialone in 10 livers at trace levels (<0.25 ppm; Table 1). Prothrombin times for the 2 bobcats whose blood we tested were 17.3 seconds and >100 seconds (normal time: 7.0–12.7 sec). The livers of all 4 mountain lions we tested indicated high levels of the 2 compounds most common in bobcats, and one mountain lion also had significant levels of difethialone and trace levels of diphacinone. In the 2 mountain lions that died of anticoagulant toxicity (see below), we detected bromadiolone at 1.27 ppm and brodifacoum at 0.57 ppm in the liver of the male (P3) and bromadiolone at 0.51 ppm and brodifacoum at 0.31 ppm in the female (P4). Two other mountain lions were killed in August 2005 (ad F P2) and June 2006 (yearling F P7) by an adult male lion. We detected bromadiolone at 0.37 ppm and brodifacoum at 0.32 ppm in the liver of P2 and bromadiolone at 0.66 ppm, brodifacoum at 0.32 ppm, difethialone at 0.66 ppm, and diphacinone at trace levels in P7.

Mange-afflicted bobcats and mountain lions exhibited severe mite encrustation on the head and shoulders (Fig. 2) in the form of proliferative dermatitis with hyperkeratosis, epidermal scaling and multiple mites, identified as *Notoedres cati*, on the surface in keratin tunnels (see also Uzal et al. 2007). In the bobcats the mange often extended over much of the body, including the hind legs. The bobcats became emaciated and increasingly diurnal in many cases, and eventually succumbed to the disease. With one exception, bobcats that died of mange did not show evidence upon necropsy of direct anticoagulant toxicity as a cause of mortality. Specifically, we did not find evidence of a

Table 1. Anticoagulant exposure of bobcats in the Santa Monica Mountains and Simi Hills, Ventura and Los Angeles Counties, California, USA, 1997–2003. Values indicate residues from liver samples (ppm). We captured and radiocollared all bobcats with identification (ID) numbers except for B050, which had an identification collar without a radiotransmitter. All bobcats with ID letters were recovered by other means, such as being recovered on a road, submitted to an animal control agency, or seen and reported by a homeowner. We also conducted tests for warfarin, coumachlor, and chlorophacinone, but we detected no residues except for a trace of warfarin (mdl = 0.05) in Bobcat 114.

Bobcat ID	Sex	Age	Bromadiolone mdl = 0.05[a]	Brodifacoum mdl = 0.01[a]	Diphacinone mdl = 0.25[a]	Difethialone mdl = 0.25[a]	Total[a]	Mange?	Yr	Cause
30	F	ad	nd	0.05	nd	nd	0.05	n	1997	anticoagulant toxicity
H	F	ad	nd	0.03	nd	nd	0.03	n	1988	roadkill
E	M	ad	nd	nd	nd	nd	nd	n	1988	unknown
25	F	ad	nd	nd	nd	nd	nd	n	1988	unknown
I	F	ad	nd	0.02	nd	nd	0.02	n	1988	roadkill
50	F	ad	tr	0.02	nd	nd	0.02	n	1999	unknown
G	M	ad	nd	0.01	nd	tr	0.01	n	1999	unknown
52	M	ad	0.11	0.07	nd	nd	0.18	n	1999	unknown
11	F	ad	nd	nd	nd	tr	tr	n	1999	predation
79	F	ad	0.48	0.22	nd	nd	0.70	y	2002	mange
54	F	ad	nd	nd	nd	nd	nd	n	2002	roadkill
98	F	juv	tr	0.02	0.58	nd	0.60	n	2002	roadkill
F	F	ad	nd	nd	nd	nd	nd	n	2002	roadkill
65	M	ad	0.36	0.37	nd	nd	0.73	y	2002	mange
66	M	ad	nd	0.09	0.30	nd	0.39	y	2002	mange
67	F	ad	tr	0.07	nd	nd	0.07	y	2002	mange
72	F	juv	nd	tr	nd	nd	tr	y	2002	mange
91	M	ad	0.50	0.14	tr	tr	0.89	y	2002	mange
92	F	ad	0.13	0.11	tr	tr	0.64	y	2002	mange
114	M	ad	0.08	0.44	nd	tr	0.52	n	2003	unknown
115	M	ad	0.09	0.31	tr	nd	0.40	n	2003	fence
A	M	ad	nd	0.03	nd	nd	0.03	y	2003	mange
B	M	ad	0.82	nd	nd	nd	0.82	n	2003	roadkill
C	F	ad	tr	nd	nd	nd	tr	n	2003	roadkill
95	M	juv	tr	nd	tr	nd	tr	n	2003	roadkill
116	M	juv	0.05	0.24	nd	nd	0.29	n	2003	roadkill
118	M	ad	0.10	0.02	nd	nd	0.12	n	2003	roadkill
D	M	ad	nd	0.11	0.29	tr	0.40	n	2003	unknown
7	M	ad	0.18	0.34	tr	tr	0.52	y	2003	mange
22	M	ad	0.10	0.17	nd	nd	0.27	y	2003	mange
70	M	juv	0.09	0.25	tr	nd	0.34	y	2003	mange
71	F	ad	0.14	0.36	tr	tr	0.50	y	2003	mange
76	M	ad	0.21	0.29	tr	tr	0.50	y	2003	mange
84	M	ad	0.11	0.05	nd	nd	0.16	y	2003	mange
88	F	ad	0.05	0.03	nd	nd	0.08	y	2003	mange
106	F	juv	0.16	0.24	nd	nd	0.40	y	2003	mange
112	F	ad	0.07	0.11	nd	nd	0.18	y	2003	mange
113	F	ad	tr	0.07	0.27	nd	0.34	y	2003	mange
121	M	juv	0.15	0.56	nd	tr	0.71	y	2003	mange

