

The Effects of Dogs on Wildlife Communities

Author(s): Benjamin E. Lenth, Richard L. Knight, Mark E. Brennan

Source: Natural Areas Journal, 28(3):218-227. 2008.

Published By: Natural Areas Association

DOI: [http://dx.doi.org/10.3375/0885-8608\(2008\)28\[218:TEODOW\]2.0.CO;2](http://dx.doi.org/10.3375/0885-8608(2008)28[218:TEODOW]2.0.CO;2)

URL: <http://www.bioone.org/doi/full/10.3375/0885-8608%282008%2928%5B218%3ATEODOW%5D2.0.CO%3B2>

BioOne (www.bioone.org) is a nonprofit, online aggregation of core research in the biological, ecological, and environmental sciences. BioOne provides a sustainable online platform for over 170 journals and books published by nonprofit societies, associations, museums, institutions, and presses.

Your use of this PDF, the BioOne Web site, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at www.bioone.org/page/terms_of_use.

Usage of BioOne content is strictly limited to personal, educational, and non-commercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

The Effects of Dogs on Wildlife Communities

Benjamin E. Lenth^{1,2}

Richard L. Knight

Department of Forest, Rangeland &
Watershed Stewardship
Colorado State University
Fort Collins, CO 80523-1472

Mark E. Brennan

Boulder County Parks and Open Space
5201 St. Vrain Rd.
Longmont, CO 80503

¹ Corresponding author:
Ben.Lenth@gmail.com

² Current address:
Grupo Ecológico Sierra Gorda
Carlos Septiem Garcia #46
Col. Cimatario, C.P. 76030
Querétaro, México

ABSTRACT: Domestic dogs (*Canis familiaris*) are frequent visitors to protected areas, but little is known about how they affect wildlife communities. We studied the effects of dogs on wildlife communities by comparing the activity levels of wildlife in areas that prohibited dogs with areas that allowed dogs. We measured wildlife activity on trails and up to 200 m away from trails using five methods: (1) pellet plots, (2) track plates, (3) remote triggered cameras, (4) on-trail scat surveys, and (5) mapping prairie dog (*Cynomys ludovicianus*) burrow locations. The presence of dogs along recreational trails correlated with altered patterns of habitat utilization by several species. Mule deer (*Odocoileus hemionus*) activity was significantly lower within 100 m of trails in areas that allowed dogs than in areas that prohibited dogs. Small mammals, including squirrels (*Sciurus* spp.) and rabbits (*Sylvilagus* spp.), also exhibited reduced levels of activity within 50 m of trails in areas that allowed dogs when compared with areas without. The density of prairie dog burrows was lower within 25 m of trails in areas that allowed dogs. The presence of dogs also affected carnivore activity. Bobcat (*Felis rufus*) detections were lower in areas that allowed dogs, and red fox (*Vulpes vulpes*) detections were higher. These findings have implications for the management of natural areas, particularly those that allow dogs to be off-leash.

Index terms: domestic dogs, mule deer, protected area management, recreation, recreational trails

INTRODUCTION

Domestic dogs (*Canis familiaris*) are ubiquitous in human society, yet we know relatively little about their ecology or interspecific interactions with wildlife. Numbering approximately 400 million worldwide, with 74.8 million in the United States alone, domestic dogs far outnumber all other canids combined (Coppinger and Coppinger 2001; APPMA 2007). Dogs frequently accompany recreationists to protected areas, and can be the most common carnivore in these areas (Butler et al. 2004). Outdoor recreation is growing rapidly in popularity with a variety of impacts to wildlife (Knight and Gutzwiller 1995). Many consider dogs to be a major component of these impacts, particularly when they are present in high densities (Sime 1999). Dogs are also a ubiquitous component of exurban development (Odell and Knight 2001; Maestas et al. 2003), which comprises 25% of all private land in the contiguous U.S. (Brown et al. 2005). The impacts of these elevated dog numbers on wildlife are presently not understood (Bekoff and Meaney 1997; Sime 1999).

Dogs have a unique ecology in natural areas, with notable differences from native canids. Unlike wild canids, dogs are inefficient hunters, but avid chasers (Serpell 1995). Most dogs in protected areas in the United States are pets, and have their food requirements met at home, allowing them ample energy with which to interact with wildlife. Because most dogs accompany

recreationists, their activity patterns are concentrated during daylight hours along trails, whereas wild canids roam freely and are most active during crepuscular and nocturnal periods, particularly when humans are frequently present (George and Crooks 2006). Also, dogs lack the defined, hierarchical social structure of native canid packs, and do not ecologically mimic their native counterparts (Fox 1971; Daniels and Bekoff 1989).

Nonetheless, dogs behave as carnivores and are capable of catching and killing prey species, such as white-tailed deer (*Odocoileus virginianus*) (Lowry and McCarthur 1978), including the endangered Key deer subspecies (*Odocoileus virginianus clavium*) (U.S. Fish and Wildlife Service 1999), small mammals (Scott and Causey 1973), herpetofauna such as the endangered gopher tortoise (*Gopherus polyphemus*) (Causey and Cude 1978), and ground-nesting birds such as wild turkeys (*Meleagris gallopavo*) (Miller and Leopold 1992). Numerous breeds of dogs have been specifically bred for hunting, with specialized traits for finding and catching prey, while others are bred for racing or fighting, making them potentially dangerous to wildlife (Serpell 1995). Even without being chased, animals that are prey of wild canids may perceive dogs as predators and may be subject to non-lethal, fear-based alterations in physiology, activity, and habitat use (MacArthur et al. 1982; Lima 1998; Miller et al. 2001), with potentially complex effects (Ripple and Beschta 2004).

Most carnivores avoid direct interaction and conflict through the use of olfactory (Gorman and Towbridge 1989) and auditory (Peters and Wozencraft 1989) communication. Carnivores, including dogs, often recognize and avoid areas scent-marked by other individuals or packs (Bekoff 1979; Gorman and Towbridge 1989). Wild canids sometimes increase their activity along the periphery of their territories, where they encounter novel stimuli and invest time in territorial surveillance and maintenance (Allen et al. 1999). Recreational trails with abundant dog scent could appear to carnivores to be linear dog territories, necessitating increased vigilance and activity. Such opportunities may arise due to carnivores' propensity to travel along trails, which often present the easiest route in rough terrain (Kohn et al. 1999). Some carnivores also interbreed with dogs, and may also be attracted to dogs for this reason (Mengel 1971; Laurenson et al. 1998). Thus, through direct and indirect interactions, dogs could potentially attract or repel native carnivores, depending on the species and nature of past interactions. Carnivores are often disproportionately important to the structure and function of ecosystems, so the ramifications of alterations in carnivore activity could be considerable, potentially cascading through an ecosystem (Soulé et al. 2005).

We investigated the cumulative effects of the presence of dogs on wildlife activity, including carnivores, ungulates, and small mammals. In 2004 and 2005, we measured the activity levels of mammals in two protected areas in Boulder County, Colorado, that prohibit dogs and in two areas that allow dogs off-leash under "voice and sight control." Within these areas, we selected trails with similar levels of recreational use, and measured dog and mammal activity along the trails and also up to 200 m off-trail. We hypothesized that the presence of dogs in protected areas would influence the activity of wildlife, and that these effects would extend away from trails. While we expected deer and small mammals to be less active where dogs are present, we did not know whether carnivores would be attracted or repelled by dogs.

