esa ECOSPHERE

Landscape characteristics affect animal control by urban residents

Anita T. Morzillo[1],† and Matthew D. Schwartz

United States Environmental Protection Agency, Western Ecology Division, 200 SW 35th Street, Corvallis, Oregon 97333 USA

Citation: Morzillo, A. T., and M. D. Schwartz. 2011. Landscape characteristics affect animal control by urban residents. Ecosphere 2(11):128. doi:10.1890/ES11-00120.1

Abstract. Ecological patterns exist within urban landscapes. Among urban patterns of biodiversity, species occurrences may coincide with interactions between humans and wildlife. However, research focused on consequences of human reaction to interactions with wildlife is limited. We evaluated landscape characteristics of rodent control behavior across two urban landscapes in California, Bakersfield, and in proximity to Santa Monica Mountain National Recreation Area (SAMO). Our data were collected prior to a recent policy ruling limiting distribution of particular rodent control products. In both locations, local biologists have observed non-target effects of rodent control products among local carnivores. Mice and rats were among the species most targeted in both locations, but squirrels and gophers also were common targets in SAMO. Carnivore species identified by biologists were among those also reported by residents as targeted for control. In both locations, those who reside in single-family structures and among lower-density development were more likely to practice rodent control. Species targeted varied by distance to open space in both locations, but by development density in SAMO only. In Bakersfield, control was distributed across the study area, but one cluster of control existed among mainly lower-density, single-family residences. In SAMO, clusters of both control ($n = 2$) and chemical use ($n = 3$) existed among single-family, lower-density areas in proximity to wash channels and relatively lush vegetation. Our results suggest possible pathways for contact between wildlife and rodent control products, but causal linkages between the two are beyond the scope of our data. Similar to other urban ecological processes, human responses to interactions with ecological phenomena may occur at both fine and landscape scales. Furthermore, our results suggest a possible feedback loop of interacting ecological and social phenomena that may provide information about human activities affecting urban wildlife populations.

Key words: human dimensions; landscape ecology; pest control; pesticides; rodenticides; wildlife management; urban ecosystems.

Received 29 April 2011; revised 2 September 2011; accepted 21 September 2011; final version received 7 November 2011; **published** 30 November 2011. Corresponding Editor: J. Marzluff.

[1] Present address: Department of Forest Ecosystems and Society, 321 Richardson Hall, Oregon State University, Corvallis, Oregon 97331 USA.

† **E-mail:** anita.morzillo@oregonstate.edu

INTRODUCTION

In urban landscapes, humans influence ecosystems as a result of land cover and land use conversion (Theobold et al. 1997, McKinney 2002, Faeth et al. 2005, Grimm et al. 2008), modification of biophysical and ecological processes (Arnold and Gibbons 1996, Pickett et al. 1997, Collins et al. 2000, Grimm et al. 2000, Paul and Meyer 2001), and alteration of species habitat and assemblages (Hope et al. 2003, Faeth et al. 2005). Research documenting relationships between urbanization and declining biodiversity, habitat degradation, policy, and human health often focuses on industry and transportation (Holdren and Ehrlich 1974, Gill and Elliott 2003, Naylor et al. 2003, Bell et al. 2004, Hadley and Wilson 2004). Although resident population is the metric used to define city size (U.S. Census Bureau data), few studies have focused specifically on residential components of urban ecosystems. With the ongoing rural-to-urban-and-suburban population shift (Hobbs and Stoops 2002, McKinney 2002), and spatial dominance of residential development, there is a need to understand the extent that residents recognize impacts they have on their local environment. This understanding may lead to better outreach and regulation that meets the needs of both humans and other species.

Within urban systems, the presence and adaptation of wildlife and conflict with humans (Luniak 2004, DeStefano and Degraaf 2003, Gehrt et al. 2010) is a consequence of broadly shared resource needs (e.g., O'Donnell and DeNicola 2006, Hill et al. 2007, Krester et al. 2008, Hostetler and Drake 2009). For instance, residential land management (Lepczyk et al. 2004*b*), intentional feeding (Fuller et al. 2008), and presence of exotic species (Crooks and Soulé 1999, Baker et al. 2005) may enable potential for conflict between humans and wildlife. Although it is known that residential activities can impact wildlife (e.g., Lepczyk et al. 2004*a*, *b*, Faeth et al. 2005), research focusing on effects of such activities is limited (Liu et al. 2003).

Background and context

Pest control is one method by which humans may respond to conflict with wildlife. Regardless of location, control often focuses on synanthropic exotics, such as black or Norway rats (*Rattus rattus* and *R. novegicus*, respectively) and house mice (*Mus musculus*). However, control may also target native species, such as gophers (e.g., *Thomomys* spp.) and moles (e.g., *Scapanus* spp.). Regardless of target, the products used for control can be indiscriminant, resulting in impacts to non-target species.

In this study, we evaluated characteristics of pest control across two urban landscapes. Of particular interest were mammals as targets and use of chemical products, specifically anticoagulants. Active anticoagulant ingredients, which inhibit the clotting of blood (Amdur et al. 1991), include warfarin, brodifacoum, and bromadiolone (USFWS 1993). Such compounds intended for household use (indoor and outdoor near structures) are marketed under a variety of trade names. Exposure of non-target species may occur by direct consumption (e.g., Eason and Spurr 1995, Brakes and Smith 2005), ingestion of non-absorbed compounds within the digestive tracts of prey (Howald et al. 1999), or indirect exposure during consumption of contaminated prey (e.g., Alterio 1996, Berny et al. 1997, Eason et al. 1999). Anticoagulants can increase risk of mortality among non-target species, but there is almost no knowledge about the mechanisms by which they travel through the environment, locations of use, and target species (Erickson and Urban 2004), and little information about general product use (e.g., US EPA 1979, Wilen 2001, Erickson and Urban 2004).

Observed non-target mortality from anticoagulants is a global phenomenon (Eason and Spurr 1995). In Europe, Brakes and Smith (2005) reported small mammals consuming bait during routine rat control, which severely affected small mammal populations. Residues have been reported in avian and terrestrial predators in Europe (Shore et al. 2003, Fournier-Chambrillon et al. 2004, Walker et al. 2008) and Asia (Duckett 1984). In Canada, use of brodificoum for rat eradication presented obvious exposure to avian scavengers (Howald et al. 1999, Albert et al. 2010). Non-target mortality has been observed among raptors, other birds, and mammals in New Zealand (Dowding et al. 1999, Eason et al. 1999, Eason et al. 2002) and the United States (Littrell 1988, Stone et al. 1999, Riley et al. 2003, Riley et al. 2007, McMillin et al. 2008). Although these reports highlight non-target effects, we are unaware of any research within a landscape context, and have limited knowledge about the role of urban residents as potential contributors to the issue (Wilen 2001).

A 2008 Environmental Protection Agency (EPA) federal ruling limits the sale and distribution of 10 anticoagulant rodenticides in the United States in an effort to minimize potential for exposure by children and non-target wildlife

(US EPA 2008). New requirements include minimum package size requirements, use site restrictions, sale and distribution restrictions, and use of bait stations for outdoor above-ground application (US EPA 2008). Our research is the first attempt to evaluate rodent control and anticoagulant product use across a landscape, and our data were collected prior to the 2008 ruling. Our objectives were to (1) identify species targeted for control and whether our carnivores of interest are among them, and (2) evaluate relationships between landscape characteristics and control behavior.

METHODS

Study area

Our study area included two urban locations in California, USA, where local biologists have observed non-target impacts on several species (Fig. 1). One location is within the southwestern section of Bakersfield, delimited by the channelized Kern River and Highway 99. Land use included mixed-density residential development and related services (e.g., shopping plazas), golf courses, a small university campus, and some industrial development. A species of particular interest is a local urban population of San Joaquin kit fox (*Vulpes macrotis mutica*; e.g., Bjurlin et al. 2005), a federally endangered species that has experienced mortality from exposure to anticoagulants (McMillin et al. 2008).

