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Pathogen and Rodenticide Exposure in American Badgers (*Taxidea taxus*) in California

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ABSTRACT: Urban and agricultural land use may increase the risk of disease transmission among wildlife, domestic animals, and humans as we share ever-shrinking and fragmented habitat. American badgers (*Taxidae taxus*), a species of special concern in California, USA, live in proximity to urban development and often share habitat with livestock and small peridomestic mammals. As such, they may be susceptible to pathogens commonly transmitted at this interface and to anticoagulant rodenticides used to control nuisance wildlife on agricultural lands. We evaluated free-ranging badgers in California for exposure to pathogens and anticoagulant rodenticides that pose a risk to wildlife, domestic animals, or public health. We found serologic evidence of badger exposure to *Francisella tularensis*, *Toxoplasma gondii*, *Anaplasma phagocytophilum*, canine distemper virus, and three *Bartonella* species: *B. henselae*, *B. clarridgeiae*, and *B. vinsonii* subsp. *berkhoffii*. Badger tissues contained anticoagulant rodenticides brodifacoum and bromadiolone, commonly used to control periurban rodent pests. These data provide a preliminary investigation of pathogen and toxicant exposure in the wild badger population.

Key words: American badger, *Anaplasma phagocytophilum*, anticoagulant rodenticide, *Bartonella henselae*, canine distemper virus, *Francisella tularensis*, *Taxidea taxus*, *Toxoplasma gondii*.

The American badger (*Taxidea taxus*), a semifossorial mustelid of the open grasslands, is listed as a Species of Special Concern in California, USA (Bolster, 1998). Populations have declined significantly since the late 1800s, probably due to indiscriminate trapping, conversion of badger habitat to agriculture, and depletion of prey populations (Larsen, 1987). Agricultural, residential, and urban development in California threatens to fragment and isolate badger populations and to endanger their preferred grassland habitat. The increasing proximity of badger populations to humans and domestic animals also creates the potential for cross-species transmission of pathogens to which badgers are susceptible.

In agricultural settings in California, the badger's primary prey items, ground squirrels (*Spermophilus beecheyi*), and Botta's pocket gophers (*Thomomys bottae*), are controlled using multiple-dose anticoagulant rodenticides, whereas in the periurban setting, slow-acting, single-dose "second generation" anticoagulant rodenticides are more often used (Clark, 1994) and can minimize above-ground exposure of nontarget predators and scavengers (Fenn et al., 1987). Because they dig for their prey, badgers are at risk of consuming poisoned rodents underground. Although the risk of nontarget poisoning in this species is well recognized (Ruder et al., 2011), the frequency of rodenticide exposure has not been investigated in American badgers.

To improve our understanding of the population health of this elusive burrowing carnivore, we conducted a basic disease survey of all badgers captured for an ecologic study in a fragmented landscape within California's central coast (Quinn, 2008). Ten badgers were captured using body snare traps and implanted with radiotransmitters (Quinn et al., 2010) between May 2005 and August 2006 at the Bureau of Land Management's Fort Ord Public Lands in Monterey County,

California (36.68°N, 121.77°W; elevation, 20–250 m). The Fort Ord Public Lands is a 6,070-ha former military base bordered by residential and agricultural development, comprised of recreational open space and habitat management areas. The land is a mix of grassland, coastal sage scrub, maritime chaparral, and coastal oak woodland habitat. Despite a major year-long trap effort, the small sample size obtained probably reflects low badger abundance in the study area and difficulties in trapping burrowing wildlife species. Four additional badgers were opportunistically collected elsewhere in California between July 2006 and July 2008.

Blood samples from live animals were obtained via cephalic or jugular venipuncture, and serum was stored at −80 C until submitted for diagnostic testing. Liver samples were obtained during postmortem examination of live-trapped animals and opportunistically collected badgers. Serologic tests for pathogen exposure were not specifically optimized for badger serum but were performed using reagents from the most closely related species (e.g., dog and ferret). Methods used for specific pathogen testing are provided in Table 1. Sera were tested for antibodies to canine distemper virus (CDV), canine parvovirus (CPV-2), and *Leptospira interrogans* serovars Canicola, Pomona, Hardjo, Icterohaemorrhagiae, Copenhagenae, and Grippotyphosa; *Borrelia burgdorferi* and *Anaplasma phagocytophilum*; *Bartonella henselae*, *B. clarridgeiae*, *B. vinsonii* subsp. *berkhoffii*, *Toxoplasma gondii*, *Francisella tularensis*, and *Yersinia pestis*; and *Mycobacterium* avium subsp. *paratuberculosis*. Testing for the presence of rodenticides brodifacoum, bromadiolone, chlorophacinone, coumachlor, difethialone, diphacinone, and warfarin was performed on serum and liver tissues by using high-performance liquid chromatography with fluorescence and photodiode array detector at the California Animal Health and Food Safety Laboratory, University of California, Davis, California (Palazoglu et al., 1998). For liver, reporting limits (minimal quantifiable concentration based upon the lowest matrix spike level) were as follows: 0.05 ppm for warfarin, bromadiolone, and coumachlor; 0.01 ppm for brodifacoum; and 0.25 ppm for diphacinone, chlorophacinone, and difethialone. For serum, reporting limits were as follows: 0.02 ppm for warfarin, bromadiolone, and coumachlor; 0.01 ppm for brodifacoum; and 0.1 ppm for diphacinone, chlorophacinone, and difethialone. Liver and serum concentrations that were below the reporting limit but above the analytical detection limit were reported as trace concentrations.

