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The status of the American Badger in the San Francisco Bay Area

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ABSTRACT

THE STATUS OF THE AMERICAN BADGER
IN THE SAN FRANCISCO BAY AREA

by Chris Lay

In the San Francisco Bay Area (SFBA), the American badger (*Taxidea taxus*) has persisted within grasslands throughout the 20th century but continues to be exposed to increasing suburban sprawl. During the winter of 2002/2003, burrow transect surveys were used to assess the current distribution of badgers at 30 sites within the SFBA. Badger presence/absence, burrow density, and gopher and ground squirrel burrow densities were determined at each site. Using GIS, percent grassland, non-grassland, suburban land, agricultural land, and road/highway lengths were characterized within a three km radius of each site. Badgers were present at 15 sites, indicating that their distribution had contracted, particularly within habitat fragments east of San Francisco Bay and along urban edges. Suburban land use ($p=0.01$) and length of roads ($p=0.06$) were both less at sites where badgers were present. The best logistic regression model predicted that badgers were most likely present in grasslands where suburban land use and road lengths were low and gopher and ground squirrel burrow densities were high. Badgers appeared to be more sensitive than other carnivores to both habitat fragmentation and edge effects, perhaps due to their patchy distribution, sensitivity to human land use, and high road crossing mortality rates. The remaining populations in the SFBA may be especially susceptible to local extirpation events and should continue to be monitored in the future.

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INTRODUCTION

The American badger (*Taxidea taxus*) is a fossorial carnivore that was once common in California but whose populations may now be at risk due to a combination of habitat loss, habitat fragmentation, rodent poisoning, and predator control (Williams 1986). Although badger ecology has not been extensively studied, badgers may have important ecological roles as bioturbators (Eldridge 2004) and predators on rodents (Murie 1992; Lindzey 1982). Williams (1986) reported that badgers, while still widespread throughout California, were much less common than reported by Grinnell (1937) and were likely threatened with significant future decline. As a result, the badger was designated a species of special concern (SSC). This designation was meant to encourage governmental agencies to prioritize badger conservation in land and resource management decisions in order to avoid state or federal endangered species listing in the future (Larsen 1987).

Although badger populations have declined throughout the state, it is still unclear which regions require the most conservation attention. Williams (1986) reported that badgers had declined dramatically in the Central Valley and survived only in low numbers along the peripheries. He reported drastic reductions and possible local extirpations in many areas of southern California. In a statewide distribution survey, Larsen (1987) agreed with Williams about populations in the Central Valley but reported numerous sightings adjacent to and in between spreading suburban areas in southern coastal California. Because his survey was based on voluntary sighting reports from land managers and licensed trappers, Larsen acknowledged that the large number of sightings reported in southern California may have been due to a larger number of observers rather than an indication of a stable or growing population. Additionally, he noted that these populations in southern California might be threatened in the future by continued suburban growth (Larsen 1987). While both Grinnell and Larsen used voluntary trapper surveys to compile a useful widespread map of the badger distribution in California, they were able to detect the presence of badgers only in locations where trapping or sightings were reported but not necessarily in places where badgers were potentially most threatened. The data also could not be used to identify regions where badgers were more common, because the level of trapping was not consistent across all parts of California.

Recent carnivore research suggests that badgers are particularly vulnerable to local extinction in rapidly urbanizing areas. In general, many mammalian carnivores are threatened in fragmented landscapes because of their relatively large home ranges and low population densities (Noss et al. 1996; Woodroffe and Ginsberg 1998). Conversion of natural habitat to human uses, such as urban development or agriculture, reduces the amount of intact and available natural habitat and fragments remaining landscapes (Saunders et al. 1991). The edges of fragments adjacent to modified landscapes can be significantly impacted, often leading carnivores to avoid occupying these areas (Riley 2006). The low connectivity that often exists between suitable habitat fragments may endanger individuals that move between fragments or isolate low-density patchy populations that rely on dispersal events to maintain a viable size and genetic diversity (Kinley and Newhouse 2008). In Southern California, Crooks (2002) observed badgers within large unfragmented control sites but in no fragmented sites. He concluded that badger populations may be especially vulnerable in fragmented habitats due to their relatively specialized niche.

The pressures from continued suburban growth on badger populations located in the San Francisco Bay Area (SFBA) made this an ideal location to assess the current distribution of badgers and determine how their distribution has changed over time. Historical records have indicated that badger populations existed in this region throughout the significant growth in human population and associated development over the last century. The large acreages of grasslands scattered throughout this region have provided badgers with substantial areas of suitable habitat. However, continued habitat loss and increased habitat fragmentation in the SFBA have left many of these grassland habitats increasingly isolated and adjacent to growing suburban sprawl.

A combination of ecological and anthropogenic factors may restrict the distribution and population density of badgers more than other similar-sized carnivores in California. For a mid-sized carnivore, badgers can use space extensively and may exhibit habitat associations at a correspondingly large spatial scale. Badgers are strongly associated with treeless habitats and may selectively use such habitats based on factors such as grazing history and plant species composition (Apps et al. 2002). Badgers may also occupy forests, especially where treeless areas are limited or patchy, but open habitats are clearly preferred (Lindzey 1982). The friability of soil is another important factor, since badgers must constantly dig to capture fossorial rodents and excavate underground dens for resting. Ideal soils for a badger have moderate permeability (well drained but remaining moist) and low shear strength and cohesion (low clay content)

(Minta 1990). Badgers have been shown to prefer fine sandy loams in Canada (Apps et al. 2002) and sands, loams, and sand/loam mixtures in central California (Quinn 2008). Finally, the population density of fossorial rodents, the badger's preferred prey, has been shown to positively correlate with badger population density (Minta 1990;1992). Fossorial rodents also can have patchy distributions (Weddell 1989), which consequently affect the distribution and population size of specialized predators, such as badgers, that depend on them. However, badgers can exhibit flexibility in prey selection when optimal prey species become scarce (Messick and Hornocker 1981). Their main diet can consist of ground squirrels (Messick and Hornocker 1981), pocket gophers (Sargent and Warner 1972), or a combination of mice, voles, rabbits, and insects (Lindzey 1971).