The other location straddled the Ventura-Los Angeles County border in proximity to the Santa Monica Mountains National Recreation Area (hereafter SAMO). This area consisted particularly of low- and medium-density residential development interspersed among natural areas, residential services, a golf course, and limited industrial areas. Species of particular interest include bobcat (*Lynx rufus*), coyote (*Canis latrans*), and mountain lion (*Puma concolor*), which have been observed as having anticoagulant residues in their tissues; toxin load was directly related to use of developed habitat by two of these species (Riley et al. 2003, Riley et al. 2007).

We received evidence of anticoagulant-related mortality from local biologists, as determined by necropsy analysis (Riley et al. 2007, McMillin et al. 2008). Biologists also provided locations where dead animals were found (e.g., in dens) and associated estimated home range areas and movements as gathered by radiotelemetry (B. Cypher, Endangered Species Recovery Program, California State University Stanislaus, *personal communication*; S. P. D. Riley, National Park Service, *personal communication*; sensu Riley et al. 2003). This information allowed us to identify residential areas to target for information about rodent control. We incorporated this knowledge into ArcView GIS 3.2 (Environmental Systems Research Institute, Redlands, California, USA), to establish boundaries of extents (sampling areas) based on major roads.

Data collection

Residential rodent control behavior.—A mail survey was used to collect information about residential pest control behavior. The sampling frame was the list of all residential street addresses within our study extents, and the sampling unit was the individual household. We purchased street address information from Marketing Systems Group (Fort Washington, PA), which compiles datasets from U.S. Postal Service delivery sequence files. We excluded PO boxes, seasonal homes, and mail drops (single delivery points for multiple addresses) because of our need to apply data to a spatial context. The Office of Management and Budget (Control Number 2080-0077), Office of Human Research Ethics at University of North Carolina-Chapel Hill (IRB # 08-0775), and Office of Research Integrity at Oregon State University (IRB # 4442) granted permission for use of human subjects.

Multiple mailings and a toll-free number for participant questions were used in an effort to increase response rate (Dillman 2000). Sample size was based on desired sampling error (±5%) and statistical power (80%), and we assumed lower-than-average response rate because of survey administration by a government agency (Dillman 2000). In September 2007, both English and Spanish versions of questionnaires were sent to randomly selected households in both locations ($n = 4{,}000$ per site, $N = 8{,}000$). The overall response rate for the survey was 25% ($n = 2{,}001$; Bakersfield = 780; SAMO = 1,221). Morzillo and Mertig (2011*a*) provide further details about surveys returned incomplete, non-respondents, and the non-response follow-up. Ultimately, responses from Bakersfield and SAMO were

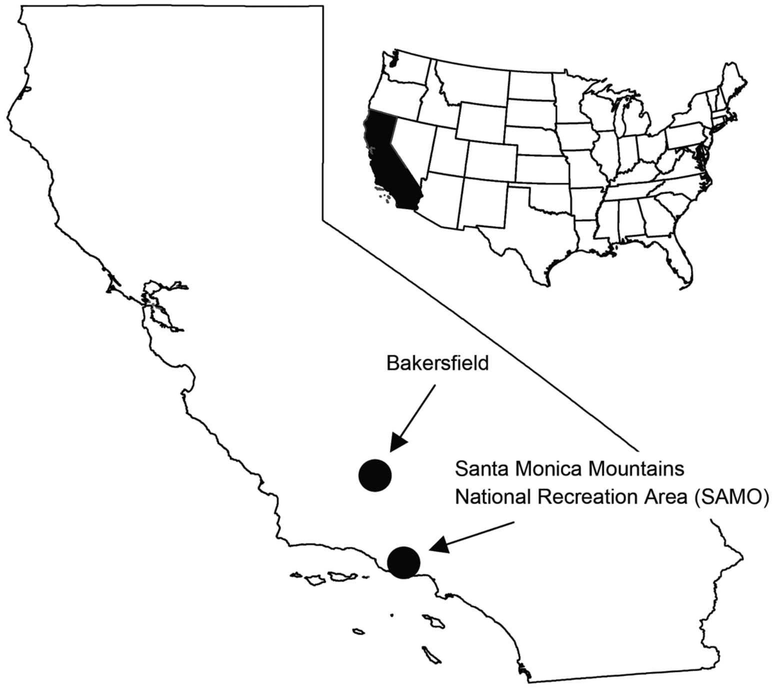

Fig. 1. Study areas in California, USA (adapted from Morzillo and Mertig 2011*b*).

evaluated separately because of demographic differences between the two locations (Morzillo and Mertig 2011*a*).

We used a two-step process to identify chemical product users among our respondents. First, we identified control behavior participants by selecting those who answered "yes" to the question, "Have you or anyone else tried to control rodents or other animals on your property" (within the past five years; Bakersfield $n = 320$, SAMO $n = 720$). Second, we identified chemical product users by selecting those who answered "yes" when asked if chemical rodenticides have been used on their property (Bakersfield $n = 141$, SAMO $n = 338$). Chemical product users then were asked to select all products used from among: (1) anticoagulants, (2) dehydration, (3) fumigants, (4) nerve agent, (5) zinc phosphide, (6) unsure, and (7) other. Examples of each chemical were provided to assist subjects with product identity. Responses were coded such that $1 =$ use of each chemical (1–7), and $0 =$ non-use, and allowed us to identify anticoagulant users specifically.

Target species.—To evaluate target species, we asked, "Which of the following types of animals have you or someone else been trying to control on your property?" Respondents were asked to select applicable species from a list provided on the survey (Appendix A). We also provided space to specify "other" wildlife not included in the list. All non-mammal species (e.g., cockroaches, rattlesnakes) not pertinent to our objectives were removed from further analysis.

Background variables.—We used eight demographic and seven behavior variables to evaluate respondent characteristics (variable names in parentheses; Appendix A). Demographic variables included household size (Hhsize), children in household (Children), residential tenure (Tenure), home ownership (Own), sex (Sex), age (Age), education (Education), and household income (Income).

Of the seven behavior variables (Appendix A), three focused on pets: presence of pets (Pets), whether pets are allowed outdoors unsupervised (PetsUnsupOut), and whether pets are fed outdoors (PetsFeedOut). The other four activity variables were based on knowledge that individual behaviors often are directly associated with personal emotional relationship with the environment (Hinds and Sparks 2008), and included participation in environmental service activities (EnvService), participation in wildlife-related activities (WldfAct), importance of environmental amenities in location of residence (NatReside), and concern about non-target effects (Concern). Morzillo and Mertig (2011*a*) provide details about data reduction techniques, scale construction, and creation of behavior variables.

Landscape variables.—We evaluated relationships between residential control behavior and four urban landscape variables: building age, building structure, development density, and distance from open space (Appendix B). Based on correlations between building age and pest presence (Turner and Bishop 1998, Berkowitz et al. 2002), we hypothesized that residents in older buildings would be no more likely to practice control than those in newer buildings. Berkowitz et al. (2002) also reported greater pest control among apartment buildings than houses, and so we hypothesized a greater likeliness of pest control among multiple- than single-family structures. More broadly, Adgate et al. (2000) suggested no differences in pesticide use patterns between urban and rural census tracts. However, ecological processes within urban systems are spatially heterogeneous (Pickett et al. 1997, McKinney 2008). Therefore, we suspected that human responses to ecological processes may follow patterns similar to the processes themselves, and hypothesized that residents among lower density development and closest to open space are more likely to practice control.

