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Effects of Management of Domestic Dogs and Recreation on Carnivores in Protected Areas in Northern California

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Abstract: *In developed countries dogs (*Canis lupus familiaris*) are permitted to accompany human visitors to many protected areas (e.g., >96% of protected lands in California, U.S.A.), and protected-area management often focuses on regulating dogs due to concerns about predation, competition, or transmission of disease and conflicts with human visitors. In 2004 and 2005, we investigated whether carnivore species richness and abundance were associated with management of domestic dogs and recreational visitation in protected areas in northern California. We surveyed for mammalian carnivores and human visitors in 21 recreation areas in which dogs were allowed offleash or onleash or were excluded, and we compared our observations in the recreation areas with observations in seven reference sites that were not open to the public. Carnivore abundance and species richness did not differ among the three types of recreation areas, but native carnivore species richness was 1.7 times greater (*$p < 0.01$*) and the relative abundances of native coyotes (*Canis latrans*) and bobcats (*Lynx rufus*) were over four times greater (*$p < 0.01$*) in the reference sites. Abundances of bobcats and all carnivores declined as the number of visitors increased. The policy on domestic dogs did not appear to affect species richness and abundance of mammalian carnivores. But the number of dogs we observed was strongly associated with human visitation (*$R^2 = 0.54$*), so the key factors associated with recreational effects on carnivores appear to be the presence and number of human visitors to protected areas.*

Keywords: carnivore, domestic dog, management policy, noninvasive animal survey, protected area, recreation

Efectos del Manejo de Perros Domésticos y Recreación sobre Carnívoros en Áreas Protegidas en el Norte de California

Resumen: *En países desarrollados, se permite que perros (*Canis lupus familiaris*) acompañen a visitantes humanos en muchas áreas protegidas (e.g., > 96% de las áreas protegidas en California, E.U.A.), y el manejo de áreas protegidas a menudo se enfoca en la regulación de perros debido a preocupaciones respecto a la depredación, competencia o transmisión de enfermedades y conflictos con visitantes humanos. En 2004 y 2005 investigamos sí la riqueza y abundancia de especies de carnívoros se asociaban con el manejo de perros domésticos y la visita recreativa en áreas protegidas en el norte de California. Muestreamos mamíferos carnívoros y visitantes humanos en 21 áreas en las que se permitían perros con o sin correa o que fueran excluidos, y comparamos nuestras observaciones en las áreas recreativas con observaciones en 7 sitios de referencia que no estaban abiertos al público. La riqueza y abundancia de carnívoros no difirió en los 3 tipos de áreas recreativas, pero la riqueza de especies de carnívoros fue 1.7 veces mayor (*$p < 0.01$*) y las abundancias relativas de coyotes nativos (*Canis latrans*) y linces (*Lynx rufus*) fueron más de 4 veces mayores (*$p < 0.01$*) en los sitios de referencia. La abundancia de linces y de todos los carnívoros declinó a medida que el incrementaba el número de visitantes. La política sobre perros domésticos pareció no afectar a la riqueza y abundancia de mamíferos carnívoros. Pero el número de perros que observamos estaba*

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fuertemente asociado con la visita de humanos ($R^2 = 0.54$), así que los factores clave asociados con los efectos de actividades recreativas sobre carnívoros parecen ser la presencia y número de visitantes humanos a las áreas protegidas.

Palabras Clave: área protegida, carnívoro, muestreo no invasivo de animales, perro doméstico, recreación

Introduction

Pet and feral domestic dogs (*Canis lupus familiaris*) occur on every continent except Antarctica (Miklosi 2007; Vanak & Gompper 2009). There were 77.5 million pet dogs in the United States in 2009 (HSUS 2009), and dogs are permitted to accompany human visitors to the majority of U.S. protected areas. For example, among protected lands in California that permit public access (GIN 2009)—including federal, state, and local parks, forests, and private nature reserves—78.7% permit unrestricted access by domestic dogs, 18.2% permit dogs only in specific areas, and only 0.2% exclude domestic dogs entirely.

A majority of protected-area visitors recognize that recreation may disturb native animal populations (Taylor & Knight 2003), and most visitors attribute the strongest negative effects to recreational activities with domestic dogs (Sterl et al. 2008). Dogs are potential disease vectors, predators, and competitors of native fauna (Butler et al. 2004). Due to concerns about their effects on natural resources and conflicts among recreational user groups (Bekoff & Meaney 1997), dog access is regulated or restricted in some protected areas (Forrest & St. Clair 2006). For example, most U.S. national parks allow dogs only on leashes, near residences and visitor centers, and in campgrounds.

