The impacts of dogs on wildlife and water quality: A literature review

Compiled by Lori Hennings, Metro Parks and Nature, April 2016

SUMMARY

Metro periodically reviews the science literature behind its natural resource policies to ensure policies are based on the most current science. Recently staff reviewed the scientific literature regarding the impacts of dogs on wildlife to inform Metro Regulatory Code Title 10.01, which excludes pets from most Metro properties. The only exceptions are service dogs, leashed dogs on some regional trails, Broughton Beach, boat ramps and properties managed by others through intergovernmental agreements that are integrated into larger parks where leashed dogs are allowed (e.g., Forest Park).

Any human related activity can disturb wildlife. In order to meet Metro's dual goals of protecting natural resources and providing access to nature, Metro has tried to strategically locate trails in less sensitive habitat and to ensure that human activity is as non-disruptive as possible. Part of that strategy has been to allow public access, while limiting certain activities such as bringing dogs into natural areas.

The evidence that dogs negatively impact wildlife is overwhelming. It is clear that people with dogs – on leash or off – are much more detrimental to wildlife than people without dogs. Dogs (*Canis lupus familiaris*) are considered to be a subspecies of wolves (*Canis lupus*), and wildlife perceive dogs as predators.[30] Impacts include:

1. **Physical and temporal displacement** – The presence of dogs causes wildlife to move away, temporarily or permanently reducing the amount of available habitat in which to feed, breed and rest. Animals become less active during the day to avoid dog interactions. Furthermore, the scent of dogs repels wildlife and the effects remain after the dogs are gone.
2. **Disturbance and stress response** – Animals are alarmed and cease their routine activities. This increases the amount of energy they use, while simultaneously reducing their opportunities to feed. Repeated stress causes long-term impacts on wildlife including reduced reproduction and growth, suppressed immune system and increased vulnerability to disease and parasites.
3. **Indirect and direct mortality** – Dogs transmit diseases (such as canine distemper and rabies) to and from wildlife. Loose dogs kill wildlife.
4. **Human disease and water quality impacts** - Dog waste pollutes water and transmits harmful parasites and diseases to people.

INTRODUCTION

Metro owns 17,000 acres of parks and natural areas and does not allow dogs or other pets on the vast majority of these lands. Exceptions include service animals, leashed dogs on some regional trails, Broughton Beach, boat ramps and certain properties managed by others through intergovernmental

agreements that are integrated into larger parks where leashed dogs are allowed (e.g., Forest Park). The policy that prohibits visitors from bringing pets to most of Metro's managed parks and natural areas was initiated by Multnomah County in the 1980s and continued in practice after Metro assumed management of those parks in the early 1990s. After a review of the scientific literature and meaningful public discourse, Metro formally adopted the pets policy into its code in 1997 (Metro Council Regulatory code Title 10.01 adopted in Ordinance 96-659A).

To ensure this decision reflects the most up-to-date information, Metro staff examined 54 peer-reviewed scientific journal articles and several research reports relating to the impacts of dogs in natural areas, including numerous literature reviews on the impacts of various types of recreation on wildlife and habitat.[10, 28, 42,54,61,63, 65,68,71,73,77] The results of our literature review are summarized below.

PHYSICAL AND TEMPORAL DISPLACEMENT

Displacement may be the most significant impact due to the amount of habitat affected. The presence of dogs causes most wildlife to move away from an area, which temporarily or permanently reduces the amount of functionally available habitat to wildlife. The research is clear that people with dogs disturb wildlife more than humans alone.[5,10,33,38,39,41,44,61,68,69] These effects reduce a natural area's carrying capacity for wildlife, and also reduces wildlife viewing experiences for visitors.

Studies on a variety of wildlife in many countries and settings demonstrate that dogs along trails and in natural areas significantly alter wildlife behavior.[9,33,39,41,49,53,58] A 2011 literature review found negative dog effects in all 11 papers that examined such effects.[65] Studies demonstrate dog-specific impacts on reptiles,[29,31,48] shorebirds and waterfowl,[24,32,51,69] songbirds,[5,9,10] small mammals,[33,39,56] deer, elk and bighorn sheep,[4,36,38,44,49,59,63] and carnivores.[22,33,52,58]

A study in France found that two hikers disturbed an area of 3.7 hectares walking near wild sheep, whereas two hikers with dogs disturbed 7.5 hectares around the sheep.[41] In Chicago, migratory songbirds were less abundant in yards with dogs.[9] Dog walking in Australian woodlands led to a 35% reduction in bird diversity and a 41% reduction in the overall number of birds.[5] The same study showed some disturbance of birds by humans, but typically less than half that induced by dogs.

Studies in California and Colorado showed that bobcats avoided areas where dogs were present, including spatial displacement[22,33,52] and temporal displacement in which bobcats switched to night time for most activities.[22] The Colorado study also demonstrated significantly lower deer activity near trails specifically in areas that allowed dogs, and this effect extended at least 100 meters off-trail.[33] This negative effect was also true for small mammals including squirrels, rabbits, chipmunks and mice, with the impact extending at least 50 meters off-trail.

Evidence suggests that some wildlife species can habituate to certain predictable, non-threatening disturbances such as people walking on a trail in a natural area; this effectively lowers the stress response. Part of this adaptation may be due to wildlife learning what is and isn't a threat, and also

avoidance of hunters.[19,55,63,70] Habituated animals still react, but amount of habitat affected is not as large.[55,56,63,70] However, dogs – especially off-leash dogs – may prevent wildlife habituation because wildlife consistently see them as predators. Dog-specific disturbance has been studied for birds, with no evidence of habituation even with leashed dogs, even where dog-walking was frequent; this effect was much weaker for people without dogs.[5]

Even the scent of dog urine or feces can trigger wildlife to avoid an area. Therefore, the impacts of dog presence can linger long after the dog is gone, even days later. One literature review found that predator odors caused escape, avoidance, freezing, and altered behavior in a large suite of wildlife species including scores of amphibian, reptile, bird, and mammal species from other studies.[30] The scent of domestic dogs has been shown to repel American beaver (*Castor Canadensis*), mountain beaver (*Aplodontia rufa*), deer (*Odocoileus* species), elk (*Cerus elaphus*), and a wide variety of wildlife native to other countries.[20,30] Mountain beaver cause economic damage to young tree stands in the Pacific Northwest, and foresters are considering using dog urine as a repellant.[20] An experimental study demonstrated that dog feces are an effective repellent for sheep, with no habituation observed over seven successive days.[1]

One Colorado study showed mixed effects of dogs on wildlife.[44] The study compared effects of pedestrians alone, pedestrians with leashed dogs and unleashed dogs alone on grassland birds. Vesper Sparrows (*Pooecetes gramineus*) and Western Meadowlarks (*Sturnella neglecta*) waited until dogs were closest to flush – that is, they fly or run away. This could be an attempt to remain undetected against the greatest threat, but could also mean that these bird species perceive humans as a greater threat than dogs. However, the same study found strong dog-specific impacts on mule deer in woodlands. A literature review found that ungulates (deer, elk and sheep) had stronger flight responses in open habitats compared to forested habitats.[63] Unlike small ground-nesting songbirds, larger animals would have no cover and could easily be seen in open habitats.

The disturbance effects of off-leash dogs are stronger than on-leash and substantially expand the amount of wildlife habitat affected,[32,59,63,69] and the unpredictability of off-leash dogs may prevent wildlife habituation in large areas of habitat.[5,10,32,61,69] The negative effects are increased even further when dogs and people venture off-trail, probably because their behavior is less predictable.[44,67] Off-leash dogs are likely to reduce the number and types of wildlife in large areas of habitat.

A Colorado study found off-leash dogs ventured up to 85 meters from the trail, although this result was from 1 square meter plots covering a very small percentage of the area.[33] Remote cameras in another study documented the same dog 1.5 miles apart in the same day.[61] In Utah, mule deer showed a 96% probability of flushing within 100 meters of recreationists located off trails; their probability of flushing did not drop to 70% until the deer were 390 meters from the recreationists.[67] A California shorebird study found that off-leash dogs were a disproportionate source of disturbance, and that plovers did not habituate to disturbance; birds were disturbed once every 27 minutes on weekends.[32]

To illustrate the potential of dogs to displace wildlife we explored two well-known local park examples that allow dogs on leash. Forest Park is one of the largest urban parks in the U.S. and was always intended to connect urban dwellers with nature; people have been walking their dogs there since before the park's 1948 dedication. Forest Park covers 5,172 acres of forest, including approximately 80 miles of trails and service. Using a very conservative 25-meter buffer around mapped trails to represent the "human + dog on leash" area of disturbance and assuming 100% compliance with leash rules, the area affected would be 1,406 acres – that's 28% of the entire park. In 651-acre Tryon Creek Natural Area, 207 acres of land (32%) is within 25 meters of a trail.

DISTURBANCE AND STRESS RESPONSE

Stress response is the functional response of an animal to an external stressor, such as seasonal changes in temperature and food availability or sudden disturbance.[3] Specific stress hormones are released to enable the animal to physically respond to the stressor. Acute stress response, when an animal reacts to an immediate situation, can benefit an animal by triggering it to respond appropriately to a threat. However, chronic stress such as repeated disturbances over time may reduce wildlife health, reproduction, growth, impair the immune system and increase vulnerability to parasites and diseases.[16,27,75]

Dogs cause wildlife to be more alert, which reduces feeding, sleeping, grooming and breeding activities and wastes vital energy stores that may mean life or death when resources are low, such as during winter or reproduction.[8,32,40,41,69] Animals release stress hormones and their heart rates elevate in response.[3,27,37,38] When stress becomes too high, animals may flush, freeze, or hide.[26,30]

Several studies document that disturbance reduces reproductive success for some wildlife species.[11,35,40,50,63] Numerous studies found that female deer and elk, and deer and elk groups with young offspring, show greater flight responses to human disturbances than other groups.[63] Stress hormones may cause male songbirds to reduce their territorial defense, females to reduce feeding of their young, nestlings to have reduced weight and poor immune systems, and adult birds to abandon nests.[11,34,35,76] A Colorado study showed that elk repeatedly approached by humans had fewer young.[50] Although research is lacking on whether dogs specifically reduce the reproductive success of wildlife, the fact that humans with dogs create much stronger disturbance effects than without dogs [5,33,38,41,44,61,68,69] implies that these stress effects would be magnified if people had dogs with them.

INDIRECT AND DIRECT MORTALITY

Dogs chase and kill many wildlife species including reptiles, small mammals, deer and foxes.[12,13,29,31,48,58,62] A Canadian study found that domestic dogs were one of the top three predators that killed white-tailed deer fawns.[4] In northern Idaho winter deer grounds, an Idaho Fish and Game conservation officer witnessed or received reports of 39 incidents of dogs chasing deer, directly resulting in the deaths of at least 12 animals.[36] A study in southern Chile revealed that domestic dogs preyed on

most of the mammal species present in the study area.[60] A 2014 literature review of dogs in parks identified 19 studies that investigated the effects of dogs preying on wildlife.[73] Of these, 13 reported observing or finding strong evidence of dog predation on wildlife. The Audubon Society of Portland's Wildlife Care Center took in 1,681 known "dog-caught" injured animals from 1987 through March 2016.[2]

Dogs transmit diseases to wildlife and vice versa including rabies, Giardia, distemper and parvovirus.[18,23,66,74] A Mexico City study concluded that feral dogs continually transmitted parvovirus, toxoplasmosis and rabies to wildlife including opossums, ringtails, skunks, weasels and squirrels.[66] Large carnivores such as cougars are especially vulnerable to domestic dog diseases including canine distemper.[74]

HUMAN DISEASE AND WATER QUALITY IMPACTS

Under the Oregon Department of Environmental Quality (DEQ), Metro is a Designated Management Agency to protect water quality in compliance with the federal Clean Water Act. Limiting dog access at most natural areas is one of Metro's commitments to DEQ, because dog feces pollute water. Feces are often delivered to waterways through stormwater.[57] The average dog produces ½ to ¾ pound of fecal matter each day – a hundred dogs can produce more than 500 pounds of waste per week.[45] The DEQ identifies pet waste as a significant contributor to one of the region's most ubiquitous and serious pollutants, *E. coli* bacteria. Contact with *E. coli*-polluted water can make people sick. Because dog waste can be a relatively simple source to reduce or eliminate exposure to *E. coli*, DEQ considers reducing or eliminating dog waste an important action item in jurisdictions' clean water implementation plans for the Willamette Basin watershed.[47]

Humans can catch parasites and diseases such as hookworms (causes rash), roundworms (may cause vision loss in small children, rash, fever, or cough) and salmonella (causes gastrointestinal illness) from dog waste.[7,57] Aside from potential illnesses, dog waste can negatively affect visitors' experience in a natural area. Dog waste left on the ground is a leading complaint in Portland parks, and violators may be fined up to $150 per incident.[14]

Several examples illustrate local dog impacts. A Clean Water Services DNA study found that dog waste alone accounts for an average of 13% of fecal bacteria in stream study sites in the Tualatin River Basin.[17] Off-leash dog walking is documented to cause erosion in Portland's Marshall Park, creating sediment problems in stream water.[15] In 2014 Portland school administrators expressed concern because playgrounds had become "a minefield for animal waste" from people using school grounds as after hours, off-leash dog parks, threatening the health of school children.[21] The City of Gresham found extremely high levels of *E. coli* bacteria in water quality samples of a very specific stretch of a stream, where dog feces were found along stream banks behind several yards with dogs.[1] The city sent letters to

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[1] Personal communication with Katie Holzer, Watershed Scientist at the City of Gresham, Oregon, 4/11/2016.

residents in the neighborhood about the incident and how to properly dispose of dog feces; the levels have not been elevated in follow-up sampling.

BELIEF, BEHAVIOR AND REALITY

People do not always take responsibility for their impacts on wildlife. Several studies demonstrate that natural area visitors, including dog owners, often don't believe they are having much of an effect on wildlife, or assign blame to different user groups rather than accepting responsibility themselves.[6,64,67,68] Some natural area visitors assume that when they see wildlife, it means that they are not disturbing the animals – or worse, that because they didn't see any wildlife, they didn't disturb any.[64]

For example, in Utah, about half of recreational visitors surveyed did not believe that recreation was having a negative impact on wildlife; of those that did, each user group blamed other groups for the strongest impacts.[67] In Austria, 56% of people surveyed at a national park agreed that wildlife is in general disturbed by human activity.[64] However, only 12% believed that they had disturbed wildlife in their visit that day, and dog-walkers ranked their activities as less disturbing than other user groups' activities. When asking different user groups to rate the impacts of overall human disturbance on wildlife, dog-walkers rated the impacts the lowest, at 2.6 out of 5 possible impact points.

Surveys indicate that many dog owners desire fewer restrictions, while non-dog owners often feel the opposite.[72,73] However dog owners don't always follow the rules, and some dog owners allow their dogs to run free in leash-only natural areas.[32,52,73] In a Santa Barbara study, only 21% of dogs were leashed despite posted leash requirements.[32] And despite regulations and claims to the contrary, dog owners often don't pick up their dog's waste.[6,32] An English study revealed that although 95% of visitors claimed to pick up their dog's waste only 19-46% actually did so, depending on location within the park.[6]

DISCUSSION

In summary, people and their dogs disturb wildlife, and people are not always aware of or willing to acknowledge the significance of their own impacts. Wildlife perceive dogs as predators. Dogs subject wildlife to physical and temporal displacement from habitat, and dog scent repels wildlife with lingering impacts. Dogs disturb wildlife which can induce long-term stress, impact animals' immune system and reduce reproduction. Dogs spread disease to and outright kill wildlife. People with dogs are much more detrimental to wildlife than people alone; off-leash dogs are worse; and off-trail impacts are the highest (Figure 1).

Urban wildlife is subjected to many human-induced stressors including habitat loss, degraded and fragmented habitat, impacts from a variety of user groups, roads, trails, infrastructure, noise and light pollution.[26] These stressors will increase with population; from July 2014 to 2015 the Portland-Vancouver metropolitan region added 40,621 new residents.[43] Current population in the region stands at 2.4 million, with another 400,000 residents expected over the next 20 years.

Figure 1. Conceptual illustration of the relative impacts on wildlife due to people without and with dogs.
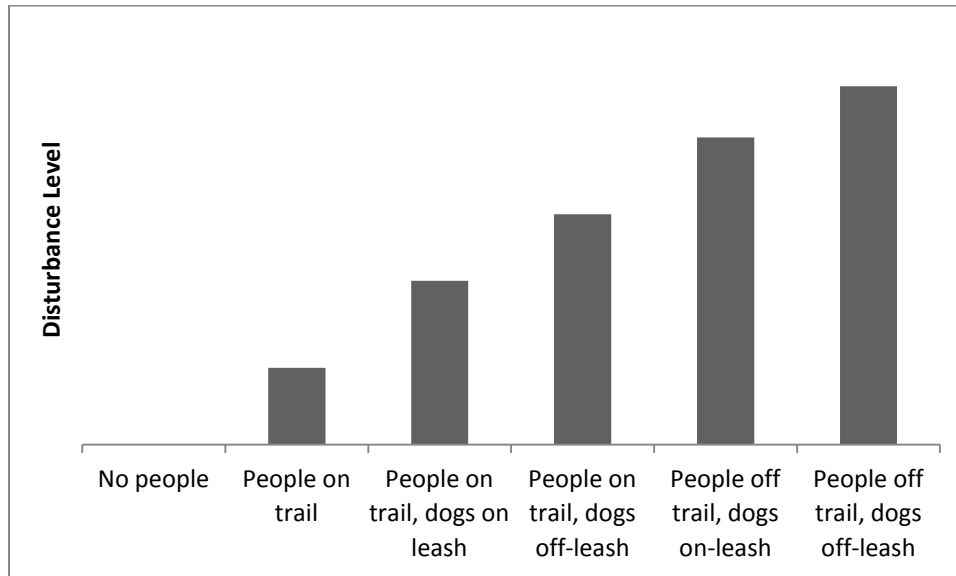
Among medium to high density cities, Portland currently ranks second in the total area covered by parks at nearly 18%, and also second in the number of park acres per resident.[25] Of 34 park providers in the Portland region, all but four allow dogs in most or all of their natural areas, typically on-leash; more than two-thirds also offer dog parks or off-leash dog areas (Table 1 at end of document).

Wildlife conservation is not the only valid reason to preserve natural areas. Park providers must weigh the trade-offs between wildlife, habitat, water quality and recreational values. But when considering different types of public access in a natural area, it is important to understand that the research is clear: people with dogs substantially increase the amount of wildlife habitat affected and are more detrimental to wildlife than people without dogs.

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Table 1. Park providers' dog policies in the greater Portland, Oregon metropolitan area.