[a] tr = positive, but amt < min. detectable limit (mdl) for that compound; nd = not detected.

coagulopathy (manifested by extensive internal hemorrhaging), indications that were seen previously in >8 coyotes and 1 bobcat that were determined to have died directly from anticoagulant toxicity (Hosea 2000, Riley et al. 2003). On the other hand, both mountain lions died directly from anticoagulant toxicity as demonstrated by the high levels of anticoagulants detected in the liver, multiple extensive hemorrhages on serosal surfaces and within body cavities, and the lack of evidence of trauma or other lesions to justify the bleeding. In addition, we obtained negative results from all the other ancillary tests performed.

Severe mange and anticoagulant exposure were highly associated as 19 of 19 bobcats with advanced mange had anticoagulant compounds in their liver, 18 at more than trace levels (Table 1). Including the 2 mountain lions, 21 of 21 wild felids (100%) with mange also had anticoagulant toxicants present. The anticoagulant levels were also generally high in bobcats with mange, and for bobcats with anticoagulant residues >0.05 ppm, the association with mange was very high (Table 2; $\chi^2 = 10.36$, $P = 0.001$). By contrast, just 8 of 20 bobcats (40%) that died of other causes exhibited a similar level of anticoagulant exposure. Overall, the total anticoagulant level in bobcats that died with severe mange ($\bar{x} = 0.39$) was higher than in bobcats that died of other causes ($\bar{x} = 0.17$; $t = 2.67$, $P = 0.011$). There did not appear to be a specific, or threshold, level of anticoagulants in bobcats with mange because 3 of the bobcats that died with mange had 0.03 ppm, 0.07 ppm, and trace levels of anticoagulants, although it is impossible to know the level of toxicant present when the mange infestation began.

In November of 2003, we captured an adult female bobcat (B108) in the early stages of mange development that also

Figure 2. Bobcat with severe mange, Simi Hills, Ventura County, California, USA, 2002.

had a prolonged partial thromboplastin time (PTT) of 50.6 seconds indicative of anticoagulant exposure (normal time: 10–28 sec). She was held captive at a wildlife rehabilitation center (California Wildlife Center, Calabasas, CA) and treated with vitamin K_1 for anticoagulant intoxication and 2 doses of ivermectin for mange. After 2 weeks, her PTT was still elevated (>100 sec), but after 4 weeks it was normal (21.0 sec) and she had no signs of mange. We released her at the capture site in December 2003, and she subsequently produced a large litter of 4 healthy kittens in the spring of 2004. However, she was apparently exposed again to mange, and she and her surviving kitten both died with severe mange infestations in the autumn of 2004.

Beginning in 2002, when the mange epizootic began, the bobcat survival rate fell from a high of 0.847 in 1999 and a 5-year average of 0.770 to 0.280 in 2003 (Table 3). Simultaneous scat surveys also showed a significant decrease in bobcat activity starting in the autumn of 2002 (Fig. 3). Finally, local extirpations of bobcats have occurred in some of the habitat fragments in the area, both large and small. In one larger patch that is surrounded by roads and development, we were radiotracking 6 bobcats (3 F, 3 M) at the beginning of 2002 (Fig. 1, inset). All 3 males and 2 of the females died with severe mange, and we lost contact with the third female's radiocollar. Scat surveys and intensive trapping for bobcats in 2004–2006 found little evidence of bobcat activity. In 2005, 2 radiocollared male bobcats occasionally visited this patch.

For bobcats in this fragmented landscape, use of developed areas was not significantly greater for bobcats with mange (% of the home range consisting of unnatural area: Mann–Whitney $U = 234$, $P = 0.351$). Although neither mange nor the presence of anticoagulants were associated with human development, the total concentration (ppm) of all anticoagulants in the livers of radiocollared bobcats was related to their use of developed areas. Total concentration was positively related to the percentage of the home range made up of developed area ($r^2 = 0.255$, $F_{1,20} = 6.85$, $P = 0.017$) or unnatural area ($r^2 = 0.163$, $F_{1,20} = 3.91$, $P = 0.062$) and to the percentage of radiolocations in developed areas ($r^2 = 0.310$, $F_{1,20} = 8.97$, $P = 0.007$) or unnatural areas (Fig. 4; $r^2 = 0.249$, $F_{1,20} = 6.64$, $P = 0.018$).

Table 2. Relationship between notoedric mange and anticoagulant exposure of >0.05 ppm in bobcats in the Santa Monica Mountains and Simi Hills, Ventura and Los Angeles Counties, California, USA, 1997–2003. Two mountain lions also had both notoedric mange and high levels of anticoagulant exposure.

	Anticoagulants >0.05 ppm	
Mange	**Yes**	**No**
Yes	17	2
No	8	12

The radiocollared mountain lions were generally less urban-associated than the bobcats, but both mountain lions (P3 and P4) diagnosed with anticoagulant intoxication died after spending the bulk of their last month in the most developed parts of their home ranges. For example, just prior to his death, there were multiple locations for the male mountain lion (P3) in the same habitat fragments used by many of the bobcats, only the third month in 16 that he utilized these patches (southern part of Simi Hills, see Fig. 1). The female mountain lion (P4) lived almost exclusively in the Santa Susana Mountains (Fig. 1), a large contiguous block of open space, and only used the more developed Simi Hills area during the month before she died. The other 2 lions (P2 and P7) that were killed in intraspecific fights lived exclusively south of the 101 Freeway in the less-developed Santa Monica Mountains (Fig. 1).