All live-trapped badgers were apparently healthy at capture and in overall good to fair body condition. Evidence of exposure to *T. gondii* was detected in six radiomarked badgers (60%), two of which had particularly high titers of 1:1,024 (badger 6) and 1:2,048 (badger 9; Table 2). Feral domestic cats (*Felis catus*), who are definitive *T. gondii* hosts, are common around the edges of the Fort Ord Public Lands due to nearby residential development. Badger exposure to the parasite may have occurred through contact with prey animals such as gophers, meadow voles (*Microtus californicus*), California ground squirrels, and ground-nesting birds that serve as intermediate hosts of the parasite. Badgers in this study did not seem to have signs of neurologic disease associated with *T. gondii* brain infection, although badger 9 was found dead from unknown causes 4 mo after her release. Low levels of antibodies to CDV (1:8–1:16) were detected in seven (70%) radiomarked badgers, three with *T. gondii* antibodies (Table 2). Canine distemper virus infection causes serious disease in a broad range of animals, particularly in the Canidae and Mustelidae families. Distemper viruses could circulate naturally among badgers or represent spillover from domestic dogs (*Canis domesticus*) in residential developments in the vicinity of the study area.

TABLE 1. Summary of laboratory methods used for pathogen exposure testing in American badgers (*Taxidea taxus*) collected in California, USA, 2006–2008.

Pathogen	Antibody test method	Suspect positive cutoff	Reagents and citations
Canine distemper virus[a]	Serum neutralization, 1:4 dilution	≥1:8	Appel and Robson, 1973
Canine parvovirus-2[a]	Hemagglutination inhibition, 1:20 dilution	≥1:20	Carmichael et al., 1980
Leptospira interrogans[a]	Microhemagglutination test, diluted 1:100–1:3200	≥1:100	Barr et al., 2005
Borrelia burgdorferi[b]	Indirect immunofluorescent assay	≥1:160	VMRD, Inc., Pullman, Washington, USA MP Biochemicals, Solon, Ohio, USA
Bartonella spp.[c]	Immunofluorescent assay, anti-ferret conjugate, 1:64 serum dilution. Reactivity scored from 0 to 4+	Reactivity score ≥2	Henn et al., 2007
Francisella tularensis[c]	Antigen slide agglutination test, 1:80 dilution. Reactivity scored from 0 to 4+	Reactivity score ≥2	Becton Dickinson, Sparks, Maryland, USA
Toxoplasma gondii[c]	Latex agglutination test	≥1:64	Toxotest-MT "Eiken" Tanabe USA Inc., San Diego, California, USA
Anaplasma phagocytophilum[b]	Immunofluorescent assay, 1:25 dilution	Single dilution 1:25 scored "positive" or "negative"	VMRD, Inc.; Kirkegaard and Perry Laboratories, Gaithersburg, Maryland, USA
Mycobacterium avium subsp. *paratuberculosis*[d]	Mycobacteria Growth Indicator Tube 960 with ParaTB medium	"Positive" or "negative" determined after 8-wk incubation	BACTEC™, Becton Dickinson Shin et al., 2007

[a] Animal Health Diagnostic Center, Cornell University, Ithaca, New York, USA.

[b] Diagnostic Center for Population and Animal Health, Michigan State University, Lansing, Michigan, USA.

[c] University of California, Davis, California, USA.

[d] University of Wisconsin Johne's Information Center, Madison, Wisconsin, USA.

Bartonella henselae antibodies were detected in the serum of two of nine (22%) animals tested (Table 2). Badger 5 had evidence of exposure to both *B. henselae* and *B. clarridgeiae*. Serum from one animal was reactive to *B. vinsonii* subsp. *berkhoffii*. These *Bartonella* species are not uncommonly reported in other domestic and wild carnivores (Chomel et al., 2006; Henn et al., 2009); however, this is the first detection of badger seroreactivity to *Bartonella* in North America. Our results need to be validated by isolation of these various *Bartonella* species, because cross-reactivity may occur between *Bartonella* species or subspecies (La Scola and Raoult, 1996).

Serum from three of nine (33%) radiomarked badgers demonstrated strong agglutination reactions (2+ to 3+) to *F. tularensis* antigen (Table 2). The few existing reports of *F. tularensis* in badgers do not describe pathogenic outcomes of infection (Nakamura, 1950; Hatch and Nicholes, 1964). Skunks and raccoons are also commonly antibody-positive in nature and potentially useful in identifying foci of enzootic transmission (Berrada et al., 2006).