METHODS

Study site selection

In Boulder County, Colorado, Boulder County Parks and Open Space (BCPOS) and the City of Boulder Open Space and Mountain Parks (OSMP) have protected over 45,810 ha of open space lands, with over 320 km of designated recreational trails that cumulatively receive over 7 million recreational visits annually (BCPOS and OSMP staff, pers. comm.). Over 25% of these visitors are accompanied by dogs, adding over 2 million dog visits annually (Mertz 2002; BCPOS staff). BCPOS manages Heil Valley Ranch (1993 ha) and Hall Ranch (1297 ha), both of which prohibit dogs and were chosen as study sites. To compare with the no-dog sites, we chose two OSMP areas where dogs are allowed off-leash under "voice and sight" control. OSMP North (~1203 ha) and OSMP South (~987 ha) were chosen to match the first two sites as closely as possible using the following criteria:

1. Ecological characteristics: All sites were within the foothills, with elevation ranging from 1615-2590 m in ponderosa pine (*Pinus ponderosa*) and Douglas fir (*Pseudotsuga mensiesii*) forests, with meadows and varied terrain.
2. Equivalent visitation: Because current visitation estimates were not available for OSMP sites, we followed staff recommendations to choose OSMP trails that were roughly matched to visitation levels for Heil Valley Ranch (48,890 annual visits in 2003) and Hall Ranch (74,112 visits) (BCPOS staff). The equivalence of visitation levels among sites was confirmed empirically using Trailmaster® trail counters to estimate average hourly recreational visitation for each trail segment (Watson et al. 2000). Counts were presumed to consistently represent visitation along a trail, with the majority caused by humans and pets, and each visitor counted only once (Watson et al. 2000). Heavy weekend visitation was disproportionately important to visitation estimates. Because the number of weekday and weekend

sampling days varied for each site, we gave equal weight to weekday and weekend hourly visitation rates using the following adjustment:

$$\text{Visitation (normalized)} = (5/7) * \text{weekday visitation} + (2/7) * \text{weekend visitation}.$$

These data were intended to test visitation rates of humans alone, but 30% of OSMP visitors are accompanied by dogs, adding to visitation counts (Mertz 2002). To test visitation rates by humans across policies, we further adjusted the event data for OSMP sites by assuming that 30% of visitors were accompanied by dogs, so the total events equaled 130% of human-triggered events. Thus, the proportion of events excluding dogs to total events was $100\% / 130\% = 0.769$, with which we multiplied all OSMP visitation estimates to calculate an adjusted hourly visitation estimate. We then tested the equivalence of visitation across dog policies using a Satterthwaite t-test (PROC TTEST in SAS). Visitation did not differ between dog policies ($df = 60$, $t = 0.57$, $p = 0.5738$).

3. In all study sites, we excluded areas that were within 300 m of roads and structures or where slope exceeded 35°. Different types of recreationists – hikers, mountain bikers, and equestrians – were assumed to have similar impacts to wildlife (Taylor and Knight 2003).

Field methods

To create indices of wildlife activity for comparison across dog policies, we used five methods: (1) pellet plots, (2) track plates, (3) remote-triggered cameras, (4) on-trail scat transects, and (5) mapping of prairie dog (*Cynomys ludovicianus*) burrow location in relation to trails. We randomly located sampling locations along trails by identifying a sampling interval (total length of trails in a site / number of transects), choosing a random number within this interval to place the first transect, then spacing subsequent transects at the pre-determined sampling intervals to

maximize trail coverage (minimum spacing between transects = 500 m to ensure independence). At each sampling location, transects of pellet plots and track plates ran perpendicular to trails on one side, avoiding other trails and steep slopes, with one sampling point placed randomly within each of three distance categories from the trail: 0-5 m, 50-100 m, and 150-200 m. Camera sampling and scat surveys were performed on-trail only, located independently, and at least 200 m from pellet plot and track plate transects. Track plates and scat surveys were not performed within 2 km of active camera traps. For all field methods, sampling effort was equivalent across the two dog policies.

1. Pellet plots: Activity and habitat utilization of herbivores (deer (*Odocoileus* spp.) and rabbits (*Sylvilagus* spp.)) were measured using pellet-group counts in 100-m² circular plots (Collins 1981). One set of plots was cleared during summer 2004 and re-checked 12 months later (n = 72), and a second set of plots was cleared early summer 2005 and re-checked three months later (n = 48).
2. Track plates: Mammal activity was measured by the use of scented track plates (n = 150 locations), which consisted of a 1 m² aluminum plate, coated with talc, with a carnivore lure (Carmen's Pro's Choice and Canine Call, Sterling Trap and Fur, Sterling, Iowa) in the middle of the plate (Sargeant et al. 2003). While these plates primarily targeted mid-sized carnivores, they were also used in the detection of small mammals (Glennon et al. 2002). Small mammal tracks were not identifiable to all species, but potentially included rabbits, squirrels (*Sciurus* spp.), chipmunks (*Tamias* spp.), ground squirrels (*Spermophilus* spp.), mice (*Peromyscus* spp., *Reithrodontomys* spp., *Onychomys* spp., *Zapus* spp., *Mus* spp.), voles (*Clethrionomys* spp., *Phenacomys* spp., *Microtus* spp.), and rats (*Neotoma* spp.) (Fitzgerald et al. 1994). For analysis, these small mammal species were lumped together. There were not enough native carnivore tracks for analysis. Plates were checked daily for three rain-free nights, for a total of 450 track nights. On each visit,

tracks were photographed and identified (Halfpenny 2001), plates were cleaned and re-sprayed with talc, and lure was reapplied. Sampling locations were considered independent, but the three nights were not independent and were collapsed into a single data point.

3. Remote-triggered cameras: TrailMaster® cameras were used to monitor a variety of mammal species with unambiguous identifications (Cutler and Swann 1999). From May to September 2005, we placed 10 to 11 cameras across recreational trails for two weeks (mean = 13.5 nights, S.D. = 2.4) at two sites simultaneously, totaling 837 camera nights. The cameras were aligned at a height of .2-.6 m to detect medium-sized carnivores, and vegetation was cleared from the beam path to prevent false events. Camera locations were baited using the same commercial carnivore lures as the track plates. Cameras were revisited every 2-5 days to check on their function, replace film and batteries, and reapply the lure. Due to high recreational visitation during the day, cameras were only active from ~8:00 PM to ~8:00 AM. The infrared trigger was set for high sensitivity (2 to 4), with a delay of 3 minutes to avoid repeated photos of a single animal. Cameras were hidden using camouflage materials and were cable-locked to trees with signs explaining their purpose.
4. On-trail scat surveys: Scat surveys were conducted from July 2004 through October 2005 on the longest continuous route of trails in each site. Every two weeks (mean = 17 days), each trail was walked and scat were identified (Halfpenny 2001) and cleared from the trail (n = 2,234).
5. Prairie dogs: We identified seven recreational trails that ran through prairie dog colonies, each with a relatively "unbounded" geography that did not limit the movement of prairie dogs or the location of their burrows (Johnson and Collinge 2004). Three of these trails were in areas that did not allow dogs, and four were in areas that allow dogs off-leash under "voice and sight

control." We selected segments of these trails where prairie dog burrows existed continuously from the trail up to at least 200 m from the trail on one side. We identified active burrows by observation of prairie dog activity, including fresh scat, evidence of digging, tracks, clear burrow openings, and prairie dogs themselves (Powell et al. 1994). With a laser rangefinder (Bushnell Yardage Pro®, accuracy +/- 2m), we measured the perpendicular distance from the trail to each active burrow within this trail segment up to 200 m from the trail.