Several anthropogenic factors may especially threaten badger populations in rapidly urbanizing regions of California. Roadkills have been a significant source of badger mortality, such as in British Columbia (Kinley and Newhouse 2008) and Idaho (Messick and Hornocker 1981). An individual badger may move long distances and have home ranges occupying areas up to 70 km^2 (Kinley and Newhouse 2008; Minta 1990; Lindzey 1982; Messick and Hornocker 1981). Dispersing young move as much as 52 km for females and 110 km for males (Messick and Hornocker 1981). Along the central coast of California, badgers had home ranges as large as 20.85 km^2 and moved up to two km per night, leading to a high number of recorded roadkills (Quinn 2008). In addition, the risk of rodent poisoning may be higher in areas near suburban developments. Historically, badgers have been susceptible to secondary poisoning from rodenticides (Lindzey 1982) which are used on agricultural fields and in and around residential areas.

Finally, badgers may also exhibit avoidance responses to human habitation. This has been observed in other carnivores such as wolves that learn to avoid roads and towns because they associate them with human persecution (Thurber et al. 1994). Avoidance responses may prevent animals from using habitats near urban areas and thus further restrict and endanger populations living in fragmented areas.

Traditional techniques have not been shown to reliably estimate badger abundance. Badgers are nocturnal, fossorial, cryptic, and live at low population densities, all of which make them hard to detect (Messick and Hornocker 1981; Lindzey 1982). Suggested indices for monitoring badger populations have included scent station surveys, spotlighting, road mortality (Messick 1987), and live-trapping (Lindzey 1971). Scent station surveys and spotlighting have not been effective measures of relative abundance because badgers were detected too infrequently (Hein and Andelt 1995). Road mortality has yet to be adequately tested, but could potentially be used as a measure of abundance over large areas (Case 1978). The frequency of live captures to estimate relative abundance has been successful in areas with relatively high-density established populations (Hein and Andelt 1995; Lindzey 1971). However, employing this time and labor-intensive method would be infeasible across large habitat regions.

A new method based on the observation of badger sign may provide a reliable and convenient way to determine whether badgers are occupying an area and how intensively that area is being used. The presence and abundance of animal sign such as tracks and burrows have been widely used to infer distribution and population trends; such indices are often inexpensive and practical monitoring tools (MacKenzie et al. 2006). For instance, analyzing the presence and abundance of footprints found along established transects has been successful at monitoring population changes of many carnivores, including cougars (Beier and Cunningham 1996), coyotes (Engeman et al. 2000), and dingos (Allen et al. 1996). Although no population monitoring has focused on counts of badger burrows, the presence and density of burrows of other fossorial species have been shown to be strongly associated with their population density, including the California ground squirrel (*Spermophilus beecheyi*) (Owings and Borchert 1975), Columbian ground squirrel (*S. columbianus*) (Weddell 1989), and Townsend's ground squirrel (*S. townsendi*) (Nydegger and Smith 1986).

The main goal of this study was to determine the current distribution of badgers in order to evaluate their conservation status in the San Francisco Bay Area. Using badger burrow surveys at or near sites where badgers were historically present, I compared their current and past distribution to determine where any changes had occurred. I also examined which ecological and human-related factors could best explain and predict their current distribution. I used these results to evaluate the current status of badger populations in the SFBA.

STUDY AREA

The San Francisco Bay Area of central California is an ecologically diverse metropolitan area home to nearly eight million people. Large urban centers, medium-sized cities, and small towns sprawl over nine counties (15,000 km^2), all connected by a large network of roads and highways. The influence of a Mediterranean climate and varied topography has created a mosaic of plant communities. Areas nearer the Pacific Ocean are characterized by relatively more rainfall in the winter and smaller temperature variations throughout the year while inland areas are generally drier, hotter during the summer, and colder during the winter.

The distribution of grassland habitats in the SFBA are restricted by both ecological factors and human land use. Historically, grasslands dominated the lowland areas within each basin. These grasslands have mostly been converted to either agricultural or suburban lands, leaving isolated patches. In the foothill regions, grasslands are found within a mosaic of oak woodland and chaparral plant communities. Grasslands dominate the drier mountain ranges east of San Francisco Bay and intermix with redwood and mixed evergreen forest in the Santa Cruz mountains south and west of San Francisco Bay.

Grasslands and other natural habitats not already heavily urbanized or converted to agriculture are separated by existing human development into nine large fragments (Figure 1). Each fragment is separated from the others either by four to eight lane freeways or dense suburban development. Each fragment contains large areas of relatively undisturbed natural habitat, although many contain sparsely developed suburban areas and numerous highways and secondary roads. Many of the natural habitats containing grasslands within each fragment are used as pasture lands or as public open-space parks.

METHODS

Historical and Current Range

I compiled a list of historical badger sightings in the SFBA using distribution studies by Grinnell (1937) and Larsen (1987). The collection databases from the University of California Berkeley's Museum of Vertebrate Zoology, the California Academy of Sciences, and the San Diego Museum of Natural History provided sites with precise location coordinates or references to nearby landmarks. I interviewed numerous land managers around the region and added their anecdotal badger sightings to my historical distribution database if they could remember the year and the exact location of the sighting. I also referred to published mammal lists that included badgers from parks found within each of the large habitat fragments.