Empirical investigations of the effectiveness of different approaches to dog management for the protection of native species are uncommon. Although the avoidance of recreational trails and heavily visited areas by native birds and mammals is well documented (Miller et al. 1998; Fairbanks & Tullous 2002; Taylor & Knight 2003), the results from the few studies that have investigated the impacts of dogs in recreation areas have been mixed. Mammal activity levels are lower near trails on which dogs are allowed compared with trails on which they are not (Lenth et al. 2008). Similarly, bird species richness and abundance are lower when a hiker is accompanied by a dog compared with a hiker walking alone (Banks & Bryant 2007). These patterns of spatial displacement are consistent with the results of behavioral studies that show elevated stress levels (MacArthur et al. 1982), increased flight distances (Miller et al. 2001), and impaired reproduction (Yalden & Yalden 1990) in birds and mammals when dogs are present. Nevertheless, the results of other studies show few effects attributable to the presence or regulation of dogs. The presence of a dog increases a hiker's area of influence relative to mule deer (*Odocoileus hemionus*), but not relative to two grassland and one forest bird species (Miller et al. 2001). In a study of 22 urban parks, dog leash laws are not associated with species richness or abundance of birds and small mammals (Forrest & St. Clair 2006).

Evaluating the effectiveness of management approaches could be confounded by the intensity of recreational visitation to a protected area because visitation levels influence the magnitude of the effects of recreation. For example, the abundances and activity levels of amphibians (Rodriguez-Prieto & Fernandez-Juricic 2005), reptiles (Garber & Burger 1995), and birds (Van der Zande et al. 1984) decrease as the number of visitors increases. Among mammalian carnivores, wolf (*Canis lupus)* packs travel along low-use trails and roads rather than trails that receive daily foot traffic or roads that receive more than 10,000 vehicles/month (Whittington et al. 2005), and in southern California, bobcats are detected less frequently along recreational trails with high levels of human activity (George & Crooks 2006).

We investigated the effects of human visitors and domestic dogs on the species richness and abundance of native mammalian carnivores in 28 protected areas in northern California. To differentiate between the effects of dogs and those of humans, we surveyed protected areas that represented the full range of dog policies (dogs offleash, onleash, or excluded), and we compared the possible influences of dog management on native carnivores between recreation areas and reference sites that did not allow public access for recreation. We also examined whether human and dog visitation levels explain the relative abundances of native carnivores.

Methods

Study Area

Our study area was a 2640-km^2 area in California's Marin, Sonoma, and Napa counties (38°18′N, 122°31′W) north of San Francisco Bay. The region has a Mediterranean climate and has high concentrations of species richness and endemism (Myers et al. 2000). The three counties support a human population approaching 1 million (U.S. Census Bureau 2006), and protected areas in Marin, Sonoma, and Napa are heavily visited recreation destinations for local people (Reed & Seymour 2008) and the more than 7 million residents of the greater San Francisco Bay Area (BAOSC 2004).

We surveyed 21 recreation areas and seven reference sites. We defined a recreation area as a tract of land (>40 ha) with natural vegetation cover that is maintained for the enjoyment of the public. The recreation areas we surveyed had three different policies on dogs: dogs permitted offleash ($n = 9$); dogs permitted only onleash ($n = 7$); and dogs excluded ($n = 5$). The reference sites ($n = 7$) were protected areas with no public access. To minimize variation in vegetation characteristics among sites, we surveyed only mixed-oak woodlands between 50 and 500 m in elevation along the foothills of the Coastal, Mayacamas, and Vaca mountain ranges. The study sites had a mean area of 287.9 ha (SD 368.3) (Table 1).

Field Surveys

We visited 15 sites one to two times each between May and October 2004 and all 28 sites once between June and September 2005. Effects of recreation on native animals are more strongly associated with weekday rather than weekend or holiday visitation patterns (Van der Zande et al. 1984). Accordingly, we visited sites on weekdays for several hours during the morning or afternoon. We conducted transect searches to detect scats of native carnivores and domestic dogs as an index of species' abundances or activity levels. Scat surveys are an efficient method with which to detect multiple species and are used frequently to gather information on the composition and species richness of carnivores (Long et al. 2008), and scat abundance is closely correlated with the species' abundance (Wilson & Delahay 2001; Harrison et al. 2004) and population densities (Stander 1998). The target species of our surveys were native carnivores that are relatively common in the study area—mountain lion (*Puma concolor*), coyote (*Canis latrans*), bobcat (*Lynx rufus*), and gray fox (*Urocyon cinereoargenteus*)—and domestic dogs.