For Bakersfield, building age and building type were derived from the Kern County Land Assessor's Office database (http://www.recorder.co.kern.ca.us/index.php; Appendix B). All land use information for Bakersfield was obtained from the Kern County Development Services Agency (http://www.co.kern.ca.us/gis/) GIS database. Residential development density was defined by the five-class Kern County general land use designations. Overlapping classes signifies that some mixed densities existed within the same block. All open space maintained relatively urban characteristics (i.e., "altered open space") and included vacant lots along Kern River, parks and recreation areas, and schoolyards.

For SAMO, building age and building type were derived from the Los Angeles (http://assessor.lacounty.gov) and Ventura (http://assessor.countyofventura.org/) County Assessor's Office databases. Building age and type were calculated similarly as for Bakersfield (Appendix B). Land use data for SAMO were obtained from the National Park Service (D. Kamradt, National Park Service, *personal communication*) and the National Land Cover Dataset (Fry et al. 2009). Residential density was determined based on existing designations. Open space included two categories: natural areas (e.g., county parks, National Recreation Area units) and "altered open" (golf courses, developed parks, schoolyards). To account for management differences, we completed calculations for natural areas alone ("natural"), and all open space collectively ("natural plus altered").

Statistical analysis.—SPSS 16.0.1 (SPSS, Chicago, Illinois, USA) was used for to evaluate relationships between survey responses and landscape variables. Pearson's r and chi-square were used to test bivariate relationships, as appropriate (Sokal and Rohlf 1995). Alpha values were defined at the 95% confidence interval ($\alpha = 0.05$).

To define scale of and evaluate spatial distribution of control behavior, ArcGIS 9.3.1 (Environmental Systems Research Institute, Redlands, California, USA) and Moran's I test (Moran 1950, Fortin and Dale 2005) were used to quantify a global spatial autocorrelation, with the null hypothesis of a random spatial pattern. Essentially, Moran's I allowed us to identify whether the pattern of values across the study area tend to be clustered, random, or dispersed. The inherent clustering of humans and our use of human activity as the variables of interest necessitated identification of a neighborhood-sized scale. Because neighborhoods were adjacent to each other, we conducted the Moran's I analysis at 100 m intervals, starting at 100 m and ending at 2,000 m from each respondent practicing control. The resulting Moran's I Z-scores from each distance were graphed to define the distance that locations of respondents maintained the greatest amount of autocorrelation.

Because global statistics such as Moran's I are designed only to evaluate general autocorrelation of a particular landscape pattern, an additional test was needed to evaluate "membership" of individual respondents among those with similar control behavior (i.e., at the appropriate scale of the behavior). Therefore, we used the Getis-Ord test (G(*i*)*; Getis and Ord 1992) to evaluate details of clustering of control behavior at the scale of control behavior. Respondents who practiced control and used chemicals served as two feature classes of interest. For large *n* sizes (i.e., >30), Getis and Ord (1996) suggest a distance band that includes at least 30 neighbors. A Zone of Indifference conceptualization of spatial relationships was selected because it allows the minimum number of neighbors to be met, and does not establish a finite boundary on neighbors that fall near the edge of the distance band. Respondents near the edge of the distance threshold influence group membership within the distance threshold, which is important for high concentration areas. The threshold distance value (greatest amount of autocorrelation) was defined by Moran's I results (above). G(*i*)* values with $Z > 1.96$ were considered significant at the 95% confidence level, and suggested rejection of a null hypothesis (i.e., distribution containing no clusters).

RESULTS

Target species

For both locations, rats and mice were the species controlled for most frequently (Fig. 2). Squirrels, gophers, and rabbits were controlled for by at least 15% of respondents in SAMO. A variety of "other" target species were identified, including kit fox in Bakersfield and the three carnivore species of interest (bobcat, coyote, mountain lion) in SAMO (Table 1).

Sample characteristics across the landscape

For Bakersfield, average (±SD) residential structure age was 23 (±14) years. A majority were single-family residences (80%), and among low (70%) and high-medium (18%) density categories. Average distance to open space was 290 (±197) m. Respondents with larger households, children in the household, younger respondents, those with less formal education, and those with lower incomes were more likely to reside further from open space (Table 2). Smaller households, households without children, those with shorter tenure, renters, younger residents, as well as those with lower incomes, without pets (and who do not let pets outside unsupervised or feed pets outside), participate less in wildlife-related activities, and have greater concern about non-target effects were more likely to reside among greater development density.

For SAMO, average residential structure age was 28 (±19) years. A majority were single-family residences (73%), and among medium- (62%) and high- (28%) density categories. Average distance to natural plus altered open space (112 ± 106 m) was less than natural open space (127 ± 106 m). Respondents with longer tenure, less formal education, lower incomes, those who leave pets out unsupervised, and those who considered natural amenities to be less important were more likely to reside further from open space (natural or natural plus altered; Table 2). Older residents were more likely to be further from natural areas. Those less likely to own their own homes and participate in environmental service activities were more likely to be further from open space. Smaller households, those with children, newer residents, renters, females, younger residents, those without pets (and who do not let pets outside unsupervised or feed pets outside), those less likely to be involved in environmental service activities, and those most concerned about non-target impacts on wildlife were more likely to reside among greater development density.

Landscape characteristics affecting control behavior

For Bakersfield, neither control ($r = 0.04$, $p = 0.29$), nor chemical use ($r = -0.04$, $p = 0.32$) varied with building age. However, those in single-family structures were more likely to control ($\chi^2 = 11.42$, df = 1, $p = 0.001$) and use chemicals ($\chi^2 = 8.33$, df = 1, $p = 0.004$) than those in multiple-family structures. Distance from open space did not vary between those who do and do not control ($r = 0.01$, $p = 0.72$), or use chemicals ($r = -0.12$, $p = 0.10$). Across all respondents who control, distance to open space did not differ for those who target mice, rats, or gophers; those targeting squirrels were more likely closer to open space ($r = 0.14$, $p = 0.009$). Respondents practicing control were more likely to reside among lower density development ($r = -0.11$, $p = 0.003$); this relationship did not hold true for chemical users ($r = -0.04$, $p = 0.61$). Compared to all respondents who practice control, species

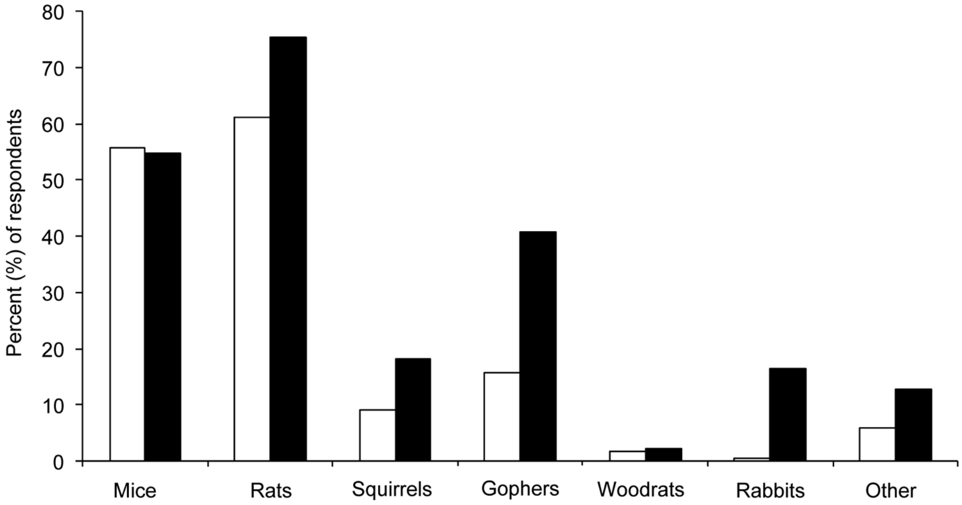

Fig. 2. Frequency (percent) of respondents who control for each target species on their property in two locations in California. Bakersfield is illustrated using white bars ($n = 317$); SAMO is illustrated using black bars ($n = 718$). See Table 1 for a detailed breakdown of the "other" category.

controlled for did not vary across development density. Density and distance were not correlated ($r = -0.04$, $p = 0.25$).