From November 2002 through March 2003, I surveyed 30 sites, each of which was at or near a historical site. In places where I was limited by access or because the historical site no longer existed (because of habitat loss), I chose a new site within 10 km of the historical site. Within a 3 km radius, each of the 30 sites contained a minimum of 2 km^2 of grassland habitat and 10 km^2 of other natural habitats such as chaparral, oak woodland, and mixed evergreen communities. Table 1 lists the 30 sites, all of which were public access parks, limited access land trust holdings, or ranchlands.

Table 1. Results of badger burrow surveys for 30 locations at or near historical sites in the SFBA in 2002/2003.

Site Name	Habitat Fragment	Burrows Seen on Transect	Transect Length (km)	Burrow Density (per hectare)	Midpoint of Transect (Lat/Long)
Fort Ord Natural Reserve	Monterey	142	6.4	44.4	36.608794 N 121.713681 W
Russian Ridge Preserve	Santa Cruz Mts. North	18	1.1	32.7	37.325739 N 122.209288 W
Swanton Pacific Ranch	Santa Cruz Mts. North	141	9.7	29.1	37.053471 N 122.235604 W
Fort Ord Natural Reserve 2	Monterey	46	3.3	27.9	36.582920 N 121.821605 W
Monte Bello Preserve	Santa Cruz Mts. North	33	4.4	15	37.321810 N 122.164045 W
UCSC Fort Ord Reserve	Monterey	41	12.0	6.8	36.702539 N 121.780795 W
Purisima Preserve	Santa Cruz Mts. North	11	4.7	4.7	37.383768 N 122.395005 W
Wilder Ranch State Park	Santa Cruz Mts. North	20	11.7	3.4	36.982924 N 122.094964 W
Driscoll Ranch Preserve	Santa Cruz Mts. North	17	10.3	3.3	37.343602 N 122.281431 W
Los Vaqueros Reservoir	Mt. Diablo	11	6.7	3.3	37.784245 N 121.738613 W
Bolsa Point Preserve	Santa Cruz Mts. North	13	16.0	1.6	37.207097 N 122.379438 W
Mission Peak Regional Park	Mt. Hamilton	8	11.7	1.4	37.496484 N 121.868329 W
Joseph D. Grant County Park	Mt. Hamilton	8	12.7	1.3	37.362593 N 121.709157 W
Round Valley Regional Park	Mt. Diablo	3	15.6	0.4	37.852867 N 121.778818 W
Henry Coe State Park	Mt. Hamilton	1	9.3	0.2	37.207640 N 121.512467 W

Table 1. Continued

Site Name	Habitat Fragment	Burrows Seen on Transect	Transect Length (km)	Burrow Density (per hectare)	Midpoint of Transect (Lat/Long)
Ano Nuevo State Park	Santa Cruz Mts. North	0	10.2	0	37.144532 N 122.235604 W
Black Diamond Regional Park	Mt. Diablo	0	15.7	0	37.955413 N 121.857493 W
Briones Regional Park	East Bay North	0	7.6	0	37.937780 N 122.171475 W
Calero County Park	Santa Cruz Mts. South	0	9.3	0	37.172952 N 121.776421 W
Dry Creek Regional Park	East Bay South	0	10.8	0	37.626845 N 121.996105 W
Edgewood County Park	Santa Cruz Mts. North	0	5.5	0	37.462800 N 122.284998 W
Elkhorn Slough Highlands	Santa Cruz Mts. South	0	10.6	0	36.849475 N 121.726282 W
Foothills Park	Santa Cruz Mts. North	0	5.7	0	37.377462 N 122.184029 W
Fremont-Older Preserve	Santa Cruz Mts. North	0	4.7	0	37.289410 N 122.058002 W
Moore Creek County Park	Santa Cruz Mts. North	0	9.4	0	36.970584 N 122.071360 W
Pleasanton Regional Park	East Bay South	0	13.1	0	37.621095 N 121.897886 W
Porter Reserve- Elkhorn Slough	Santa Cruz Mts. South	0	5.3	0	36.873071 N 121.740306 W
Santa Teresa County Park	Santa Cruz Mts. South	0	12.4	0	37.210366 N 121.783986 W
Tunitas Open Space Preserve	Santa Cruz Mts. North	0	8.5	0	37.383734 N 122.366025 W
Wildcat Canyon Regional Park	East Bay North	0	15.1	0	37.943043 N 122.291153 W

Measuring Badger Abundance

I used visual sign observations along transects at each of the 30 sites to assess the presence and relative abundance of badgers in potential habitat. The most obvious sign created by badgers are their burrows, which are recognizable, distinct, and long-lasting (Messick and Hornocker 1981; Lindzey 1982). Badgers frequently excavate burrows to hunt fossorial rodents. They also frequently dig burrows for sleeping during daylight hours and rarely remain in a burrow for more than 24 hours. They may dig new burrows or re-excavate old burrows either for rest or to look for newly resident prey species (Messick & Hornocker 1981; Lindzey 1982).

I developed specific criteria for the direction, minimum length, and width of each transect. Although the starting point was constrained by the accessibility to each of the sites, each transect was a randomly chosen path through exclusively grassland habitat. At places along each transect where I needed to change direction due to inhospitable terrain, change of habitat, or property boundaries, I randomly selected a new direction of travel that would not cross the path of the previously searched part of the transect. To determine the minimum length of a transect, I analyzed badger burrow density at a site where badgers were known to be present. By counting the number of burrows found along randomly chosen transects of known length and width, I estimated the density of badger burrows per square kilometer of habitat. Using this estimate, I created a model of this burrow density and then constructed 30 randomly selected transects. The mean length of transect to first detection was 2.25 km with a variance of 2.29 km. I used the upper limit of the 95% confidence interval, approximately six km, as the minimum transect length for each site. At three study sites, the transect length I walked was less than six km because the property that I had access to was not large enough to contain a longer transect. If no badger burrows were found along a transect of this minimum length, I presumed that badgers were absent from the site. I only counted burrows that were found within five meters to either side of the transect line, the maximum distance that I could reliably identify a badger burrow in tall grass. If I saw a badger burrow at a distance greater than five meters, I did not include it in density counts at sites where badgers were present, but recorded it at sites where badgers would otherwise have been considered absent.