DISCUSSION

We frequently detected anticoagulant rodenticides in the wild felids in this landscape; including the 4 mountain lions, 91% of the cats we tested were positive for ≥1 compound. Bobcats are strict carnivores and the cases were widespread geographically and temporally, so we expect that most if not all exposure is secondary, from bobcats consuming poisoned prey. The presence of multiple compounds in 27 of 35

Table 3. Survival rate of radiocollared bobcats in the Santa Monica Mountains and Simi Hills, Ventura and Los Angeles Counties, California, USA, from 1997 to 2003, showing decrease in survival rate caused by mange.

Yr	No. of bobcats	No. of deaths	No. of mange deaths	Survival rate
1997	22	3	0	0.836
1998	33	7	0	0.707
1999	19	3	0	0.847
2000	20	3	0	0.796
2001	34	8	1	0.685
2002	31	15	8	0.516
2003	25	15	10	0.280

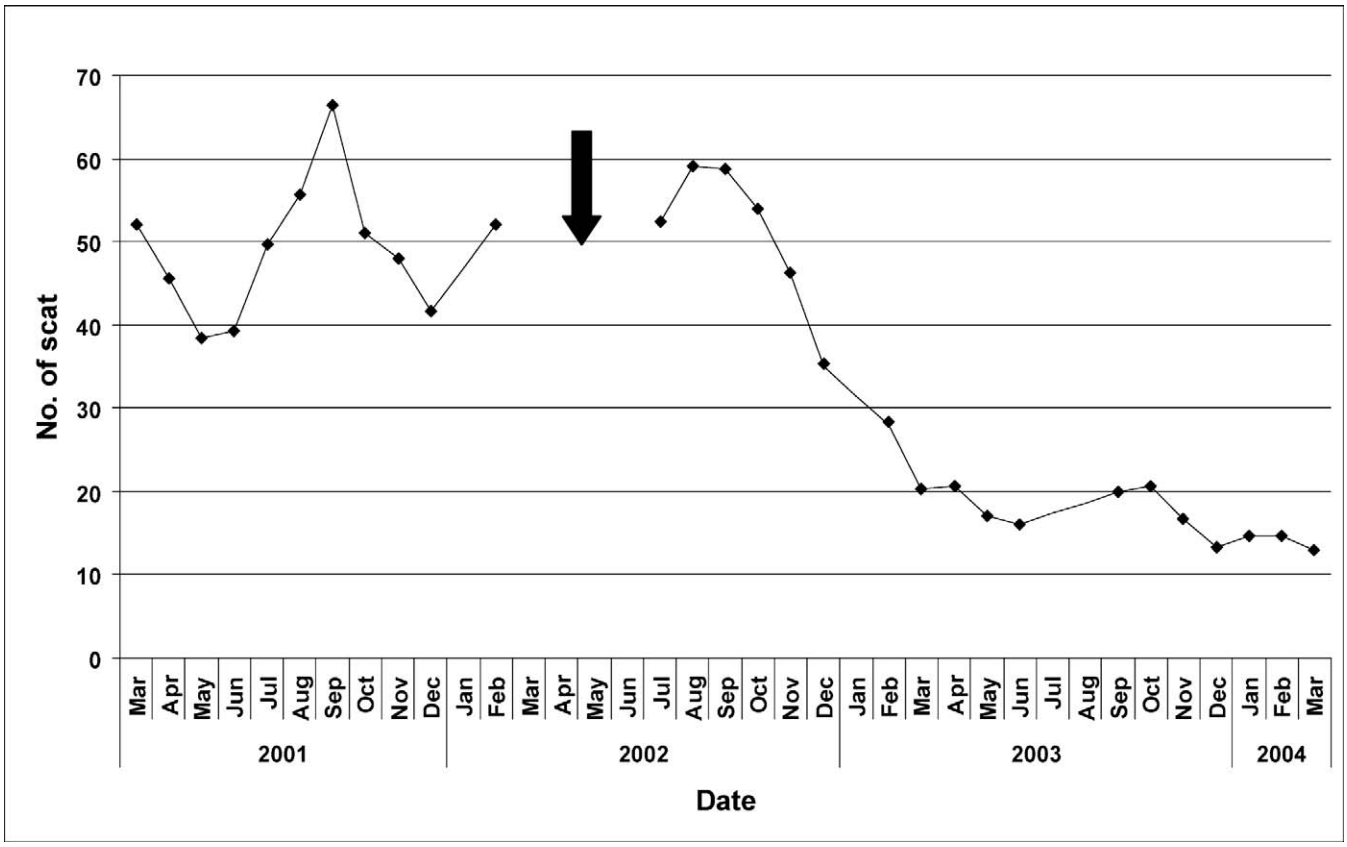

Figure 3. Three-month running average of the number of bobcat scat collected on standardized scat transects from 2001 to 2004 in the Santa Monica Mountains and Simi Hills, Ventura and Los Angeles Counties, California, USA. The arrow indicates the beginning of the mange epizootic.