In each site we established four, 500-m transects. Transects were located along mapped recreational trails in the recreation sites and along closed roads or trails in the reference sites. The trails and roads we surveyed had a gravel or natural surface and were 1–5 m wide. To minimize possible effects of adjacent land use on our inferences about carnivore distributions, we stratified the locations of transects between the edge (<500 m from the perimeter) and interior (>500 m from the perimeter) of each site.

We collected and recorded the location of each probable mammalian carnivore scat and stored the scat in a paper bag with a clay desiccant pack (Desi-Pak, Texas Technologies, Cedar Park, Texas). We also recorded the coordinates of all domestic dog scats detected with a geographic positioning system. Because there were a large number of dog scats present, we did not collect them when we could identify them visually as dog scat. We

Table 1. Site characteristics and recreational visitation as a function of domestic-dog management policy in 28 protected areas in northern California.*

Variable	*Range*	*Offleash*	*Onleash*	*Excluded*	*Reference*	F	p	*Means comparison*
Site characteristic								
area (ha)	41.7–1962.2	316.1 (165.8)	150.6 (191.2)	626.8 (760.8)	147.0 (96.9)	2.43	0.090	
mean elevation (m)	33.6–524.0	158.8 (77.5)	146.7 (167.9)	226.2 (118.4)	202.2 (95.9)	0.63	0.602	
mean slope (°)	2.4–25.3	18.7 (4.2)	8.5 (6.6)	14.8 (2.1)	14.9 (3.6)	6.66	0.002	offleash>onleash
herbaceous cover (%)	0–100	33.9 (26.5)	36.2 (39.2)	14.2 (7.9)	41.7 (24.4)	1.01	0.404	
hardwood cover (%)	0–97.4	56.3 (26.7)	31.3 (32.9)	65.2 (11.2)	34.9 (18.6)	2.81	0.061	
Recreational visitation								
trail length (km)	2.0–33.2	10.9 (7.6)	7.8 (4.1)	18.3 (11.5)		2.71	0.094	
trail density (km/ha)	0.5–16.8	3.6 (1.4)	8.1 (4.5)	5.4 (3.9)		3.57	0.049	onleash>offleash
adjacent properties	24–3668	1279.6 (1085.4)	593.3 (410.9)	777.2 (885.3)		1.33	0.289	
human visitation* (per hour)	0–29.4	3.8 (4.2)	9.6 (10.7)	4.0 (4.9)		1.49	0.253	
dog visitation* (per hour)	0–8.9	2.0 (2.5)	3.1 (3.6)	0		1.97	0.168	

**Mean values (SD) for all surveys conducted in 2004 and 2005.*

also recorded the coordinates and number of people and dogs in each group of recreational visitors encountered during the transect surveys.

Scat Identification

We analyzed all scats collected in 2005, but only scats collected from a subset of sites in 2004 due to budget constraints. We took two subsamples (approximately 500 mg) of each scat within 3 d of collection and stored them at −80 °C. Between October 2005 and September 2006, we used QiagenQIAamp DNA stool extraction kits (Qiagen, Valencia, California) to extract DNA from the scats. We performed polymerase chain reaction (PCR) with the HCarn200 (Bidlack et al. 2007) and CanidL1 (Paxinos et al. 1997) primers to amplify the first 196 bp of the mitochondrial cytochrome b gene. We then used restriction fragment length polymorphisms (RFLP) to identify the amplified DNA fragments to species. Laboratory methods for DNA extraction, amplification, and identification are described in detail in Bidlack et al. (2007) and Reed & Merenlender (2008). We repeated PCR-RFLP analyses for scats collected in each study site until we had identified a minimum of 75% of the samples to species.

Spatial Analyses

We used a spatial database of protected lands in the San Francisco Bay Area (BAOSC 2009) to identify the locations of all recreation and reference sites in ArcGIS 9.1 (ESRI, Redlands, California). When two recreation areas were contiguous and managed by the same agency, we considered them a single study site. We calculated the total area of each site, mean elevation, and slope from a 30-m digital elevation model (DEM) and the proportion of land cover in dominant vegetation types (hardwood and herbaceous) (USFS 2005).