Badger burrows were mainly distinguished from those of other species such as coyotes, foxes, skunks, and ground squirrels by their shape and depth. Characteristic badger burrows are 16-30 cm wide, mostly elliptical in shape (wider than tall), and greater than 50 cm deep (Hetlet 1968) with an obvious mound of newly dug soil at the entrance (Eldridge 2004). In addition, each deep hole is usually accompanied by numerous shallow digs within a ten meter radius. Sometimes, several large deep holes are clustered together (Minta 1990). Rarely, there are large obvious claw marks on the sides of the holes or distinctive footprint tracks made on top of the soil mound (personal observation). Old excavations are common over the home range of a badger and may be recognizable for months or even years depending on weather and livestock usage. New plants eventually establish themselves in the disturbed soil mounds at the entrance to each hole (Lindzey 1982; Platt 1975). Badgers were considered to be present at a site if at least one elliptical burrow 16-30 cm wide and greater than 50 cm deep was found with no established plants sprouting from the soil mound. If more than one badger burrow was present, I counted the number of burrows meeting the above criteria along each transect.

To assess whether badger population levels had changed, I compared the current and historical badger distributions. Because the historical distribution data were not collected using the same method as the current distribution data, I qualitatively compared these groups of data to determine if there were any significant differences.

To determine if any landscape-scale differences existed between sites where badgers were present or absent, I measured large-scale habitat and human-disturbance variables at each of the 30 sites. Using 1:24,000 USGS topographic maps and aerial photographs, I characterized the landscape within a three km radius of the midpoint of each transect at each site (a 28 km^2 area). I chose this scale because it encompassed the spread of home ranges found by Quinn (2008) along the central California coast. Within this three km circle, I measured the areas of grassland, suburban land use, agricultural land use, and combined area of non-grassland natural habitats (including chaparral, oak woodland, mixed evergreen, and redwood forest). I summed the length of all paved roads and officially designated highways, excluding sections of roads or highways that bordered or were surrounded by large densely populated suburban areas.

To establish prey densities at each site, I measured sign densities along transects of the two largest and most common fossorial rodents in the SFBA, the California ground squirrel (*Spermophilus beecheyi*) and Botta's pocket gopher (*Thomomys bottae*). Both species leave distinctive burrows. California ground squirrels excavate and live in extensive underground burrow systems in grasslands, but will avoid areas where plant cover is high enough to obstruct their view. The openings of ground squirrel burrows are nearly circular in shape and can have large amounts of loose soil strewn about the entrance. To measure ground squirrel sign density, I counted the number of burrows along each transect. Pocket gophers excavate extensive burrow systems by moving soil to the ground surface and depositing it in characteristic mounds. These mounds vary greatly in size and may cover large portions of their habitat. To estimate gopher abundance, I performed three minute counts of gopher mounds at 5 to 10 randomly selected sections of each transect at each site.

I used a one-way multivariate analysis of variance (MANOVA) (Tabachnik & Fidell 2006) to compare the suite of habitat and prey variables between sites where badgers were present and where they were absent. One-way univariate analysis of variance (ANOVA) was used to evaluate the relative importance of each of the individual variables. Because badgers may have been extirpated from the East Bay fragments before this survey, I performed the same habitat characteristic analysis between present and absent sites while excluding the four sites I sampled within these fragments. To develop a predictive model for the presence or absence of badgers, I used backwards stepwise logistic regression (Tabachnik & Fidell 2006) to identify which variables were the best predictors of badger occupancy at a study site. Finally, I used multiple regression analysis to determine which variables were correlated with the density of badger burrows at each study site.

RESULTS

I found badger burrows at 15 of the 30 sites I visited (Table 1; Figure 1). I found between one (at only one site) and 142 badger burrows with a median of 17 burrows at each of the 15 sites. At the remaining 15 sites, I found no evidence of any badger burrows, including old burrows, or burrows observed more than five meters from the transect line. Transect lengths at the absent sites ranged from 4.6 km to 15.7 km with a median length of 9.4 km (Table 1).

Badgers were not found within the East Bay fragments. Unlike any of the other habitat fragments in the SFBA, the most recent recorded historical sightings in the East Bay dated back to the 1920s and 1930s, much earlier than any other fragments sampled. Additionally, none of the current species lists at the four parks I surveyed included badgers, while some, or all, listed bobcats, coyotes, foxes, and mountain lions.

I also did not find badger activity along the southwestern edge of heavily urbanized areas from South San Francisco to South San Jose, or in agricultural regions in northern Monterey county. Nine of the 15 absent sites were located along suburban edges within public access parks. Five of these nine sites were along the southwestern edge of urban areas from South San Francisco to San Jose and one was bordering the suburban edge of Santa Cruz. The remaining three of these nine sites were within the East Bay fragments. Two absent sites in northern Monterey County were in patches of grassland located within a mosaic of cultivated and non-cultivated lands with relatively