Statistical analyses

We established $\alpha = 0.1$ a priori for model selection and statistical tests to limit the probability of Type II errors (Holling and Allen 2002). All variables and interactions included in full models were selected a priori as relevant to the biology of the response organisms, and did not include all possible combinations of variables. With the exception of the prairie dog and track plate data, mixed model analyses of variance (ANOVA) were performed using the method of Restricted Maximum Likelihood (REML) with PROC MIXED in Statistical Analysis Software (SAS Institute 1999). Model effects were eliminated one at a time, while ensuring interaction terms were dropped before their component variables, using $\alpha = 0.1$ as criteria to retain variables. Study sites were considered fixed effects, limiting inference to these specific areas.

1. Pellet plots: The density of pellet piles per ha sampled was square-root transformed to stabilize the variance. For both rabbit and mule deer (*Odocoileus hemionus*) pellet densities, the ANOVA model included fixed effects of dog policy, site (nested within policy), distance from trail (three categories, nested within policy), and the interactions of policy x distance from trail and site x distance from trail. The random effect was transect location (nested within site and policy). When the Type-III F-test was significant for distance categories or the interaction of distance categories and dog policy, pairwise comparisons were made with Fisher's-protected least-

significant-difference method (Ott and Longnecker 2001).

2. Track plates: The three nights of track plate data were combined into one whole number count of each species detected at each location, and were converted to an index of detection frequency (I) by dividing the count of detections per species (X) by the number of trap stations (n): $I = X/n$ (Sargeant et al. 1998). These data were then analyzed using a mixed model ANOVA for binomial data using PROC GLIMMIX in SAS. Full model variables and interactions were the same as in the pellet plot analysis described above. Response variables included the tracks of domestic dogs and a combination of small mammals including squirrels, rabbits, chipmunks, mice, and voles.
3. Remote triggered camera photo data: An index (I) of activity for photos was calculated by dividing the number of photos (X) for each species by the number of nights (n) the cameras were active: $I = X/n$. This dataset was square-root transformed to stabilize the variance, then analyzed using an ANOVA with the fixed effects of dog policy and site (nested within policy) and the random effect of transect location (nested within site and policy) (PROC MIXED in SAS). We also tested the correlation of dog activity with average visitation for each trail segment by fitting a linear regression between these variables (PROC REG in SAS).
4. On-trail scat surveys: Each surveyed trail was broken into 1-km segments ($n = 35$), and data were converted to a density of scats per km for each species. These densities were square-root transformed to stabilize the variance. Due to the difficulty of identifying scats morphologically (Green and Flinders 1981; Johnson and Beldon 1984), all native carnivore scat was combined. Densities for each trail segment were averaged per month, and these data were analyzed using a mixed model repeated-measures ANOVA. We initially considered the fixed effects of dog policy, site (nested within policy), month, the pres-

ence of a trailhead (nested within site), and 2-way interactions between policy, site, and trailhead. Kilometer segment location was considered a random effect and month as a repeated measures variable. We expected these data to be both temporally and spatially autocorrelated, so we modeled this autocorrelation using a first-order autoregression matrix AR(1) on both the month and kilometer segment variables (Ott and Longnecker 2001). We tested the appropriateness of the AR(1) covariance structure with asymptotic Wald Z-tests on the covariance parameter estimates within each model and eliminated the autocorrelation parameter when it was not significantly different from zero (SAS 1999). The simplest model was used for Type-III F-tests on each effect.

5. Prairie dog burrow location: Distance from each prairie dog burrow to the trail was pooled by dog policies and normalized for colony size by dividing the raw number of burrows extending up to 200 m from the trail by the length of the trail segment to create a density of burrows per meter of trail: $density = \# burrows / meters\ of\ trail$. This density was calculated for five a-priori truncations of the dataset focusing progressively closer to the trail: 200 m (full dataset), 100 m, 50 m, 25 m, and 10 m. Within each distance from the trail, we compared the mean burrow densities across dog policies using Satterthwaite t-tests (PROC TTEST in SAS).

RESULTS

Pellet plots

Pellet plot data indicated that the activity of mule deer and rabbits were both lower along trails in areas that allowed dogs and that the strength of this effect was influenced by distance from the trails. For both 12-month and 3-month summer pellet plots, dog policy and distance from the trails were significant predictors of deer activity (Figure 1). In areas that allowed dogs, deer pellet density was significantly lower 0-5 m from trails than 50-100 m

from trails and also 50-100 m than 150-200 m from trails (Table 1). In areas that prohibited dogs, deer activity was also lower within 5 m of trails than 50-100 m of trails, but deer activity did not differ between 50-100 m and 150-200 m from trails. Where dogs were allowed, deer were significantly less active than where dogs were prohibited both within 5 m and 50-100 m from trails.

Rabbit activity was significantly lower along trails in areas that allowed dogs, but trends varied between the 12-month and 3-month plots (Figure 2). For the one-year plots, dog policy ($F_{22} = 4.93, p = 0.04$) and distance from trail ($F_{44} = 2.89, p = 0.07$) were significant predictors of rabbit activity, but over the summer, only dog policy was significant ($F_{12} = 9.56, p = 0.01$). Over 12-months in areas that allowed dogs, rabbit activity was similarly low within 5 m from trails and 50-100 m from trails, but was significantly higher 150-200 m from trails (Table 2). Comparing between dog policies, areas that allowed dogs had lower rabbit activity over the course of a year at two distance categories from trails: within 5 m and within 50-100 m of trails.

Track plates

Dogs were not detected in areas where they were prohibited. In areas that allowed dogs, dogs traveled up to 85 m from trails, but most dog detections were within 5 m of trails. Track plate data indicated that activity of small mammals was inversely correlated with the presence of dogs (Figure 3). Within 5 m of trails, small mammal activity was significantly lower in areas that allowed dogs than in areas that prohibited dogs ($T_{94} = 3.36, p < 0.01$). Within areas that allowed dogs, small mammals were less active within 5 m of trails than 50 m or further from trails ($T_{94} = -3.63, p < 0.01$).

Remote-triggered cameras

Dog policy was a significant predictor of activity levels for a variety of species, including dogs, red foxes (*Vulpes vulpes*), bobcats (*Lynx rufus*), and all native carnivores combined (Table 3).