We also calculated several variables that we hypothesized were proxies of intensity of visitation to the recreation areas: trail length, trail density, and adjacent human population density. We used trail maps provided by the managing agencies to determine the total length of the trails, and we divided the trail length by site area to calculate trail density. We calculated the number of residential properties within 500 m of the site boundaries as an index of adjacent human population density.

Statistical Analyses

We performed all statistical analyses in JMP 6.0 (SAS Institute, Cary, North Carolina). We used one-way analyses of variance (ANOVA) to compare area, elevation, slope, and land cover of study sites with different dog policies and to compare trail length, trail density, number of adjacent residential properties, and observed numbers of human and dog visitors among sites.

We examined variation in the number and location of visitors and the relative abundance of scats over time to determine whether data from 2004 and 2005 could be pooled. We used paired-sample t tests (Zar 1999) to compare the rates of visitation (number of people and dogs detected per hour) in six sites between 2004 and 2005 and to compare the total abundance of carnivore scats collected in 15 sites between 2004 and 2005.

We hypothesized that scats could accumulate after the last substantial rain event of the year, which typically occurs in April. Alternatively, scats could be trampled on or removed from the survey transects. Therefore, we tested for trends in scat accumulation with a linear regression of total scat abundance versus the number of days since the first transect survey. To test whether the relative abundance of all carnivore scats could serve as a reasonable proxy for relative abundance of native carnivore scats, we examined the correlation between the total number of scats collected in each site and the number of scats attributed to native carnivores in PCR-RFLP analyses.

To investigate whether dog policies influenced carnivores in protected areas, we used scats to compare native carnivore species richness, relative abundance of each species, and relative abundance of all native carnivores among the three management types and reference sites. We calculated scat abundance as the number of carnivore scats detected divided by the length of the transect (Harrison et al. 2004), and we approximated total carnivore abundances for each transect by extrapolating the overall proportions of scats from each species detected in the site to samples we were unable to identify in the laboratory. Because we expected the distributions of species' scats among sites to violate the assumption of normality for parametric tests (Potvin & Roff 1993), we rank-transformed the species richness and abundance data and compared the ranked values among the four site types. When we found differences ($p < 0.05$) among the site types in an ANOVA, we used Tukey's honestly significant difference (HSD) test to identify differences between pairs of means.

We also examined the relations between the numbers of human and dog visitors and the relative abundance of carnivore scats in the study sites. We calculated human and dog visitation rates as the number of people and dogs observed divided by the time spent surveying each transect. We used a model-selection approach (Burnham & Anderson 2002) to identify the factors that best explained variation in total scat abundance and the abundances of scats of the most common native carnivore species. In addition to the human and dog visitation rates, we included as covariates interactions between the two visitation rates; site area, elevation, slope, and land cover; and trail distance, trail density, and number of adjacent residential properties. We transformed the variables to meet the assumption of normality and compared univariate models for each of the 14 covariates with Akaike information criterion with a small sample size adjustment (AIC_c). When a model including human or dog visitation rate had strong support ($w_i > 0.5$), we used quantile regression (Cade & Noon 2003) to further explore the relation between visitation rate and relative abundances of scats.

Results

Differences among Sites and over Time

There were no significant differences in area or elevation among the recreation areas and reference sites, but sites where dogs were required to be onleash had shallower slopes than where dogs could be offleash ($F = 6.66, p < 0.01$; Table 1). The study sites had a mean of 47% hardwood cover and 33% herbaceous cover, and sites that excluded dogs had the highest percentage of hardwood cover (65%; $F = 2.81, p = 0.06$). Sites where dogs were required to be onleash had the highest density of recreational trails ($F = 3.57, p = 0.05$). Human and dog visitation rates were highly variable among study sites.

We found no significant differences in paired comparisons of the number of human visitors ($t = 0.520$, $p = 0.63$) or domestic dogs ($t = 1.058$, $p = 0.34$) between years. Overall abundance of scats was greater in 2005 than 2004 ($t = 2.141$, $p = 0.05$). Some of this difference may have been attributable to the fact that we averaged scat abundance values for sites visited twice in 2004. We did not find evidence of a significant trend in scat accumulation or removal over time. The number of scat detections increased slightly over the course of the season in 2005 (0.055 scats·km^{-1}·day^{-1}), but the correlation was very weak ($R^2 = 0.04, p = 0.31$).

We identified an average of 86.6% of the scats collected in each site in PCR-RFLP analyses. There was a strong, positive correlation ($R^2 = 0.98, p < 0.01$; Fig. 1) between the total number of scats detected in each site and the number of scats attributed to native carnivores (mountain lions, coyotes, bobcats, and gray foxes).