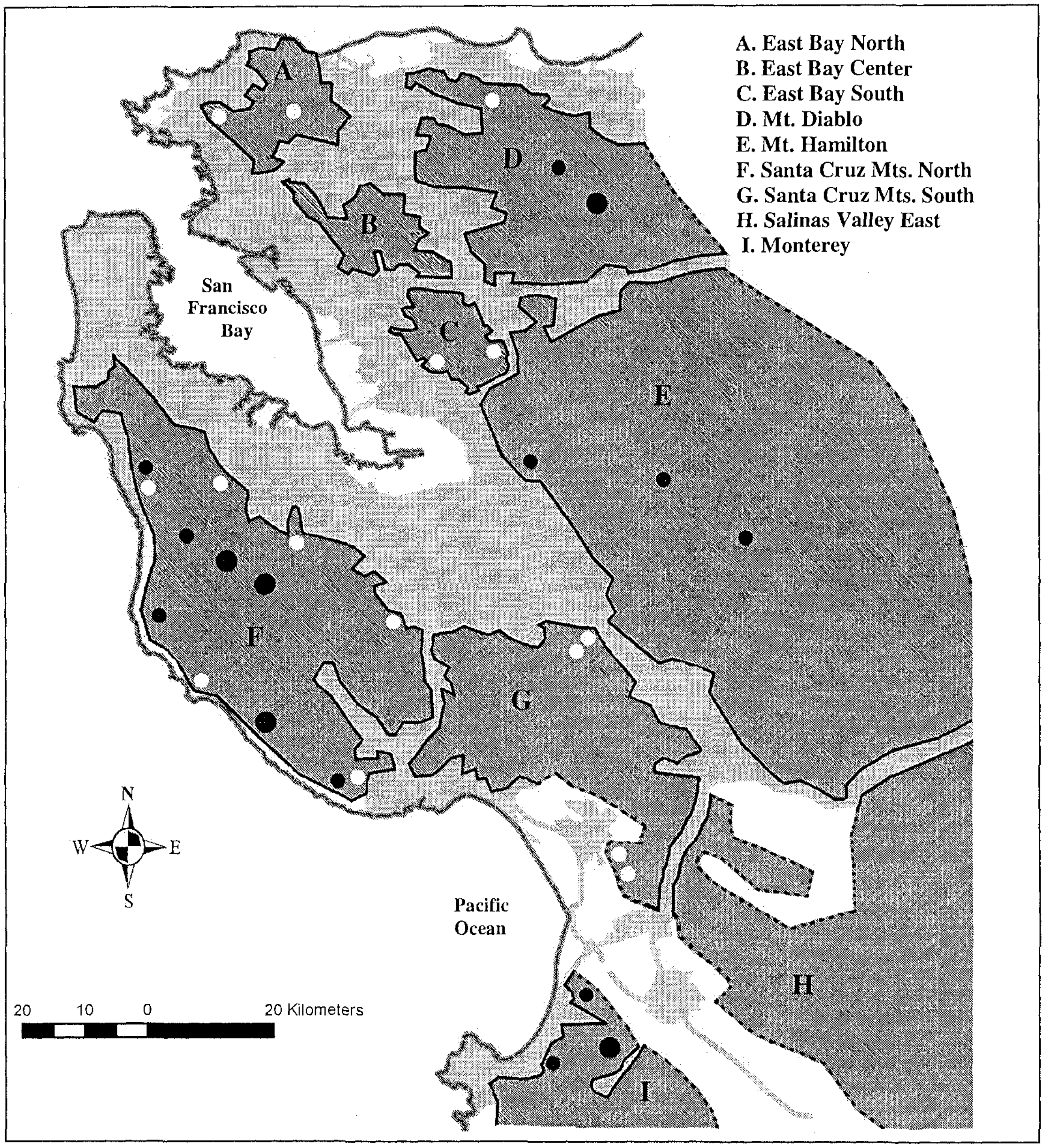


Figure 1: Badger presence/absence and relative burrow densities at 30 sites at or near historical sites within remaining habitat fragments (A through I) in the San Francisco Bay Area. Black circles are sites where badgers were present (n=15). Larger black circles indicate sites with high burrow densities (n=5); small black circles indicate sites with low burrow densities (n=10). White circles are sites where badgers were absent (n=15). Light gray areas contain dense suburban development and/or four to eight lane freeways. Dark gray areas are habitat fragments without significant suburban or agricultural land development. These areas contain grasslands and other natural habitats. White areas are agricultural regions. Solid black lines indicate a boundary between suburban development and any of the above habitats. Dashed black lines indicate a boundary between agricultural land and the above habitats.

high road densities. The remaining four absent sites were in grassland habitats with no adjacent human land use within a three kilometer radius; at each of these sites the gopher and ground squirrel sign densities were either very low or zero.

The MANOVA test using all eight habitat-related variables showed that there were likely differences ($p=0.068$) in habitat characteristics between sites where badgers were present and absent (Table 2). Univariate ANOVA tests on each single habitat variable highlighted one major difference, surrounding suburban land use, which was significantly less ($p=0.010$) around sites where badgers were present (Table 2). Although agricultural land use by itself was not significantly different ($p= 0.50$), the combination of suburban land use and agriculture land use into one human land use variable was also significantly different ($p=0.007$). Roads were also less extensive at sites where badgers were present but the results were not significant ($p= 0.06$). The length of highways alone did not differ between sites with and without badgers ($p=0.71$). The length of roads and highways together was not statistically significant ($p=0.092$). Gopher sign density ($p=0.84$), ground squirrel sign density ($p=0.26$), area of grassland habitat ($p=0.25$), and area of forest/chaparral habitats ($p=0.42$) all did not differ between sites in which badgers were present or absent. When sites in the East Bay were excluded, the results were unchanged.

Table 2: Univariate (ANOVA) and multivariate (MANOVA) results for eight habitat variables between sites where badgers were present and absent (Badger P/A).