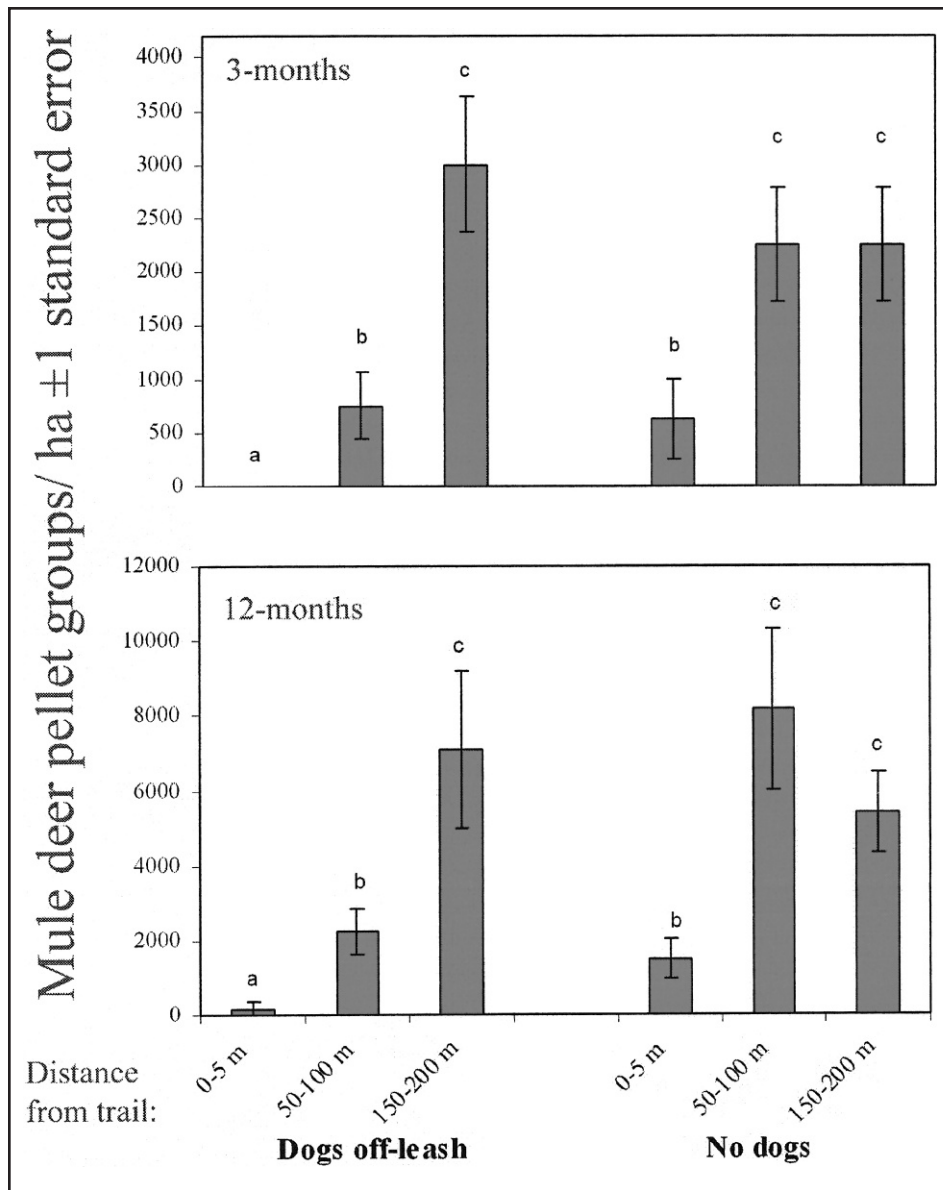


Figure 1. Twelve-month and three-month deer pellet densities by dog policy and distance from trail. Different letters above columns indicate significant differences ($p < 0.1$) for comparisons between adjacent distance categories within policies, and for the same distance category between policies, based on a square root transformation of the data presented.

Other carnivores detected included grey foxes (*Urocyon cinereoargenteus*), black bears (*Ursus americanus*), mountain lions (*Felis concolor*), striped skunks (*Mephitis mephitis*), coyotes (*Canis latrans*), and raccoons (*Procyon lotor*). Red foxes ($n = 67$) constituted 49% of all native carnivore photos ($n = 130$). As expected, dogs were photographed significantly more on trails in areas that allowed dogs than in areas that prohibited dogs. Dog activity was also correlated with human visitation ($R^2 = 0.218$, $F_{1,29} = 1.82$, $p = 0.01$). On

trails that allowed dogs, activity was also higher for all native carnivores combined, including native canids and especially red foxes, than along trails that prohibited dogs. Dog activity was inversely correlated with bobcat activity and rabbit activity.

On-trail scat surveys

On-trail scat surveys also showed dog policy to be a strong predictor of dog activity ($F_{1,34.5} = 61.32$, $p < 0.01$). Similar to the photo data, trails that allowed dogs

also had higher levels of native carnivore activity ($F_{1,38.2} = 19.01$, $p < 0.01$). Dog policy was not the sole significant predictor of scat density, however. For both dogs and native carnivores, seasonal variation was considerable, with higher scat density in the spring and summer (dogs: $F_{11,230} = 2.18$, $p = 0.02$; carnivores: $F_{11,231} = 3.17$, $p > 0.01$). In areas that allowed dogs, the presence of a trailhead within a kilometer segment increased dog activity ($F_{1,24.5} = 15.12$, $p > 0.01$) and decreased carnivore activity ($F_{1,42.2} = 5.95$, $p = 0.02$) (Figure 4). For dogs, the strength of the trailhead effect depended on dog policy ($F_{1,34.5} = 14.26$, $p > 0.01$) and also on the month ($F_{21,207} = 1.86$, $p = 0.01$).

For both dogs and native carnivores, modeling the temporal autocorrelation between adjacent months using an AR(1) autocovariance structure significantly explained the variance in the final model (dogs: $z = 3.03$, $p < 0.01$; carnivores: $z = -1.65$, $p = 0.09$).

Prairie dogs

In areas where dogs were prohibited, there were significantly higher densities of prairie dog burrows within 25 m ($t_{4.59} = 3.78$, $p = 0.02$) and 10 m of trails ($t_{4.65} = 3.86$, $p = 0.01$) than where dogs were allowed. Dog policy did not significantly predict prairie dog burrow density within 200 m ($t_{2.3} = 1.14$, $p = 0.36$), 100 m ($t_{3.65} = 1.07$, $p = 0.35$), or 50 m of the trail ($t_{3.17} = 1.72$, $p = 0.18$).

DISCUSSION

We found that the presence of dogs correlated with altered patterns of habitat utilization for mule deer, small mammals, prairie dogs, and bobcats. For mule deer and small mammals, the results tease out the role of dogs beyond the cumulative disturbance of recreationists (Figure 5). Even in areas that prohibited dogs, mule deer were less active up to 50 m from recreational trails. But in areas that allowed dogs, deer showed reduced activity within at least 100 m of trails. Similar results were found for small mammals including squirrels, rabbits, chipmunks, and mice,

and also for prairie dog burrow location. The differences in these distances, when considered along the lengths of these trails, represent areas of otherwise suitable mule deer habitat that are potentially unsuitable because of dogs. Because of this depth-of-edge effect associated with dogs along recreational trails, for every protected area that allows dogs off leash, there is a certain percentage of that area that is unsuitable for certain species of wildlife, even though the habitat may be perfectly suitable otherwise. Understanding this effect can be important when planning the location of new trails, closing trails, or implementing restrictions regarding dogs and recreationists.

Wildlife species that are sensitive to recreational disturbance are generally most sensitive to unpredictable spatial and temporal patterns of disturbance (Knight and Cole 1995). Predictable activities, such as recreation restricted to trails, may allow wildlife to habituate to those activities (Whittaker and Knight 1999). The spatial behavior of dogs off-leash is unpredictable; and when dogs wander off-trail, they are more likely to elicit flushing responses from deer, even if the dogs do not give chase (Miller et al. 2001). On two study sites, dogs were allowed to travel off-leash, under "voice and sight control," and frequently traveled off-trail. Though leash rules have been found in certain urban parks to have no effect in protecting local biodiversity (Forrest and St. Clair 2006), the enforced use of leashes could restrict dog activity to a narrower trail corridor and minimize dogs' influence on wildlife.