Parks provider	No dogs allowed	Some parks allow dogs	Dogs allowed	On-leash	Free to roam	Off-leash areas or dog park
Audubon Society of Portland	X					
City of Beaverton		X[2]		X		X
City of Cornelius			X	X[3]		
City of Durham			X	X		X
City of Fairview		X[4]		X		
City of Forest Grove			X	X		X
City of Gladstone			X	X		X
City of Gresham			X	X		X
City of Happy Valley			X	X[5]		X
City of Hillsboro			X	X		X
City of Lake Oswego			X	X		X
City of Milwaukie[6]			X	X		X
City of Oregon City			X	X		X[7]
City of Portland		X		X[8]		X[9]
City of Sherwood			X	X		X
City of Tigard			X	X		X
City of Troutdale		X[10]		X		X[11]
City of Tualatin			X	X		X
City of West Linn			X	X		X[12]
City of Wilsonville			X	X		X
City of Wood Village			X	X		
Clackamas County			X	X		X
Clean Water Services (Fernhill Wetlands)	X					

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[2] All parks except fountain provided by Tualatin Hills Parks & Recreation District.

[3] Considering off-leash dog area at Water Park.

[4] Dogs on leash allowed at all parks except Salish Ponds (no dogs).

[5] Dogs on leash except prohibited in playgrounds.

[6] All city parks are operated by North Clackamas Parks and Recreation Department.

[7] The City of Oregon City is currently testing off-leash areas in three parks.

[8] Dogs on-leash except prohibited at Foster Floodplain Natural Area, Tanner Springs Park, Whitaker Ponds Nature Park, Riverview Natural Area, and the amphitheater at Mt Tabor Park.

[9] 33 off-leash dog areas.[46]

[10] Most parks: dogs not allowed. Exception: Sunrise Park and large Beaver Creek Greenway, leash only. Considering two more on-leash dogs allowed parks.

[11] Plans for an off-leash area at Sunrise Park.

[12] One off-leash dog area: field near parking lot at Mary S. Young Park. Off-leash dogs were identified as an issue by parks board.

Parks provider	No dogs allowed	Some parks allow dogs	Dogs allowed	On-leash	Free to roam	Off-leash areas or dog park
Federal / State (Sandy River Natural Area)			X[13]	X	X	X
Metro		X[14]				
N. Clackamas Parks & Recreation			X			X
OR Department of Fish and Wildlife			X	X[15]	X	X
OR Parks & Recreation Department			X	X		X
Port of Portland		X[16]		X		
The Nature Conservancy	X					
The Wetlands Conservancy			X[17]	X	X	
Tualatin Hills Park and Rec. District		X[18]		X		X
U.S. Fish & Wildlife Service	X					
U.S. Forest Service[19]			X	X	X	X

[13] Leashes required only on/near Confluence Trail and in parking area. Leash-off everywhere else. Region's largest off-leash area, and heavily used.

[14] Metro does not allow dogs except for service dogs, leashed dogs on regional trails, Broughton Beach, boat ramps and properties managed by others through intergovernmental agreements that are integrated into larger parks where leashed dogs are allowed (e.g., Forest Park).

[15] All dogs must be on leash, except while hunting during seasons authorized on Sauvie Island Wildlife Area, or pursuant to a valid "Competitive Hunting Dog Trial Permit" or "Sauvie Island Wildlife Area Individual Dog Training Permit."

[16] Includes Vanport Wetlands and mitigation sites. No dogs allowed except Government Island State Recreation Area (leased to Oregon Parks Department).

[17] No formal policy.

[18] Dogs allowed on-leash except Tualatin Hills Nature Park and Cooper Mountain Nature Park.

[19] Refers specifically to the Sandy River Delta, owned and administered by the National Forest Service, Columbia River Gorge National Scenic Area.

Four-legged friend or foe? Dog walking displaces native birds from natural areas

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Dog walking is among the world's most popular recreational activities, attracting millions of people to natural areas each year with diverse benefits to human and canine health. But conservation managers often ban dog walking from natural areas fearing that wildlife will see dogs as potential predators and abandon their natural habitats, resulting in outcry at the restricted access to public land. Arguments are passionate on both sides and debate has remained subjective and unresolved because experimental evidence of the ecological impacts of dog walking has been lacking. Here we show that dog walking in woodland leads to a 35% reduction in bird diversity and 41% reduction in abundance, both in areas where dog walking is common and where dogs are prohibited. These results argue against access by dog walkers to sensitive conservation areas.

Keywords: habituation; human disturbance;
ecotourism; predation risk; domestic dog

1. INTRODUCTION

For thousands of years, dogs (*Canis lupus familiaris*) have been a favoured pet of human societies around the world (Serpell 1996). In the twenty-first century, dog ownership is as popular as ever, and dog walking is a major motivator for outdoor recreational activity (Wood *et al.* 2005) with diverse benefits to human and canine health (Bauman *et al.* 2001): it is even a legal requirement for animal welfare in some European cities. Dogs, or their close ancestors, have also evolved as top predators in many ecosystems and hunt a wide range of fauna (Macdonald & Sillero-Zubiri 2004). It is poorly known whether wildlife perceives domestic dogs as a predation risk and they may even habituate to such risk if threats are frequent and not realized (Lima & Bednekoff 1999). Recent extensive research has shown that human walkers (without dogs) can induce anti-predator responses in birds including vigilance and early flight, which may lead to a cascade of related responses that negatively affect birds (Blumstein & Daniel 2005). Off-lead dog walking can also disturb some species of breeding shorebirds from their nests (Lord *et al.* 2001). Cautious conservation managers and government legislation therefore typically ban domestic dogs from sensitive areas such as

national parks and reserves. However, these bans induce strong protest from dog-walking lobbyists who cite a lack of evidence because multispecies responses of wildlife to dog walking are unknown.

In this study we experimentally manipulated dog walking at 90 sites in woodland on the urban fringe of Sydney, Australia and monitored the responses of multispecies bird assemblages, one of the key fauna groups at risk from disturbance (Hill *et al.* 1997). We used three treatments; walkers with dogs, walkers without dogs and a control (no walkers or dogs), and then counted birds seen and heard along 250 m transects for 10 min after treatments were applied. To test whether habituation to dog walking may occur, we surveyed in sites where dog walking was permitted and frequent, and in national park sites where dog walking was prohibited. To control for variation in dog behaviour, we also used a range of dog sizes and breeds and a range of different walkers, and dogs were kept on leads.

2. MATERIAL AND METHODS

The study was conducted at 90 sites located on urban fringe woodland of the Hornsby–Berowra–Cowan region, approximately 35 km north of Sydney. The vegetation is classified broadly as (Hawkesbury) sandstone woodland with Sydney sandstone gully and Sydney sandstone ridge top. In these types of habitat in eastern Australia, birds occur in 9.5% of scats of wild dogs, which include hybrids of domestic dogs and dingoes (*Canis lupus dingo*), Australia's native dog (Mitchell & Banks 2005). This area was chosen because it contains large remnants of woodland with trails that are either frequently dog walked or where dog walking is prohibited, and the use of the area is coming under increased pressure from residents of neighbouring suburbs. Frequently dog-walked sites ($n=45$) occurred on Crown land, council land and regional parkland around three suburbs where off-the-lead dog walking was prohibited. Infrequently dog-walked sites ($n=45$) occurred in two national parks. Dog-walking activity at frequented sites was on average 10 dog walkers and 12 walkers per hour in the morning (07.30–09.30 hours) and 6 dog walkers and 7 walkers in the afternoon (14.30–16.30 hours). Only two walkers in total were seen during all surveys of unfrequented sites and no dog walking was observed.

Native birds were surveyed along 250 m transects along well-established fire trails (width 3–5 m) randomly chosen from 1 : 25 000 maps of the area, allowing at least 150 m from forest edge to prevent edge effects. Each site received only one of the three treatments randomly allocated and no sites within 1 km of another were surveyed on any one day.

The dog-walking treatment involved a person walking a domestic dog on lead along the trail; the human-walking treatment was a procedural control in which a person alone walked along the trail; and the control treatment was where no treatment was imposed upon the site. The dogs were from a variety of breeds (and therefore temperaments, sizes and shapes) and ages, and each dog was used only a maximum of four times randomly allocated to treatments. A variety of walkers of various heights were also used, allocated at random to replicate surveys.

Dog walker and walker subjects walked at the pace at which they would normally walk a dog and moved beyond the transect end to prevent concentration of the treatment effect. Immediately following the 'treatment' (commencing 20 s after the walker/dog walker had set off), the transect was surveyed for birds over 10 min by a single observer (JB). All birds seen or heard within 50 m of the trail were included as the maximum likely zone of influence of a dog; birds flying overhead were excluded. We recorded the position in the strata (canopy, understorey or ground) and distance from trail (0–10, 10–20 and 20–50 m) ensuring that double counts were minimized. Surveying was confined to fine weather (no rain and wind less than 10 km h^{-1}), and we also recorded temperature (°C) and wind speed (km h^{-1}) and scored cloud cover on a 1–10 scale. Surveys were conducted in the periods around dawn and dusk, between 07.30 and 10.00 hours, and then 14.00 and 16.30 hours when birds are generally most active.

A priori power analysis from pilot study samples indicated that at least 13 replicates would be required to detect an effect size of 20% between treatment and control, deemed a reasonably subtle effect of dog walking likely to be of concern to land managers. This sample size was increased to 15 replicate surveys of each treatment.

Because walkers alone induced an effect on birds intermediate to that caused by the addition of dogs, we then tested whether two persons walking would also cause a greater response in birds compared with one person walking alone (Beale & Monaghan 2004). This experiment used identical protocols to those described above using only two treatments; one walker or two walkers, of a range of sizes and body shapes and randomly allocated to surveys. We surveyed 30 sites in frequently dog-walked areas and 30 sites in infrequently dog-walked areas; 15 sites for each treatment.

In the tests for dog-walking effects, neither temperature nor cloud cover showed a relationship to the number of bird species (diversity) or individuals (abundance) observed ($p > 0.25$) and so were excluded from analyses. As expected, diversity and abundance showed a negative relationship with wind speed ($km\,h^{-1}$), and wind speed was included as a covariate in an ANCOVA for treatment and history effects. Normality was confirmed by visual analysis of distributions and normal quantile plots and homogeneity of variances confirmed using Levene's test in JMP (v. 6; SAS Institute, Inc., Cary, NC, 1989–2005). Homogeneity of slopes was confirmed by initially running models with all possible interactions between the covariate and main effects, and any terms with $p > 0.25$ were dropped from the model.

Changes in the distribution of birds in the forest due to treatment effects were examined in two ways: first, using the proportion of the total number of bird individuals observed (seen and heard), detected at a distance of 0–10 m from the trail, and second, by the proportion of the total number of bird individuals detected in the canopy layer. This approach was used to avoid problems of independence associated with multiple categories in proportional data, but targeted the key predictions of a response to dog threat. Single linear regressions confirmed that the distribution variable was not related to any of the weather covariates. The test for multiple walker effects followed the same protocols except that no weather covariates were associated with bird diversity or abundance, so ANOVA's were used.

3. RESULTS

Dog walking caused a 41% reduction in the numbers of bird individuals detected ($F_{2,83} = 14.73$, $p < 0.001$) and a 35% reduction in species richness ($F_{2,83} = 10.76$, $p < 0.001$) compared with untreated controls (figure 1). Humans walking alone also induced some disturbance but typically less than half that induced by dogs (Tukey's *post hoc* test: dog walking < walking < control for diversity and abundance). Notably, there was no interaction between dog-walking treatments and prior access by dog walkers. Ground dwelling birds appeared most affected; 50% of the species recorded in control sites were absent from dog-walked sites. For birds which did not flee the site, there were 76% fewer individuals within 10 m of the trail ($F_{2,83} = 13.72$, $p < 0.001$) when dog walking occurred compared with control sites, suggesting that birds were seeking refuge away from the immediate vicinity of the threat. In the experiment testing bird responses to single and multiple walkers without dogs, bird abundance ($F_{1,56} = 0.04$, $p = 0.83$) and diversity ($F_{1,56} = 0.14$, $p = 0.70$) did not change with the addition of another human. This confirms that birds responded uniquely and additively when dogs accompany walkers.

4. DISCUSSION

These results reveal that even dogs restrained on leads can disturb birds sufficiently to induce displacement and cause a depauperate local bird fauna. These effects were in excess of significant impacts caused by human disturbance, which also caused to decline in diversity and abundance. Responses to transient human disturbance are well known
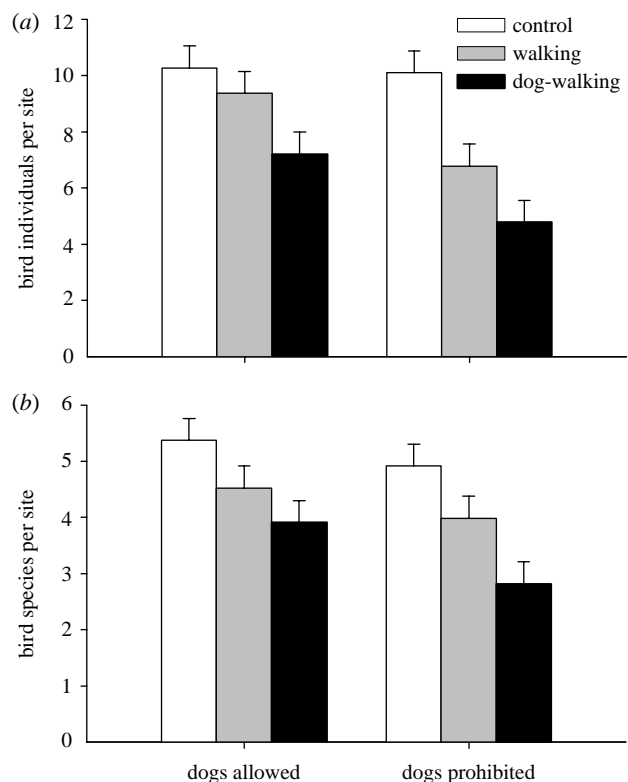
Figure 1. Dog walking in natural areas reduces (*a*) bird abundance and (*b*) bird diversity. Ninety sites were treated with either walkers with dogs on leads (black bars), walkers alone (grey bars) or no treatment (white bars). Half the sites were in areas where dog walking was permitted and the other where dogs were prohibited. Values represent least-squared means ±s.e. from an ANCOVA which included significant wind effects.

(Blumstein *et al.* 2005) and predicted to lead to population-level impacts on some birds species (Hill *et al.* 1997). We found no net difference in bird diversity or abundance between areas with and without regular dog walking receiving the same treatment, suggesting that long-term impacts in this area may be small.

That the effects of dogs occurred even where dog walking was frequent suggests further that local wildlife does not become habituated to continued disturbance. Foraging theory predicts that risk-aversive behaviour will be lost if cues to predation risk are not spatially or temporally variable, or if they are not reinforced (Blumstein & Daniel 2005; but see Blumstein 2006; Blumstein *et al.* 2006). Factors inducing habituation to predation risk in wild animals are relatively understudied, but there is evidence that some birds in urban areas habituate to disturbance by humans when risk is not realized (Keller 1989). In our study areas, it is unlikely that predation risk from dog walking is frequently realized because off-the-lead dog walking is not allowed, although it did occur occasionally. It is probable though that roaming domestic dogs maintain predation pressure on birds, even though their numbers would be very low compared with the intensity of use by dog walkers.

The dramatic reduction in bird diversity and abundance in response to dog walking has immediate implications for other popular recreational activities

pursued by humans. This includes bird watching and ecotourism where visitor satisfaction shows a strong relationship to numbers of species seen (Naidoo & Adamowicz 2005). Wildlife surveys, which are used throughout the world to map bird distributions and factors affecting spatial patterns (e.g. Blackburn *et al.* 1999), could also be compromised if conducted when and where dog walking had recently occurred. It is also possible that the particular sensitivity of ground dwelling birds to dog walking (Blumstein *et al.* 2005) may lead to a cascade of potential behavioural changes in birds with implications for their local conservation (Hill *et al.* 1997). Our results therefore support the long-term prohibition of dog walking from sensitive conservation areas.

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CHAPTER 4

Dogs as agents of disturbance

Michael A. Weston and Theodore Stankowich

4.1 Introduction

The mere presence of a predator in an environment can affect prey in subtle, sublethal, indirect, yet apparently deleterious ways (Preisser et al., 2005; Zanette et al., 2011). The response of wildlife to the presence of a threatening stimulus, such as a dog, is referred to as 'disturbance,' and these responses involve the disruption of normal activities or states, and often evoke antipredator behaviors, commonly vigilance, flight, retreat to refuge, freezing behavior, or hiding (Hockin et al., 1992). Behavioral changes in the presence of a threatening stimulus have been widely documented and often involve ceasing normal activities (e.g., foraging, parental care, resting, display). A growing body of literature also points to physiological changes, such as hormone release or altered heart rates (e.g., MacArthur et al., 1982). Studies (e.g., Gill et al., 1996) demonstrate population-level effects of disturbance, essentially because disturbance effectively lowers habitat quality and thus reduces carrying capacities. A diverse range of stimuli can disturb wildlife. Dogs, often as companions to humans, are increasingly recognized as prevalent, wide-ranging stimuli that often evoke particularly strong and typically deleterious responses among wildlife (Williams et al., 2009). This may be especially true where wildlife and dogs co-occur at high densities in constrained areas, such as coasts and recreational parks. Increasingly, management solutions are being sought to mitigate the problem of dog disturbance to wildlife (Williams et al., 2009). One key information gap in relation to disturbance of wildlife, however, is differentiating the extent to which disturbance is a welfare issue, primarily impacting individual animals, and the extent to which it is a conservation issue, reducing viability of wildlife populations (Hockin et al., 1992). This, and the way humans value and protect wildlife and their dogs, means managing dog disturbance to wildlife is a controversial topic (Williams et al., 2009).

While most studies focus on 'pet' dogs accompanying their owners, a few have described wildlife being disturbed by herding or hunting dogs (e.g., Sastre et al., 2009), and only a handful have considered free-ranging (a.k.a., 'free-running' or 'free-roaming'), mostly unaccompanied dogs (Berger et al., 2007). Very little is known about the disturbance caused by dogs not accompanied by humans (but see Miller et al., 2001; Sastre et al., 2009), though an expanding literature examines the interaction between wildlife and dogs accompanied by people (Box 4.1). Thus, this chapter necessarily emphasizes the latter, and we acknowledge that more information is needed on disturbance caused by unaccompanied dogs. We also acknowledge a bias in available literature, which tends to focus on dog–wildlife conflicts in urban, coastal, forest, and heathland recreational areas (i.e., those areas where humans engage in leisure time activities; Box 4.1). Additionally, while there are many critical information gaps in relation to disturbance to wildlife caused specifically by dogs, some general principles of wildlife responses to threats are used here to discuss likely factors influencing disturbance to wildlife by dogs. This chapter emphasizes wild birds and mammals; while dog disturbance is also likely to occur to many reptilian and amphibian species (see Holderness-Roddam, 2011), publications are limited, and less text is devoted to these groups.