Also for Bakersfield, we rejected our null hypothesis that control was randomly distributed ($Z = 1.95$, $p = 0.05$); maximum autocorrelation existed at a distance of 1,800 m (Fig. 3). Although no prominent clusters emerged for chemical use, one prominent cluster emerged for control ($n = 95$). This cluster corresponded to both the western boundary of the extent, and was in proximity to both a golf course and multiple areas of ongoing residential construction. Among this cluster, average structure age, and average distance to (altered) open space were less than that for the overall sample (Table 3). All but one structure were single family residences, and most were among the low and high-medium density development categories. Mice and rats were the main species targeted, but at a lower proportion than across all respondents who control. Neither control nor use of chemicals exhibited global autocorrelation based on Moran's I scores. One potential "hotspot" of control existed among an area with relatively lower density and newer buildings near the extent boundary.

For SAMO, whether or not a respondent practiced control did not vary by building age ($r = -0.01$, $p = 0.84$); this was consistent for chemical ($r = -0.01$, $p = 0.69$) users. However, those who control ($\chi^2 = 65.10$, df = 2, $p < 0.001$) and use chemicals ($\chi^2 = 30.16$, df = 1, $p < 0.001$) were more likely to reside in single-family rather than multiple-family structures. Respondents closer to open space were more likely to control for rodents than those further away, regardless of whether open space was natural ($r = -0.11$, $p < 0.001$) or natural plus altered ($r = -0.06$, $p = 0.044$). This relationship held true for chemical users (natural $r = -0.12$, $p < 0.001$; natural plus altered $r = -0.07$, $p = 0.017$). Across all

Table 1. "Other" target species identified for control by survey respondents in two locations in California.

Species	Bakersfield	SAMO
Bats	x	
Voles		x
Rats†	x	x
Moles	x	x
House cats	x	x
Kit foxes	x	
Dogs	x	x
Skunks	x	x
Opossums	x	x
Raccoons		x
Bobcats		x
Coyotes	x	x
Deer		x
Mountain lions		x

† Identified within "other" category by respondents as tree rats, wire rats, and fence rats. Because we are unable to determine the appropriate category for these items, they are listed separately.

Table 2. Distribution of survey respondent demographics as related to proximity to open space (m) and development density (units/ha) in Bakersfield ($n = 771$) and SAMO ($n = 1{,}214$), California.

	Distance from open space (m)			Development density (units/ha)	
Characteristic	Bakersfield	SAMO†	SAMO‡	Bakersfield	SAMO
Hhsize	0.111§,¶*	0.027	0.049	−0.131*	−0.307*
Children	0.090*	−0.045	−0.013	−0.061*	#*
Tenure	0.040	0.171*	0.144*	−0.211*	−0.204*
Own	−0.056	−0.039	−0.075*	−0.477*	#*
Sex (female = 1)	−0.016	0.028	0.029	0.049	#*
Age (years)	−0.116*	0.062*	0.009	−0.120*	−0.106*
Education	−0.103*	−0.112*	−0.121*	−0.048	−0.070*
Income	−0.075*	−0.150*	−0.145*	−0.201*	−0.436*
Pets	0.062	−0.039	−0.033	−0.169*	#*
PetsUnsupOut	−0.089	0.073*	0.080*	−0.183*	#*
PetsFeedOut	0.045	0.023	0.028	−0.122*	#*
EnvService	−0.040	−0.054	−0.063*	−0.060	−0.066
WldfAct	0.001	0.032	0.025	−0.092*	0.021
NatReside	0.034	−0.074*	−0.070*	0.025	−0.008
Concern	−0.014	−0.028	−0.046	0.085*	#*

† Distance from open space = natural areas only.

‡ Distance from any open space = natural areas + "altered open space."

§ Test statistic = Pearson correlation coefficient (r) unless otherwise noted (#).

¶ $P < 0.05$ indicated by an asterisk (*).

Test statistic = Chi-square; Children ($\chi^2 = 36.09$, df = 1), Own ($\chi^2 = 262.00$, df = 2), Sex ($\chi^2 = 20.56$, df = 2), Pets ($\chi^2 = 26.94$, df = 2), PetsUnsupOut ($\chi^2 = 58.55$, df = 2), PetsFeedOut ($\chi^2 = 5.75$, df = 2), and Concern ($\chi^2 = 14.68$, df = 4).

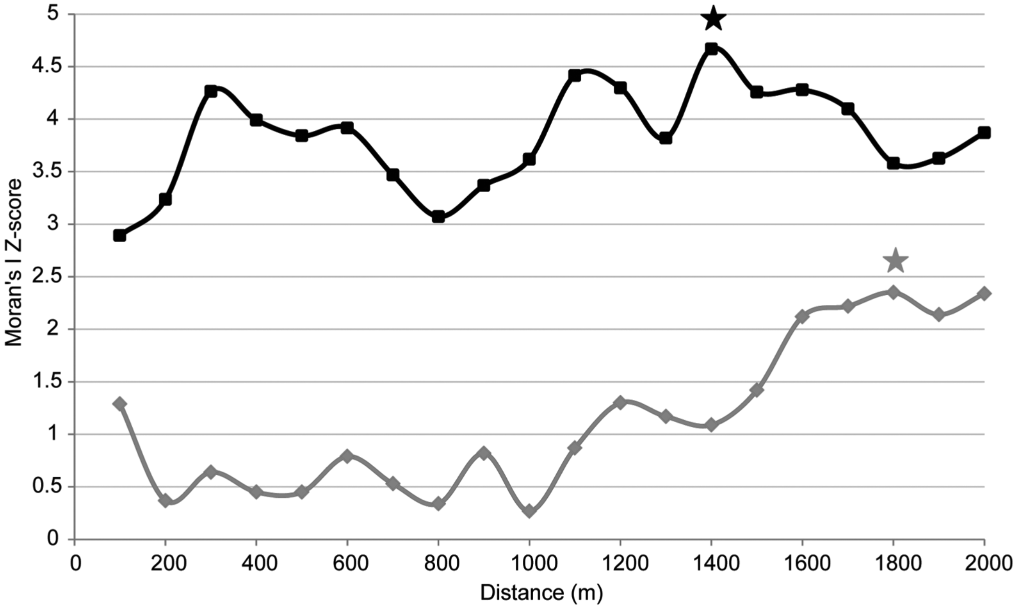

Fig. 3. Z-score values of distance bands from Moran's I test were used to determine level of spatial autocorrelation of respondents that practiced control in Bakersfield (gray) and SAMO (black). Greater Z-scores indicate greater spatial autocorrelation (i.e., clustering of similar behavior). A star denotes maximum value of spatial autocorrelation for each location.

Table 3. Collective descriptive results of clustered respondent characteristics (as relevant) for control behavior, chemical use, and anticoagulant use for Bakersfield and SAMO.