We found wildlife species that are preyed upon by native canids demonstrated sensitivity to the presence of domestic dogs. The appearance and behavior of dogs are similar to wild canids, and ungulates and small mammals may perceive dogs as such. Mule deer and small mammals were both less active in the presence of dogs, and both are typical prey of wolves (*Canis lupus*), coyotes, and foxes throughout their evolutionary history (Fitzgerald et al. 1994). Without even giving chase, dogs can elicit behavioral reactions from mule deer (Miller et al. 2001), prairie dogs (Bekoff and Ickes 1999), and other species. Bobcats may also be sensitive to

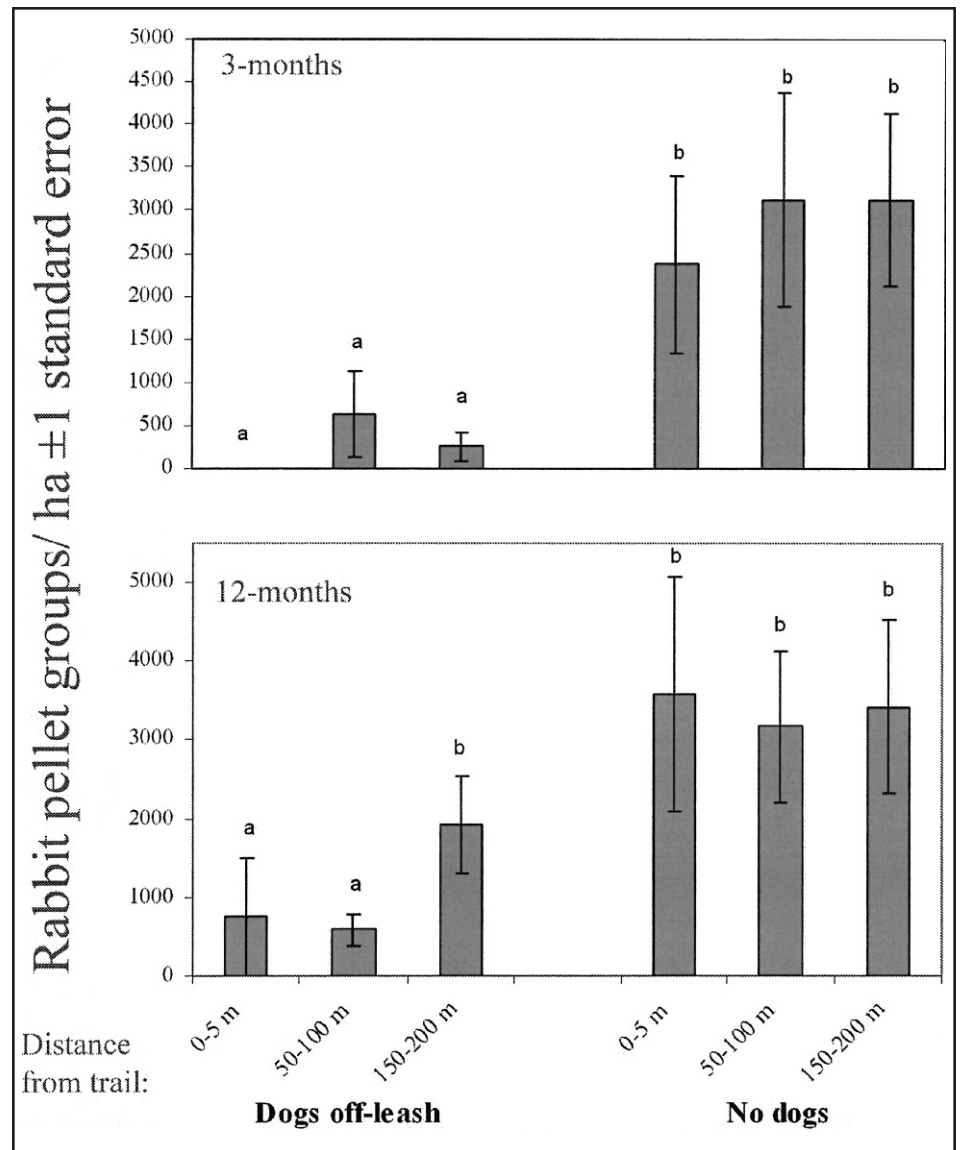


Figure 2. Twelve-month and three-month rabbit pellet densities by dog policy and distance from trail. Different letters above columns indicate significant differences ($p < 0.1$) for comparisons between adjacent distance categories within policies, and for the same distance category between policies, based on a square root transformation of the data presented.

dogs, which may mimic coyotes, a natural predator (Fitzgerald et al. 1994).

Several relationships between the activity of dogs and native carnivores were revealed by on-trail scat surveys and remote-triggered photos. In areas that allow dogs, dog scat densities were highest and native carnivore scats were lowest within a kilometer of trailheads. Indeed, dogs often defecate very soon after arriving at a trail, and many visitors do not walk dogs much beyond the trailhead (OSMP, unpubl. data). The opposite was true up-trail, where dog scat densities were lower and native carni-

vore scat densities were higher. However, where dogs were prohibited, the presence of trailheads had no influence on carnivore activity. These inverse correlations of dog and native carnivore activity in areas that allow dogs indicate that native carnivores may be avoiding trailheads where dog activity is concentrated. Alternatively, carnivore activity may be elevated up-trail where the dog scent-markings along a trail may be relatively novel stimuli to native carnivores, potentially instigating increased vigilance and investigation by native carnivores within their home ranges (Henry 1977; Allen et al. 1999).

Table 1. Pairwise comparisons for mule deer pellet densities between combinations of dog policy and distance from trail. These comparisons were performed only when overall F-tests for treatment effects were significant. Denominator degrees of freedom for 12-month plots = 44; for 3-month plots = 28.

Dog policy & distance from trail		Pairwise comparisons			
		12-month plots		3-month plots	
		<i>F</i>	<i>P</i>	<i>F</i>	<i>P</i>
Dogs: 0-5 m	Dogs: 50-100 m	-3.28	<0.01	-2.25	0.03
Dogs: 50-100 m	Dogs: 150-200 m	-3.97	<0.01	-4.07	<0.01
No dogs: 0-5 m	No dogs: 50-100 m	-5.38	<0.01	-3.45	<0.01
No dogs: 50-100 m	No dogs: 150-200 m	1.49	0.14	-0.22	0.83
Dogs: 0-5 m	No dogs: 0-5 m	1.89	0.07	1.73	0.09
Dogs: 50-100 m	No dogs: 50-100 m	3.56	<0.01	2.93	<0.01
Dogs: 150-200 m	No dogs: 150-200 m	0.80	0.43	0.90	0.37

Table 2. Pairwise comparisons for rabbit pellet densities between combinations of dog policy and distance from trail. These comparisons were performed only when overall F-tests for treatment effects were significant. Denominator degrees of freedom for 12-month plots = 44; for 3-month plots = 28.