exposed bobcats and all 4 mountain lions tested also points to secondary exposure and to the potential for accumulation of toxicity as a result of multiple exposure events. Anticoagulants are highly persistent in tissue (Eason et al. 2002, Erickson and Urban 2004, Wobeser 2006), with liver retention times of up to 256 days for bromadiolone, and >250 days for brodifacoum (see Eason et al. 2002, table 6 for review, references). Target rodents may also ingest a much larger than lethal dose in the days between initial bait ingestion and eventual death (Erickson and Urban 2004), in part because of the delayed onset of toxic effects (often 3–5 d) following ingestion (Murphy and Talcott 2006), thereby increasing the amount of toxicant available to a carnivore. The lack of a significant relationship between either mange or anticoagulant exposure and urban association suggests that even bobcats with low levels of development within their home ranges were close enough to developed or altered areas to be exposed to anticoagulants. Of particular concern is the finding that toxicant concentrations increased in bobcats that more frequently utilized developed areas. This is consistent with repeated exposures, and it also suggests that as development continues to encroach upon remaining habitat, anticoagulant exposure among carnivores may increase.

The compounds that we detected, brodifacoum, bromadiolone, diphacinone, and difethialone, are widely available as household and landscape rodenticides. In our study area, those known to have used anticoagulants to target rodents

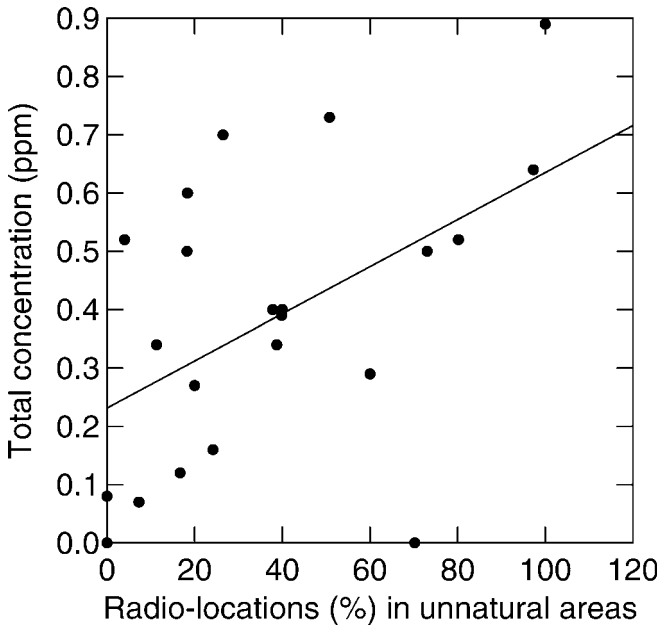

Figure 4. Linear regression of total concentration of all anticoagulants (ppm) found in the livers of radiocollared bobcats and the percentage of radiolocations for those bobcats in unnatural areas (developed + altered areas), in the Santa Monica Mountains and Simi Hills, Ventura and Los Angeles Counties, California, USA, 1997–2003.

include private homeowners, golf courses, office parks, schools, water utilities, apartment complexes, and park agencies. Brodifacoum, bromadiolone, and difethialone, which represent 67 of the 79 anticoagulant detections, are registered specifically for use in or adjacent to buildings to control commensal rodent pests, specifically Norway rats (*Rattus norvegicus*) and house mice (*Mus musculus*). They are not designated for the control of species such as rabbits (*Sylvilagus audubonii*), woodrats (*Neotoma* spp.), pocket gophers (*Thomomys bottae*), and ground squirrels (*Spermophilus beecheyi*) that make up the dominant prey of bobcats in this area (Fedriani et al. 2000; C. S. Schoonmaker, National Park Service [NPS], unpublished data). The high prevalence of these compounds in wild carnivores suggests widespread exposure of native, free-ranging, nontarget (at least according to the regulations) species.

The deaths of 2 mountain lions as a direct result of anticoagulant toxicity (see also Uzal et al. 2007) and the exposure of all 4 lions tested indicate the pervasiveness of these toxicants across the landscape and that they are reaching the highest levels of the food chain (see also Littrell 1988). Rodents commonly constitute a significant component of bobcat diets (Anderson and Lovallo 2003), but mountain lions specialize on ungulate prey, and 157 (95.2%) of 165 known lion kills in our study (through 2004) were mule deer (*Odocoileus hemionus*). Anticoagulant residues have not been widely reported in ungulates (but see Stone et al. 1999, Eason et al. 2002), but we only recovered kills requiring $\geq$1 day to eat, so we would generally not detect smaller prey items. We did find coyotes killed by radiocollared lions, and coyotes made up 15% and 7% of the kills for the 2 lions that died of anticoagulant intoxication but only 4% of kills overall. Anticoagulant toxicity was previously documented as a leading cause of death for coyotes in this area (Riley et al. 2003), and if coyotes are retaining anticoagulants, a lion eating a coyote could ingest a large quantity of toxicant at once. Both mountain lions consumed coyotes during the last month before they died.

The association between anticoagulants and mange suggests that synergistic interactions between natural and anthropogenic stressors can occur in terrestrial ecosystems. In particular, bobcats that have been exposed to anticoagulant rodenticides appear highly susceptible to succumbing to severe mange infestations, although not all anticoagulant-exposed bobcats necessarily contract mange, presumably because not all bobcats encounter *Notoedres* mites. There has been much recent discussion in the ecological literature about the enhanced effects of multiple stressors and, in particular, of natural and human-caused stressors (e.g., Sih et al. 2004). However, the empirical work has generally been in aquatic systems and in laboratory or artificial pond settings (e.g., Mills and Semlitsch 2004, Rohr et al. 2004). Here, we have documented what appear to be significant population effects in the field.