Behavior	Bakersfield	SAMO	
	Control	Control	Chemical use
n	95	108	156
Mean structure age (yr)	12 (±7)	26 (±12)	30 (±12)
Frequency of single family structure	99%	72%	82%
Development density (most relevant)	75% low; 15% high-medium	59% low 19% medium 30% high	35% low 46% medium 19% high
Mean distance to open space (altered; m)	230 (±137)	na	na
Mean distance to open space (natural; m)	na	60 (±58)	88 (±86)
Mean distance to open space (natural + altered; m)	na	59 (±58)	84 (±82)
Species targeted (most relevant)	mice = 33% rats = 33% gopher = 9%	mouse = 51% rat = 56% squirrel = 15% gopher = 43% rabbit = 17%	mouse = 44% rat = 59% squirrel = 16% gopher = 38% rabbit = 17%

Note: Values in parentheses are standard deviations.

respondents who control, distance to open space (natural or natural plus altered) did not differ for those targeting mice, rats, squirrels, but was less for those targeting gophers (natural $r = -0.08$, $p = 0.028$; natural plus altered $r = -0.07$, $p = 0.035$). Respondents practicing control ($r = -0.18$, $p < 0.001$), and those using chemicals ($r = -0.20$, $p < 0.001$) were more likely to reside among lower density development. Respondents in lower density development were more likely to target gophers ($\chi^2 = 18.57$, df $= 2$, $p < 0.001$) and rabbits ($\chi^2 = 10.35$, df $= 2$, $p = 0.006$). Density and distance were not correlated ($r = -0.03$, $p = 0.24$ for natural areas and $r = -0.02$, $p = 0.48$ for all open space).

Also for SAMO, we also rejected our null hypothesis that survey respondents practicing control were randomly distributed ($Z = 2.98$, $p = 0.003$); maximum autocorrelation existed at a distance of 1,400 m (Fig. 3). Among respondents exhibiting control behavior, two prominent "hotspot" clusters ($n = 108$) emerged in the northeastern and southern parts of the study area. Both were among low density development and in proximity to wash channels that contained more lush vegetation than surrounding hills. Compared to the overall sample, landscape characteristics generally were similar among those who control (Table 3). However, notable distinctions among the clusters include closer proximity to open space, and less frequency in targeting rats. Three prominent "hotspot" clusters ($n = 156$) emerged among respondents using chemicals, two of which overlapped with the two control clusters and a third at the western boundary of the extent. The third cluster was located among a medium density and single-family structure area that abutted natural open space. Compared to the overall sample, landscape characteristics for clustered chemical users generally illustrated similar trends as for those who control (Table 3). However, compared to those who control, chemical users were more frequently among single-family structures, medium development density, and slightly further from open space. The southern cluster that emerged for control and chemical use suggested a high concentration of anticoagulant users among it, and coincided with proximity to land being converted to new residential development. Therefore, control and use of chemicals exhibited global autocorrelation, with "hotspots" among single family structures in relatively lower density development categories near open space.

DISCUSSION

Urbanization impacts ecosystem pattern (Luck and Wu 2002) and processes (McDonnell and Pickett 1990, McDonnell et al. 1997, Neil and Wu 2006). Few studies have evaluated impacts of human activities at the household scale (Liu et al. 2003), or human reaction to environmental effects. While evaluating urban residential pest control behavior, we discovered that patterns of pest control may mimic underlying ecological processes.

The ubiquitous targeting of mice and rats may be a function of the adaptability of these species to urban areas and inside buildings, as well as a psychological phenomenon. Rats generally are not well-liked (Kellert and Berry 1980) and, in another part of our study, a direct relationship existed between negative attitudes toward rodents and control behavior (Morzillo and Mertig 2011*b*). Others have linked reaction to rats to perception of human welfare (Bratt 2009). Beyond the scope of our analysis, we speculate that exotic rats and mice are more likely observed indoors and less likely to be perceived as part of the local environment than other species, which contributes to widespread control behavior of them.

The carnivores of interest (coyote, bobcat, mountain lion, kit fox) were among the species targeted for control. Three (of 15) respondents who reported targeting those species also reported use of anticoagulants; all were from SAMO and all targeted coyotes (Morzillo unpublished data). Collectively, those respondents reside in 15- to 22-year-old single-family structures among varying development densities and distances from open space and place control products both outdoors and indoors. Indoor and outdoor observation of pests and property damage initiated control for all three respondents, who were minimally or not concerned about non-target effects on wildlife. Our integration of survey and ecological data allow us to observe potential pathways for possible contact between carnivores and anticoagulants, but conclusions about resident misuse or intentional use of anticoagulants to harm carnivores are beyond the scope of our data. Also, although anticoagulant use and targeting of carnivores corresponds with areas of observed impacts (Riley et al. 2007, McMillin et al. 2008), we cannot make causal inferences linking specific locations of use, target, and non-target effects.

Addressing our second objective, particular infrastructure characteristics are linked to a greater likelihood of control behavior. Similar to our first hypothesis, building age did not affect likeliness to control. Similar to our second hypothesis, those among single-family structures were more apt to control than those among multiple-family structures. Response bias toward single-family homes likely exists because in both locations the proportion of both homeowners and residents of single-family structures was greater than actual (U.S. Census Bureau data). Underrepresentation of multiple-family units may be attributed to property managers and landlords assuming pest control (Morzillo and Mertig 2011*b*). Regardless, factors beyond building characteristics affect control behavior.

For both locations, our data supported our third hypothesis (more control among lower-density development), but our fourth hypothesis (more control closer to open space) was supported only in SAMO. We speculate that landscape configuration likely affects patterns of control. Geographic (Redman 1999) and gradient characteristics (McDonnell et al. 1997, Dow 2000) are phenomena of urban systems. Generally, inverse relationships exist between species richness and distance from urban core (Blair and Launer 1997, Clergeau et al. 1998, Germaine and Wakeling 2001, Williams et al. 2005, McKinney 2008). Although a gradient-related biodiversity analysis was beyond the scope of our objectives, human responses to interactions with ecological phenomena may occur at both fine and landscape scales.

Although targeting mice and rats was widespread, spatial variation existed in control of other species. Community-level diversity often is greatest at intermediate levels of residential development (Blair and Launer 1997, Blair 2004, Buchans and Thompson 2006). In Bakersfield, control behavior for squirrels may operate as a function of land cover, whereas both land cover and land use are factors in SAMO (Theobold 2004). Bakersfield is topographically flat with development in gridded patterns and limited natural open space. Scrubland and intensive agriculture surround Bakersfield, whereas urban residential areas contain squirrel habitat features including canopy cover (Williamson 1983, McPherson and Nilon 1987, Bowers and Breland 1996, Gurnell et al. 2002, Nelson et al. 2005) and water (Peterson et al. 1999) not as available elsewhere. Therefore, in Bakersfield, residential areas may function as habitat islands (Gehrt and Chelsvig 2004), from which squirrels have difficulty dispersing (Angold et al. 2006). Comparatively, for SAMO, landscape influences distribution based on both topography and ownership. Natural areas of SAMO contains both chaparral and wooded riparian zones, and the interspersion of both may aid in squirrel movement out of, yet aid gophers and rabbits movement into, residential areas.

Thus, we suspect that fine-scale features affect spatial variation in control for native wildlife, as well. Fraterrigo and Wiens (2005) suggested that building density as well as fine-scale habitat features affect species persistence. Fine-scale features may include vegetation cover (Hennings and Edge 2003, Chamberlain et al. 2004, Atwood et al. 2004) and complexity (Germaine and Wakeling 2001, Crooks et al. 2004), as well as berry-producing shrubs (Melles et al. 2003), birdfeeders (Fuller et al. 2008), and den sites and available foraging area (Randa and Yunger 2006). In our study areas, the propensity of non-native lush vegetation and fruit trees in yards likely attract wildlife; resulting damage prompts control. In fact, several survey respondents noted use of control products when yard fruit is ripe, or commented that they have observed pests "chewing on tree fruit," and "eating fruit off of the trees. Others suggested causes of pest presence such as "neighbor needs to trim grapefruit trees" or "property owners neglect[ing] of existing fruit trees." Thus, we suspect that both landscape and fine-scale characteristics both influence wildlife processes that, in turn, result in patterns of human reaction to them.

We also highlight possible influence of socioeconomics on observed trends. For instance, income was related consistently to both distance and density variables. Income has been positively associated with leaf area index in Indiana (Jensen et al. 2004), as well as plant diversity across Phoenix, another desert metropolis containing expanses of non-native vegetation (Hope et al. 2003). We also speculate potential for cognitive dissonance (Festinger 1957), such that those closer to open space in SAMO were more likely to indicate importance of natural features near their residence, yet more likely to participate in control behavior that consequentially may affect the nearby natural features such as wildlife.