ANOVA results	Source	df	MS	F	p
% Grassland	Badger P/A	1	40.454	1.379	0.250
	Error	28	29.331		
% Forest/Chaparral	Badger P/A	1	16.425	0.681	0.416
	Error	28	24.116		
% Agricultural land	Badger P/A	1	2.195	0.473	0.497
	Error	28	4.641		
% Suburban	Badger P/A	1	111.357	7.560	0.010
	Error	28	14.730		
Road Length	Badger P/A	1	140.046	3.840	0.060
	Error	28	36.468		
Highway length	Badger P/A	1	1.016	0.140	0.711
	Error	28	7.255		
G. Squirrel Sign Density	Badger P/A	1	756321.947	1.335	0.258
	Error	28	566446.424		
Gopher Sign Density	Badger P/A	1	70.533	0.043	0.837
	Error	28	1640.832		

MANOVA results	Pillai Trace	df	F	p
8 variables combined	0.459	8, 21	2.228	0.068

Logistic regression analysis showed that badger activity could be predicted with 80% accuracy using five habitat characteristic variables. The model was:

$$\frac{e^{-0.841*\text{ suburban } + 0.081*\text{gopher } + -0.352*\text{ roads } + 0.003*\text{ground squirrel } + 0.158*\text{ non-grassland}}}{1+e^{-0.841*\text{ suburban } + 0.081*\text{gopher } + -0.352*\text{ roads } + 0.003*\text{ground squirrel } + 0.158*\text{ non-grassland}}}$$

Badgers were more likely to be present when (in order of importance) suburban land use was low (p=0.001, coeff = -0.841), gopher sign density was high (p=0.002, coeff = 0.081), length of roads was low (p=0.005, coeff = -0.352), ground squirrel sign density was high (p=0.047, coeff = 0.003), and possibly when non-grassland habitat was high but the latter was not significant (p=0.378, coeff = 0.158). When non-grassland habitat was excluded from the model the overall percentage of correct predictions declined from 80% to 73.3% so the variable was retained in the model.

Badger burrow density did not correlate with any of the measured variables at each site. However, burrow density varied greatly at the 15 present sites. Densities ranged between 7.5 - 22 burrows per kilometer of transect among the five sites with high burrow densities, while the remaining 10 ranged between 0.1 - 3.4 burrows per kilometer of transect (Table 1).

DISCUSSION

Habitat fragmentation likely played a significant role in the apparent extirpation of badgers within the East Bay fragments. The rapid urbanization that occurred in the East Bay area over the last 50 years may have completely isolated a small group (or groups) of badgers residing in each of the East Bay fragments. Because badger breeding rates can be low (with females reproducing only every other year) and juvenile mortality rates high (Quinn 2008), maintaining a viable population size may have been difficult. In British Columbia, researchers observed the extirpation of a sparse badger population with extremely large home ranges. Researchers theorized that a decrease in successful dispersal events from other populations and an increase in death rate, mainly due to roadkill, may have driven this northern population to extinction (Kinley and Newhouse 2008). While badgers in the SFBA have smaller home ranges than observed in British Columbia, the barriers to successful long-distance dispersal and threats posed by crossing roads are greater in the SFBA. Thus, more heavily fragmented habitats may threaten badger populations that operate at smaller spatial scales.

Badgers may have been extirpated in the East Bay fragments during the past when other anthropogenic threats to their survival were greater than in 2003. For instance, due to an increase in demand, the number of badger pelts sold in North America greatly increased from 2,000 in 1972 to 42,000 in 1978 (Long and Killingley 1983). Badgers were also heavily trapped from 1978 to 1987, in response to the U.S. Department of Agriculture Animal Damage Control service reporting agricultural resource loss because of badger digging (Quinn 2008). These threats may have additionally strained populations isolated in each of the three fragments and helped cause their eventual extirpation. Since then, badgers from nearby occupied habitats may have been unable to re-colonize these areas due to barriers caused by urbanization. For instance, badgers were present in the Mt. Hamilton fragment in 2003 within only 20 km of the southern-most East Bay fragment. The narrow but significant presence of human development (including an eight lane freeway) that separated the two fragments appeared to be preventing recolonization.

Badgers were also generally not found at or near historical sites along suburban edges, perhaps because badgers face heightened mortality risks due to high road densities. Susceptibility to roadkill may be a result of a badger's poor vision (Minta 1993) and short legs, which prevent them from crossing roads with concrete medians (Quinn 2008). Males are particularly susceptible to roadkill during the breeding months (Case 1978), because they greatly increase their movements and home ranges to find females (Goodrich and Bushkirk 1998). If male badgers in the SFBA have home ranges as large as those measured in Monterey (up to 26 km^2), these individuals travel distances large enough to guarantee frequent contact with roads. Similarly, juvenile badgers face increased roadkill mortality risks while dispersing long distances from their mother's home range. In British Columbia, seven of 10 radio-collared badgers along with 13 untagged individuals were killed crossing transportation corridors (Hoodicoff 2003). Likewise, Messick and Hornocker (1981) reported 59% of 157 badger mortalities in an Idaho population resulted from vehicle collisions. In Monterey county, CA, Quinn (2008) reported eight untagged road-killed badgers during a nine month period. In 2006-

07, seven road-killed badgers were reported in southern Santa Clara County in the vicinity of two of my study sites (T. Diamond, pers. comm., July 16, 2008). Given this apparent trend in other studies, the lack of a statistically significant difference between road lengths at the present and absent sites in this study may be attributable to a low sample size rather than to the absence of an effect.

The threat from poisoning may also help to explain why badgers were nearly absent along urban edges and in agricultural areas. Although ingestion of anticoagulants by badgers has not been documented previously in the SFBA, badgers are probably at elevated risk of secondary poisoning because they not only consume entire rodent carcasses but also poisoned rodents that return to their underground burrows (Quinn 2008). Rodenticides were a significant source of mortality in a coyote population living within an urbanized region of southern California (Riley et al. 2003). While coyotes are omnivorous and more adapted to living in urbanized areas than badgers (Crooks 2002), even coyotes in natural areas near urban zones were killed by secondary poisoning (Riley et al. 2003). In addition, rodenticides were detected in 31 of 39 bobcats and caused the death of two mountain lions living near urbanized areas in southern California (Riley et al. 2007). Historically, badgers have also been targeted by farmers and ranchers, because their burrows can cause damage to livestock, crops, and earthen dams (Lindzey 1982). This may still be occurring in the SFBA and may help to explain why badgers were not found at sites near agricultural lands.