Antibodies to *A. phagocytophilum* were detected in the serum of one badger (Table 2). In California, this agent of human granulocytic anaplasmosis is generally transmitted by *Ixodes pacificus* ticks

TABLE 2. Pathogen and rodenticide exposure in radiomarked American badgers (*Taxidea taxus*) trapped in Monterey County, California, USA, 2005–2006.

Animal No.	Age and sex[a]	Capture date	Sample type	*Francisella tularemia*[b]	*Bartonella* spp.	*Toxoplasma gondii*[c]	Canine distemper virus[c]	*Anaplasma phagocytophilum*	Rodenticide
1	JM	14 May 2005	Serum	Negative	Negative	Negative	1:16	Negative	Negative
2	AF	25 May 2005	Serum	Negative	*B. henselae*	1:256	Negative	Negative	Negative
3	JF	25 May 2006	Serum	Negative	Negative	Negative	1:8	Negative	Negative
4	AF	15 June 2005	Serum	Negative	*B. v. berkhoffii*	1:256	1:8	Negative	Negative
5[d]	AF	24 June 2005	Serum	Negative	*B. henselae* and *B. clarridgeiae*	Negative	1:12	Negative	Negative
5[d]			Liver	NA[e]	NA	NA	NA	NA	Negative
6	JM	18 August 2005	Serum	3+	Negative	1:1024	1:8	Negative	Negative
7	AM	22 August 2005	Serum	2+	Negative	1:512	Negative	Negative	Negative
8	JF	15 October 2005	Serum	Negative	Negative	Negative	1:8	Positive	Negative
9[f]	JF	5 November 2005	Serum	2+	Negative	1:2048	1:8	Negative	Negative
9[f]			Liver	NA	NA	NA	NA	NA	Negative
10	AM	30 May 2006	Serum	Negative	Negative	1:128	Negative	Negative	Negative

[a] JM = juvenile male; AM = adult male; AF = adult female; JF = juvenile female.

[b] Scores refer to slide agglutination reactivity.

[c] Titers given indicate the highest dilution at which a positive result was detected.

[d] Animal died of sepsis related to implanted radiomarker. For details, see Quinn et al., 2010.

[e] NA = data not available.

[f] Animal found dead 18 April 2006 outside of den. Cause of death unknown.

TABLE 3. Rodenticide exposure in liver samples of American badgers (*Taxidea taxus*) opportunistically collected from Los Angeles, Shasta, and Tehama counties, California, USA, 2006–2008.

Animal No.	Age and sex[a]	County	Circumstances	Carcass recovery date	Habitat type (latitude/longitude)	Rodenticide[b]
11	AM	Los Angeles	Roadkill	26 July 2006	Data not available	Trace brodifacoum
12	JM	Shasta	Shot	5 July 2008	Rural/agricultural (40.52°N, 121.70°W)	Brodifacoum (0.55 ppm) Bromadiolone (0.12 ppm)
13	AF	Shasta	Roadkill	20 November 2007	Rural/agricultural (40.24°N, 122.40°W)	Brodifacoum (0.09 ppm) Trace bromadiolone
14	AF	Tehama	Roadkill	21 April 2008	Rural/agricultural (39.82°N, 122.20°W)	Trace bromadiolone

[a] JM = juvenile male; AM = adult male; AF = adult female; JF = juvenile female.

[b] Tests performed at the California Animal Health and Food Safety Laboratory, University of California, Davis, USA.

to rodent reservoirs (Foley et al., 2004). Only *Dermacentor variabilis* (American dog tick), not considered an *A. phagocytophilum* vector, were collected from other antibody-negative badgers. The reservoir potential of American badgers for *A. phagocytophilum* is not well understood. However, other carnivorous medium-sized mammals such as raccoons are implicated in *A. phagocytophilum* transmission in the eastern USA (Levin et al., 2002). We did not detect evidence of badger exposure to *L. interrogans*, *M. avium* subsp. *paratuberculosis*, *B. burgdorferi*, *Y. pestis*, or CPV-2. Small sample size and lack of assay optimization for use in badgers could explain negative results.

Four of six badger livers (67%) tested were positive for exposure to one or more anticoagulant rodenticides (Tables 2 and 3). Brodifacoum and bromodiolone were detected in roadkill and gunshot badgers from Los Angeles, Shasta, and Tehama counties. Only the animal from Tehama County had potentially toxic liver concentrations (0.55 ppm brodifacoum and 0.12 ppm bromodiolone) based upon limited diagnostic data available. These animals were probably exposed to rodenticides used to reduce nuisance wildlife or commensal populations of rats (*Rattus* sp.) and house mice (*Mus musculus*) in nearby residential developments. Rodenticides were not detected in the serum or liver tissue of the 10 free-ranging badgers live-trapped in Monterey County between 2005 and 2006, but sera generally exhibit low sensitivity for rodenticide detection.

Our goals were to establish baseline pathogen and rodenticide exposure data for badgers in California and to identify diseases that warrant further investigation, perhaps through the dedicated search for infected animals and carcasses and the expansion of disease screening to other geographic areas. Our preliminary data are limited, but they suggest badgers may be at risk of disease spillover associated with anthropogenic activities in fragmented habitat. Further investigation is needed to determine the extent of the risk and health outcomes in badgers.

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