Our results suggest a possible feedback loop of interacting ecological and social phenomena (McIntyre et al. 2000) that calls for further exploration. Humans create appealing wildlife habitat, wildlife use this habitat, presence of and actions by wildlife causes human reaction to wildlife, and humans repair and reinforce appealing habitat thereby attracting wildlife. We speculate whether further exploration of the social pattern and processes of pest control may reveal similar patterns of ecological processes at both local and landscape scales (Melles et al. 2003, Chamberlain et al. 2004, Sparks et al. 2005, Herrmann et al. 2010), but intra-site control patterns reflect landscape heterogeneity. From a policy and management perspective, such human-wildlife conflict may be resolved by encouraging residents in lower density areas and near open space to adhere to manufacturer guidelines for pest control product use and minimizing presence of attractants on their property.

ACKNOWLEDGMENTS

We thank B. Cypher, C. Davis, A. Fairbrother, J. Hagar, D. Kamradt, A.G. Mertig, E. Minor, D. Olszyk, S.P.D. Riley, R. Sauvajot, M. Santelmann, one anonymous reviewer, and all of the California residents who completed the survey. The information in this document has been funded in part by the U.S. Environmental Protection Agency. It has been subjected to review by the National Health and Environmental Effects Research Laboratory and approved for publication. Approval does not signify that the contents reflect the views of the Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use. This is contribution number WED-11-091 of the Western Ecology Division.

LITERATURE CITED

Adgate, J. L., A. Kukowski, C. Stroebel, P. J. Shubat, S. Morrell, J. J. Quackenboss, R. W. Whitmore, and K. Sexton. 2000. Pesticide storage and use patterns in Minnesota households with children. Journal of Exposure Analysis and Environmental Epidemiology 10:159–167.

Albert, C. A., L. K. Wilson, P. Mineau, S. Trudeau, and J. E. Elliott. 2010. Anticoagulant rodenticides in three owl species from western Canada, 1988-2003. Archives of Environmental Contamination and Toxicology 58:451–459.

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.

Amdur, M. O., J. Doull, and C. D. Klaassen. 1991. Casarett and Doull's toxicology: the basic science of poisons. Fourth edition. Pergamon Press, New York, New York, USA.

Angold, P. G., J. P. Sadler, M. O. Hill, A. Pullin, S. Rushton, K. Austin, E. Small, B. Wood, R. Wadsworth, R. Sanderson, and K. Thompson. 2006. Biodiversity in urban patches. Science of the Total Environment 360:196–204.

Arnold, C. L., and C. J. Gibbons. 1996. Impervious surface coverage. Journal of the American Planning Association 62:243–257.

Atwood, T. C., H. P. Weeks, and T. M. Gehring. 2004. Spatial ecology of coyotes along a suburban- to-rural gradient. Journal of Wildlife Management 68:1000–1009.

Baker, P. J., A. J. Bentley, R. J. Ansell, and S. Harris. 2005. Impact of predation by domestic cat *Felis catus* in an urban area. Mammal Review 35:302–312.

Bell, M. L., A. McDermott, S. L. Zeger, J. M. Samet, and F. Dominici. 2004. Ozone and short- term mortality in 95 US urban communities, 1987–2000. Journal of the American Medical Association 19:2372–2378.

Berkowitz, G. S., J. Obel, E. Deych, R. Lapinski, J. Godbold, Z. Liu, P. J. Landrigan, and M. S. Wolff. 2002. Exposure to indoor pesticides during pregnancy in a multiethnic urban cohort. Environmental Health Perspectives 111:79–84.

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.

Bjurlin, C. D., B. L. Cypher, C. M. Wingert, and C. L. Van Horn Job. 2005. Urban roads and the endangered San Joaquin kit fox. Report to the California Department of Transportation. Contract #65A0136. Endangered Species Recovery Program, California State University, Stanislaus, Fresno, California, USA.

Blair, R. 2004. The effects of urban sprawl on birds at multiple levels of biological organization. Ecology and Society 9:2.

Blair, R. B., and A. E. Launer. 1997. Butterfly diversity and human land use: species assemblages along an urban gradient. Biological Conservation 80:113–125.

Bowers, M. A., and B. Breland. 1996. Foraging of gray squirrels on an urban-rural gradient: use of the Gud to assess anthropogenic impact. Ecological Applications 6:1135–1142.

Brakes, C. R., and R. H. Smith. 2005. Exposure of non-target small mammals to rodenticides: short-term effects, recovery and implications for secondary poisoning. Journal of Applied Ecology 42:118–128.

Bratt, S. 2009. Human attitudes toward animals in relation to species similarity to humans: a multivariate approach. Bioscience Horizons 2:180–190.

Buchans, D. E., and F. R. Thompson. 2006. Songbird abundance and parasitism differ between urban and rural shrublands. Ecological Applications 16:394–405.

Chamberlain, D. E., A. R. Cannon, and M. P. Toms. 2004. Associations of garden birds with gradients in garden habitat and local habitat. Ecography 28:589–600.

Clergeau, P., J. P. L. Savard, G. Mennechez, and G. Falardeau. 1998. Bird abundance and diversity along and urban-rural gradient: a comparative study between two cities on different continents. The Condor 100:413–425.

Collins, J. P., A. Kinzig, N. B. Grimm, W. F. Fagan, D. Hope, J. Wu, and E. T. Borer. 2000. A new urban ecology: modeling human communities as integral parts of ecosystems poses special problems for the development and testing ecological theory. American Scientist 88:416–425.

Crooks, K. R., A. V. Suarez, and D. T. Bolger. 2004. Avian assemblages along a gradient of urbanization in a highly fragmented landscape. Biological Conservation 15:451–462.

Crooks, K. R., and M. E. Soulé. 1999. Mesopredator release and avifaunal extinctions in a fragmented system. Nature 400:563–566.

DeStefano, S., and R. M. Degraaf. 2003. Exploring the ecology of suburban wildlife. Frontiers in Ecology and the Environment 1:95–101.

Dillman, D. A. 2000. Mail and internet surveys: the tailored design method. Second edition. John Wiley & Sons, New York, New York, USA.

Dow, K. 2000. Social dimensions of gradients in urban ecosystems. Urban Ecosystems 4:255–275.

Dowding, J. E., E. C. Murphy, and C. R. Veitch. 1999. Brodifacoum residues in target and non- target species following an aerial poisoning operation on Motuihe Island, Hauraki Gulf, New Zealand. New Zealand Journal of Ecology 23:207–214.

Duckett, J. E. 1984. Barn owls (*Tyto alba*) and the "second generation" rat-baits utilized in oil palm plantations in Peninsular Malaysia. Planter, Kuala Lumpur 60:3–11.

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., L. Milne, M. Potts, G. Morriss, G. R. G. Wright, and O. R. W. Sutherland. 1999. Secondary and tertiary poisoning risks associated with brodifacoum. New Zealand Journal of Ecology 23:219–224.

Eason, C. T., and E. B. 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 bird and nontarget mammals: a comparative approach. U.S. Environmental Protection Agency, Office of Pesticides Programs, Environmental Fate and Effects Division, Washington, D.C., USA.

Faeth, S. H., P. S. Warren, E. Shochat, and W. A. Marussih. 2005. Trophic dynamics in urban communities. BioScience 55:399–407.

Festinger, L. 1957. A theory of cognitive dissonance. Stanford University Press, Palo Alto, California, USA.

Fortin, M. J., and M. R. T. Dale. 2005. Spatial analysis: a guide for ecologists. Cambridge University Press, Cambridge, UK.