The interaction between mange and anticoagulant rodenticides also appears to be critical because each stressor by itself would likely not have the same impact based on available evidence and previous studies. Notoedric mange has been rarely reported in wild felids, never at epizootic levels, and never in free-ranging adult mountain lions (Uzal et al. 2007). In domestic cats, young animals and those debilitated by retroviral disease are more susceptible to mange (Sparger 1990, Guaguère 1999), suggesting that complicating factors are important in disease development. Pence et al. (1982) report cases in an adult male bobcat and a litter of kittens. Wassmer et al. (1988) found that 4 of 17 captured bobcats (24%) showed evidence of mange, one of which died of the disease. However, the other 3 bobcats had only bare patches "suggesting a current or former mild mange infestation" (Wassmer et al. 1988:176). This population was also experiencing a concurrent epizootic of feline panleukopenia virus, so this disease may have contributed to the mange incidence. Despite 5 deaths from mange (notoedric and sarcoptic) in an endangered lynx (*Lynx lynx*) population in Switzerland, Ryser-Degiorgis et al. (2002) conclude that an epidemic is unlikely because of the less social nature of felids. In our study, the appearance of severe, widespread mange in adult animals prompted us to look at other factors, including anticoagulants.

Anticoagulant poisoning alone also appears to be less of a direct threat to bobcats. Although it was the most common source of mortality in coyotes, we documented one case of potential anticoagulant poisoning in bobcats in the first 5 years of our project (Riley et al. 2003). Laboratory research on anticoagulants has determined that felids have up to 100 times greater resistance than canids to certain compounds, including brodifacoum (Roder 2001, Morgan et al. 2003, Erickson and Urban 2004). There is also previous evidence of the interactive effects of anticoagulants and other stressors in mammals. In laboratory experiments with rabbits, anticoagulant levels that produced zero mortality alone resulted in 40%–70% mortality when combined with other stressors (e.g., frostbite), and similar results were obtained with rats (Jacques 1959). In a more recent study of free-ranging merino sheep (*Ovis aries*; Robinson et al. 2005), anticoagulants had a greater effect than in a similar study of sedentary sheep, and stress (specifically shearing) in combination with anticoagulant exposure caused more mortality than anticoagulant exposure alone. Bobcats and mountain lions are certainly susceptible to direct mortality from anticoagulant toxicity as demonstrated by the deaths of 1 bobcat and 2 lions.

Although we have demonstrated a strong association between anticoagulant exposure and notoedric mange, this is not the same as establishing cause and effect. Experimental evidence would be ideal, but this kind of manipulative experiment would be logistically and ethically very difficult, if not impossible, to pursue with wild felids. Wobeser (1994), reviewing Susser (1973), discusses 5 criteria or guidelines for inferring causal relationships related to disease in wild animals: strength of association, specificity of association (one cause produces one effect), time sequence, consistency (similar results in other populations), and

coherence with current knowledge about the disease. In medicine and epidemiology, these five are sometimes broadened to nine, including biological gradient (a dose response), biological plausibility (similar to coherence), experimental evidence, and analogy (Hill 1965).

Many of these criteria will not be met even in cases where a cause does produce an effect (e.g., specificity: 1 cause can produce >1 effect, and vice versa), and they are often difficult to evaluate in wildlife populations. However, the criteria can be useful in evaluating the potential for a causal relationship, in this case whether exposure to anticoagulants causes increased susceptibility to advanced mange disease (not necessarily increased exposure to *Notoedres cati*). We believe that the strength and the specificity of the association are clear in this case, as every felid with mange was also exposed to anticoagulants, and there is a highly significant association between the two. There is also evidence of a biological gradient, as bobcats with mange had significantly higher levels of exposure to anticoagulants. We have less information for the other criteria, and there are potential alternative explanations for our results. We address both of these issues below. Further research is certainly needed to more fully resolve this question. However, we believe that the available evidence points to anticoagulant exposure contributing to advanced and fatal mange disease.

In the case of each bobcat, we do not know that the anticoagulant exposure preceded the infestation, or specifically the manifestation, of notoedric mange. It is possible that the bobcats contracted mange, the mange infestation became advanced, and the bobcats were then more likely to prey on animals contaminated with anticoagulants. Several factors argue against this alternative. If anticoagulant exposure was the result of animals with mange eating prey exposed to anticoagulants, we would not expect to find anticoagulant exposure in bobcats prior to the beginning of the mange epizootic. However, on the contrary, 7 of 9 tested bobcats that died before 2002 were positive for anticoagulant exposure (Table 1). Under this alternative, we would also not expect to find bobcats with significant anticoagulant levels that did not have mange. In fact 6 animals that died after the beginning of the mange epizootic, but had no evidence of mange, had high levels of anticoagulants. Finally, this alternative presumes that bobcats weakened by mange would eat prey weakened by anticoagulants but that healthy bobcats would not. There is no reason to believe that healthy bobcats would pass up potential prey animals, including ones that were less able to escape.