Badgers may be sensitive to the presence of humans and thus may generally avoid edge habitats. Many of the natural open-space areas adjacent to the highly urbanized regions of the SFBA serve multiple purposes, including conserving biodiversity and providing outdoor recreation opportunities for people. These two purposes conflict when native species are negatively affected by recreational activities such as hiking, biking, and horseback riding (Ruliffson et al. 2003). In other parts of California, both spatial and temporal shifts in carnivore behavior have been observed in habitat areas that receive higher human use. For instance, bobcats were detected less often along trails with higher human activity, and their activity patterns shifted to being more nocturnal (George and Crooks 2006). Cougar habitat use was shown to be negatively correlated with areas used heavily for mountain biking (Markovchick-Nicholls et al. 2008). Bobcats and coyotes occupying habitats in and around suburban areas have larger home ranges than individuals living in more natural areas, perhaps because they need to travel farther to find secure resting and denning areas (Riley et al. 2003). In an urbanizing area in the northern SFBA, the home ranges of female bobcats were found exclusively in undisturbed habitats within a large park, presumably because the females felt more secure raising their young (Riley 1999). Badgers could be more sensitive than other carnivores to human use in open-space parks and thus occupy less disturbed habitats found within the interiors of the remaining fragments in the SFBA.

The decreased number of badgers occupying edge habitats could threaten badger populations remaining within the large fragments of habitat in the SFBA. It is possible, for instance, that the inability of badgers to successfully occupy edge habitat contributed to the extirpations that occurred in the East Bay fragments by reducing usable fragment size and increasing isolation. This suggests that the minimum fragment size necessary to sustain a badger population could be large, perhaps larger than 180 km^2, the area of the largest East Bay fragment. Furthermore, a strong edge effect may threaten extant populations due to reduced genetic mixing, because badgers may avoid the use of narrow corridors that connect to other populations.

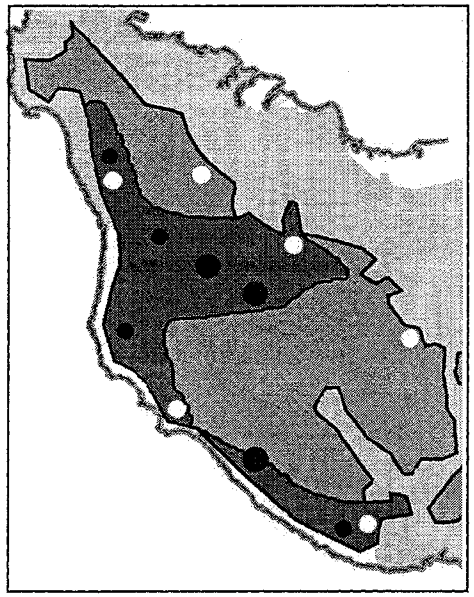
At a fine scale, the high burrow densities I observed at five of the 15 study sites may have represented core use areas where one or more badgers were spending larger periods of time hunting and sleeping. The location of these core use areas may have reflected underlying soil conditions and/or the local abundance and type of available prey. The distribution of optimal soil characteristics may vary significantly across potential badger habitat, causing badgers to selectively utilize some areas more intensively than others. Availability of prey correlates with an increase in badger burrows (Goodrich & Buskirk 1998, Eldridge 2004). However, the type of prey being sought may also affect local burrow density, as badgers that consume more non-fossorial prey species presumably dig fewer burrows. This may have been the case at sites within the Mt. Hamilton fragment, a large undisturbed area (3,500 km^2) characterized by different soil characteristics than other parts of the SFBA as well as a mosaic of several plant communities that may support larger non-fossorial prey populations. Despite this possible difference, a larger non-fossorial prey base may not completely explain the markedly low burrow densities at the three Mt Hamilton sites, since badgers continually excavate deep burrows for sleeping as well as hunting.

On the other hand, high burrow densities may also correspond to areas occupied by female badgers. Because female badgers have consistently smaller home ranges than males, females must concentrate their burrows within smaller areas, leading to higher burrow densities. In addition, females construct natal dens, special burrows used to rear young. The association between females and their young lasts from 10 to 12 weeks, with cubs not coming above ground for the first four to five weeks (Lindzey 1982). During this time, a female is less mobile and may concentrate her hunting activity, leading to higher burrow densities. However, after four to five weeks, females may move their cubs to new dens within their home range (Minta 1990).

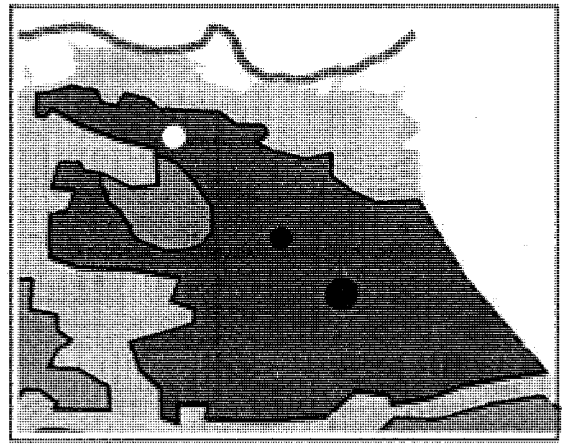
The low burrow densities at the remaining 10 study sites corresponded to areas used less heavily. These areas may be infrequently visited by badgers because of poorer soil quality, lower prey availability, or a lack of large contiguous acreages of grassland. Alternatively, badgers with larger home ranges, such as males, may have occupied these sites. Low burrow density sites could also indicate transient use by a dispersing badger that occupied the area for a very short time. An illustration of such transient use occurred at Round Valley Regional Park in the Mt. Diablo fragment, where I encountered only three clearly inactive burrows within about 30 m of one another along a 15 km transect. Although I considered badgers to be present at this site for purposes of analysis, no badger at that time occupied the large area of grassland I surveyed. This finding was especially provocative given that the site was close to another occupied site in an undisturbed region with large acreages of continuous grassland and significant densities of both gophers and ground squirrels.