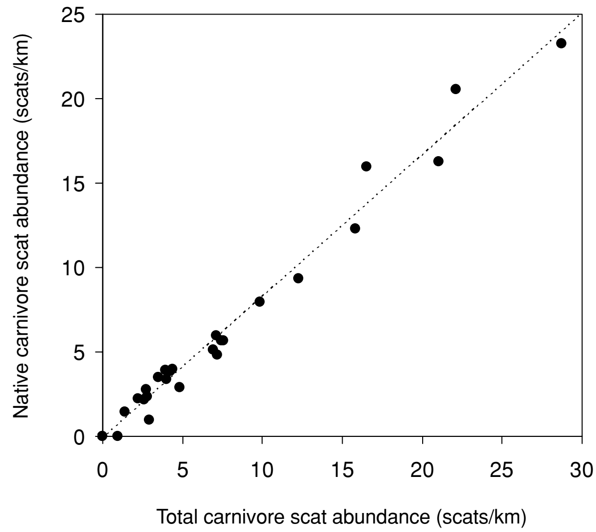

Figure 1. Total abundance of mammalian carnivore scats observed (excluding domestic dog) versus the abundance of native carnivore (coyote, bobcat, gray fox, mountain lion) scats identified by PCR-RFLP analysis in 28 protected areas in northern California.

Influence of Dog Policy

We detected scats from fewer native species in the recreation areas than in the reference sites ($F = 4.80, p < 0.01$), but there were no significant differences among recreation areas with different dog policies (Fig. 2a). Mean scat abundances for both coyotes ($F = 10.69, p < 0.001$) and bobcats ($F = 5.32$, $p < 0.01$) were much greater in the reference sites than in the three types of recreation areas (Figs. 2b & 2c). Sample sizes for mountain lion and gray fox scat were too small to detect differences in the ANOVA. Mountain lion scats, however, were detected only in the reference sites, and abundance of gray fox scat was 3.4 times greater in the reference sites than in the recreation areas. Pooling results for 2004 and 2005, total abundance of carnivore scat was also greater in the reference sites than in the three types of recreation areas ($F = 10.62, p < 0.01$; Fig. 2d). The relative abundance of domestic dog scats varied by dog policy and was much greater in sites where dogs were permitted (offleash and onleash) than in sites where dogs were not permitted (excluded and reference) ($F = 25.29, p < 0.01$; Fig. 2e). Scats from domestic cats and red foxes were detected infrequently, and we did not observe any variation in their abundances by dog policy.

Influence of Recreational Visitation

None of the models of site characteristics or visitation rates explained variation in coyote scat abundance across the study area (Table 2). In contrast, the total weight of visitation models for both bobcat ($\Sigma w_i = 0.994$) and total carnivore ($\Sigma w_i = 0.983$) scat abundances far exceeded the model weights for topography and land cover or proxy measures of recreational activity. The additive model of human and dog visitation explained the most variation in both bobcat and total carnivore scat abundances. None of the measures of topography or vegetation that varied among sites with different dog policies (Table 1) were strongly related to carnivore scat abundance in regression models (Table 2).

In quantile regression analyses, the slopes of the relations between bobcat and total carnivore scat abundances and additive visitation (humans + dogs) decreased as scat abundances increased (Fig. 3). The slope decreased from 0 to -0.090 in the interquartile range of bobcat scat abundances and decreased from -0.089 to -0.195 in the interquartile range of total carnivore scat abundances.