It is also possible that the mange and anticoagulant exposure were simply coincident. This alternative is also related to the consistency criterion: why has this interaction not been documented in the past? Given the paucity of studies of carnivores in urban areas, and specifically of bobcats, this is not surprising. Although other studies are underway, to date we know of 2 published studies of radiocollared bobcats in urban areas, one in the San Francisco Bay area (Riley et al. 2004, Riley 2006) and this project. The northern California study also documented a case of mortality caused by anticoagulant poisoning (Riley 1999, Hosea 2000), although not any cases of mange. However, our study is the only long-term study of bobcats in urban areas and is, to our knowledge, the longest continuous radiotracking study of bobcats ever undertaken (E. M. Anderson, University of Wisconsin—Steven's Point, personal communication). Without intensive and long-term study, periodic changes in disease prevalence or interactions between a disease and toxicants would be very difficult to document. Moreover, although anticoagulants have been in use for a long time, the second-generation anticoagulants implicated here came into widesprad use more recently (e.g., brodifacoum in the 1990s; Eason et al. 2002).

Another potential alternative is that the severe mange is related to exposure to other diseases. Advanced mange, both notoedric and sarcoptic, is generally associated with debilitation by some other factor (Samuel 1981, Pence and Ueckermann 2002), including disease. There was no evidence of other disease in the 4 bobcats upon which full necropsies (with ancillary tests, see Methods) were performed, although the general poor condition as a result of the advanced mange may have masked signs of other conditions. We have tested bobcats serologically for a number of viral diseases including feline panleukapenia virus, feline infectious peritonitis, feline herpes virus, and feline calicivirus (J. E. Foley, NPS, unpublished data), and there is no indication that animals that died of mange had greater evidence of exposure to these diseases.

Although we have not been able to investigate specific mechanisms that could be responsible for the potential interaction between mange and anticoagulants, it is certainly conceivable that anticoagulant exposure could increase the likelihood of severe mange infestation (the coherence and biological plausibility criteria). Anticoagulant poisoning causes a broad spectrum of clinical signs resulting from hypovolemia from hemorrhage, organ dysfunction, or bleeding into cavities (Searcy 2001). A sub-lethal, chronic anemia, in turn, may lead to increased susceptibility to disease and leave the animals more vulnerable to mange or other stressors. Other studies have also found sub-lethal effects of anticoagulants. For example, female sheep (*Ovis aries*) exposed to anticoagulants had more aborted or stillborn lambs (up to 50%), male sheep had lower sperm motility (Robinson et al. 2005), and barn owls (*Tyto alba*) fed difenacoum-killed rats exhibited sub-lethal haemorrhaging (Mendenhall and Pank 1980). Other chronic, sub-lethal effects have included decreased food intake in sheep (Oliver and Wheeler 1978), liver damage in brushtail possums (*Trichosurus vulpecula*; Jolly et al. 1994, Littin et al. 2002), and a decrease in body weight in brushtail possums (Littin et al. 2002). Decreases in feeding and weight in particular could affect overall condition and thereby disease resistance. Sub-lethal effects may also be more likely in a species such as bobcats that is less susceptible to direct, lethal coagulapathy than, for example, coyotes.

MANAGEMENT IMPLICATIONS

At present, anticoagulant rodenticides are seen as an effective and inexpensive method of killing rodents. However, anticoagulant applicators, including homeowners, landscape professionals, pest control operators, and land and resource managers, should consider that these chemicals can have significant impacts on nontarget wildlife. Especially in areas of high anticoagulant use such as urban areas, exposure of nontarget carnivores to anticoagulant rodenticides may be extensive and can result in direct mortality and possibly sublethal effects, potentially including complex interactions with other factors such as our data suggest. Increased awareness and the use of alternative pest control methods should reduce risks to nontarget wildlife, including carnivores. Where species of conservation concern may be exposed, further regulation of the use of anticoagulant rodenticides may be warranted. Managers should also be aware that the effects of anticoagulant rodenticides may be difficult to document without intensive study, but that a range of species may be affected. Finally, our results indicate that severe notoedric mange in bobcats, previously undocumented as an epizootic, can have population-level effects, and that those effects may be particularly significant in fragmented landscapes where local extirpations can occur.

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LITERATURE CITED

Alterio, N. 1996. Secondary poisoning of stoats (*Mustela erminea*), feral ferrets (*Mustela furo*), and feral house cats (*Felis catus*) by the anticoagulant poison, brodifacoum. New Zealand Journal of Zoology 23:331–338.

Anderson, C. R., and F. G. Lindzey. 2003. Estimating cougar predation rates from GPS location clusters. Journal of Wildlife Management 67: 307–316.

Anderson, E. M., and M. J. Lovallo. 2003. Bobcat and lynx. Pages 758–786 *in* G. A. Feldhammer, B. C. Thompson, and J. A. Chapman, editors. Wild mammals of North America: biology, management, and conservation. John Hopkins University Press, Baltimore, Maryland, USA.

Berny, P. J., T. Buronfosse, F. Buronfosse, F. Lamarque, and G. Lorgue. 1997. Field evidence of secondary poisoning of foxes (*Vulpes vulpes*) and buzzards (*Buteo buteo*) by Bromadiolone, a 4-year survey. Chemosphere 35:1817–1829.

Berny, P. J., L. A. de Oliveira, B. Videmann, and S. Rossi. 2006. Assessment of ruminal degradation, oral bioavailability, and toxic effects of anticoagulant rodenticides in sheep. American Journal of Veterinary Research 67:363–371.

Brooks, W. 2000. Notoedric mange. Mar Vista Animal Medical Center website. <http://www.marvistavet.com/html/body_notoedric_mange>. Accessed 12 Mar 2007.