Pairwise comparisons: 12-month plots			
Policy & distance from trail	Policy & distance from trail	<i>F</i>	<i>P</i>
Dogs: 0-5 m	Dogs: 50-100 m	-0.89	0.38
Dogs: 50-100 m	Dogs: 150-200 m	2.10	0.04
Dogs: 0-5 m	No dogs: 0-5 m	2.49	0.02
Dogs: 50-100 m	No dogs: 50-100 m	2.32	0.03
Dogs: 150-200 m	No dogs: 150-200 m	0.73	0.47

Dog activity correlated with increased photo detections of red foxes and decreased detections of bobcats. Red foxes may be resilient to the presence of dogs, while bobcats may be sensitive to the presence of dogs. Red foxes may be common on OSMP lands because they are a highly resilient species able to thrive in close proximity to humans (Major and Sherburne 1987), whereas bobcats may be scarce on OSMP lands because they are secretive and elusive from humans (Woolf and Hubert 1998).

In addition to the altered spatial patterns of wildlife activity described in our study, dogs could also alter temporal patterns of wildlife activity. Bobcats and coyotes have demonstrated temporal shifts in their activity to avoid peak times of human recreational visitation (George and Crooks 2006). Examining both spatial and temporal patterns of wildlife activity is necessary to understand how wildlife co-exists with high levels of human recreation and dogs in a limited area.

Management Implications

Regulating the activity of dogs in natural areas may be of particular importance when conservation goals include the management of species that may perceive dogs as predators. The potential for such disturbance may be inferred by identifying if target species

Table 3. Camera detections and comparisons by dog policy.

Species	Photo detection frequency		<i>n</i>	<i>F</i>	<i>d.f.</i>	<i>P</i>
	Dog areas	No-dog areas				
Dogs	1.04	<0.01	228	77.19	1,57	<0.01
Native carnivores	0.25	0.07	130	16.09	1,60	<0.01
Native canids	0.17	0.03	82	16.6	1,60	<0.01
Red foxes	0.14	0.01	67	13.97	1,60	<0.01
Coyotes	0.01	0.02	12	0.11	1,60	0.75
Mule deer	0.03	0.03	28	0.16	1,60	0.69
Mountain lions	0.01	0.01	9	0.16	1,59	0.69
Bobcats	<0.01	0.02	10	8.53	1,60	<0.01
Black Bears	0.03	0.02	16	1.38	1,59	0.33
Striped skunks	0.01	0.02	11	0.08	1,60	0.78
Rabbits	0.03	0.06	32	0.88	1,60	0.35

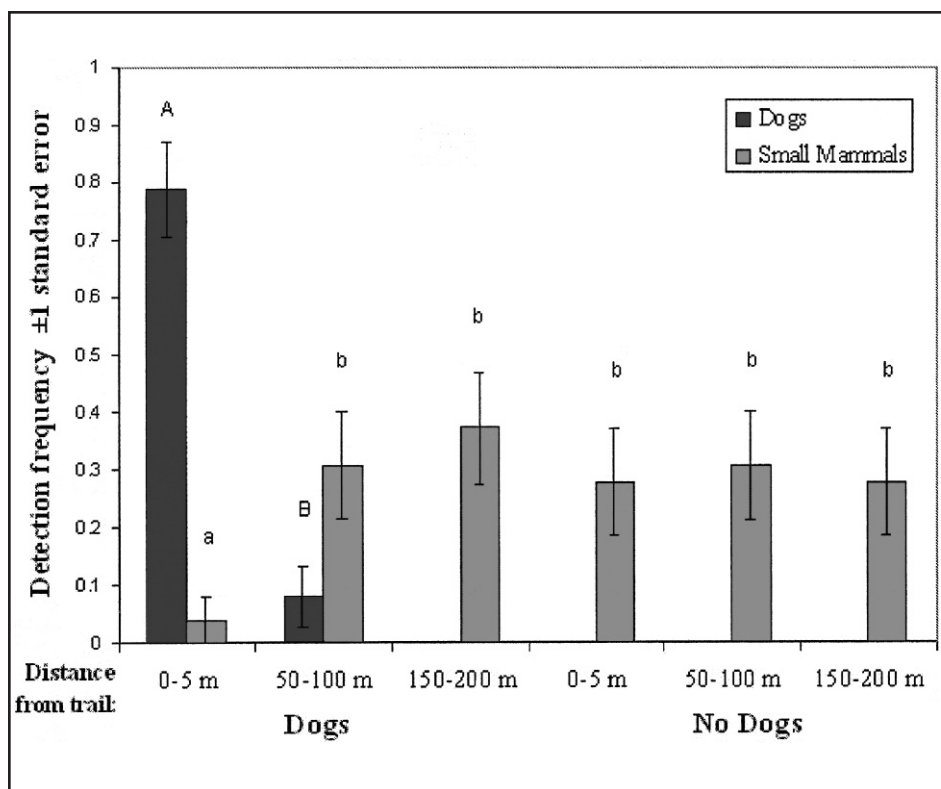


Figure 3. Track plate detection frequencies for dogs and small mammals. Different letters above columns indicate significant differences ($p < 0.1$) between policies and distance categories for small mammals (lower case letters) and dogs (capital letters) based on a square root transformation of the data presented.

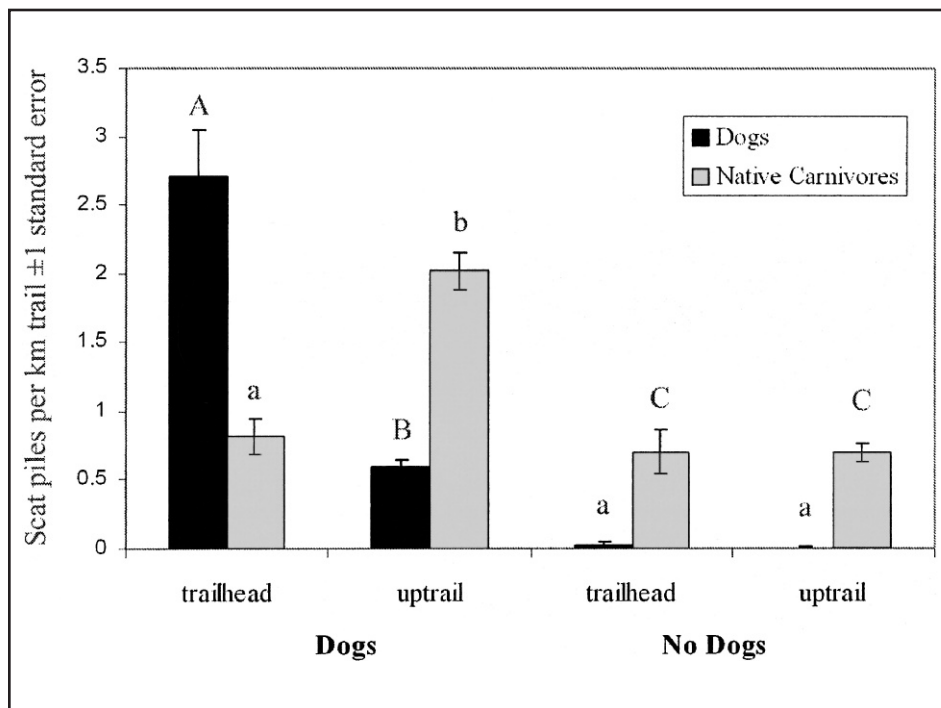


Figure 4. On-trail scat densities by dog policy, within 1 km of trailheads or uptrail, for dogs and combined native carnivores, including coyotes, red foxes, grey foxes, bobcats and mountain lions. Different letters above columns indicate significant differences ($p < 0.1$) for dogs (capital letters) and native carnivores (lower case letters) based on a square root transformation of the data presented.

have wild canids as natural predators. Trails that are kept dog-free or with dogs closely restricted to trails could protect against the demonstrated ecological impacts that dogs have on wildlife communities and could facilitate wildlife viewing opportunities for trail users.