The low burrow densities found at most of the sites where badgers were present and the notable absence of badgers at some non-edge sites illustrate the low population density and patchy distribution of badgers in the SFBA. Although the area of human land use surrounding each site was the strongest predictor of badger presence, gopher sign density, length of roads, and ground squirrel sign density were also important predictors in the logistic regression model. This suggests that badgers survive best in habitats within the interior of each remaining fragment where prey is abundant and the need to cross roads is minimized. These conditions could have created the few core use areas surrounded by low use and vacant areas within the Santa Cruz Mountains North fragment (Figure 2a). The two sites where badgers were absent in this fragment that were not located along suburban edges were in areas where gopher and ground squirrel sign densities were low or absent. In contrast, the sites where badgers were absent or had a low burrow density within the Mt. Diablo fragment could not be explained by a lack of abundant prey or high road densities (Figure 2b). The population in this fragment may be declining, leaving more and more suitable habitat areas unoccupied, or the population may have declined in the past and now be stable or increasing.

Badger populations in fragmented areas are especially at risk due to a combination of their patchy distribution and their sensitivity to human land use. In non-fragmented ecosystems, badgers are able to maintain viable populations despite their patchy distribution. Badgers accomplish this by densely populating (up to 6 badgers per km^2) localized areas of optimal habitat and successfully dispersing long distances as juveniles through many different types of habitats. These characteristics helped to explain the high levels of genetic variability and evidence of gene flow observed among



2a



2b

Figure 2. Badger occupancy and activity and the extent of major grassland habitat within the Santa Cruz Mts. North fragment (2a) and the Mt. Diablo fragment (2b). Large black circles depict sites where badger activity was high, small black dots where badger activity was low, and white dots where no badger activity was found. The darkest gray regions represent areas where grasslands are a dominant (but not necessarily the only) plant community. Medium gray regions represent areas where other non-grassland plant communities dominate. Light gray regions are suburban areas. Both maps illustrate the patchy distribution of remaining badger populations and the small number of areas where burrow density was high.

three of four distant badger populations in Alberta, British Columbia, and central Montana (Kyle 2004). The fourth isolated population had lower genetic variability and minimal gene flow with the other three populations, presumably because a significant barrier (a mountain range) separated this population from the other three (Apps et al. 2002). Similar genetic structuring due to both natural and anthropogenic barriers has been observed in other wide-ranging mammalian carnivores, such as cougar populations in California (Ernst et al. 2003). Although badgers can disperse large distances like cougars, they are less able to safely travel through human-modified landscapes and thus may be more negatively impacted by increasing fragmentation.

Compared to other carnivores, badgers may be more impacted by the large-scale fragmentation of their habitat occurring in the SFBA and other urbanizing areas in California. At the time of this survey, there appeared to be few high density groups of badgers persisting in the SFBA. The distribution of these groups was patchily distributed within the interiors of some of the remaining habitat fragments. Barriers to successful dispersal between fragments consisted of a growing inhospitable matrix of suburban land use and decreased badger occupancy of edge habitats. The remaining groups of badgers may be more isolated and thus more susceptible to stochastic events that can lead to local extirpation (Hanski 1999).

Recommendations

Badger burrow surveys should be used to continue to monitor the distribution of badgers in the SFBA. The advantages of burrow surveys to assess presence/absence of badgers at a study site included ease and rapidity, low cost, and a low probability of false absences. Using this method, I was able to complete each survey using only one person-day per site. Permission to conduct my surveys at each site was easy to obtain and no special permits were required. My sign surveys detected badger presence more reliably than sighting data. Several land managers I spoke with stated they had never seen a badger on their land and several park brochures failed to list badgers as present in their park, even though I observed recently excavated badger burrows during my surveys. This suggests that badgers may be more common than visual encounters would imply.

Burrow surveys should be continued over time to provide insight into whether or not populations in the SFBA are increasing, decreasing, or shifting their use of habitat. Continued monitoring efforts should also include searching for natal dens, since their presence is a strong indication of an established and successfully reproducing population. New sites in the SFBA should also be surveyed, especially in regions that were sparsely surveyed as part of this study. In particular, it is important to survey more sites in the East Bay fragments to confirm the apparent loss of badgers there.

Further surveys within the SFBA may help to clarify how susceptible badgers are to human impacts. For instance, badgers could be re-introduced and monitored within the East Bay fragments which might help to distinguish the degree to which habitat fragmentation, edge effects, and rodent poisoning contributed to their local extirpation.

In addition, DNA samples from badgers residing in different fragments should be collected and analyzed to estimate the level of connectivity and gene flow between each region.

The logistic regression model generated from these data should be tested at new sites and then used to create a habitat suitability map to help specify important habitat and potential corridor regions. Suitable grassland habitats identified by the model should be protected. Particular attention should be focused on identifying key corridor areas that connect populations within and between fragments. A roadkill database should be organized region-wide to help prioritize which of these corridor areas warrant the construction of safer alternatives for badgers to cross roads.

The results of this study strengthen the original designation of badgers as a Species of Special Concern and highlight the importance of bolstering future efforts to monitor badger populations and mitigate the threats they face in the SFBA and other urbanizing areas within their range.

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