Eason, C. T., E. C. Murphy, G. R. G. Wright, and E. B. Spurr. 2002. Assessment of risks of brodifacoum to non-target birds and mammals in New Zealand. Ecotoxicology 11:35–48.

Eason, C. T., and E. E. Spurr. 1995. Review of the toxicity and impacts of brodifacoum on non-target wildlife in New Zealand. New Zealand Journal of Zoology 22:371–379.

Erickson, W., and D. Urban. 2004. Potential risks of nine rodenticides to birds and nontarget mammals: a comparative approach. Environmental Protection Agency Office of Prevention, Pesticides and Toxic Substances, Washington, D.C., USA.

Fedriani, J. M., T. K. Fuller, R. M. Sauvajot, and E. C. York. 2000. Diets of three sympatric carnivores in the Santa Monica Mountains of California: the importance of habitat, human presence and interspecific competition. Oecologia 125:258–270.

Foley, R. H. 1991. A notoedric mange epizootic in an island's cat population. Feline Practice 19:8–10.

Fournier-Chambrillon, C., P. J. Berny, O. Coiffier, P. Barbedienne, B. Dasse, G. Delas, H. Galineau, A. Mazet, P. Pouzenc, R. Rosoux, and P. Fournier. 2004. Evidence of secondary poisoning of free-ranging riparian mustelids by anticoagulant rodenticides in France: implications for conservation of European Mink (*Mustela lutreola*). Journal of Wildlife Diseases 40:688–695.

Gervais, J. A., and R. G. Anthony. 2003. Chronic organochlorine contaminants, environmental variability, and the demographics of a burrowing owl population. Ecological Applications 13:1250–1262.

Guaguère, E. 1999. Ectoparasitic skin diseases. Pages 3.1–3.14 *in* E. Guaguère and P. Prélaud, editors. A practical guide to feline dermatology. Merial, Paris, France.

Heisey, D. M., and T. K. Fuller. 1985. Evaluation of survival and cause-specific morality rates using telemetry data. Journal of Wildlife Management 49:668–674.

Hill, A. B. 1965. The environment and disease: association or causation. Proceedings of the Royal Society, London 58:295–300.

Hosea, R. C. 2000. Exposure of non-target wildlife to anticoagulant rodenticides in California. Proceedings of the Vertebrate Pest Conference 19:236–244.

Jacques, L. B. 1959. Dicoumarol drugs and the problem of haemorrhage. Canadian Medical Association Journal 81:848–854.

Jolly, S. E., C. T. Eason, C. Frampton, and R. C. Gumbrell. 1994. The anticoagulant pindone causes liver damage in the brushtail possum (*Trichosurus vulpecula*). Australian Veterinary Journal 71:220.

Kiesecker, J. M. 2002. Synergism between Trematode infection and pesticide exposure: a link to amphibian limb deformities. Proceedings of the National Academy of Science 15:9900–9904.

Kiesecker, J. M., A. R. Blaustein, and L. K. Belden. 2001. Complex causes of amphibian population declines. Nature 410:681–683.

Kohn, M. H., E. C. York, D. A. Kamradt, G. Haught, R. M. Sauvajot, and R. K. Wayne. 1999. Estimating population size by genotyping feces. Proceedings of the Royal Society of London, Series B 266:657–663.

Littin, K. E., C. E. O'Connor, N. G. Gregory, D. J. Mellor, and C. T. Eason. 2002. Behaviour, coagulopathy and pathology of brushtail possums (*Trichosurus vulpecula*) poisoned with brodifacoum. Wildlife Research 29:259–267.

Littrell, E. E. 1988. Wild carnivore deaths due to anticoagulant intoxication. California Fish and Game 74:183.

Maehr, D. S., E. C. Greiner, J. E. Lainier, and D. Murphy. 1995. Notodedric mange in the Florida panther (*Felis concolor coryi*). Journal of Wildlife Diseases 31:251–254.

McDonald, R. A., S. Harris, G. Turnbull, P. Brown, and M. Fletcher. 1998. Anticoagulant rodenticides in stoats (*Mustela erminea*) and weasels (*Mustela nivalis*) in England. Environmental Pollution 103:17–23.

Mendenhall, V. M., and L. F. Pank. 1980. Secondary poisoning of owls by anticoagulant rodenticides. Wildlife Society Bulletin 8:311–315.

Mills, N. E., and R. D. Semlitsch. 2004. Competition and predation mediate the indirect effects of an insecticide on southern Leopard frogs. Ecological Applications 14:1041–1054.