Policies regulating types of recreational use in protected areas should be considered within a regional context, considering both the relative ecological and recreational values of an area. The types of recreational uses allowed on trails influences the rates of recreational visitation and their associated ecological impacts. On multiple-use trails with high levels of recreational use, user conflicts – particularly those involving dogs – can occur more frequently, influencing an area's social carrying capacity and presenting an important consideration for managing recreational use on public lands (Manning et al. 1996; Bauer 2004).

To further explore the effects of dogs on wildlife communities, we recommend before-after control-impact studies with new trails that are created, investigations into the role of dogs in wildlife disease, and larger-scale studies that consider trail densities and rates of recreational visitation.

ACKNOWLEDGMENTS

We are grateful to Kevin Crooks, Cameron Ghalambor, Mark Gershman, Gary White, and Buffy Lenth for advice on study design, Colin Talbert for assistance with GIS, Marty Colón for teaching field crews the art of tracking, and Art Roberts, Kelly Matheson, Renée Culver, Sam Clapper, Tim Sichmeller, Heather Hill, Justin Severyn, Colin Talbert, Buffy Lenth, Dave Hoerath, John Justus, and Charlie and Annie Lenth for their tireless field work. Trailmaster cameras were provided by Robert Skorkowsky, of Hahn's Peak/Bears Ear Ranger District, Medicine Bow National Forest, and Roland Wostl, of the Colorado Department of Transportation, via Carron Meaney. Phil Chapman provided assistance with statistical analysis and Emily Ruell with scat identification. Two anonymous reviewers provided helpful comments. Funding was provided by Boulder County

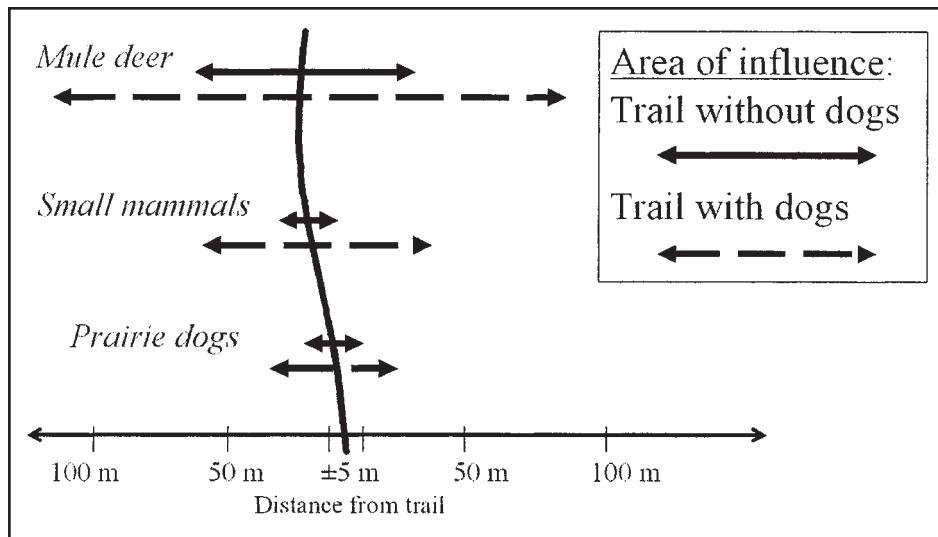


Figure 5. Conceptual diagram of the effects of recreationists alone or recreationists with dogs on mule deer and small mammal activity and prairie dog burrow location within a trail corridor in a protected area.

Parks and Open Space, the City of Boulder Open Space and Mountain Parks, and the Boulder County Nature Association.

Ben Lenth received a BA in Biology from Wesleyan University and an MS in Ecology from Colorado State University. He is currently a Peace Corps volunteer in Mexico, working in the Sierra Gorda Biosphere Reserve with a local NGO, the Grupo Ecológico Sierra Gorda.

Rick Knight is a professor of wildlife conservation at Colorado State University. His interests deal with land use and land health in the American West.

Mark Brennan is a wildlife biologist with Boulder County Parks and Open Space. He has a BS in Ecology and an MS in Wildlife Sciences. His interests are in the impacts of urbanization and recreation on wildlife communities and the management of modified habitats for wildlife.

LITERATURE CITED

- Allen, J.J., M. Bekoff, and R.L. Crabtree. 1999. An observational study of coyote (*Canis latrans*) scent-marking and territoriality in Yellowstone National Park. *Ethology* 105:289-302.
- [APPMA] American Pet Products Manufacturers Association. 2007. 2007-2008 APPMA National Pet Owners Survey. American Pet Products Manufacturers Association, Greenwich, Conn.
- Bauer, M. 2004. Recreation conflict at six Boulder County Parks and Open Space Properties: a baseline study. Boulder County Parks and Open Space, Longmont, Colo.
- Bekoff, M. 1979. Scent-marking by free-ranging domestic dogs – olfactory and visual components. *Biology of Behavior* 4:123-139.
- Bekoff, M., and R. Ickes. 1999. Behavioral interactions and conflict among domestic dogs, black-tailed prairie dogs, and people in Boulder, Colorado. *Anthrozoos* 12:105-110.
- Bekoff, M., and C. Meaney. 1997. Interactions among dogs, people and the environment in Boulder, Colorado: a case study. *Anthrozoos* 10:23-31.
- Brown, D.G., K.M. Johnson, T.R. Loveland, and D.M. Theobald. 2005. Rural land-use trends in the conterminous United States, 1950-2000. *Ecological Applications* 15:1851-1863.
- Butler, J.R.A., J.T. du Toit, and J.A. Bingham. 2004. Free-ranging domestic dogs (*Canis familiaris*) as predators and prey in rural Zimbabwe: threats of competition and disease to large wild carnivores. *Biological Conservation* 115:369-378.
- Causey, M.K., and C.A. Cude. 1978. Feral dog predation of the gopher tortoise in Southeast Alabama. *Herpetological Review* 9:94-95.
- Collins, W.B. 1981. Habitat preferences of mule deer as rated by pellet-group distributions. *Journal of Wildlife Management* 45:969-972.
- Coppinger, R., and L. Coppinger. 2001. *Dogs: a Startling New Understanding of Canine Origin, Behavior, and Evolution*. Scribner, New York.
- Cutler, T.L., and D.E. Swann. 1999. Using remote photography in wildlife ecology: a review. *Wildlife Society Bulletin* 27:571-581.
- Daniels T.J., and M. Bekoff. 1989. Spatial and temporal resource use by feral and abandoned dogs. *Ethology* 81:300-312.
- Fitzgerald, J.P., C.A. Meaney, and D.M. Armstrong. 1994. *Mammals of Colorado*. University of Colorado Press, Niwot.
- Forrest, A., and C.C. St. Clair. 2006. Effect of dog leash laws and habitat type on avian and small mammal communities in urban parks. *Urban Ecosystems* 9:51-66.
- Fox, M.W. 1971. *Behaviour of Wolves, Dogs and Related Canids*. Harper and Row, New York.
- George, S., and K Crooks. 2006. Recreation and large mammal activity in an urban nature reserve. *Biological Conservation* 133:107-117.
- Glennon, M.J., W.F. Porter, and C.L. Demers. 2002. An alternative field technique for estimating diversity of small-mammal populations. *Journal of Mammalogy* 83:734-742.
- Gorman, M.L., and B.J. Trowbridge. 1989. The role of odor in the social lives of carnivores. Pp. 57-88 in J.L. Gittleman, ed., *Carnivore Behavior, Ecology and Evolution*. Cornell University Press, Ithaca, N.Y.
- Green, J.S., and J. Flinders. 1981. Diameter and pH comparisons of coyote and red fox scats. *Journal of Wildlife Management* 45:765-767.
- Halfpenny, J.C. 2001. *Scats and Tracks of the Rocky Mountains*, 2nd ed. Globe Pequot Press, Guilford, Conn.
- Henry, J.D. 1977. Use of urine marking in scavenging behavior of red foxes, *Vulpes vulpes*. *Behaviour* 61:82-106.
- Holling, C.S., and C.R. Allen. 2002. Adaptive inference for distinguishing credible from incredible patterns in nature. *Ecosystems* 5:319-328.
- Johnson, M.K., and R.C. Belden. 1984. Differentiating mountain lion and bobcat scats. *Journal of Wildlife Management* 48:239-244.
- Johnson, W.C., and S.K. Collinge. 2004. Landscape effects on black-tailed prairie dog colonies. *Biological Conservation* 115:487-497.
- Knight, R.L., and D. Cole. 1995. Wildlife