Box 4.1 The limited information base for dog disturbance of wildlife

Not only is little information evident, but clear biases exist in the available information pertaining to dog disturbance of wildlife, and we acknowledge these biases will necessarily be reflected in the emphases of this chapter. Of those biases evident, we note that most available studies are from the developed world, mostly from temperate regions, and most deal with accompanied dogs (thus not representative of most of the world's dogs). Table 4.1 presents and character-izes selected studies which deal with the issue of dog distur-bance in some substantive way ($n = 35$). These studies have increased exponentially over time (Figure 4.1); 40 and 34% originate from North America and Europe respectively, the remainder from Australasia and the Middle East. Most stud-ies (60%) deal with a single species of wildlife. Most focus on open habitats, notably coasts (49%), and 40% involved some form of experimental delivery of stimuli to wildlife, the remainder used observational techniques.

Although literature specific to dog disturbance of wildlife is limited, there has been a growing body of literature con-cerning the broader topic of anthropogenic disturbance of wildlife over the past 40 years, and this has been frequently and adequately reviewed (e.g., Hockin et al., 1992; Weston et al., 2012). The vast majority of this literature involves wildlife responses to humans on foot, with less attention paid to motorized transport (vehicles, boats, aircraft, etc.) or dogs (see Weston et al., 2012). This literature describes great variation in response (extent, type, etc.) and consequences of disturbance to wildlife, and documents disturbance regimes (type, extent, and frequency of occurrence of stimuli, and the rate at which they evoke responses). The literature also elucidates some general principles that undoubtedly apply to the response of wildlife to dogs. These include: an inverse relationship between distance of a stimulus and probabil-ity and extent of the response to it, that unpredictable and 'non-benign' stimuli are associated with enhanced response, and that several attributes of wildlife (most notably increas-ing body mass) are associated with increased response dis-tances (Hockin et al., 1992; Weston et al., 2012).

Despite this substantial body of work, key information gaps remain. These center around the need to explore the higher-order consequences of individual responses to disturbance (Weston et al., 2012). In particular, to date only a few studies document the population-level impacts of disturbance (Mallord et al., 2007). Few examine the consequences of disturbance-mediated declines in habi-tat quality. If disturbance represents an influential process

No. studies $= 6E\text{-}77e^{0.089 \text{ Year}}$
$R^2 = 0.98$
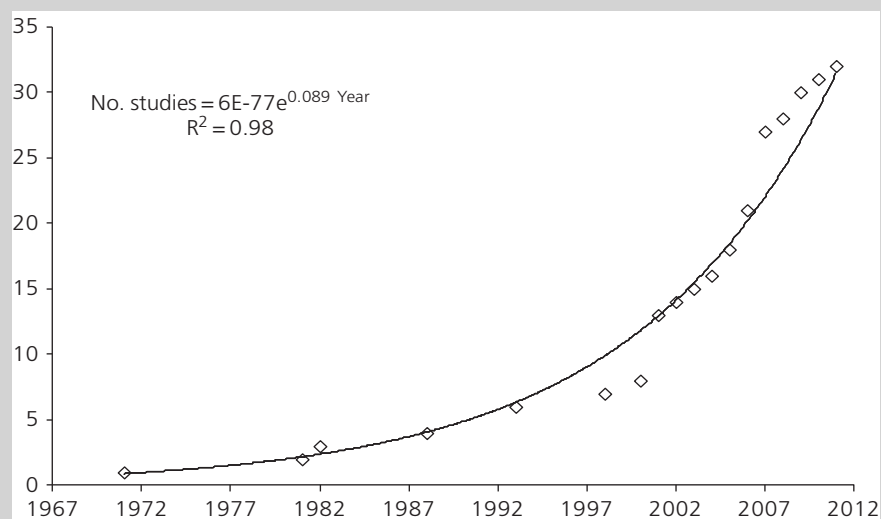
Figure 4.1 The cumulative number of 'major' studies of disturbance to birds and mammals that include dogs as a substantive stimulus, over time.

Box 4.1 *Continued*

Table 4.1 Selected 'major' studies of dog disturbance to wildlife presented in alphabetical order within group (bird or mammal). Criteria for inclusion are that studies involve dogs as a stimulus (directly, not indirectly via dog management zonation or incidental occurrence) and focus on the response and its impact on wildlife, present data, and are published in peer-reviewed journals. Similar articles are grouped.

Group	Study	Approach	Wildlife species	Predominant type of dog	Habitat	Country
Birds	Banks and Bryant 2007	Experimental	Bird assemblages	Leashed	Woodland	Australia
	Burger 1981; Burger et al. 2007; Lafferty 2001a, b	Observational	Coastal birds	Accompanied dogs	Marine shores	USA
	Dunbrack and Dunbrack 2010	Experimental	Glacous-winged gulls and north-western crows	Closely accompanied	Open fields	USA
	Fernández-Juricic and Tellería 2000	Observational	Common blackbird	Accompanied	Urban parks	Spain
	Dowling and Weston 1999; Weston and Elgar 2005, 2007	Observational	Hooded plover (breeding)	Accompanied	Beaches	Australia
	Fitzpatrick, and Bouchez 1998; Kirby et al. 1993; Robinson and Pollitt 2002	Observational	Shorebirds	Accompanied	Coasts, estuaries, wetlands	UK
	Glover et al. 2011	Experimental	Shorebirds	Leashed	Coasts and wetlands	Australia
	Lafferty et al. 2006	Experimental	Coastal birds	Accompanied	Coasts	USA
	Lord et al. 2001	Experimental	New Zealand dotterel (breeding)	Leashed	Beaches	New Zealand
	Mallord et al. 2007	Observational and modeling	Woodlark	Accompanied	Heathlands	UK
	Miller et al. 2001	Experimental	Grassland and forest birds, plus one deer species	Accompanied (but one treatment where some separation from people occurred)	Forest	USA
	Murison et al. 2007	Observational	Dartford warbler	Accompanied	Heathlands	UK
	Randler 2006	Experimental	Eurasian Coot	Recording of barks	Wetlands	Germany
	Sastre et al. 2009	Observational	Great bustard	Accompanied and unaccompanied	Dry agriculture	Spain
	Taylor et al. 2007	Observational	Stone curlew	Accompanied	Fields (open access)	UK
Mammals	Cooper et al. 2008	Experimental	Eastern gray squirrel	Leashed	University campus	USA
	Gingold et al. 2009	Observational	Mountain gazelle	Guard dogs	Grassland	Jordan

Box 4.1 *Continued*

Table 4.1 *Continued*

Group	Study	Approach	Wildlife species	Predominant type of dog	Habitat	Country
	Hamr 1988	Experimental and observational	Alpine chamois	Leashed and unleashed	Alpine forests and pastures	Austria
	Kloppers et al. 2005	Experimental	Elk	Unleashed herding dogs	Urban, wetlands, forest	Canada
	MacArthur et al. 1982	Observational and experimental	Bighorn sheep	Leashed	Forest	Canada
	Mainini et al. 1993	Experimental	Marmot	Leashed	Alpine areas	Switzerland
	Manor and Saltz 2003, 2004	Observational	Mountain gazelle	Feral dogs	Coastal plain	Israel
	Martinetto and Cugnasse 2001	Experimental	Mouflon	Leashed and unleashed	Woodland and rocky	France
	Pelletier 2006	Observational	Bighorn sheep	Leashed and unleashed	Grassy slopes	Canada
	Sweeney et al. 1971	Experimental	White-tailed deer	Unleashed hunting dogs	Forests, pastures, cropland	USA

that degrades habitat quality, then it might be one of several ecological processes which effectively create 'ecological traps'; insidious situations whereby animals select habitat based on cues that no longer reflect actual habitat quality (Schlaepfer et al., 2002). For example, animals may select habitat on the basis of the presence of resources for foraging and breeding (e.g., the presence of suitable hollows or prey), but may be unable to breed successfully because of disturbance while breeding. Such populations may represent attractive 'population sinks' (Schlaepfer et al., 2002). The episodic and extreme variation in human (and dog) presence in many areas means animals might settle in highly disturbed habitats during undisturbed periods.

4.2 Dogs as stimuli

The depth of evolutionary history and extent of wildlife interactions with wild canids have presumably shaped how wildlife perceive dogs, and the way dogs and wildlife behave during encounters (instances when wildlife and dogs interact). Canids may instinctively hunt wildlife and therefore dogs may be perceived as particularly threatening by wildlife (Gabrielsen and Smith, 1995). Among the diverse array of stimuli encountered by wildlife (e.g., humans, vehicles, predators, etc.), dogs as stimuli are associated with a specific set of features. First, like other predators, dogs evoke some of the most dramatic responses among wildlife and are therefore apparently perceived as especially threatening (Weston and Elgar, 2007). Unlike benign stimuli, in which wildlife responses can be considered unnecessary (e.g., to recreationists on beaches), dogs are frequently 'non-benign' stimuli that often actively pursue wildlife during encounters, for example, by chasing (9% of dogs chased birds on a Californian beach, Lafferty, 2001b; 11.1% of disturbance to shorebirds on beaches around Mackay, Queensland, involved dogs chasing birds, Bloor, 2005). The

lack of an adequate response by wildlife may result in injury or death during such encounters. Dogs are associated with unique visual, auditory, and olfactory cues (e.g., shape, barking or howling, and scent marking) as well as more holistic cues such as posture, gait, and behavior. These cues may evoke responses among wildlife separately or in combination, however the specific canine cues (stimulus attributes) that are detected by wildlife and used to judge risk and inform response are unknown. Apparently, few studies test these cues separately, but it is unlikely that the visual cues are the only ones used to detect and assess risk by wildlife. Barking increases vigilance among preening Eurasian coots (*Fulica atra*; Randler, 2006), but apparently no information exists on disturbance by scent marking. Other native carnivores may respond to the scent of dogs on trails or in areas where dogs are allowed to roam freely, resulting in changes in activity in these areas (Lenth et al., 2008; Vanak et al., 2009).

4.2.1 Dogs as agents of disturbance

Several pieces of evidence suggest that dogs are prominent agents of wildlife disturbance, and that their role as agents of disturbance is often underestimated. First, experimental studies may underestimate dog disturbance. Most experimental studies of dog disturbance to wildlife mimic the most common types of stimuli because they seek management solutions and do not unravel specific aspects of a stimulus that cause disturbance. Studies of humans or other stimuli behaving as dogs do (e.g., by roaming) could enlighten as to whether it is dog behavior or dogs per se that contribute to the observed intense responses by wildlife (see Box 4.2). One key limitation of the current data available for dogs as an agent of disturbance to wildlife is the reliance on restrained dogs as experimental stimuli (Banks and Bryant, 2007; Faillace, 2010; Glover et al., 2011; Lord et al., 2001; Vanak et al., 2009). Thus, the most extreme wildlife responses may go unreported by experimental studies, while observational studies may better reflect the wildlife responses during more realistic encounters.

Second, dogs are among the most commonly encountered predator stimulus in at least some areas and circumstances (e.g., urban and recreational parks and coasts; Antos et al., 2007; Butler et al., 2004; Scott, 1989; Underhill-Day and Liley, 2007). In some natural areas, walkers and dogs are the most common source of disturbance (response) recorded, such as in wetlands in the UK (Robinson and Pollitt, 2002). The frequency of dog encounters with wildlife probably stems from three main factors: (1) dogs are common companions of humans; (2) they are capable of roaming over large areas of habitat; and (3) they tend to be year-round residents. When unrestrained they can occupy larger parts of the wildlife habitats in which they occur compared to humans (Figure 4.2). The higher area of occupancy of owned dogs results from both the mobility of their owners and from dog 'roaming' (i.e., the distance they move from their owners). Dog walkers can be rather mobile; on the Thames Basin heaths, UK, the mean length of route for dog walkers was 2,500 m, more than walkers and picnickers (2,300 and 1,200 m, respectively), but less than joggers, cyclists, and horse riders (3,900, 4,900, and 3,200 m, respectively) (Underhill-Day and Liley, 2007). Unrestrained dogs roam within coastal habitats perhaps more than any other stimulus type (Coombes et al., 2008) except possibly predatory birds. They also roam in non-coastal habitats (e.g., Sastre et al., 2009), although in at least some areas their roaming has been regarded as more modest, perhaps because of low penetrability of thick trailside vegetation (Bekoff and Meaney, 1997; Forrest and St. Clair, 2006; Mallord et al., 2007). Owned dogs, especially in urbanized societies, enjoy regular walks; for example, of 380 coastal residents in south-eastern Australia, 36.8% owned a dog of which 93.6% took their dog to the beach (Maguire et al., 2011a). This means dogs tend to be present in wildlife habitat year-round (Figure 4.3 provides an example of complete temporal overlap between unleashed companion dogs and a vulnerable life history stage of a sensitive wildlife species). For owned dogs, human social factors such as weekends and holidays influence their occurrence in many areas (Sastre et al., 2009), and presumably climate also dictates seasonality of occurrence, perhaps especially in higher latitudes. Resident village dogs are also often present year round, and presumably so too are free-ranging dogs. Despite the already high densities of accompanied dogs in many parts of the
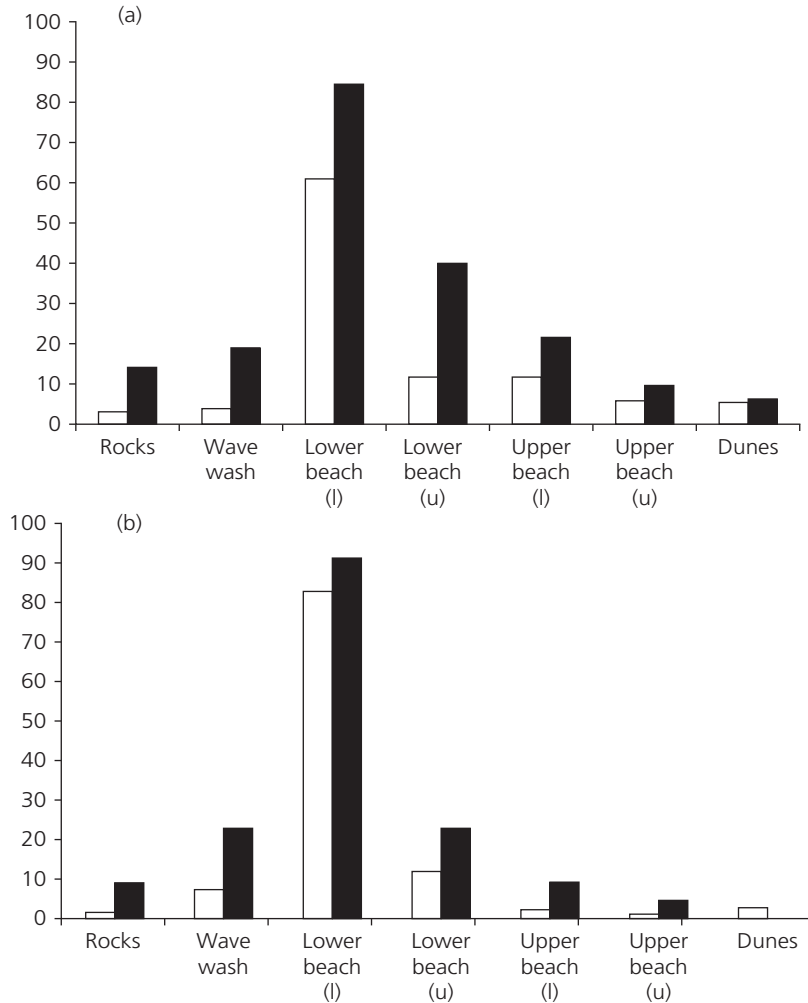
Figure 4.2 The habitat use of walkers (a, top panel) and joggers (b, lower panel) as they passed hooded plover (*Thinornis rubricollis*) nests on beaches in Victoria, Australia (see Weston and Elgar, 2007 for details; 'l' is the lower half, 'u' is the upper half) (unpublished data). The percentage of recreationists in each beach zone (averaged across nests) is shown. Open bars indicate that no dogs accompanied recreationists and closed bars indicate recreationists were accompanied by dogs off the leash. Walkers and joggers with dogs on leash were omitted due to small sample sizes.

world, projections suggest this activity will increase in future (Brickner, 2000); in some parts of the UK, 3.8–7.3% increases in dog walkers by 2080 are predicted (Coombes et al., 2008).

Finally, unrestrained dogs often move 'unpredictably' (i.e., their direction and speed varies frequently) and sometimes harass wildlife, traits that do not promote 'habituation,' the process whereby wildlife learn to reduce response intensities or frequencies with increasing exposure to a stimulus (Lafferty, 2001b; Sastre et al., 2009). Rather, these

attributes promote 'sensitization,' or enhanced response frequencies or intensities with increasing exposure to stimuli (Glover et al., 2011). Roaming (usually erratic central place movements around an owner) influences three factors used by many wildlife species to judge degree of threat: predictability (in behavior and to some extent occurrence), proximity, and speed (Glover et al., 2011). While some dogs roam without accompanying humans, many others are kept indoors or in yards, and roam during 'walks.' During walks, some highly trained
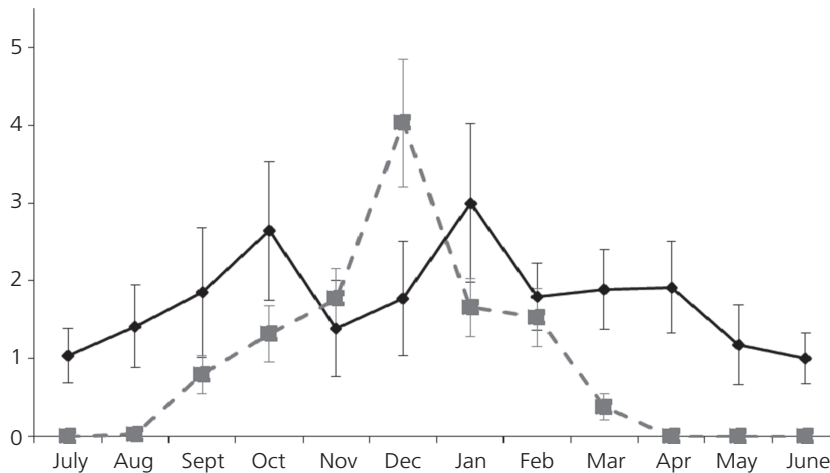
Figure 4.3 The average number of walkers with dogs off the leash (1,571 surveys of 69 beaches in Victoria, Australia, 1995–98; unpublished data; black lines) in relation to the average number of nests of hooded plover on those beaches (gray dotted line). Means and one standard error are shown; 6.1% of 743 dogs were leashed and are excluded from the graph.

dogs are effectively controlled by voice commands, but restraint in the form of a leash is by far the most common method of effectively managing dog roaming during walks. However, leashing rates are often low, with unleashed dogs apparently occupying more habitat than leashed dogs (Box 4.2).