Morgan, R. V., R. M. Bright, and M. S. Swartout. 2003. Handbook of small animal practice. Saunders, Philadelphia, Pennsylvania, USA.
Murie, O. J. 1954. A field guide to animal tracks. Houghton-Mifflin, Boston, Massachusetts, USA.
Murphy, M. J., and P. A. Talcott. 2006. Anticoagulant rodenticides. Pages 563–577 *in* M. E. Petersen and P. A. Talcott, editors. Small animal toxicology. W. B. Saunders, Philadelphia, Pennsylvania, USA.
Oliver, A. J., and S. H. Wheeler. 1978. The toxicity of the anticoagulant pindone to the European rabbit, *Oryctogalus cuniculus* and the sheep, *Ovis aries*. Australian Wildlife Research 5:135–142.
Palazoglu, M., E. Tor, D. Holstege, and F. Galey. 1998. Multiresidue analysis of nine anticoagulant rodenticides in serum. Journal of Agriculture and Food Chemistry 46:4260–4266.
Pence, D. B., F. D. Matthews, and L. A. Windberg. 1982. Notoedric mange in the bobcat, *Felis rufus* from south Texas. Journal of Wildlife Diseases 18:47–50.
Pence, D. B., M. E. Tewes, D. B. Shindle, and D. M. Dunn. 1995. Notoedric mange in an ocelot (*Felis pardalis*) from southern Texas. Journal of Wildlife Diseases 31:558–561.
Pence, D. B., and E. Ueckermann. 2002. Sarcoptic mange in wildlife. Reviews of Science and Technology 21:385–398.
Penner, L. R., and W. N. Parke. 1953. Notoedric mange in the bobcat, *Lynx rufus*. Journal of Mammalogy 35:458.
Relyea, R. 2003. Predator cues and pesticides: a double dose of danger for amphibians. Ecological Applications 13:1515–1521.
Riley, S. P. D. 1999. Spatial organization, food habits and disease ecology of bobcats (*Lynx rufus*) and gray foxes (*Urocyon cinereoargenteus*) in National Park areas in urban and rural Marin County, California. Dissertation, University of California, Davis, USA.
Riley, S. P. D. 2006. Spatial ecology of bobcats and gray foxes in urban and rural zones of a national park. Journal of Wildlife Management 70:1425–1435.
Riley, S. P. D., J. E. Foley, and B. B. Chomel. 2004. Exposure to feline and canine pathogens in bobcats and gray foxes in urban and rural zones of a national park in California. Journal of Wildlife Diseases 40:11–22.
Riley, S. P. D., R. M. Sauvajot, T. K. Fuller, E. C. York, D. A. Kamradt, C. Bromley, and R. K. Wayne. 2003. Effects of urbanization and habitat fragmentation on bobcats and coyotes in southern California. Conservation Biology 17:566–576.
Robinson, M. H., L. E. Twigg, S. H. Wheeler, and G. R. Martin. 2005. Effect of the anticoagulant, pindone, on the breeding performance and survival of merino sheep, *Ovis aries*. Comparative Biochemistry and Physiology, Part B 140:465–473.
Roder, J. D. 2001. Veterinary toxicology. Butterworth Heinemann, Boston, Massachusetts, USA.
Rohr, J. R., A. A. Elskus, B. S. Shepherd, P. H. Crowley, T. M. McCarthy, and J. H. Niedzwiecki. 2004. Multiple stressors and salamanders: effects of an herbicide, food limitation, and hydroperiod. Ecological Applications 14:1028–1040.
Ryser-Degiorgis, M. P., A. Ryser, L. N. Bacciarini, C. Angst, B. Gottstein, M. Janovsky, and U. Breitenmoser. 2002. Notoedric and sarcoptic mange in free-ranging lynx from Switzerland. Journal of Wildlife Diseases 38: 228–232.
Samuel, W. M. 1981. Attempted experimental transfer of sarcoptic mange among red fox, coyote, wolf and dog. Journal of Wildlife Diseases 17: 343–347.
Searcy, G. P. 2001. The hemopoietic system. Pages 325–379 *in* M. D. Mcgavin, W. W. Carlton, and J. F. Zachary, editors. Thomson's special veterinary pathology. Mosby, St Louis, Missouri, USA.
Shore, R. F., J. D. S. Birks, P. Freestone, and A. Kitchener. 1996. Second generation rodenticides and polecats (*Mustela putorius*) in Britain. Environmental Pollution 91:279–282.
Sih, A., A. M. Bell, and J. L. Kerby. 2004. Two stressors are far more deadly than one. Trends in Ecology and Evolution 19:274–276.
Sparger, E. E. 1990. Feline immunodeficiency virus infection. Pages 334–345 *in* C. E. Greene, editor. Infectious diseases of the dog and cat. W. B. Saunders, Philadelphia, Pennsylvania, USA.
Stone, W., J. C. Okoniewski, and J. R. Stedelin. 1999. Poisoning of wildlife with anticoagulant rodenticides in New York. Journal of Wildlife Diseases 35:187–193.
Stone, W., J. C. Okoniewski, and J. R. Stedelin. 2002. Anticoagulant rodenticides and raptors: recent findings in New York, 1998–2001. Bulletin of Environmental Contaminants and Toxicology 70:34–40.
Susser, M. 1973. Causal thinking in the health sciences: concepts and strategies of epidemiology. Oxford University Press, Oxford, England.
Uzal, F. A., R. S. Houston, S. P. D. Riley, R. Poppenga, J. Odani, and W. M. Boyce. 2007. Notoedric mange in free-ranging mountain lions (*Puma concolor*). Journal of Wildlife Diseases 43:274–278.
Valenzuela, D., G. Ceballos, and A. Garcia. 2000. Mange epizootic in white-nosed coatis in western Mexico. Journal of Wildlife Diseases 36: 56–63.
Wassmer, D. A., D. D. Guenther, and J. N. Layne. 1988. Ecology of the bobcat in south-central Florida. Bulletin of the Florida State Museum, Biological Sciences 33:159–228.
Wobeser, G. A. 1994. Investigation and management of disease in wild animals. Plenum Press, New York, New York, USA.
Wobeser, G. A. 2006. Essentials of disease in wild animals. Blackwell, Ames, Iowa, USA.

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