Fournier-Chambrillon, C., P. J. Berny, O. Coiffier, P. Barbedienne, B. Dassé, 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.

Fraterrigo, J. M., and J. A. Wiens. 2005. Bird communities of the Colorado Rocky Mountains along a gradient of exurban development. Landscape and Urban Planning 71:263–275.

Fry, J. A., M. J. Coan, C. G. Homer, D. K. Meyer, and J. D. Wickham. 2009. Completion of the National Land Cover Database (NLCD): 1992-2001 Land Cover Change Retrofit Product #2008-1379. U.S. Geological Survey, Washington, D.C., USA.

Fuller, R. A., P. H. Warren, P. R. Armsworth, O. Barbosa, and K. J. Gaston. 2008. Garden bird feeding predicts the structure of urban avian assemblages. Diversity and Distributions 14:131–137.

Germaine, S. S., and B. F. Wakeling. 2001. Lizard species distributions and habitat occupation along an urban gradient in Tucson, Arizona, USA. Biological Conservation 97:229–237.

Getis, A., and J. K. Ord. 1992. The analysis of spatial association by use of distance statistics. Geographical Analysis 24:189–206.

Getis, A. and J. K. Ord. 1996. Local spatial statistics: an overview. Pages 261–278 *in* P. A. Longley and M. Batty, editors. Spatial analysis: modelling in a GIS environment. Geoinformation International, Cambridge, UK.

Gehrt, S. D., S. P. D. Riley, and B. L. Cypher. 2010. Urban carnivores: ecology, conflict, and conservation. The John Hopkins University Press, Baltimore, Maryland, USA.

Gehrt, S. D., and J. E. Chelsvig. 2004. Species-specific patterns of bat activity in an urban landscape. Ecological Applications 14:625–635.

Gill, C. E., and J. E. Elliott. 2003. Influence of food supply and chlorinated hydrocarbon contaminants on breeding success of bald eagles. Ecotoxicology 12:95–111.

Grimm, N. B., J. M. Grove, S. T. A. Pickett, and C. L. Redman. 2000. Integrated approach to long-term studies of urban ecological systems. BioScience 50:571–584.

Grimm, N. B., S. H. Faeth, N. E. Golubiewski, C. L. Redman, J. Wu, X. Bai, and J. M. Briggs. 2008. Global change and the ecology of cities. Science 319:756–760.

Gurnell, J., M. J. Clark, P. W. W. Lurz, M. D. F. Shirley, and S. P. Rushton. 2002. Conserving red squirrels (*Sciurus vulgaris*): mapping and forecasting habitat suitability using a geographic information systems approach. Biological Conservation 105:53–64.

Hadley, G. L., and K. R. Wilson. 2004. Patterns of small density and survival following ski-run development. Journal of Mammalogy 85:97–104.

Hennings, L. A., and W. D. Edge. 2003. Riparian bird community structure in Portland, Oregon: habitat, urbanization, and spatial scale patterns. The Condor 105:288–302.

Herrmann, J. D., D. Bailey, G. Hofer, F. Herzog, and M. H. Schmidt-Entling. 2010. Spiders associated with the meadow and tree canopies of orchards respond differently to habitat fragmentation. Landscape Ecology 25:1375–1384.

Hill, N. J., K. A. Carbery, and E. M. Deane. 2007. Human-possum conflict in urban Sydney, Australia: public perceptions and implications for species management. Human Dimensions of Wildlife 12:101–113.

Hinds, J., and P. Sparks. 2008. Engaging with the natural environment: the role of affective action and identity. Journal of Environmental Psychology 28:109–120.

Hobbs, F., and N. Stoops. 2002. Demographic trends of the 20th century. U.S. Census BureauWashington, D.C., USA.

Holdren, J. P., and P. R. Ehrlich. 1974. Human population and the global environment. American Scientist 62:282–292.

Hope, D., C. Gries, W. Zhu, W. F. Fagan, C. L. Redman, N. B. Grimm, A. L. Nelson, C. Martin, and A. Kinzig. 2003. Socioeconomics drive urban plant diversity. Proceedings of the National Academy of Sciences 100:8788–8792.

Hostetler, M., and D. Drake. 2009. Conservation subdivisions: a wildlife perspective. Landscape and Urban Planning 90:95–101.

Howald, G. R., P. Mineau, J. E. Elliott, and K. M. Cheng. 1999. Brodifacoum poisoning of avian scavengers during rat control on a seabird colony. Ecotoxicology 8:431–447.

Jensen, R., J. Gatrell, J. Boulton, and B. Harper. 2004. Using remote sensing and geographic information systems to study urban quality of life and urban forest amenities. Ecology and Society 9:5.

Kellert, S. R., and J. K. Berry. 1980. Knowledge, affection, and basic attitudes toward animals in American society, Phase III. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C., USA.

Krester, H. E., P. J. Sullivan, and B. A. Knuth. 2008. Housing density as an indicator of spatial patterns of reported human-wildlife interactions in northern New York. Landscape and Urban Planning 84:282–292.

Lepczyk, C. A., A. G. Mertig, and J. Liu. 2004*a*. Assessing landowner activities related to birds across rural-to-urban landscapes. Environmental Management 33:110–125.

Lepczyk, C. A., A. G. Mertig, and J. Liu. 2004*b*. Landowners and cat predation across rural-to-urban landscapes. Biological Conservation 115:191–201.

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

Liu, J., G. C. Daily, P. R. Ehrlich, and G. W. Luck. 2003. Effects of household dynamics on resource consumption and biodiversity. Nature 421:530–533.

Luck, M., and J. Wu. 2002. A gradient analysis of urban landscape pattern: a case study from the Phoenix metropolitan region, Arizona, USA. Landscape Ecology 17:327–339.

Luniak, M. 2004. Synurbinization—adaptation of animal wildlife to urban development. Pages 50–55 *in* W. W. Shaw, L. K. Harris, and L. VanDruff, editors. Proceedings of the 4th International Urban Wildlife Symposium, Tucson, Arizona, USA.

McDonnell, M. J., and S. T. A. Pickett. 1990. Ecosystem structure and function along urban-rural gradients: an unexplored opportunity for ecology. Ecology 71:1232–1237.

McDonnell, M. J., S. T. A. Pickett, P. Groffman, P. Bohlen, R. V. Pouyat, W. C. Zipperer, R. W. Parmelee, M. M. Carreiro, and K. Medley. 1997. Ecosystem processes along an urban-to-rural gradient. Urban Ecosystems 1:21–36.

McIntyre, N. E., K. Knowles-Yánez, and D. Hope. 2000. Urban ecology as an interdisciplinary field: differences in the use of “urban” between the social and natural sciences. Urban Ecosystems 4:5–24.

McKinney, M. L. 2008. Effects of urbanization on species richness: a review of plants and animals. Urban Ecosystems 11:161–176.

McKinney, M. L. 2002. Urbanization, biodiversity, and conservation. BioScience 52:883–890.

McMillin, S. C., R. C. Hosea, B. F. Finlayson, B. L. Cypher, and A. Mekebri. 2008. Anticoagulant rodenticide exposure in an urban population of San Joaquin kit fox. Pages 163–163 *in* R. M. Timm and M. B. Madon, editors. Proceedings of the 23rd Vertebrate Pest Conference. University of California, Davis, California, USA.

McPherson, E. G. and C. Nilon. 1987. A habitat suitability index model for gray squirrel in an urban cemetery. Landscape Journal 6:21–30.

Melles, S., S. Glenn, and K. Martin. 2003. Urban bird diversity and landscape complexity: species-environment associations along a multiscale habitat gradient. Conservation Ecology 7:5.

Moran, P. A. P. 1950. Notes on continuous stochastic phenomena. Biometrika 37:17–23.