4.2.2 Birds

A prerequisite for disturbance of wildlife is the temporal and/or spatial co-occurrence of stimuli and wildlife. The extent of overlap with wildlife populations and the frequency with which encounters occur is critical when judging possible impacts of disturbance. Birds probably frequently encounter dogs, though information on encounter rates (i.e., where an interaction is possible) is limited mostly to parks and beaches (see Section 4.2.1), where dogs are reported as the most, or among the most, frequently occurring stimuli (Antos et al., 2007; Mallord et al., 2007). While these studies often focus on recreational disturbance, and thus presumably present a biased 'heavily disturbed' sample, the potential for conflict between dogs and birds is high. Some information is available on the occurrence of dogs in or near bird habitat, and that information, while restricted to urban and wetland areas, suggests dogs are common sometimes even

in 'off-limits' nature reserves dedicated to bird conservation (e.g., 8.5 times per weekend day; Antos et al., 2007). The hooded plover, a threatened beach-nesting shorebird, experiences many natural and anthropogenic stimuli on Victorian beaches, Australia, where 18–19% of encounters with nests or broods involved dogs, at a rate of 0.47 encounters per hour (Weston and Elgar, 2005, 2007). Off-leash dogs and dogs chasing birds were the third and fourth most common causes of disturbance to shorebirds around Mackay, Queensland (Bloor, 2005). Dogs accompanying people were the third most common stimulus causing flushing among blackbirds *Turdus merula* in urban parks in Madrid, Spain (Fernández-Juricic and Tellería, 2000). Of all stimuli encountered by roosting shorebirds on the Dee Estuary, UK, 1986–91, 26–41% involved dogs (Kirby et al., 1993). Little information is available on encounter rates between unattended dogs and birds; in Madrid unattended dogs represented 1.3% of potentially disturbing activities for great bustards (*Otis tarda*; Sastre et al., 2009), and on Victorian beaches, unattended but apparently owned dogs represented 0.9% of stimuli passing hooded plover nests (Weston and Elgar, 2007).

Not all birds are threatened by dogs in the same way or to the same extent, so the perception of dogs as threatening probably varies taxonomically (see

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**Box 4.2 Leashing as a tool to reduce roaming**

'Leashing' refers to the attachment of a tether to a collar or harness on a dog to control the dog's movements in relation to a mobile human. Leashing is considered the most effective way of reducing harmful dog–wildlife interactions in areas where pet dogs are exercised in areas where they may encounter wildlife. It is often considered more effective and enforceable than 'effective control' (e.g., through voice commands), which are difficult to measure and enforce.

Leashing presumably reduces wildlife responses (e.g., Weston and Elgar, 2005) by reducing dog roaming rather than the presence of a leash per se. Thus, there is presumably a maximum leash length that effectively reduces the roaming of dogs to the point where most wildlife decrease their responses (this is likely to vary between species; Glover et al., 2011). A review of commercially available leashes on the Internet reveals a significant difference in length of different types of leashes ($n = 58$, Kruskal Wallis $= 38.83$, $p < 0.001$). Traditional, commercially available, leashes constrain dogs to within 1–2 m of their owners, though retractable leashes are longer (typically 5–8 m in length) and some non-retractable leashes are up to 15 m in length (Figure 4.4). As leashing laws have become more prevalent, and with the advent of retractable (longer) leashes, it seems likely that, on average, leash length has increased over time.

Despite a great variety of leashing options, in at least some areas, the majority or at least a substantial proportion of dogs are unrestrained. For example, on Australian (90%

unleashed, Weston and Elgar, 2005; Williams et al., 2009) or US beaches (93%, Lafferty, 2001b), including areas where dogs are not permitted off-leash or at all, such as national parks (88%, 1991–98, Dowling and Weston, 1999; Arnberger et al., 2005), recreation reserves (22%, Austria, Arnberger and Eder, 2008), wetland reserves (100%, Antos et al., 2007) and buffers (68%, Weston et al., 2009). In heathland sites (UK), generally most or all dogs were unleashed (92%, Mallord et al., 2007; Underhill-Day and Liley, 2007). Thus, in at least many parts of the world, wildlife most frequently encounter free-ranging dogs regardless of prevailing local regulations (Lafferty et al., 2006). Miller et al. (Chapter 12) discuss the decisions made by owners in relation to leashing.

Although there have been virtually no studies, leashing appears to constrain dog roaming, at least in habitats where dog roaming is not constrained by vegetation or other impediments to movement. For example, on beaches in Victoria, Australia, where active hooded plover nests occurred, walkers and joggers accompanied by unleashed dogs occupied more levels of the beach than walkers or joggers without dogs (Figure 4.2). Walkers and joggers without dogs occupied fewer beach zones compared with when their recreational group (people and dogs) included unleashed dogs (walkers, 1.0 versus 2.0 beach zones occupied respectively (medians), $n = 1081$, $U = 21.69$, $p < 0.001$; joggers, 1.0 versus 1.5 zones, $n = 161$, Kruskal Wallis $= 28.25$, $p < 0.001$).
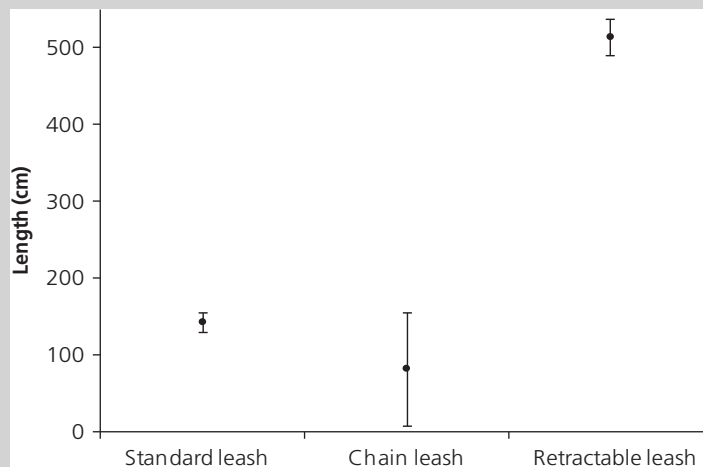
Figure 4.4 The length of commercially available leashes for dogs (not puppies; in cm), as revealed by an Internet search of several major pet supply stores ($n = 58$ products). Standard leashes are made of nylon or leather. Means and 95% confidence intervals are shown. Two 'recall' leashes (9 and 15 m) and leash extenders (up to 1 m) are excluded.

also Box 4.3). Many birds use trees, cliffs, open wa-ter, or spend much of their lives on the wing; such species are presumably immune or buffered from any negative impacts of dogs, and it might be pre-dicted that dogs are not perceived as especially threatening by these species (but see Banks and Bryant, 2007). Dogs sometimes enter waterbodies where they can disturb waterbirds (Kramer, 1986). However, flightless species or those that become flightless when molting, ground-dwelling, and especially ground-nesting birds are most likely to interact with dogs, and have been the subject of most research on dog–bird interactions. In this way, there may be a bias in existing literature, whereby the species most vulnerable to negative interactions with dogs may have been documented most. Nev-ertheless, bird–dog "conflicts" are reported from around the world.

4.2.3 Mammals

Unlike birds, where for some species researchers can monitor all disturbances for a group of birds over an extended period of time, encounter rates between wild mammals and dogs are less evident. In regions where dogs primarily travel with own-ers, the rate at which mammals may encounter dogs should be positively related to their distance from restricted trails where leashed dogs may oc-cur and the prevalence of dogs off-leash in the area. Accompanied dogs, however, are typically found in recreational areas during daylight hours, while many mammals are nocturnal, reducing the potential for direct encounters. Free-ranging dogs, however, tend to be nocturnal and show great vari-ation in their home range sizes (from 1 ha up to about 2,500 ha) with potentially much greater dis-turbance effects on wild mammals (Meek, 1999). Unlike birds, which typically have the option to fly away, most mammals (excluding bats, aquatic, semi-aquatic, and arboreal mammals) are lim-ited to terrestrial escape and are, therefore, more greatly affected by the tendency for dogs to roam widely across a landscape. While most types of dogs are better chasers than they are efficient hunt-ers (cf., dingoes), they are able to capture and kill a variety of mammals (see Ritchie et al., Chapter 2)

and generations of selective breeding have pro-vided subsets of dogs with specialized traits fa-vorable for hunting, locating and capturing prey, fighting, and racing (Serpell, 1995). Trained hunt-ing dogs can induce prolonged disturbance bouts. Sweeney et al. (1971) found that hunting dogs (*n* = 65) chased white-tailed deer (*Odocoileus virgin-ianus*) for an average of 33 min (up to 155 min) and an average of 3.9 km (up to 21.6 km). While no mortality occurred during these chases, 78% of the experimental chases resulted in the deer leav-ing their home range, with most returning within a day. While these were controlled experimental cases, untrained free-ranging dogs have much greater home range sizes (Meek, 1999) and should, therefore, be more likely to initiate long chases and move wildlife from their own home ranges. Unleashed dogs on beaches may be particularly dangerous for marine mammals. Several stud-ies report harassment and killing of harbor seals (*Phoca vitulina*; Allen et al., 1984) and Hawaiian monk seals (*Monachus scbauinslandi*; Gerrodette and Gilmartin, 1990; Kenyon, 1972) by dogs, sug-gesting that uncontrolled dogs could be particular-ly detrimental to populations of pinnipeds, which move slowly and awkwardly on land. Clearly, the impact of free-ranging dogs is a function of breed, training, past experiences with wildlife, and the prey encountered. Ultimately, dogs can prey upon a wide variety of wild mammals, including ter-restrial (e.g., hedgehogs *Erinaceus europaeus*; Don-caster, 1994), arboreal (Lumholtz's tree-kangaroos *Dendrolagus lumholtzi*; Newell, 1999), and marine mammals (Allen et al., 1984; Barnett and Rudd, 1983), thus mammalian responses to dogs are ex-pected to be substantial.

Wild mammals (perhaps except very large herbi-vores or carnivores) may alter their spatial distri-bution in areas where dogs are permitted to roam to reduce the likelihood of encountering poten-tially dangerous canines. Lenth et al., (2008) stud-ied signs of mammal activity nearby and far from trails in parks where leashed dogs were permitted on-trail and in parks where dogs were prohibited. They found lower signs of activity of mule deer (*O. hemionus*), rabbits (*Sylvilagus* spp.), prairie dogs (*Cynomys ludovicianus*), and other small mammals
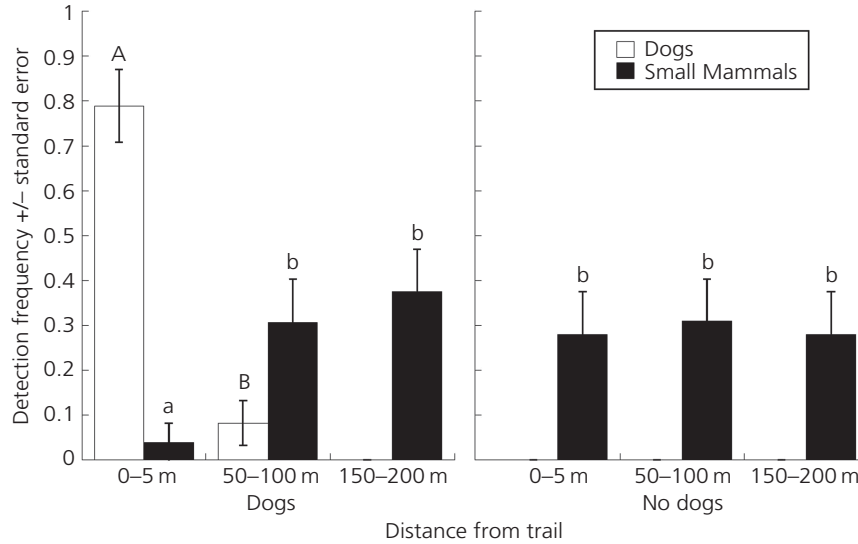
Figure 4.5 Detection frequencies of dogs and small mammals on track plates at different distances from trails where dogs are permitted or prohibited in a natural area. Different uppercase letters above columns indicate significant differences (p <0.1) in dog detection frequencies, and different lowercase letters indicate significant differences (p <0.1) in small mammal detection frequencies. Redrawn and reprinted with permission from the Natural Areas Association from Lenth et al., (2008).

on trails where dogs were permitted, compared to dog-free trails (Figure 4.5). Native carnivore activity, however, was higher near the end of trails where dogs were permitted but lower near trail heads, suggesting that carnivores avoided dog cues when abundant (i.e., trail heads) but may be attracted to them as novelty when they are present but rare (i.e., ends of trails). Bobcats (*Lynx rufus*) avoided dog trails altogether, perhaps because of the similarity between dog cues and those of coyotes (*Canis latrans*), a natural potential predator (which showed no difference in activity between sites). Similarly, mesocarnivores tend to avoid areas of high dog activity; bobcats (George and Crooks, 2006) and Indian foxes (*Vulpes bengalensis*) (Vanak and Gompper, 2010) showed reduced activity in areas where dogs were most active.

4.2.4 Other vertebrates

Comparatively little information is available on the role dogs play as stimuli for non-avian or non-mammalian vertebrates (henceforth 'other vertebrates'). In addition to visual, auditory, and olfac-

tory cues, some reptiles (e.g., snakes) also perceive vibrations in the ground associated with the approach of a threat (Young, 1983).

In many terrestrial areas, there is probably substantial temporal and spatial overlap between other vertebrates and dogs, though the extent of any interaction is virtually undocumented. Despite this, dog disturbance and 'harassment' is considered a conservation problem for amphibians and reptiles (e.g., British Columbia Government, 2004). While dogs have been present in many habitats for millennia, in some habitats they are relatively new arrivals, and have quickly established themselves as predators, and agents of disturbance, of vertebrates apart from birds and mammals. One example is on the Galapagos Islands, where marine iguanas (*Amblyrhynchus cristatus*), isolated from terrestrial predators for 5–15 million years, apparently first encountered dogs on some islands only *ca.* 150 years (Berger et al., 2007). The increase in dogs (and cats) has coincided with human settlement in the islands and now causes disturbance and mortality among iguanas.

Box 4.3 Persecutor to protector; dog disturbance protecting wildlife

Not all dog–wildlife disturbance results in negative out-comes for wildlife. Dogs also disturb pest and nuisance spe-cies, and in circumstances where wildlife are more tolerant or less vulnerable than pests, or where dogs are trained specifically to defend wildlife, then dogs essentially become their protectors. Additionally, disturbance can be used as a non-lethal alternative to achieve management objectives that reduce human–wildlife conflict, and so effectively ben-efit wildlife.

In urban backyards of some Australian cities, the presence of pet dogs decreases the probability of denning by the intro-duced pest species, the red fox (*V. vulpes*; Marks and Bloom-field, 2006). This presumably permits a variety of wildlife to persist which otherwise could not. Carefully trained guard dogs defend a handful of threatened species or significant wildlife colonies (e.g., burrow and surface nesting seabirds) against introduced or problematic predators (van Bom-mel, 2010); in the same way they can defend stock against predators and so reduce farmer–wildlife conflict (Coppinger et al., 1987; VerCauteren et al., Chapter 9). Some airports use dogs to reduce bird hazards to aircraft as a non-lethal management alternative (Froneman and van Rooyan, 2003). Dogs have even been used as aversive conditioning stimuli to dishabituate elk *Cervus canadensis* and other ungulates in areas where they are heavily encroaching on human set-tlements (Kloppers et al., 2005; VerCauteren et al., 2008; Walter et al., 2010). In these cases, dogs of different breeds

have been effective hazing tools for wildlife managers. Livestock and crop protection dogs have also been used to chase away wild ungulates from cattle ranches (thereby limiting the spread of zoonoses like brucellosis to cattle), golf courses, orchards, and forest plantations (VerCauteren et al., 2005, 2008; Walter et al., 2010); and breeds that are territorial and patrol open spaces (e.g., Siberian Husky, Alaskan Malamute) have been most effective (VerCauteren et al., 2005).

Finally, the ability of dogs to detect wildlife that would be otherwise undetectable, often by honing in on their scent and evoking a flight reaction, has supported the conserva-tion effort of many cryptic species such as kiwi (*Apteryx aus-tralis*) in New Zealand (Taborsky, 1988), black grouse (*Tetrao tetrix*) in England (Baines and Richardson, 2007), or Mojave desert tortoises (*Gopherus agassizii*) in the USA (Heaton et al., 2008). This ability to locate cryptic wildlife can be har-nessed to capture individuals for their use in threatened spe-cies programs or to survey sites to assess their suitability for human development, or general wildlife surveys (Gutzwiller, 1990; Woollett et al., Chapter 10). Additionally, dogs have played a critical role in pest eradication aimed at ecological restoration, such as in the attempts to eradicate European rabbits (*Oryctolagus cuniculus*) from the sub-Antarctic Mac-quarie Island (Australian Government, 2012). Such efforts cause short-term disturbance but can result in long-term beneficial conservation outcomes.

4.3 The response of wildlife

Disturbance responses among wildlife are generally accepted to have evolved as anti-predator respons-es, and are adaptive among populations exposed to predators. Wildlife responses to dogs range from vigilance and crypsis to active defense such as ag-gression or flight, and are adjusted in relation to a range of internal and external factors (Glover et al., 2011). Optimal escape theory posits that responses can be considered in a cost–benefit framework, whereby escape entails costs (often energetic costs) but delivers benefits (notably enhanced survival) (Ydenberg and Dill, 1986), and in an optimality framework, whereby escape permits gain of fitness after the interaction whereby death leads to loss of all future fitness (Cooper and Frederick, 2007, 2010).

Based on differential responses, wildlife have the capacity to discriminate between stimuli, includ-ing discriminating between dogs and other stimuli (Glover et al., 2011; Lord et al., 2001). Given all wild-life have to respond to threatening stimuli in some way, a key question is how response rates or inten-sities in relation to dogs compare with those caused by other stimuli, natural or anthropogenic.