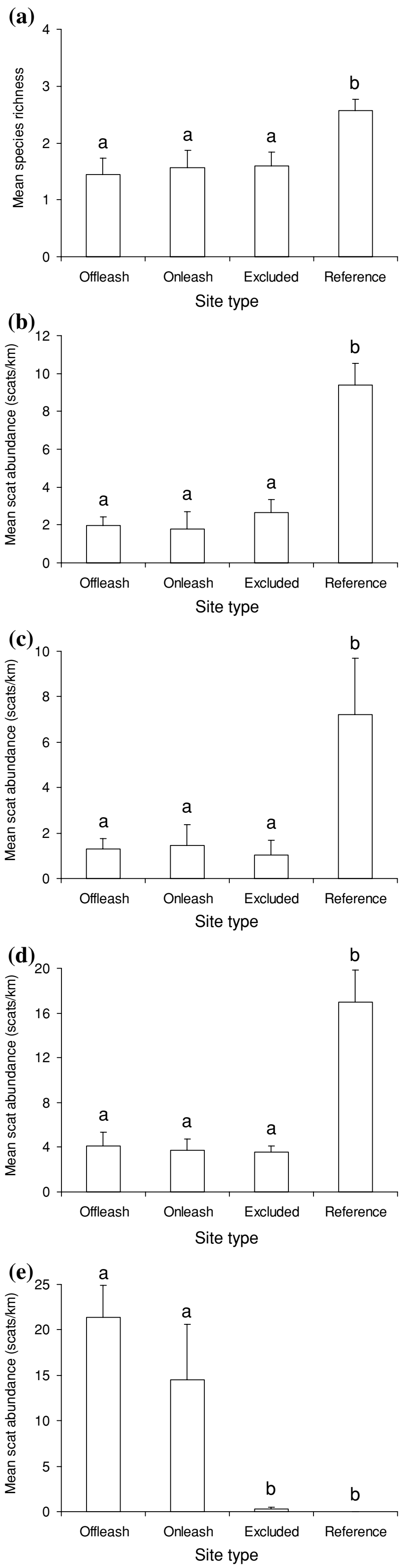

Figure 2. Association with domestic dog policy in protected areas and (a) species richness of native carnivores detected in scat surveys (2005), (b) coyote scat abundance (2005), (c) bobcat scat abundance (2005), (d) total carnivore scat abundance (2004–2005), and (e) domestic dog scat abundance (2005) (offleash, dogs allowed off leash, n = *9 sites; onleash, dogs allowed only onleash,* n = *7; excluded, humans allowed dogs excluded,* n = *5; reference, no public access,* n = *7); letters above bars, indicate means that are different [*p *< 0.05] according to a Tukey's honestly significant difference test).*

Discussion

We detected significantly more scats attributed to native carnivore species in the reference sites than in the recreation sites (Fig. 2a). Coyote and total carnivore scat abundances were over four times greater and bobcat scat abundances were over five times greater in reference sites (Figs. 2b–d). Among the three types of recreation areas, native carnivore abundance and species richness did not differ significantly. These results suggest the dog policies at the sites we studied do not mitigate the effects of recreation on native carnivores in protected areas. The key factor associated with effects of visitors on carnivores was whether a reserve was open to the public—a result that is consistent with our findings in a different suite of research sites (Reed & Merenlender 2008).

We did not observe any dogs during our surveys in human-only recreation areas (Table 1), but we found domestic dog scats in all the recreation sites we surveyed, including a small number in sites where dogs were not allowed (Fig. 2e). Stray and feral dogs are not common in our study area; 90–95% of dogs captured by county animal control programs had owners who were contacted successfully (K. Fenneland and R. Garcia, personal communication). Thus, given the strong, positive correlation between human and dog visitation rates we observed ($R^2 = 0.54$, $p < 0.01$), we speculate that the presence of domestic dog scats in human-only recreation areas was primarily attributable to illegal dog walking. We also observed dogs offleash in sites where they were required to be onleash. Limited compliance with dog regulations may obscure the effects of dog policies on native animal populations in protected areas (Forrest & St. Clair 2006).

Despite the infractions we inferred, the relative abundance of domestic dog scats was 158 times greater in sites where they were permitted than in sites where they were excluded (Fig. 2e). In contrast to other studies (e.g., Lenth et al. 2008), we did not find a strong, negative correlation between the relative abundances of domestic dog scats and native carnivore scats (Table 2). This difference may have occurred because we investigated the relations between dog and native carnivore scat abundances at the site-level rather than along individual transects. It could also be attributable to variable enforcement of regulations

Table 2. Results of linear regression models of the response of coyote and bobcat scat abundance and total carnivore scat abundance to site characteristics (area, elevation, slope, and land cover), proxy measures of visitation (trail length, trail density, and number of adjacent residential properties), and observed rates of visitation by humans and dogs in 21 recreation areas in northern California.