Morzillo, A. T., and A. G. Mertig. 2011*a*. Urban resident attitudes toward rodents, rodent control products, and environmental effects. Urban Ecosystems 14:243–260.

Morzillo, A. T., and A. G. Mertig. 2011*b*. Linking human behavior to environmental effects using a case study of urban rodent control. International Journal of Environmental Studies 68:107–123.

Naylor, R. L., J. Eagle, and W. L. Smith. 2003. A global industry with local impacts. Environment 45:18–39.

Neil, K., and J. Wu. 2006. Effects of urbanization on plant flowering phenology: a review. Urban Ecosystems 9:243–257.

Nelson, R., C. Keller, and M. Ratnaswamy. 2005. Locating and estimating the extent of Delmarva fox squirrel habitat using an airborne LiDAR profiler. Remote Sensing of Environment 96:292–301.

O’Donnell, M. A., and A. J. DeNicola. 2006. Den site selection of lactating female raccoons following removal and exclusion from suburban residences. Wildlife Society Bulletin 34:366–370.

Paul, M. J., and J. L. Meyer. 2001. Streams in urban landscapes. Annual Review of Ecology and Systematics 32:333–365.

Peterson, K. A., L. B. McDowell, and C. A. Martin. 1999. Plant life form frequency, diversity, and irrigation application in urban residential landscapes. HortScience 34:491.

Pickett, S. T., W. R. Burch, Jr., S. E. Dalton, T. W. Foresman, J. M. Grove, and R. Rowntree. 1997. A conceptual framework for the study of human ecosystems in urban areas 1:185–199.

Randa, L. A., and J. A. Yunger. 2006. Carnivore occurrence along an urban-rural gradient: a landscape-level analysis. Journal of Mammalogy 87:1154–1164.

Redman, C. L. 1999. Human dimensions of ecosystem studies. Ecosystems 2:296–298.

Riley, S. P., R. M. Sauvajot, R. 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.

Riley, S. P. D., C. Bromley, R. H. Poppenga, F. A. Uzal, L. Whited, and R. M. Sauvajot. 2007. Anticoagulant exposure and notoedric mange in bobcats and mountain lions in urban southern California. Journal of Wildlife Management 71:1874–1884.

Shore, R. F., J. D. S. Birks, A. Afsar, C. L. Wienburg, and A. C. Kitchener. 2003. Spatial and temporal analysis of second-generation anticoagulant rodenticide residues in polecats (*Mustela putorius*) from throughout their range in Britain, 1992-1999. Environmental Pollution 122:183–193.

Sokal, R. R. and F. J. Rohlf. 1995. Biometry. Third edition. W.H. Freeman and Company, New York, New York, USA.

Sparks, D. W., C. M. Ritzi, J. E. Duchamp, and J. O. Whitaker, Jr. 2005. Foraging habitat of the Indiana bat (*Myotis sodalis*) at an urban-rural interface. Journal of Mammalogy 86:713–718.

Stone, W. B., J. C. Okoniewski, and J. R. Stedelin. 1999. Poisoning of wildlife with anticoagulant rodenticides in New York. Journal of Wildlife Diseases 35:187–193.

Theobold, D. M. 2004. Placing exurban land-use change in a human modification framework. Frontiers in Ecology and the Environment 2:139–144.

Theobold, D. M., J. R. Miller, and N. T. Hobbs. 1997. Estimating the cumulative effects of development on wildlife habitat. Landscape and Urban Planning 39:25–36.

Turner, B. D., and J. Bishop. 1998. What's bugging your kitchen? An analysis of the incidence of psocids in domestic kitchens: the PPFA 1997 household survey. Environmental Health Journal 106:310–314.

Walker, L. A., A. Turk, S. M. Long, C. L. Wienburg, J. Best, and R. F. Shore. 2008. Second generation anticoagulant rodenticides in tawny owls (*Strix aluco*) from Great Britain. Science of the Total Environment 392:93–98.

Wilen, C. A. 2001. Survey of residential pesticide use and sales in the San Diego Creek Watershed of Orange County, California. California Department of Pesticide Regulation, Sacramento, California, USA. http://www.cdpr.ca.gov/docs/sw/contracts/sdcrk.pdf

Williams, N. S. G., J. W. Morgan, M. J. McDonnell, and M. A. McCarthy. 2005. Plant traits and local extinctions in natural grasslands along an urban-rural gradient. Journal of Ecology 93:1203–1213.

Williamson, R. D. 1983. Identification of urban habitat components which affect eastern gray squirrel abundance. Urban Ecology 7:345–356.

US EPA [U.S. Environmental Protection Agency]. 2008. Risk mitigation decision for ten rodenticides. U.S. Environmental Protection Agency, Washington, D.C., USA. http://www.epa.gov/oppsrrd1/reregistration/rodenticides/finalriskdecision.htm

US EPA [U.S. Environmental Protection Agency]. 1979. National household pesticide usage survey, 1976-1977. EPA 540/9-80-002. Office of Pesticides and Toxic Substances, U.S. Environmental Protection Agency, Washington, D.C., USA.

USFWS [U.S. Fish and Wildlife Service]. 1993. Effects of 16 vertebrate control agents on threatened and endangered species. U.S. Fish and Wildlife Service Biological Opinion PB96-172671. U.S. Fish and Wildlife Service, Washington, D.C., USA.

APPENDIX A

Table A1. Description of target species and background variables used for analysis. Target species and background variable data were provided by survey respondents. Construction of background variables is described in detail by Morzillo and Mertig (2011*a*).

Variable	Data	Coding on survey
Target species	Mice; Rats; Squirrels; Gophers; Woodrats; Rabbits; Other	1 = targeted by respondent; 0 = not targeted by respondent
Hhsize	Respondent provided number of residents	Integer value
Children	Respondent provided number of children	1 = $\geq$1 child; 0 = no children
Tenure	Respondent provided number of years current home occupied	Integer value
Own	Own or rent	1 = own; 0 = not own
Sex	Female or male	1 = female; 0 = male
Age	Respondent provided year born	Year subtracted from 2007
Education	Seven categories ranging from less than high school to graduate or professional degree	1–7; numerical value increased with increasing amount of formal education completed
Income	Nine categories grouped in $25,000 increments ranging from <$25,000 to >$199,999	1–9; numerical value increased with increasing income value
Pets	Yes or no	1 = yes; 0 = no
PetsUnsupOut	Yes or no	1 = yes; 0 = no
PetsFeedOut	Yes or no	1 = yes; 0 = no
EnvService	See Morzillo and Mertig (2011a) for details	Greater values = more participation
WldfAct	See Morzillo and Mertig (2011a) for details	Greater values = more participation
NatReside	See Morzillo and Mertig (2011a) for details	Greater values = more importance of amenities
Concern	See Morzillo and Mertig (2011a) for details	Greater values = greater concern

APPENDIX B

Table B1. Description of landscape variables used for analysis. Landscape variables were derived separately from the survey (see methods section), and based on locations of respondents.

Variable	Data	Coding on survey
Building age	Year structure was built	Year subtracted from 2007
Building type	Multiple- or single-family structure	2 = multiple 1 = single
Residential density		
Bakersfield	Low (≤7.26 dwelling units/net acre)	1 = low
	Low-medium (>4 but ≤10 dwelling units/net acre)	2 = low-medium
	Low and low-medium mixed	3 = low and low-medium mixed
	High-medium (>7.26 but ≤17.42 dwelling units/net acre)	4 = high-medium
	High (>17.42 but ≤72.6 dwelling units/net acre)	5 = high
SAMO	Low (single family dwellings <2 units per acre, estates, and ranches)	1 = low
	High-medium single (single family residences >2 units per acre)	2 = high-medium single
	High-medium multiple (multi-family residences, single family dwellings >6 units/acre, and mixed single-multiple residence dwellings)	3 = high-medium multiple