Many studies of disturbance report wildlife re-sponding frequently and substantially to dogs, despite at least many decades, if not centuries or millennia, of exposure. Wildlife responses are like-ly to be shaped at two distinct time-scales: within lifetimes and over evolutionary time. Changes to responses within lifetimes are driven by learning, that is altered responses on the basis of individual

experience. The persistence of responses in circumstances where the stimuli do not apparently represent substantive threats (i.e., to human recreationist) suggests that habituation, if it occurs, is often modest (Glover et al., 2011). Responses will also have been shaped by evolution. Continuing (apparently costly) responses of wildlife to dogs, despite long-term exposure, presumably mean that such responses are adaptive, in other words, the avoidance of dog predation despite the cost of responses has presumably conferred fitness benefits. In many places (such as Europe and North America) dogs

may be considered as functional analogs, albeit at elevated densities, of now-extinct or rare predators such as wolves *C. lupus*; in other areas (such as New Zealand and many other islands) mammalian terrestrial predators are evolutionarily novel. This creates an interesting paradox (Figure 4.6); among wildlife which is evolutionarily 'better-prepared,' dog-related disturbance may sometimes be higher (and yet levels of predation lower) than in areas with largely naïve native faunas, where disturbance may be relatively modest but predation levels high (e.g., Berger et al., 2007).
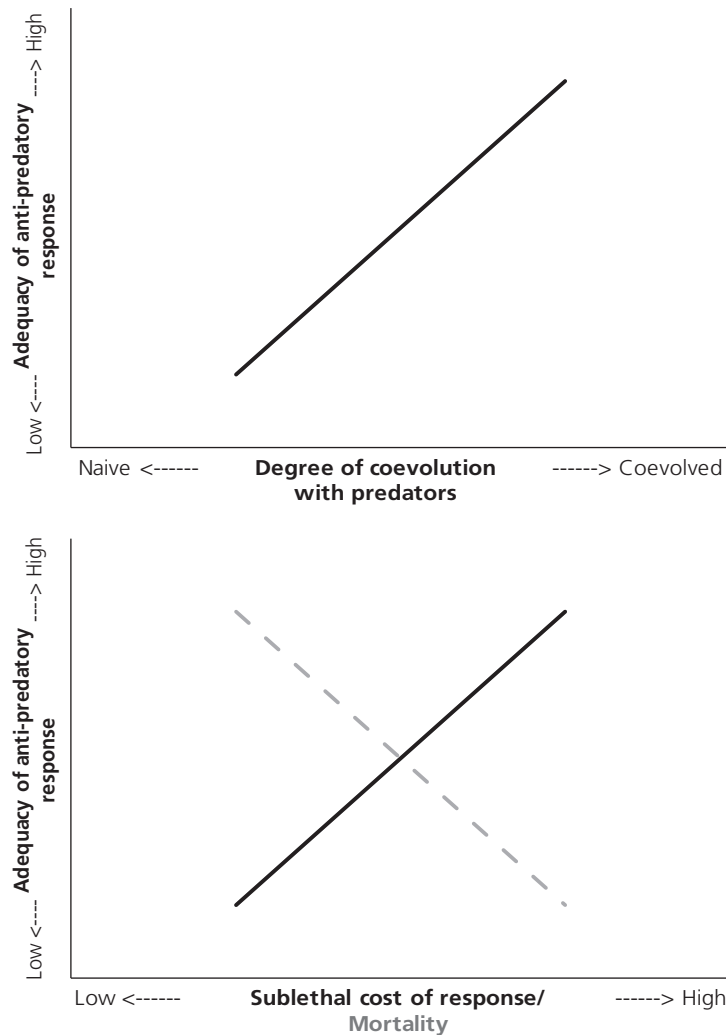
Figure 4.6 Diagrammatic representation of a conceptual model of the 'Disturbance–Predator Paradox.' Evolutionarily naïve species may not exhibit strong anti-predator responses (top panel) which means they may not incur substantial sublethal costs from maladaptive responses to benign stimuli. However, they may experience high mortality when stimuli are not benign (bottom panel). Black solid lines indicate sublethal effects; dashed gray lines indicate lethal effects.

4.3.1 Birds

Birds flee dogs—on foot, on the wing, by climbing, swimming, or diving. One measure of response intensity is Flight Initiation Distance (FID), the distance at which an animal flees from an approaching stimulus. Apart from flight (fleeing) a variety of responses are given to dogs. These include vigilance, absences from nests or young, distraction, and reductions in, or cessation of, foraging (Colwell and Sundeen, 2000; Weston and Elgar, 2005, 2007). Aggression is also reported, with aggressive ground- (e.g., lapwings, *Vanellus vanellus*) and tree-nesting species (e.g., Australian magpies, *Gynmorhina tibicens*) swooping some dogs (M.A. Weston, unpublished data). These responses are all associated with energetic and other consequences, which are generally poorly known and require more study.

Observational studies report higher response rates or intensities of ground-nesting birds to unleashed dogs over other anthropogenic stimuli, although naturally occurring stimuli may still evoke more frequent or longer lasting responses (Burger, 1981; Taylor et al., 2007; Weston and Elgar, 2005; 2007). Walkers accompanied by dogs often evoke greater responses in ground-dwelling birds than humans alone (Lord et al., 2001; Sastre et al., 2009; Sime, 1999). For example, stone curlews (*Burhinus oedicnemus*) show FIDs to dog walkers that sometimes exceed 500 m (Taylor et al., 2007). Dogs caused higher rates of flushing at prairie chicken (*Tympanuchus cupido*) leks compared with visits by foxes (Hamerstrom et al., 1965). Few studies of the response of birds to unattended dogs are available, but those results that are available suggest that the degree to which dogs unaccompanied by people disturb birds is context specific. Unattended dogs in steppes around Madrid represented 1.3% of potentially disturbing stimuli for great bustards, but caused 2.9% of responses; the probability of causing a disturbance was higher for dogs than for any anthropogenic activity recorded, including hunting, vehicles, and aircraft (Sastre et al., 2009). On the other hand, two grassland birds in the USA (vesper sparrows, *Pooecetes gramineus*, and western meadowlarks, *Sturnella neglecta*), were disturbed least by unattended lone dogs, and more so by walkers and walkers with dogs (Miller et al., 2001). Perhaps the height of an approaching stimulus alters the distance at which stimuli are detected, especially where lower strata, such as grass, limit the field of view.

Observational studies of disturbance to birds have focused on attended dogs, usually on coasts, wetlands, or in parks, and have demonstrated that dog–bird interactions are common worldwide, and that birds respond frequently and substantially to dogs. Walkers and dogs were the most common source of disturbance recorded at coastal and inland wetlands in the UK, although they were more likely to cause disturbance to waterbirds at coastal sites, probably because of the nature of the habitats and the degree of spatial overlap between human activities and birds (Robinson and Pollitt, 2002). On the Dee Estuary, UK, 1986–91, dogs caused high rates of disturbance to shorebirds (27–72% of all disturbance events) compared with walkers (20–34%), even though walkers were more commonly encountered (Kirby et al., 1993). On the other hand, dogs did not influence vigilance rates of shorebirds foraging on a rocky beach at Belfast Lough, UK (Fitzpatrick and Bouchez, 1998). On a beach in Santa Barbara, California, 10% of humans and 39% of dogs disturbed birds (Lafferty, 2001a). On beaches around Mackay, 14.8% of all disturbances to shorebirds (involving 24.6% of shorebirds present) were caused by dogs (birds flew up to at least 250 m; Bloor, 2005). Dogs were the most common cause of disturbance to breeding Dartford warblers (*Sylvia undata*) in heathland sites in Dorset, UK (Murison et al., 2007). At Esquimalt Lagoon, Canada, dog walking caused 18% of observed anthropogenic disturbances to waterbirds (Clowater, 2008). Observational studies such as these have underpinned the perception among managers that dog disturbance of wildlife is a high priority for management (Le Corre et al., 2009). While observational studies map the occurrence of stimuli and response in space and time, they don't unravel the specific stimulus–response– consequence mechanisms that permit deeper analysis of the issue. The consequences of disturbance responses are not obvious at the individual level, let alone the population level. For example, it is generally unknown how the rate or intensity of response is associated with fitness, and whether the relationship is linear or nonlinear, with or without 'thresholds.'

Several experimental studies of wildlife disturbance explicitly investigate the influence of stimulus type on response (reviewed in Weston et al., 2012) but very few use dogs as one of the stimuli tested. Glover et al. (2011) showed that of eight shorebirds tested, stimulus type (walker, jogger, walker with leashed dog) significantly influenced FID of three species. Excluding joggers, all three species had highest FID when approached by a person with a leashed dog, rather than by a person alone. Snowy plovers (*Charadrius alexandrinus*) react at twice the distance to dogs than to pedestrians (Fahy and Woodhouse, 1995; Lafferty, 2001b), and disruptions to incubation caused by investigator approaches to northern New Zealand dotterel (*C. obscurus aquilonius*) nests were longer when a leashed dog was present (Lord et al., 2001). North-western crows (*Corvus caurinus*) and glaucous-winged gulls, (*Larus glaucescens*) took bread at greater distances from a human and dog than from a human alone, reversing the outcome of food competition between these species (Dunbrack and Dunbrack, 2010).

Other measures of response include the amount of time before the resumption of normal activities. Similar to the New Zealand dotterel, snowy plovers remained away from their nests for longer durations when a walker with a leashed dog approached, compared with a walker alone, on one Florida island (although not on another) (Faillace, 2010). A variety of internal and external factors influence response rates to stimuli, and these presumably also apply to responses of birds to dogs. Body mass, wing shape, diet, age, sex, group size, experience including geographical isolation from predators, personality, site attributes including distance from cover and the presence of barriers such as fences or canals, whether stimuli occur on- or off-trail, and weather, among other things, may influence responses (see Stankowich and Blumstein, 2005; Weston et al., 2012). There will also doubtless be attributes of dogs that alter response, potentially including size and personality (reflecting breeds in some cases), group size, vocalizations, propensity to roam, age, and so on. Habitat mediates the responses of some birds, perhaps because some habitats are impenetrable to dogs (Mallord et al., 2007; Robinson and Pollitt, 2002). In forests, the American robin (*Turdus migratorius*) responded similarly to walkers

alone and those accompanied by a dog, while two grassland species responded more strongly when a walker with a dog approached (Miller et al., 2001). Thus, it is possible that habitat mediates the responses of birds to dogs.

4.3.2 Mammals

Many studies have measured the direct disturbance effects of human recreation on wild mammals (see Knight and Gutzwiller, 1995; Stankowich, 2008; Stankowich and Blumstein, 2005). Mammals typically respond to dogs by fleeing to a burrow or tree, but larger mammals that lack these options often escape over long distances and are more likely to be displaced from their home range, stressed physiologically, and experience the negative effects of escape for longer durations. As a consequence, ungulates have been a common focus of disturbance studies, especially in response to dogs. Generally, the presence of a human has a greater impact on wildlife behavior in areas with relatively low human density, and one explanation of this is the possibility that animals habituate to humans in a non-threatening context (Stankowich, 2008). The effect of dogs relative to humans is less clear. While some studies find wild mammals to be less fearful of humans alone compared to humans accompanied by dogs (e.g., Hone, 1934), others have observed that mammals responded in the same manner irrespective of the presence of dogs (e.g., Hamr, 1988). While the most common response to the presence of a dog is to become alert and flee, the presence of dogs may also alter physiological responses. Bighorn sheep (*Ovis canadensis*) had greater heart rates when approached by a human with a dog compared to a human alone (MacArthur et al., 1982) and domestic sheep (*O. aries*) showed greater fear and avoidance of a dog compared to a human or a goat (Beausoleil et al., 2005). The presence of dogs during captures by wildlife managers may exacerbate these physiological effects (Sime, 1999). Marmots (*Marmota marmota*) were more likely to flee to burrows and to emit warning whistles, and they took longer to re-emerge from burrows after escape when dogs were present with humans, compared to humans alone (Figure 4.7). Interestingly, in some cases, the presence of a dog may actually reduce the degree of response altogether (where

'degree of response' refers to the level of behavioral response in a typical hierarchy of responses that escalate with increasing risk). Eastern gray squirrels (*Sciurus carolinensis*), in the presence of a dog compared to a human alone, tended to run *less* often and were more likely to freeze, erect, or flick their tails (Cooper et al., 2008). In addition to these immediate reactions to the presence of dogs, some species may increase their group size to gain protection. Mountain gazelles (*Gazella gazella*) had larger group sizes in areas with more feral dogs (Manor and Saltz, 2003), which prey on gazelle neonates, and the culling of feral dogs significantly increased the kid:female ratio in subsequent years (Manor and Saltz, 2004).

Wild mammals may be more attuned to dogs as potential predators, and in their presence may have a greater zone of awareness (the bounds of which are the maximum distance at which an animal will become alert and monitor a potential predator; Stankowich and Coss, 2006). Marmots became alert to trail hikers led by dogs and hikers with free-ranging dogs at significantly greater distances than to off-trail hikers or trail hikers without dogs (Mainini et al., 1993), but there was no difference between leashed and free-ranging dogs. Mule deer were more likely to become alert, and became alert at greater distances, when hikers were accompanied by leashed dogs off-trail compared to when hikers were alone (Miller et al., 2001). While

the presence of a dog with a hiker elicited greater alert distances from eastern gray squirrels in areas with high human activity, interestingly, there was no corresponding effect in areas of low human activity, where alert distances were much greater for both types of stimuli (Cooper et al., 2008), suggesting that wild mammals may have an easier time habituating to humans when they are common, but dogs will always be perceived as dangerous regardless of their ubiquity.

The decision to flee is based on a substantial array of factors, including past experience with the stimulus type (i.e., learning effects), the type of stimulus (i.e., predator identity), and threatening behavior of the stimulus (e.g., approach speed, directness) (Stankowich, 2008; Stankowich and Blumstein, 2005). Therefore, it is predicted that, similar to alert distances, animals should flee from more threatening stimuli at greater distances than less threatening stimuli. Indeed, marmots fled from hikers with leashed or free-ranging dogs at greater distances than hikers without dogs, but, again there was no difference between leashed and unleashed dogs, although the minimum FIDs in response to off-leash dogs were much greater than for leashed dogs (Figure 4.7). Identical results were found for mouflon (*O. musimon*; Martinetto and Cugnasse, 2001) and mule deer also had a greater probability of fleeing and a greater FID in response to hikers with a
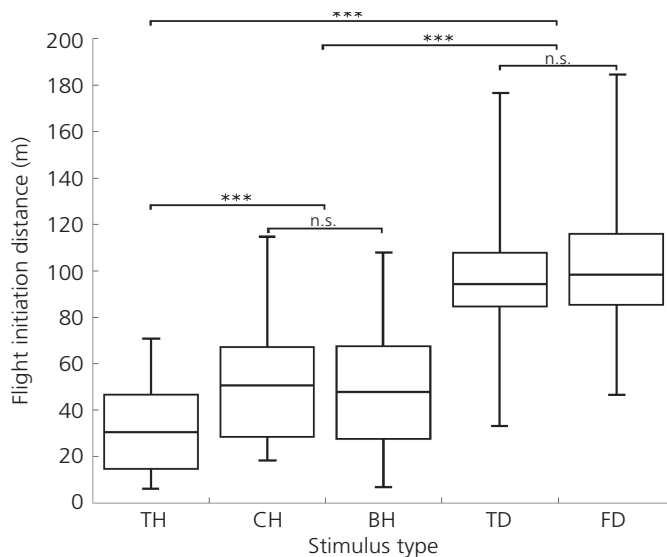
Figure 4.7   Flight initiation distance (median, IQR, min., max.) of marmots in response to people hiking on marked trails (TH), hikers walking cross-country off trails (CH), people hiking off trails across burrows (BH), people hiking on trails with leashed dogs (TD), and people hiking off trails with dogs on a 10 m leash to simulate free-ranging dogs (FD). $n = 20$ for each stimulus; *** $p < 0.001$. Redrawn and reprinted with permission from Elsevier from Mainini et al., (1993).

leashed dog, compared with hikers without dogs (Miller et al., 2001). Interestingly, elk fled at similar distances to humans alone and humans accompanied by dogs, both before aversive conditioning (experimental harassment by humans and dogs) and afterwards (Kloppers et al., 2005). This population, however, was highly habituated to humans and was encroaching on a settlement prior to conditioning, so the generality of this result is questionable. Finally, due to thousands of years of co-evolution with other wild canids, wildlife escape responses to dogs may be influenced by subtle behavioral cues shared by hunting canids: caribou (*Rangifer tarandus*) herds allow wolves to approach closely until they recognize behaviors indicating the wolves' intentions (Bergerud, 1974).

Once an animal has fled, the distance they move from the source of disturbance may also be an indicator of the perceived threat of the disturbance, however, results are conflicting. Similar to the findings for FID and alert distance noted above, bighorn sheep fled similar distances in response to humans with leashed dogs in comparison with free-ranging dogs (Pelletier, 2006). While mule deer tended to flee greater distances when humans approached with dogs off-trail compared to humans without dogs, they found no such difference on-trail (Miller et al., 2001). In contrast, alpine chamois (*Rupicapra rupicapra*) that haven't been exposed to wolves for many generations, were more curious of trained stationary dogs; and when unaccompanied-but-trained dogs were allowed to pursue, chamois fled shorter distances compared to humans alone but defended themselves with horns if overtaken and cornered (Hamr, 1988). Given these results, it appears that the distance that wild mammals move in response to dogs may depend more upon their past experiences with them and the landscape in which the encounter occurs.

Being on or off trail influences many wildlife responses to dogs (Mainini et al., 1993; Miller et al., 2001), but many other factors may mediate fright responses. Larger group sizes may ameliorate physiological effects on mammals of dog presence and increase perceptions of safety; MacArthur et al., (1982) found a negative association between group size and heart rate in mountain sheep when humans approached with a dog but not when humans approached with-

out a dog. Many seasonal differences influence the response of wildlife to dogs, including difficulties of escape in snow, over rugged terrain, or when accompanied by offspring (Sime, 1999; Stankowich, 2008). As the effects of the presence of dogs during human–mammal encounters have received little attention, other interacting effects have yet to be studied, although they likely include past experiences of wildlife with dogs or other wild canids, human density in the area, size and defensive ability of the wildlife species, and the availability of, and distance to, refuge.

4.3.3 Other vertebrates

Reptiles and amphibians are preyed on by dogs (e.g., Koenig et al., 2002), so it is unsurprising that they respond to the presence of dogs. They respond to disturbance by fleeing on land or in water, climbing, and often use refuges, for example in crevices or vegetation. Snakes may defend themselves against dogs by rearing and striking, resulting in a much publicized dog–wildlife interaction, which is often characterized in the media as 'snake attacks' (e.g., Levy, 2011), but which are more likely to be an aggressive defensive response to the approach of a dog. Snake bites of dogs occur worldwide; 44% of domestic animals in Australia suffering from snake bites, and which were presented to veterinarians, were dogs (*n* = 1590; Mirtschin et al., 2008).

While escape behavior in reptiles, usually running, has been used as a general model of developing and testing theoretical frameworks for flight (e.g., Cooper and Wilson, 2007), little information is available of the response of reptiles to the presence of dogs. Mojave Desert tortoises (*Gopherus agassizii*) did not alter their movement patterns when detected by dogs as opposed to by a person without a dog (Heaton et al., 2008). Marine iguanas on islands with free-ranging dogs (and cats) exhibited higher FIDs in response to human approaches and human chasing and had higher corticosterone levels than those on islands without dogs (Berger et al., 2007). The species is capable of habituating to human disturbance, but dogs are an actual predator (i.e., a non-benign stimulus) so responses are likely to be adaptive, although currently they are not effective at avoiding predation (Berger et al., 2007; Rödl et al., 2007). Blue-tongued lizards (*Tiliqua scincoides*)

may persist in suburbia, partly because their use of hard cover refuges in response to threats may avoid predation by dogs (Koenig et al., 2001).