	Coyote scat abundance (scats/km; 2005)						Bobcat scat abundance[a] (scats/km; 2005)						Total scat abundance (scats/km; 2004–2005)					
Model	*est*	*log*(L)	K	AIC_c	d_i	w_i	*est*	*log*(L)	K	AIC_c	d_i	w_i	*est*	*log*(L)	K	AIC_c	d_i	w_i
Null		−179.115	2	17.916	0	0.159		117.280	2	−10.312	14.520	0.001		−405.085	2	39.437	10.948	0.003
Area[b,c]	0.0936	−194.778	3	20.248	2.332	0.050	0.018	107.339	3	−8.525	16.307	0.000	−0.00831	−425.075	3	42.181	13.692	0.001
Elev[c,d]	0.0999	−197.634	3	20.520	2.604	0.043	0.217	125.798	3	−10.283	14.549	0.001	0.493	−411.750	3	40.912	12.423	0.001
Slope[e]	0.000655	−199.115	3	20.661	2.745	0.040	0.0272	109.428	3	−8.724	16.108	0.000	0.0848	−414.029	3	41.129	12.640	0.001
P_heb[c,f]	−0.862	−194.442	3	20.216	2.300	0.050	1.31	142.587	3	−11.882	12.950	0.001	−1.39	−420.728	3	41.767	13.278	0.001
P_hwd[g]	0.640	−195.618	3	20.328	2.412	0.048	−1.12	142.671	3	−11.890	12.942	0.001	−0.332	−424.749	3	42.150	13.661	0.001
Trail[h,i]	−0.0987	−198.558	3	20.608	2.692	0.041	−0.127	100.860	3	−7.908	16.924	0.000	−1.18	−394.404	3	39.260	10.771	0.003
Trail_dens[j]	−1.05	−182.189	3	19.049	1.133	0.090	−0.376	105.480	3	−8.348	16.484	0.000	−2.05	−401.502	3	39.936	11.447	0.002
Adj_par[i,k]	−0.0749	−194.085	3	20.182	2.266	0.051	−0.104	137.285	3	−11.377	13.455	0.001	−0.344	−383.726	3	38.243	9.754	0.005
Dog_scat[a,l]	0.0546	−198.395	3	20.592	2.677	0.042	−0.0448	101.124	3	−7.933	16.899	0.000	−0.135	−421.834	3	41.872	13.383	0.001
Humans[c,m]	−0.320	−190.400	3	19.831	1.915	0.061	−0.582	247.440	3	−21.868	2.964	0.180	−2.01	−313.533	3	31.558	3.069	0.130
Dogs[a,n]	−0.527	−178.430	3	18.691	0.775	0.108	−0.529	190.761	3	−16.470	8.362	0.012	−1.53	−312.809	3	31.489	3.000	0.134
Humans[c,o] + dogs	−0.883			−0.338	−187.386	3	19.544	1.628	0.070		−0.568	278.562	3	−24.832	0	0.793	−2.00	–
281.309	3	28.489	0	0.603														
Humans* dogs[c,p]	−0.288	−172.004	3	18.079	0.163	0.146	−0.248	185.522	3	−15.971	8.861	0.009	−0.903	−315.948	3	31.788	3.299	0.116

[a] *Variable transformed to meet the assumption of normality for linear regression:* $x^{\frac{1}{2}}$.
[b] *Site area (ha).*
[c] *Variable transformed to meet the assumption of normality for linear regression:* $x^{1/2}$.
[d] *Mean elevation (m).*
[e] *Mean slope (°).*
[f] *Herbaceous land cover (%).*
[g] *Hardwood land cover (%).*
[h] *Total length of recreational trails (km).*
[i] *Variable transformed to meet the assumption of normality for linear regression: log(x).*
[j] *Trail density (km/ha).*
[k] *Number of adjacent residential properties.*
[l] *Abundance of domestic dog scats (scat/km).*
[m] *Human visitation rate (humans/hour).*
[n] *Dog visitation rate (dogs/hour).*
[o] *Additive interaction between human and dog visitation rates (humans + dogs/hour).*
[p] *Multiplicative interaction between human and dog visitation rates (humans*dogs/hour).*

requiring dog owners to remove their pets' scats or to an unmeasured effect of the scent-marking behavior of native carnivores or domestic dogs (Lenth et al. 2008). In general, however, carnivore scat abundance was not related to proxy measures of human visitation to the recreation areas (trail length, trail density, and number of adjacent residential properties). Instead, estimates of human and dog activity levels obtained from direct observation were more closely associated with abundance of carnivore scats (Table 2). Many researchers note there are few data on recreational visitation to protected areas (e.g., Hill & Courtney 2006; Lenth et al. 2008; Balmford et al. 2009), and this data gap may limit the measurement and prediction of impacts of recreation on native species.