- responses to recreationists. Pp. 51-69 in R.L. Knight and D. Cole, eds., *Wildlife and Recreationists: Coexistence Through Management and Research*. Island Press, Washington D.C.
- Knight, R.L., and K.J. Gutzwiller (eds.). 1995. *Wildlife and Recreationists: Coexistence Through Management and Research*. Island Press, Washington, D.C.
- Kohn, M.H., E.C. York, D.A. Kamradt, G. Haught, R.M. Sauvajot, and R.K. Wayne. 1999. Estimating population size by genotyping faeces. *Proceedings of the Royal Society of London* 266:657-663.
- Laurenson, K., C. Sillero-Zubiri, H. Thompson, F. Shiferaw, S. Thirgood, and J. Malcolm. 1998. Disease as a threat to endangered species: Ethiopian wolves, domestic dogs and canine pathogens. *Animal Conservation* 1:273-280.
- Lima, S.L. 1998. Nonlethal effects in the ecology of predator-prey interactions: what are the ecological effects of anti-predator decision-making? *Bioscience* 48:25-34.
- Lowry, D.A., and K.L. McArthur. 1978. Domestic dogs as predators on deer. *Wildlife Society Bulletin* 6:38-39.
- MacArthur, R.A., V. Geist, and R.H. Johnston. 1982. Cardiac and behavioral responses of mountain sheep to human disturbance. *Journal of Wildlife Management* 46:351-358.
- Maestas, J.D., R.L. Knight, and W.C. Gilgert. 2003. Biodiversity across a rural land-use gradient. *Conservation Biology* 24:36-42.
- Major, J.T., and J.A. Sherburne. 1987. Interspecific relationships of coyotes, bobcats and red foxes in western Maine. *Journal of Wildlife Management* 51:606-616.
- Manning, R.E., N.L. Ballinger, J. Marion, and J. Roggenbuck. 1996. Recreation management in natural areas: problems and practices, status and trends. *Natural Areas Journal* 16:142-146.
- Mengel, R.M. 1971. A study of dog-coyote hybrids and implications concerning hybridization in *Canis*. *Journal of Mammalogy* 52:316-336.
- Mertz, S. 2002. Compliance with Leave No Trace frontcountry principles—a preliminary examination of visitor behavior. City of Boulder Open Space and Mountain Parks, Boulder, Colo.
- Miller, J.E., and B.D. Leopold. 1992. Population influences: predators. Pp. 119-128 in J.G. Dickson, ed., *The Wild Turkey: Biology and Management*. Stackpole Books, Mechanicsburg, Pa.
- Miller, S.G., R.L. Knight, and C.K. Miller. 2001. Wildlife response to pedestrians and dogs. *Wildlife Society Bulletin* 29:124-132.
- Odell, E., and R.L. Knight. 2001. Songbird and medium-sized mammal communities associated with exurban development in Pitkin County, Colorado. *Conservation Biology* 15:1143-1150.
- Ott, R.L., and M. Longnecker. 2001. *An Introduction to Statistical Methods and Data Analysis*, 5th ed. Duxbury, Pacific Grove, Calif.
- Peters, G., and W.C. Wozencraft. 1989. Acoustic communication by fissiped carnivores. Pp. 14-56 in J.L. Gittleman, ed., *Carnivore Behavior, Ecology and Evolution*. Cornell University Press, Ithaca, N.Y.
- Powell, K.L., R.J. Robel, K.E. Kemp, and M.D. Nellis. 1994. Aboveground counts of black-tailed prairie dogs—temporal nature and relationship to burrow entrance density. *Journal of Wildlife Management* 58:351-355.
- Ripple, W.J., and R.L. Beschta. 2004. Wolves and the ecology of fear: can predation risk structure ecosystems? *Bioscience* 54:755-766.
- Sargeant, G.A., D.H. Johnson, and W.E. Berg. 1998. Interpreting carnivore scent-station surveys. *Journal of Wildlife Management* 62:1235-1245.
- Sargeant, G.A., D.H. Johnson, and W.E. Berg. 2003. Sampling designs for carnivore scent-station surveys. *Journal of Wildlife Management* 67:289-298.
- SAS Institute. 1999. *SAS/STAT user's guide*. Version 8.0. SAS Institute, Cary, N.C.
- Scott, M.D., and K. Causey. 1973. Ecology of feral dogs in Alabama. *Journal of Wildlife Management* 37:253-265.
- Serpell, J. 1995. *The Domestic Dog: Its Evolution, Behavior and Interactions With People*. Cambridge University Press, Cambridge, U.K.
- Sime, C.A. 1999. Domestic dogs in wildlife habitats. Pp. 8.1-8.17 in G. Joslin and H. Youmans, coordinators, *Effects of recreation on Rocky Mountain wildlife: a review for Montana*. Committee on Effects of Recreation on Wildlife, Montana Chapter of The Wildlife Society, Helena, Mont.
- Soulé, M.E., J.A. Estes, B. Miller, and D.L. Honnold. 2005. Strongly interacting species: conservation policy, management, and ethics. *Bioscience* 55:168-176.
- Taylor, A.R., and R.L. Knight. 2003. Wildlife responses to recreation and associated visitor perceptions. *Ecological Applications* 13:951-963.
- U.S. Fish and Wildlife Service. 1999. South Florida multi-species recovery plan. Fish and Wildlife Service, Atlanta, Ga.
- Watson, A.E., D.N. Cole, D.L. Turner, and P.S. Reynolds. 2000. *Wilderness recreation use estimation: a handbook of methods and systems*. General Technical Report RMRS-GTR-56, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, Utah.
- Whittaker, D., and R.L. Knight. 1999. Understanding wildlife responses to humans. *Wildlife Society Bulletin* 26:312-317.
- Wolf, A., and G.F. Hubert, Jr. 1998. Status and management of bobcats in the United States over three decades: 1970s-1990s. *Wildlife Society Bulletin* 26:287-293.