We were unable to locate any literature on dog disturbance of amphibians, though fleeing, cypsis including the cessation of calling, and other responses are expected.

4.4 The impacts of dog disturbance on wildlife

The question as to whether disturbance is a welfare and/or a conservation issue is critical to the way dogs should be managed in natural areas. Management priorities may not include mitigating disturbance unless it is perceived to be a conservation risk. Once again, the most studied impacts of disturbance by dogs on wildlife involve coasts and parks, and owned dogs.

4.4.1 Birds

Disturbance represents a conservation threat if it negatively influences wildlife population viability. Population parameters that influence viability include average reproductive success, recruitment, survival, and habitat use. Most evidence of deleterious impacts of dog disturbance derives from readily measured behavioral responses, which involve the disruption of critical behaviors such as compromised parental care (Weston and Elgar, 2005, 2007). A few findings infer that such disruption can affect key population parameters, such as through depressed reproductive success. For example, effective dog management zones are associated with higher reproductive success among hooded plovers (Dowling and Weston, 1999).

Only a handful of studies link population or community level impacts of disturbance, and even fewer focus specifically on dogs as agents of disturbance. An increase in recreational disturbance, which mostly constituted dog walkers and unleashed dogs in heathland sites at Dorset, UK, resulted in a 17% decrease in breeding productivity of the ground-nesting woodlark (*Lullula arborea*). A range of access scenarios indicated that a doubling of current recreational levels does not apparently influence the woodlark breeding population size, but a more evenly distributed occurrence of

recreationists would impact populations substantially (Mallord et al., 2007). Little direct evidence is available to link dogs with altered usage of habitat. In an Australian woodland park, there was a 35% reduction in bird diversity and 41% reduction in abundance due to the presence of leashed dogs, both in areas where dog walking is common and where dogs are prohibited (Banks and Bryant, 2007). The critical issue of whether dog disturbance is a conservation issue for birds remains virtually undocumented, partly because studies are complex and require substantial quantities of data.

4.4.2 Mammals

Like birds, there is a lack of empirical work on the broader impacts of dog disturbance on wild mammals. The scant evidence available implies broad and potentially significant effects: (1) in areas where dogs on leashes are common; (2) where feral or free-ranging dogs are abundant; and (3) for small mammals. In addition to the potential effects on group sizes discussed in Section 4.3.2 above, free-ranging dogs also have a direct negative influence on the kid:female ratio of mountain gazelles (Manor and Saltz, 2004), suggesting the potential for significant impact on population growth and viability (Gaillard et al., 1998). When some of the dogs were removed from a particularly abundant population near a garbage dump, the kid:female ratio increased significantly. Gingold et al. (2009) found similar results for mountain gazelle responses to guard dogs, where increased vigilance and time spent running came at the expense of time resting and walking, which led to decreased numbers of fawns per female. The burrows of small mammals may become damaged by dogs (Sime, 1999), and even dogs walking over top of burrows may cause a disturbance (Mainini et al., 1993). Finally, Gerrodette and Gilmartin (1990) attribute the recovery of Hawaiian monk seals at Kure Atoll, after the species was listed as endangered in 1976, to US Coast Guard efforts aimed at reducing disturbance by dogs and automobiles.

Free-ranging dogs can act as predators of a variety of mammals (Ritchie et al., Chapter 2), and this may have significant population- and community-level effects. These effects, however, may be most relevant for feral or free-ranging dogs as there is little evidence that leashed or controlled dogs in recreational

areas have any effect on species richness or abundance. Forrest and St. Clair (2006) found minimal effects of off-leash dogs on the diversity and abundance of small mammals (and birds) in urban parks. While native carnivore species richness was lower in public areas where dogs were permitted, compared to non-public protected sites (especially for coyotes and bobcats), overall carnivore species richness and abundance was unaffected (Reed and Merenlender, 2011). Therefore, while controlled dogs may influence the activity and movement patterns of wild mammals, there is currently little evidence to suggest they have broad community-level effects.

4.4.3 Other vertebrates

Virtually nothing is known about the impacts of disturbance by dogs on other vertebrates. However, Section 4.3.4 clearly documents a range of responses to dogs, which are likely to have consequences at least at the individual level. While not specific to dogs, human disturbance can decrease the habitat occupancy of amphibians (Rodríguez-Prieto and Fernández-Juricic, 2005).

4.5 Managing dog disturbance

The high usage of natural areas by dog walkers, their high numbers and mobility, and their high potential to cause disturbance means that in some areas they may represent a high management priority for mitigating disturbance to wildlife (Le Corre et al., 2009; Underhill-Day and Liley, 2007). This section focuses on owned dogs. Managing disturbance by dogs will involve either constraining their occurrence, or altering the way they are perceived by wildlife by reducing threatening aspects of dog behavior or by mitigating the deleterious effects of wildlife responses.

4.5.1 Constraining the occurrence of dogs

'Off limit' areas, or restrictions on seasons or periods of the day when dogs are permitted, are commonplace (e.g., banning dogs from islands with monk seal colonies; Gilmartin, 1983), but available data indicate that compliance is rather low (see Box 4.2). Variants of spatial restrictions include buffers (separation distances between natural values and incompatible uses) but recreationists, including dog walkers, are allowed in some 'buffers' (Weston et al., 2009). In particular, natural parks and reserves in many parts of the world prohibit owned dogs, though exceptions occur in some coastal parks (e.g., in Australia). Such restrictions can work (Lafferty et al., 2006). Key to the success of restriction is achieving adequate compliance, which can be promoted through the provision of 'dog-areas' that allow off-leash exercise for dogs and educational initiatives (Williams et al., 2009).

4.5.2 Altering the stimulus

Leashing reduces the speed, degree of roaming, and chasing by dogs and generally decreases response rates and distances among wildlife (Bloor, 2005; Hudson, 1982; Lafferty, 2001b; Weston and Elgar, 2007). For example, unleashed dogs disturbed seven times more red grouse (*Lagopus lagopus*) than leashed dogs (Hudson, 1982). Leashing not only alters problematic aspects of dog behavior, but could also underpin habituation on the part of the wildlife. On one Californian beach, once a protection area for birds became established, leashed dogs no longer caused any bird disturbance, while all disturbance in the protected area from dogs was from unleashed dogs (Lafferty et al., 2006). However, leashing does not prevent barking or other potentially disturbing cues (Randler, 2006).

The designation of leashing laws has not proven to be a major barrier to effective coexistence between dog walking and wildlife, and in many countries 'leash-only' zonation is common in public lands. Rather, the main barrier appears to be the low compliance rates with these regulations (see Box 4.2). Low compliance with leashing laws may explain the failure of some 'gradient' studies to correlate avian or mammal species diversity with prevailing dog regulations (Forrest and St. Clair, 2006). The requirement for human social change with respect to complying with leash laws is undeniable, though better information and signage is often required to more clearly demarcate different dog zones. Managers may be reluctant to tackle the unpopular and apparently insurmountable problem of low compliance with leashing laws, but over the medium to long term, compliance may be improved. Even where compliance with leashing regulations is low,

sustained efforts by managers can increase leashing rates (Dowling and Weston, 1999). The presence of a strong social norm among dog walkers suggests that if leashing becomes frequent enough, and therefore expected, many dog owners would leash their dogs on beaches (Williams et al., 2009). Many codes of conduct are available, such as advice to take particular care with dogs around seals or beach-nesting birds (e.g., New Zealand Department of Conservation, 2007).

4.5.3 Mitigating deleterious responses

Responses potentially compromise energy balances, reduce survival, or compromise parental care. Theoretically, if responses cannot be prevented, then management that mitigates the processes that lead to deleterious effects can reduce the impact of disturbance. Examples may include the use of nest cages or shelters for flightless young, which provide thermal insulation and protection of unattended young from predators including dogs (Maguire et al., 2011b).

4.6 Research needs

Compared with other sources of disturbance to wildlife, such as walkers and aircraft, relatively few studies consider disturbance by dogs (e.g., only 2.4% of 211 articles on disturbance to waterfowl mention dogs; Dahlgren and Korschgen, 1992). This chapter has demonstrated a series of critical information gaps regarding disturbance of wildlife by dogs.

First, in terms of dogs as a stimulus, there is a poor understanding of dog occurrence in space and time, in relation to the occurrence of wildlife. An important aspect of space use by dogs is their roaming in natural habitats. How far owned dogs stray from their owners and which types of habitat are penetrated and to what extent, represent research questions that, if addressed, would map the extent of any problem and offer management solutions. While relatively inexpensive, commercially available GPS loggers exist for dogs, these do not appear to have been used to study dog movements. Virtually nothing is known about disturbance by un-owned dogs or unmonitored owned dogs. Additionally, few studies have attempted to separate the visual, auditory, and olfactory cues associated with dogs, and the extent to which these disturb wildlife. Barking, in particular, may be detectable at greater distances than sight or smell of dogs and therefore warrants investigation.

Second, two aspects of wildlife response to stimuli represent research priorities:

1. With few exceptions, only behavioral studies of the response of wildlife to dogs are available, so physiological responses remain largely unknown (but see, for example, Berger et al., 2007; MacArthur et al., 1982). The available evidence suggests they may occur in the absence of behavioral responses, and so be subtle and underestimated. Additionally, physiological responses may occur at greater distances than behavioral responses (i.e., may be precursors to behavioral responses) and so may occur more frequently. They may also be costly, at the individual level manifesting potentially themselves as poorer condition or lower 'health' (e.g., disease resistance), and at the population level potentially manifesting themselves as lower average survival or longevity.

2. The consequences of responses for individuals have rarely been investigated, in general or specifically for dogs, yet these will underpin population responses to disturbance. Scaling up, perhaps the most critical information gap is the link between wildlife population viability and disturbance by dogs, in particular the specific role of dogs in systems where dog disturbance is one of a variety of forms of disturbance. Tolerable disturbance thresholds for populations, if they exist, remain unknown. The influence of disturbance on population viability is likely to be highly context-specific, for both sites and species. Beyond populations, further investigation of the evolutionary costs and benefits of disturbance responses in relation to predator environments might aid predator and species management programs.

Finally, very few instances exist of successful management of disturbance by dogs (possibly some remain undocumented), and this hampers management. A critical element of this will involve social research. The lack of uptake of adaptive dog–wildlife management is regrettable, because this

could engage behavioral ecologists with managers to tackle, and hopefully help resolve, the controversial issue of dogs as agents of disturbance.

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RESEARCH ARTICLE

Nutrient fertilization by dogs in peri-urban ecosystems

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Abstract

1. (Semi-)natural ecosystems provide many important benefits to nature and people, but are often located near populated and urbanized areas across the globe. During recreational activities, many people bring dogs into peri-urban forests and nature, but their nutrient inputs per unit space and time via dog faeces and urine into ecosystems remain scarcely quantified.

2. Here, we estimate net fertilization rates of dogs in peri-urban ecosystems, with a focus on nitrogen (N) and phosphorus (P) because of their evident effects on plant biodiversity. We used 487 direct-count censuses over 1.5 years to collect accurate dog abundance data per hectare per year in four sites in peri-urban forests and nature reserves in Belgium. Based on estimated dog densities and a systematic literature search of nutrient concentrations in urine and faeces, we calculate N and P fertilization rates from urine and faeces deposits, also propagating uncertainty and variability in these estimates.

3. We find that canine N and P fertilization rates on average amount to 11 kg N (more or less equally from urine and faeces) and 5 kg P (predominantly from faeces) per hectare per year, respectively. These estimated amounts are substantial when compared to atmospheric inputs of N and extractable amounts via traditional nature management (e.g. mowing and hay removal).

4. Our estimated dog N and P fertilization rates in peri-urban forests and nature are substantial. Such levels of nutrient inputs may considerably influence biodiversity and ecosystem functioning, and co-determine restoration outcomes. Our results underpin the need for managers and policy makers to more often (i) consider currently neglected nutrient inputs by dogs in management plans and restoration goals, (ii) communicate to dog walkers the role of their dog as 'fertilizer' and highlight the necessity to remove at least canine solid faecal waste, (iii) in sensitive oligotrophic ecosystems with species adapted to nutrient-poor soils, establish nearby off-leash dog parks, enforce the use of short leashes and/or apply dog bans such that high dog abundances can be avoided.

1 | INTRODUCTION

Peri-urban ecosystems such as forests, (semi-)natural grasslands, wetlands and heathlands in populated areas across the globe provide many important benefits to nature and people such as biodiversity conservation, carbon drawdown, nutrient cycling, climate regulation, wood and food production and recreation (Perring et al., 2013). In many instances, such ecosystems are on the one hand of important conservation concern, but on the other hand also experience significant amounts of daily human visitors, especially when located near relatively densely populated and urbanized areas. The impacts of human recreationists on disturbance of wildlife such as breeding birds are relatively well-quantified (Arnesen, 1999; Lenth et al., 2008). However, many people also bring domestic dogs (*Canis familiaris*) on recreational activities. While effects of dogs on wildlife via direct mortality, disturbance and disease transmission have been relatively well documented, their fertilization effects have received considerably less attention (Weston et al., 2014).

There are an estimated 87 million dogs in Europe and 72 million in the United States (FEDIAF, 2019; Paradeis et al., 2013). In Europe and the United States, about 25% and 49% of households owns at least one dog, respectively (Allen et al., 2020; FEDIAF, 2019). Via their urine and solid waste (faeces), dogs bring in significant amounts of nutrients into ecosystems but this disturbance and its associated effects on biodiversity have been often neglected so far. Dog faeces and urine count as net inputs, because dogs are fed at home with a protein-rich diet, in contrast to grazing cattle (*Bos taurus* L.), sheep (*Ovis aries* L.) or foraging birds that feed off the land and recycle nutrients within the ecosystem. While several studies have detected significantly elevated soil nutrient concentrations in areas with many dogs (Allen et al., 2020; Bonner & Agnew, 1983; Oates et al., 2017; Paradeis et al., 2013), dog fertilization rates per unit time and space (kg per ha per year), however, have not been quantified at the ecosystem level such that management actions with regard to dogs tend to only focus on their effects on wildlife.

Nutrient inputs from canine urine and faeces can have important effects on soil nutrient concentrations, particularly in terms of the macronutrients nitrogen (N) and phosphorus (P). In areas with a lot of dog walkers, and especially near walking paths, elevated soil P and N concentrations are found and stable isotope analyses confirmed dogs as the source (Allen et al., 2020; Bonner & Agnew, 1983). These patterns were still apparent even 3 years after an imposed dog ban (Bonner & Agnew, 1983). Paradeis et al. (2013) also detected strong soil nutrient and pH impacts of dog urine within off-leash dog parks. Finally, also on marine recreational beaches, dog faeces can result in significant nutrient inputs and marine pollution (Oates et al., 2017). Elevated

N and P inputs have been shown to strongly negatively impact biodiversity and ecosystem function (Bobbink et al., 2010). In plant communities, for instance, N addition decreases species richness in a wide range of ecosystems (De Schrijver et al., 2011), whereas P fertilization eradicates the niche of many threatened species (Wassen et al., 2021). In many ecosystems, also in populated areas, forest and nature management is specifically directed towards lowering soil nutrient concentrations via practices such as mowing with hay removal, local topsoil removal and phytoextraction (sometimes also referred to as mining) (Pegtel et al., 1996; Schelfhout et al., 2015, 2017, 2019). Neglecting the nutrient inputs from dogs in such cases might result in an underestimation of the time needed for ecological restoration and the costs involved. Misinformed restoration advice might negatively affect biodiversity and the associated ecosystem services.

Here, we quantified N and P inputs from canine urine and faeces in peri-urban forests and nature reserves specifically managed for biodiversity conservation and consisting of small forest patches, wetlands and grasslands with vulnerable, species-rich vegetation. Innovative to our approach is that we used nearly 500 dog density transect counts across a time span of 1.5 years to estimate N and P inputs. Combined with a systematic review of dog urine and faeces N and P concentrations, this approach enabled us to calculate dog densities and fertilization rates from both urine and faeces per unit space and time across the peri-urban ecosystems.