The number of human visitors and dogs was associated with many fewer observations of scats of bobcats than coyotes (Table 2). This finding for bobcats is consistent with prior observations in protected areas in southern California and Colorado (George & Crooks 2006; Lenth et al. 2008). Total carnivore scat abundance also decreased as visitation rates increased. Although coyote scats were widespread and abundant throughout the study area, total carnivore scat abundance more closely resembled that of bobcats, presumably because scats of the less common mountain lions and gray foxes also declined in abundance as the visitation rates of humans and dogs increased. Our laboratory analyses suggested that when it is possible to visually distinguish domestic dog scats, total mammalian carnivore scat abundance is a reliable indicator of the relative abundance of scat of native species (Fig. 1).

Due to the relation between human and dog visitation rates (Table 1), we could not separate the effects of human from the effects of dogs. In fact, the additive interaction between the visitation rates of humans and dogs best explained variation in both bobcat and total carnivore scat abundances (Table 2), which suggests carnivores may be responding to the overall level of recreation in a site. Moreover, in quantile regressions, the slope of the relation with additive visitation decreased—and thereby the magnitude of species' response to recreational activity increased—for increasing quantiles of both bobcat and total carnivore scat abundances (Fig. 3). This means that in places where carnivore abundances are high, recreation could have a greater effect on carnivores.

Given the uncertainty about the effectiveness of domestic dog policies and costs associated with enforcing management regulations (Dixon & Sherman 1991), we believe that enforcing leash laws may not be the best use of limited management resources. Prohibiting dogs in protected areas, however, may affect human visitation rates. Although many factors affect visitation to protected areas, including distance and accessibility to human population centers, topography, land cover, and site amenities (Hill & Courtney 2006; Reed & Seymour 2008), in our study, recreation areas that allowed dogs had 60% more human visitors than those that did not (Table 1). This suggests that people may be more attracted to sites where they are permitted to bring dogs. Visitation, in turn, was associated with the distribution and relative abundances of native carnivore scats in our study sites (Table 2). Because controlling visitation is likely to be even more difficult and expensive than enforcing domestic dog policies, we suggest that designating some sites as recreation areas open to the public and others as nature reserves closed to the public may be the most efficient strategy for managing the effects of recreation on carnivores.

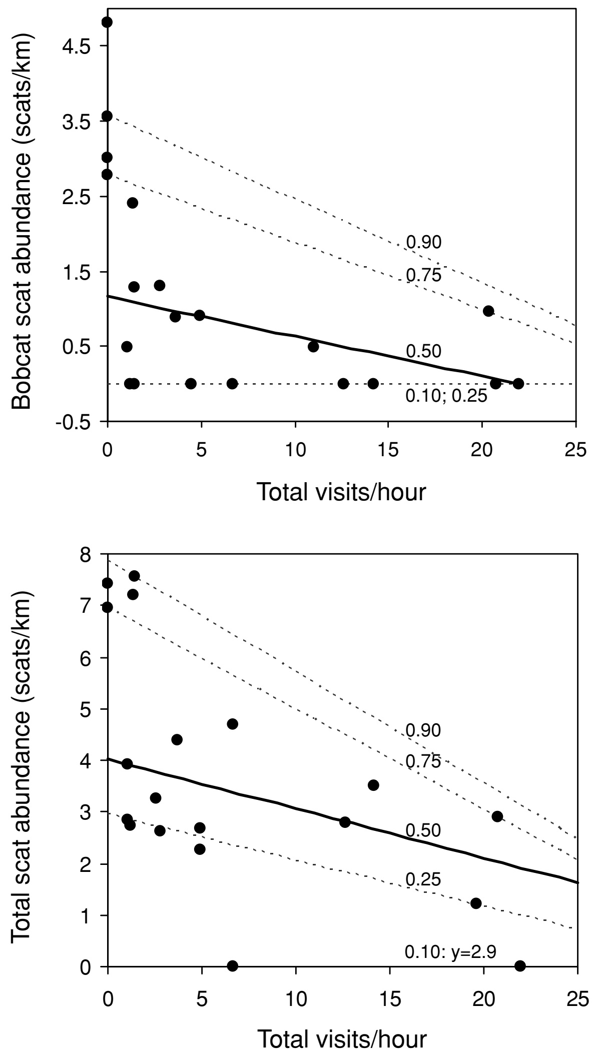

Figure 3. Bobcat scat abundance (2005 only) and total carnivore scat abundance (2004–2005) versus human and dog visitation rates in 21 recreation areas in northern California. Linear-regression model estimates are shown for the 0.90, 0.75, 0.50, 0.25, and 0.10 quantiles of the distributions of scat abundances.

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