2 | METHODS

2.1 | Study area

This study was conducted near Ghent, a medium-sized city (about 260,000 inhabitants) in Belgium with a temperate climate (mean annual temperature of 10.3°C and mean annual precipitation of 789 mm between 1970 and 2000; Fick & Hijmans, 2017). Atmospheric N deposition was 22.7 kg N ha^{-1} year^{-1} in 2019 in the study area (Flemish Environmental Agency, 2020). We selected four study sites in peri-urban nature reserves less than 5 km from the city centre (Figure 1). The study sites are popular for recreation but also hold important biodiversity values. The study sites differ in size, in vegetation type, in management and in accessibility (Table 1), with visitors in study sites 1, 2 and 3 restricted to trails but without physical boundary to the vegetation and with visitors in site 4 legally permitted to leave the trails and walk freely in the reserve. All study sites are part of larger nature reserves and were delineated based on the physical ability of dogs to enter when off leash (borders of the study sites were often demarcated by rivers, fences or roads).
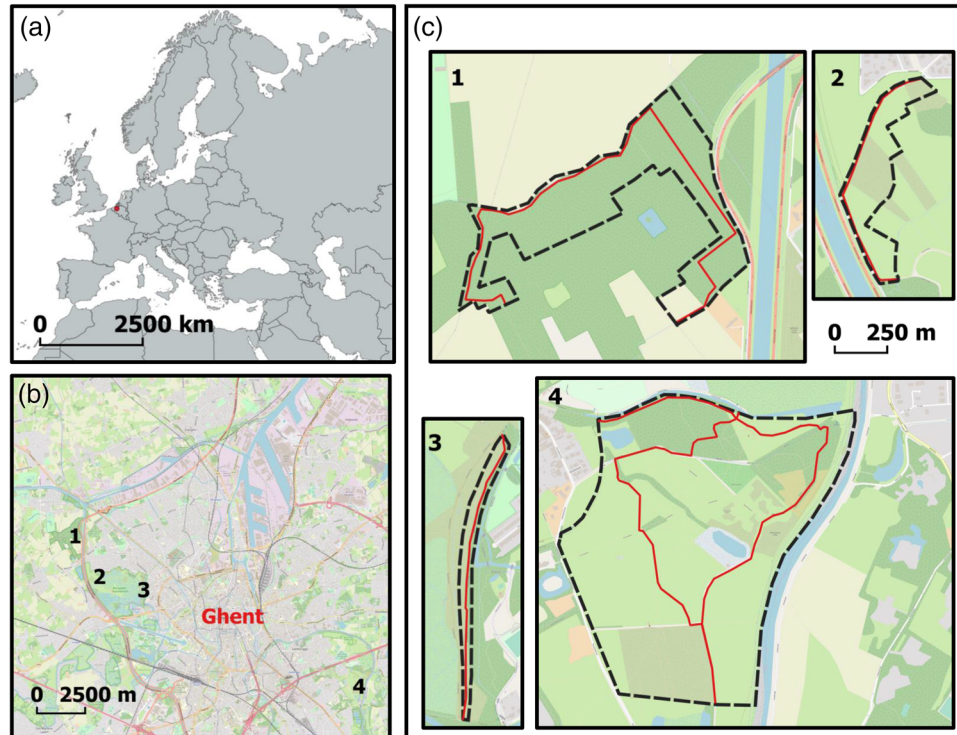
FIGURE 1 Study area. (a) Location of Ghent, Belgium in Europe (red circle). (b) Location of the four study sites around the city centre of Ghent. Numbers of sites (1-4) also refer to Table 1. (c) Detailed map of the four study sites (black dashed lines) and the covered direct count transects (red line)

TABLE 1 Overview of the characteristics of the four study sites: Location (numbers refer to the map in Figure 1), area, dominant vegetation type, management and access

Study site	Location (latitude, longitude)	Area (ha)	Dominant vegetation type (with Natura 2000 code)	Current management	Access restricted to
1. Vinderhoutse Bossen	51.08°N, 3.65°E	18.4	Alluvial forest (H91E0)	No intervention management	Paths
2. Meerskant, Bourgoyen	51.07°N, 3.66°E	5.9	Calthion grassland (H6410)	Mowing with hay removal	Paths
3. Spoorwegberm, Bourgoyen	51.06°N, 3.68°E	3.3	Lowland hay meadow (H6510)	Mowing with hay removal	Paths
4. Gentbrugse Meersen	51.04°N, 3.79°E	49.4	Oak-hornbeam-forest (H9160) and lowland hay meadow (H6510)	Low-density livestock grazing	Entirely accessible, no need to stay on paths

2.2 | Dog counts

Dogs were counted along transects in the four study sites between February 2020 and June 2021 for a total of 487 censuses. We followed a modified direct-count census to accurately and representatively quantify dog presence in each reserve (Oates et al., 2017). The transects were laid out in a way that the whole study site could be inspected when the transect was covered. A single observer per study area recorded all unique dogs on and off-leash (recorded separately) while covering the transect at a constant speed. By accounting for the size of the study site and by assuming a mean presence of the dogs of 1 h in the larger study sites 1 and 4, and of half an hour in the smaller study sites 2 and 3 and a mean daylength of 12 h, the data of every census were expressed as a number of dogs per ha per day (cf. Oates et al.,

2017). Transect counts were executed two to four times weekly in each site, regardless of weather and at varying times throughout the day. In total, 487 counting events took place, more or less spread throughout the week: 46 counts on Mondays, 66 on Tuesdays, 76 on Wednesdays, 82 on Thursdays, 71 on Fridays, 61 on Saturdays and 85 on Sundays. No permission was needed for this fieldwork.

2.3 | Nutrients in urine and faeces

For the nutrient concentrations of canine urine and faeces, we performed a systematic literature search and used the mean and variation across the primary studies (Table S1). We searched for studies in Web of Science using the keywords 'dogs and (phosph* or

nitrogen) and (digestib* or excretion) and (urinary or f?ecal)' in early Nov. 2021. This search resulted in 180 potentially suitable studies. Those 180 papers were then manually screened for studies that met the following criteria: (i) N and/or P concentrations of dog urine and/or faeces were reported or could be calculated from available data; (ii) if treatments of diets or diseases were reported, we only included the control treatments and diets that could be considered as common practice. Nutrient concentrations were obtained either (i) directly if the concentrations were mentioned in the original papers or (ii) if digestibility of N (or crude protein) or P was reported, faecal concentrations were calculated based on food intake, dry matter concentration in the diet, dry matter concentration of the faeces, dietary N or P concentrations and digestibility coefficients, according to the principle of apparent digestibility calculations: Digestibility of N (or P) (%) = 100 − 100 × [(faeces (g) × faeces N (or P) concentration (g/kg)) / (food (g) × food N (or P) concentration (g/kg))]. Finally, faecal N concentrations were based on 19 diets from six studies (Beynen et al., 2002; Cargo-Froom et al., 2019; De Smet et al., 1999; Forster et al., 2012; Pinna et al., 2018; Wood et al., 2004), whereas faecal P concentrations were based on 17 diets from five studies (the same, except Forster et al., 2012). Urinary N concentrations were based on two studies (Beynen et al., 2002; Castrillo et al., 2001), whereas urinary P concentrations were based on 10 diets from three studies (Atwal et al., 2021; Stevenson et al., 2003; Wood et al., 2004), including one very well-documented study (Atwal et al., 2021).

Because dogs are carnivores and mainly fed with a protein-rich diet, the nutrient concentrations in urine are relatively high. Urine N and P concentrations amount on average to 18.7 g N L^{-1} and to 484.6 mg P L^{-1} (Table S1). Cattle urine, for comparison, has typical N concentrations of 0.7–10.2 g N L^{-1} (Hoogendoorn et al., 2010). We adopt canine faecal concentrations of 44.3 mg N g^{-1} faecal dry mass and 32.0 mg P g^{-1} faecal dry mass (Table S1). These concentrations are, again for comparison, higher than N and P concentrations of 10–30 mg N g^{-1} and 1–4 mg P g^{-1} reported for savanna ruminants (Sitters et al., 2014) and P concentrations of cattle, deer and sheep dung which ranges between 5.5 and 8 mg P g^{-1} (McDowell & Stewart, 2005). For solid waste (faeces), we assume that each dog produces faeces once on each trip with a mean dry scat weight of 100 g (de Molenaar & Jonkers, 1993). For urine, we assume that each dog deposits one quarter of the daily 736 ml urine volume production per day (Beaver, 1999; Paradeis et al., 2013) during a walk to a dog park, and thus that 184 ml urine is deposited per dog walk in the nature reserves.

2.4 | Data analyses

2.4.1 | Nutrient deposition modelling

We estimated the annual deposition of N and P through urine and faeces with an intercept-only mixed-effect model using the *lme*-function from the *nlme*-library (Pinheiro et al., 2021) with the day (numeric, counting the days from the first measurement) and site (four levels) as random-effect terms and including a temporal autocorrelation term, with a continuous time covariate. The hierarchical nature of our data

and the repeated measurements within each site (time series) was hence taken into account.

Second, since there are several factors that can lead to overestimation or underestimation of our inferred fertilization rates (e.g. variation in nutrient concentrations as a result of dog food quality and quantity, imperfect detection of dogs during transect census counts, the amount of urine or faeces deposited as dependent on dog size, walk duration, dog size distribution and faeces collection rates), we also propagated uncertainty and variability on parameters as a second step. Therefore, we resampled 999 bootstrap samples from the 487 censuses in the different study sites and implemented the estimated mean and standard deviation from the nutrient concentrations obtained in the literature review (Table S1). For the parameter values for which no literature estimates were available (urine volume, faeces mass and dog residence time), we calculated the standard deviation as a value of 20% of the mean to obtain a normal distribution of estimates. For these bootstrapped estimates of the total N and P inputs per ha per year, we then report the mean and 5 and 95 percentiles of the distribution. The variability in the model parameters is shown in Figure S1. All data analyses were executed in R version 4.0.4 (R Core Team, 2021) and graphs produced with the ggplot2-library (Wickham, 2016).

2.5 | Scenario analysis

To investigate the effect of dog owner behaviour on N and P deposition, we also modelled the effect of owners keeping all dogs on a short leash (2 m) and collecting all solid faecal waste (not possible with urine), as actually prescribed by the current legislations in the different nature reserves (note there is no legal limit to leash length). If all dogs are kept on a leash of 2 m, the area of the fertilized zone is strongly reduced for study site 1 (reduced to 0.744 ha), study site 2 (0.317 ha) and study site 3 (0.348 ha). In this scenario analysis, we did not consider study site 4, because visitors there are legally permitted to leave the trails and are allowed to roam freely with dogs on a leash; the disturbed area thus remained the same.

3 | RESULTS

3.1 | Dog densities

Across the four study sites and 487 count events, we counted 1629 dogs. We calculate a mean dog density of 1.3 dogs ha^{-1} day^{-1} off leash and a mean of 2.9 dogs ha^{-1} day^{-1} on leash for a total estimated dog density of 4.2 dogs ha^{-1} day^{-1} (Figure 2). This is the equivalent of 1530 dogs ha^{-1} $year^{-1}$. There was significant among-site variation in dog densities as well as in leash use. Dog densities were highest at site 3 (which has a nature target value as species-rich grassland) where we counted a mean dog density of not less than 11.0 dogs ha^{-1} day^{-1}. Overall, 66% of encountered dogs was on leash and 34% off leash. [Correction added on 7 February 2022 after first online publication: percentages have been updated from 68% and 32% to 66% and 34%.] Yet, the proportion of off-leash dogs strongly varied among reserves
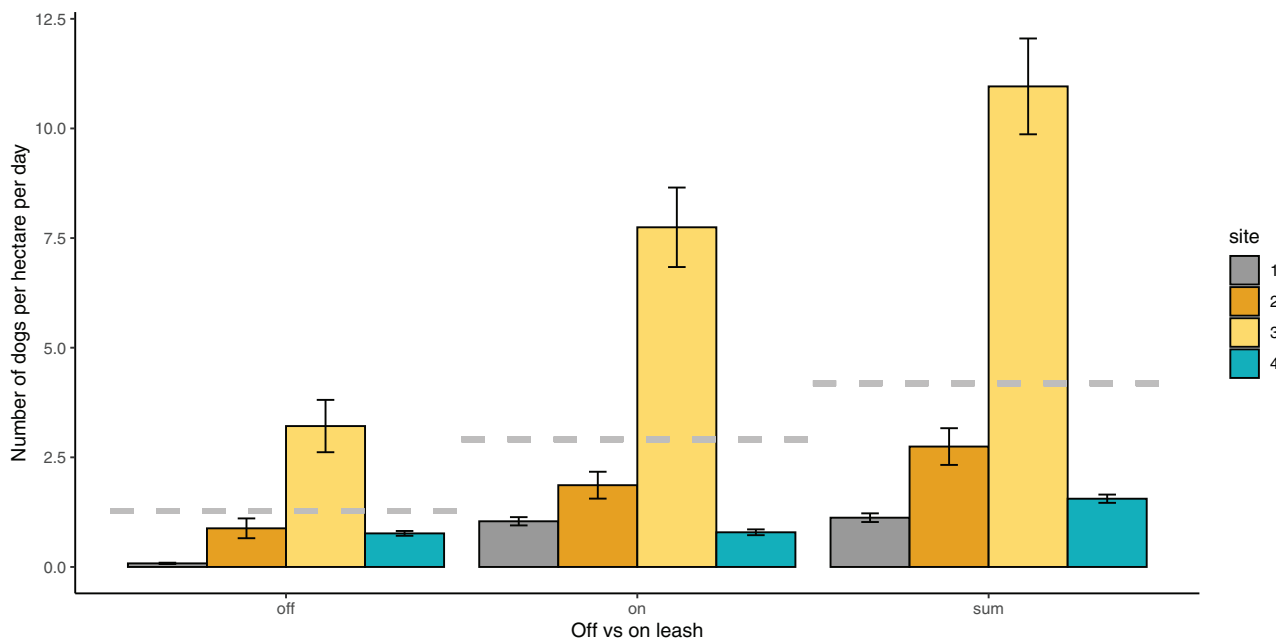
FIGURE 2 Estimated dog densities (number ha^{-1} day^{-1}), off and on leash, and their summed contributions, across the four study sites. Error bars denote standard errors. The grey dashed lines represent the mean across the four study sites

(most probably as a result of different management, policies and enforcement), from merely 8% in site 1 to 29%–49% in the other sites (Figure 2). [Correction added on 7 February 2022 after first online publication: percentages have been updated from 9% and 27%–52% to 8% and 29%–49%.]

3.2 | Estimated annual fertilization rates

Based on the estimated dog densities and intercept-only mixed-effect modelling considering temporal autocorrelation, we estimate overall N and P inputs from faeces to amount to 6.5 ± 3.7 kg N ha^{-1} year^{-1} and 4.7 ± 2.7 kg P ha^{-1} year^{-1}, respectively. Urine-based inputs of N and P amounted to 5.0 ± 2.9 kg N ha^{-1} year^{-1} and 0.13 ± 0.07 kg P ha^{-1} year^{-1}. The estimated total input of N and P across the four study sites is then 11.5 ± 6.5 kg N ha^{-1} year^{-1} and 4.8 ± 2.7 kg P ha^{-1} year^{-1}. There was again significant among-site variation driven by the variation in estimated dog densities with maximum inputs of 31.3 kg N ha^{-1} year^{-1} and 13.1 kg P ha^{-1} year^{-1} at site 3 (Figure 3).

3.3 | Scenario analysis: What if all dogs are on leash and faeces is removed

Finally, we analysed a scenario in which all detected dogs are on leashes of maximum 2 m length (excluding study site 4, cf. Section 2). Nutrients are then deposited in a significantly smaller area and concentrated in the near vicinity of the trails. This then leads to N and P deposition values of 175.3 ± 63.5 kg N ha^{-1} year^{-1} and 73.2 ± 26.5 kg P ha^{-1} year^{-1} within a zone 2 m left and 2 m right of each path (values again estimated from intercept-only mixed-effect models). If the faeces would be

removed using, for example, disposal bags, urine-only inputs amount to 76.6 ± 27.8 kg N ha^{-1} year^{-1} and 2.0 ± 0.7 kg P ha^{-1} year^{-1}, that is a reduction of 56% of N deposition and 97% of P deposition.

3.4 | Uncertainty and variability in model parameters: Bootstrap approach

The resampling approach across 999 bootstraps samples propagating variation and uncertainty into our estimates of N and P concentrations of urine and faeces, urine volume, faeces mass and dog residence times resulted in mean inputs of 12.2 kg N ha^{-1} year^{-1} (with 5 and 95 percentiles of 0.0 and 63.2 kg N) and 5.2 kg P ha^{-1} year^{-1} (with 5 and 95 percentiles of 0.0 and 24.1 kg P) (Figure S1).

4 | DISCUSSION

4.1 | Fertilization by dogs is substantial and non-negligible

Dogs appear to be a non-negligible, substantial and underestimated source of nutrients into peri-urban ecosystems. Dog N input was 11.5 kg N ha^{-1} year^{-1} across all sites, with a peak of 31.3 kg N ha^{-1} year^{-1} in the study site with the highest dog densities. The dog P input was 4.8 kg P ha^{-1} year^{-1} across all sites, with a peak of 13.1 kg P ha^{-1} year^{-1} in the site with most dogs. Our estimates become even more significant when compared to (i) the potential annual nutrient removal rates with mowing and hay removal (traditional management in semi-natural grasslands) that amount to 10–70 kg N and 2–20 kg P ha^{-1} year^{-1} in grasslands (Oelmann et al., 2009; Schelfhout et al., 2015) and (ii) atmospheric N deposition inputs
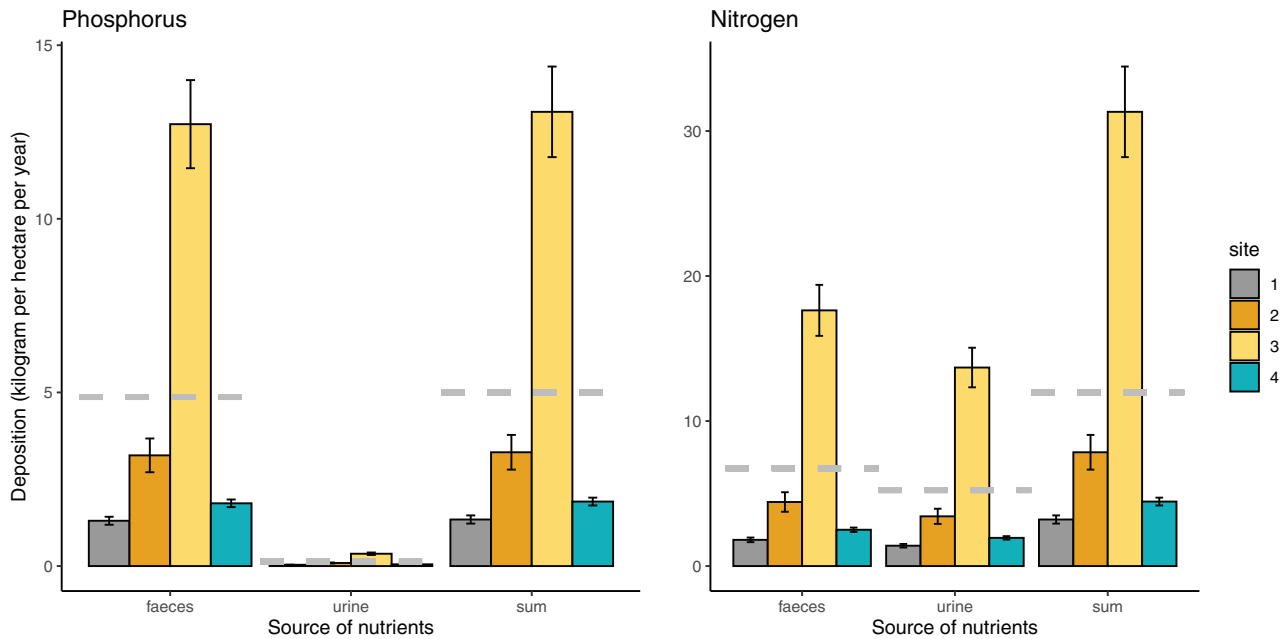
FIGURE 3 Estimated inputs (kg ha^{-1} year^{-1}) of phosphorus (P) and nitrogen (N) via dog fertilization as faeces and urine, and their summed contributions, across the four study sites. Error bars denote standard errors. The grey dashed lines represent the mean across the four study sites

(5–25 kg N ha^{-1} year^{-1} across most of Europe; based on EMEP data in Staude et al., 2020).

Unlike atmospheric N or fertilizer N and P in grasslands under agricultural use, nutrients deposited by animals are not deposited uniformly, but in patches. Carnivores, for instance, have the tendency to deposit faeces on (aboveground) landmarks, for example near entrance gates and trail intersections (Oates et al., 2017). In the case of dogs, urine deposition is patchy, even when only 1 m away from park paths (Allen et al., 2020). Half (44%) of the N deposited by dogs is via their urine. Within urine patches deposited by grazing sheep and cattle, the N loads are in the range of 500–2000 kg N ha^{-1}. The N deposit in a dog's urine patch is expected to be even higher as dog urine (18.7 g N L^{-1}) (Table S1) is more concentrated than cow (0.7–10.2 g N L^{-1}) or sheep urine (1.4–6.1 g N L^{-1}) (Hoogendoorn et al., 2010). The N in urine has a very rapid effect on vegetation: within 2 days after excretion, it is completely transformed in plant available forms of N (ammonia and nitrate) (Lantinga et al., 1987). The N deposited in urine patches, however, is prone to losses through volatilization (NH$_3$) or leaching (NO$_3^-$) depending on vegetation, soil type, temperature and precipitation. Research on the fate of urine N of grazing dairy cows shows that the proportion of the N recovered in the herbage varies between 58% and 32% for spring and autumn applied urine, respectively (Decau et al., 2003). An important but unknown part of the N deposited in winter and autumn will not be taken up by the vegetation in the urine patches but is prone to leaching and volatilization.

Only 3% of the total P deposited by dogs is via their urine. Unlike N, P in the soil is much less mobile and will become gradually available to plants in the next growing seasons (Jarvis, 2000). The P and N deposited through faeces thus represent 97% and 56% of the total deposited P and N, respectively. This portion is less prone to leaching or

volatilization losses and will become more gradually available for plants compared to urine. These nutrients will only affect the vegetation in the direct neighbourhood of the place where the faeces was deposited: for instance, cattle dung pats covering 0.05 m^2 affected grass growth in an area of about 0.25 m^2 surrounding the dung and can have a measurable effect on grass growth for up to 2 years (Lantinga et al., 1987).

4.2 | Effects on biodiversity

It is clear that the levels of fertilization by dogs estimated here can potentially exert negative effects on biodiversity and ecosystem functioning of species-rich vegetation that are often pursued in forest and nature management. Higher nutrient levels lead to increased plant growth, mostly by a limited number of nutrient-demanding species that will outcompete specialists, particularly by taking away the available light (Hautier et al., 2009), causing plant species loss (De Schrijver et al., 2011) and homogenization of plant communities (Staude et al., 2020). This well-known effect of N pollution on vulnerable ecosystems has led to the concept of *critical deposition loads*, which is defined as the limit ('effect threshold') above which habitat quality risks to be significantly damaged by the impact of N deposition (Bobbink et al., 2010; Wamelink et al., 2021). For the vegetation types of our study sites 1–3, this critical deposition load is 20 kg N ha^{-1} year^{-1}, whereas it ranges for study site 4 between 20 and 34 kg N ha^{-1} year^{-1} depending on the vegetation type (Van Dobben et al., 2012). With a current atmospheric N deposition of 5–25 kg N ha^{-1} year^{-1} across most of Europe (Staude et al., 2020), it is clear that the estimated canine N input of 11.5 kg N ha^{-1} year^{-1} can have an important additional impact. Specifically, within the urine patches N deposition has a strong effect on

plant biodiversity and ecosystem processes (e.g. carbon and nutrient cycling) on a microscale. On-site management such as mowing with hay removal can compensate much of the negative effects of N deposition, but mostly fails to reduce the ecosystem N levels due to the constant input through deposition and is relatively expensive (Jones et al., 2016). It is highly questionable that on-site management can also compensate the negative effects of N deposition in dog urine patches, given the much higher concentrations compared to more uniform atmospheric deposition.

Also, excess P, most often due to former agricultural fertilization, has a well-known negative effect on plant species richness (Ceulemans et al., 2014; Schelfhout et al., 2021; Wassen et al., 2021). Moreover, in contrast to N, P is one of the least mobile mineral nutrients and legacies of P fertilization can last for centuries (Schelfhout et al., 2017). This P immobility leads to difficult and slow on-site P removal management. Heavily fertilized, intensively managed agricultural grassland in Belgium yields about 14 mg dry matter ha^{-1} year^{-1} and exports 52 kg P ha^{-1} year^{-1} (Cougnon et al., 2018). In *Nardus* grasslands under restoration, however, removal rates are 2–20 kg P ha^{-1} year^{-1} under mowing with hay removal (Schelfhout et al., 2019). More drastic restoration techniques such as phytomining and topsoil removal can increase P exports, but are also more expensive and have strong impacts on other abiotic properties. Because the average P fertilization by dogs in our study almost levels the annual export rates by mowing with hay removal, it is clear that dogs can potentially have a strong impact on the vegetation and the management of these sites. Currently, these sites are under restoration management and mowing with hay removal is applied to reduce P levels in the soil to promote plant biodiversity; this process will be significantly slowed down by the import of canine P. In the forests, the current management of no intervention and low-density livestock grazing is less oriented towards P removal, but these management types presume a more or less closed P-cycle. Also, here, the effects of continuous P fertilization by dogs can eventually lead to eutrophication.

4.3 | Recommendations for management: Applications

Given the potentially high fertilization rates by dogs in peri-urban ecosystems, guidelines for management should be directed towards moderating these inputs such that critical load exceedance, biodiversity loss and delay of restoration goals be avoided. Based on our results, we propose land managers, especially in ecosystems with species adapted to nutrient-poor soils, take actions to (i) stimulate visitors to take away solid faecal waste (the most important source of P) by emphasizing the fertilization effect of their dogs in addition to other more widely known negative impacts, for example on wildlife, (ii) enforce leash use more stringently, (iii) establish more off-leash dog parks and (iv) consider more often entire dog bans in oligotrophic ecosystems. First, as faeces contained 97% of the P and 56% of the N deposited, taking away the faeces using, for instance, disposal bags and pooper-scooper stations can greatly decrease potential nutrient

enrichment (see Oates et al., 2017 for a discussion of other, more expensive management options). In addition, removing dog faeces prevents the infection of grazing animals with zoonotic diseases, such as *Neospora caninum*. Dogs are the definitive hosts of this obligate intracellular parasite, but many other animal species can get infected. In wild ruminants like roe deer (*Capreolus capreolus* L.) but especially domesticated grazers like cattle and sheep, infection with *Neospora* is a main cause of abortion (Almería, 2013). Our findings also underpin that a 'stick and flick' strategy to reduce the nuisance of treading in dog faeces (as currently considered by, e.g., the Forestry Commission in Britain) is to be avoided. Second, keeping the dogs leashed (short leashes of ~2 m) concentrated the depositions in the vicinity of the trails saving the rest of the area, but this then results in very high deposition rates of 175 kg N ha^{-1} year^{-1} and 73 kg P ha^{-1} year^{-1} near the paths. This N dose even nearly corresponds to the legal threshold set by the EU Nitrate directive (91/676/EEC) for N from livestock manure in the European Union. At this fertilization level, grasses dominate the vegetation and many forbs are outcompeted. A survey on French permanent grasslands, for example, showed that once N fertilization exceeds 150 kg N ha^{-1} year^{-1}, a presence of more than 10% legumes in the biomass becomes very rare (Jeuffroy et al., 2015). The P dose of 73 kg P ha^{-1} year^{-1} largely exceeds the local legal threshold for fertilization of agricultural grassland and arable land (i.e. 30–50 kg P ha^{-1} year^{-1} depending on the P concentration of the soil) and the potential P export through the grass harvest (see above). Leashing dogs and removing their faeces reduced deposits to 77 kg N ha^{-1} year^{-1} and 2 kg P ha^{-1} year^{-1} in the vicinity of the path. The mowing frequency near the path could of course be enhanced (e.g. five to eight times per year) to export more nutrients than the rest of the area. Third, enforcement also seems to have a clear effect when we compare data from site 1 where off-leash dogs only accounted for 8% of total dog numbers (a law enforcement officer strictly cautions and, on second infringement, fines every off-leash dog owner) with sites 2–4 where the legal obligation to leash dogs is not enforced and off-leash dogs represented 29%–49% of dogs. [Correction added on 7 February 2022 after first online publication: percentages have been updated 9% and 27%–52% to 8% and 29%–49%.] Obviously, enforcing codes does not always change behaviour (Oates et al., 2017). Fourth, specifically designed nearby fenced off-leash dog parks where dogs are allowed to roam freely, together with a dog ban in sensitive oligotrophic ecosystems with plants adapted to nutrient-poor soils, could take away the pressure on areas that are important for biodiversity conservation. Finally, the hitherto often neglected fertilization effect by dogs should better be included in management plans, in media campaigns and in public education programs with regard to dogs in (semi-)natural peri-urban ecosystems.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

All authors conceived the study design and co-wrote the paper. P.D.F., G.P.J.J. and P.V.G. collected and analysed data.

DATA AVAILABILITY STATEMENT

All raw data and code are available via figshare at https://doi.org/10.6084/m9.figshare.17054171.v1 (De Frenne et al., 2021).

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

RESEARCH ARTICLE

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The Effects of Dogs on Wildlife Communities

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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:

Visitation (normalized) =
$(5/7)$*weekday visitation +
$(2/7)$*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 Sattherwaite 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 35º. 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-m^2 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 m^2 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 α = 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 α = 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 Sattherwaite 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).
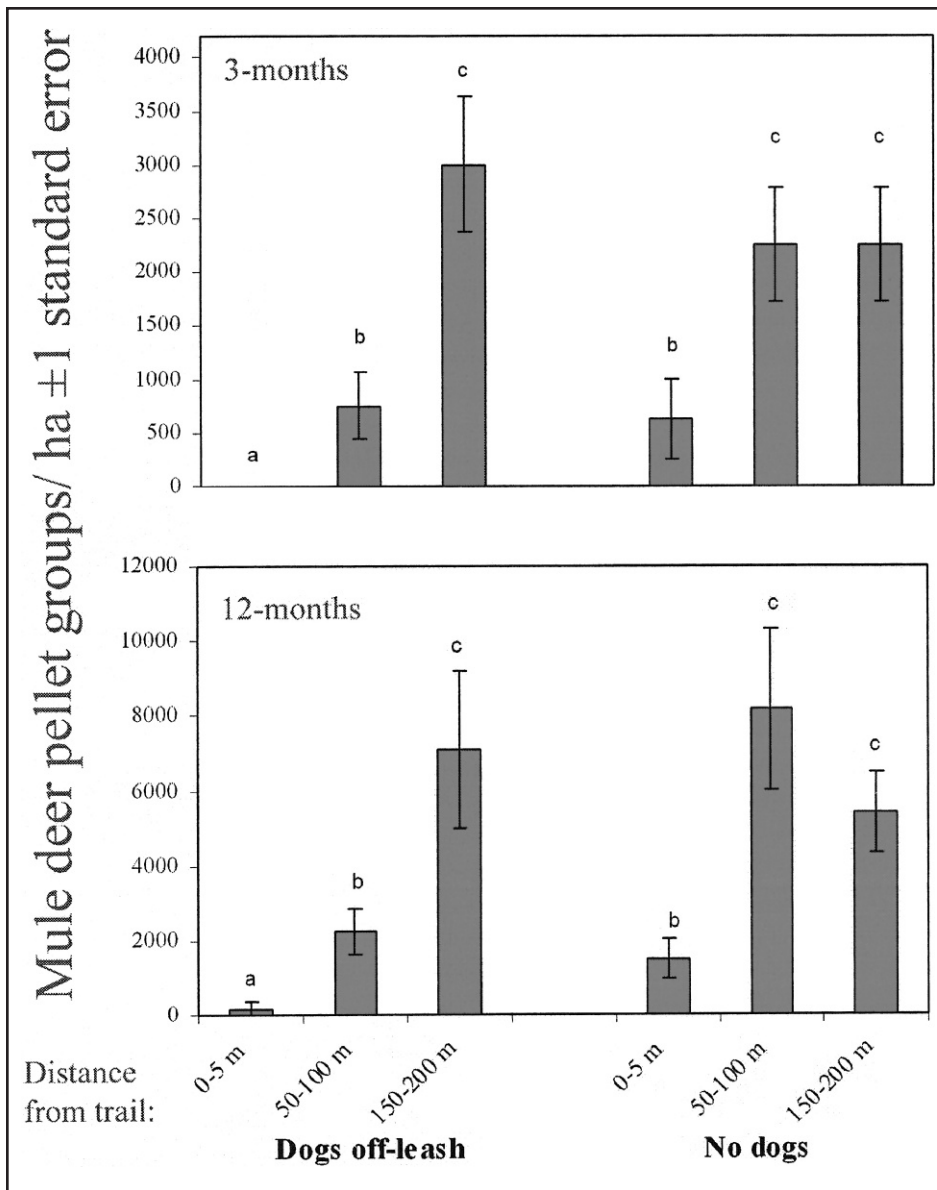
Figure 1. Twelve-month and three-month deer pellet densities by dog policy and distance from trail. Different letters above columns indicate significant differences ($p < 0.1$) for comparisons between adjacent distance categories within policies, and for the same distance category between policies, based 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 lupis*), 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
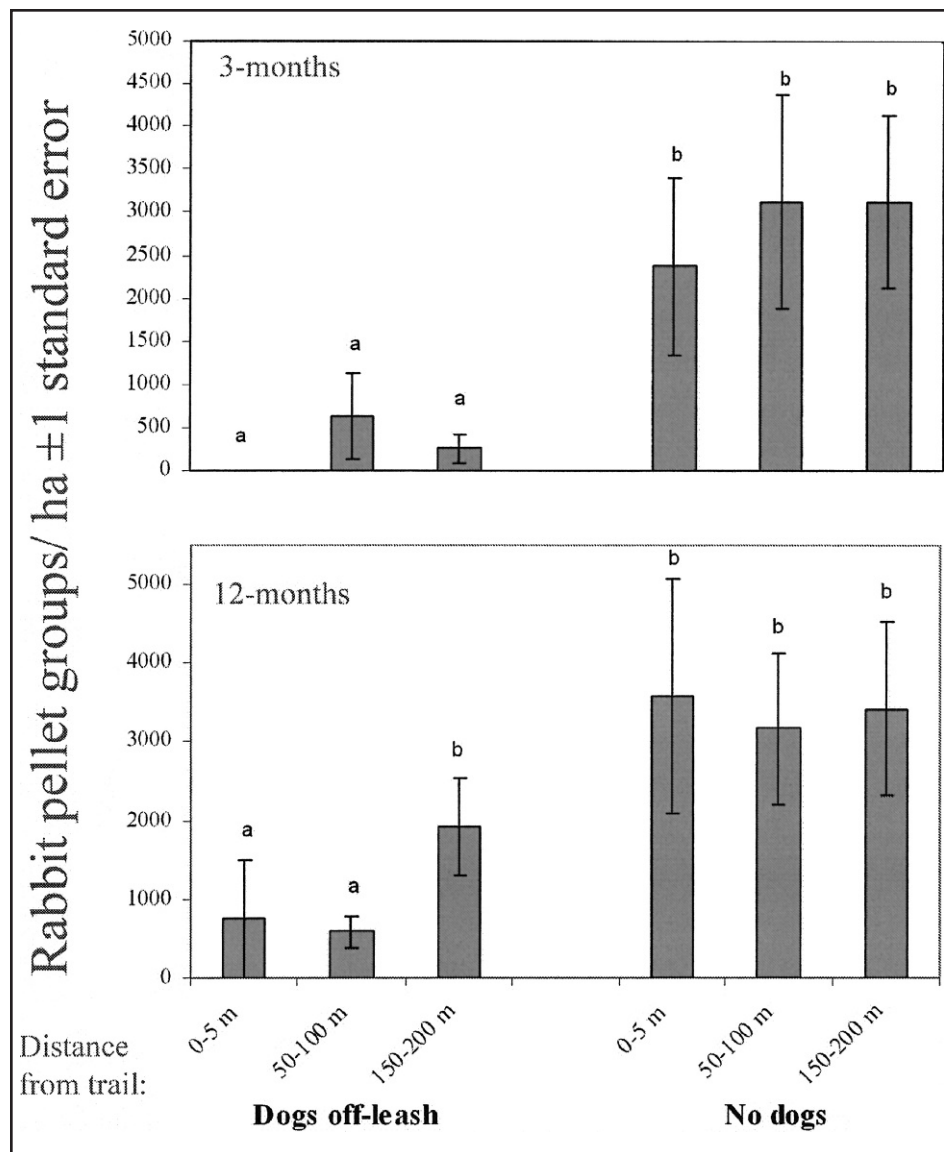

Figure 2. Twelve-month and three-month rabbit pellet densities by dog policy and distance from trail. Different letters above columns indicate significant differences ($p < 0.1$) for comparisons between adjacent distance categories within policies, and for the same distance category between policies,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

		Pairwise comparisons			
		12-month plots		3-month plots	
Dog policy & distance from trail		F	P	F	P
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	F	P
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

Table 3. Camera detections and comparisons by dog policy.

Species	Photo detection frequency		n	F	d.f.	P
	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

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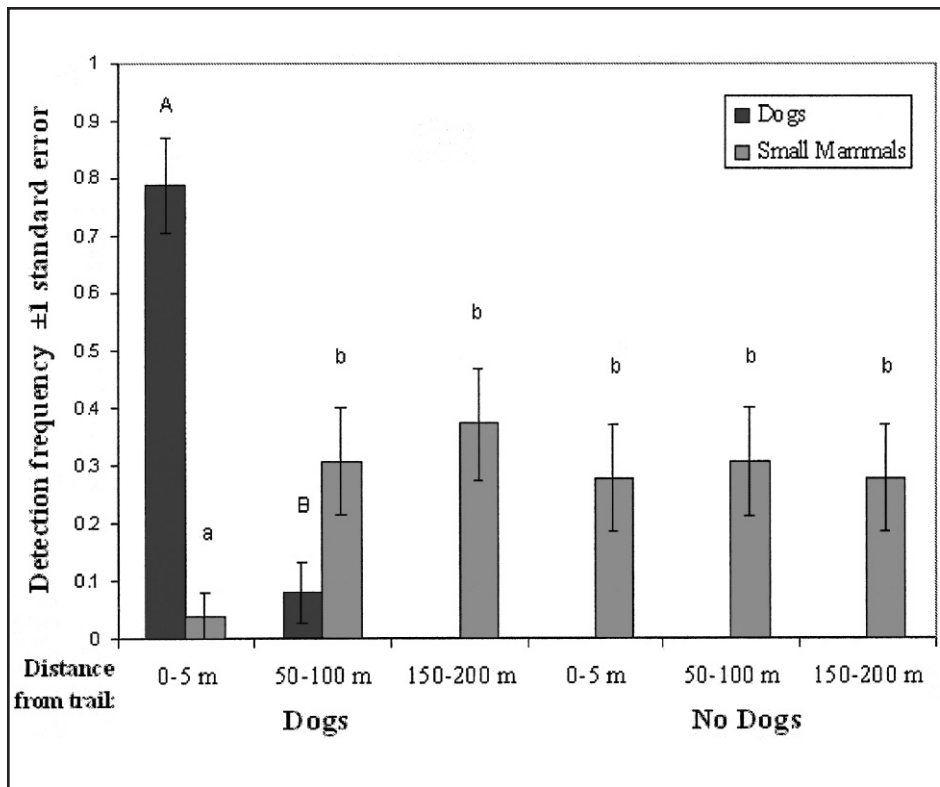
Figure 3. Track plate detection frequencies for dogs and small mammals. Different letters above columns indicate significant differences (p < 0.1) between policies and distance categories for small mammals (lower case letters) and dogs (capital letters) based on a square root transformation of the data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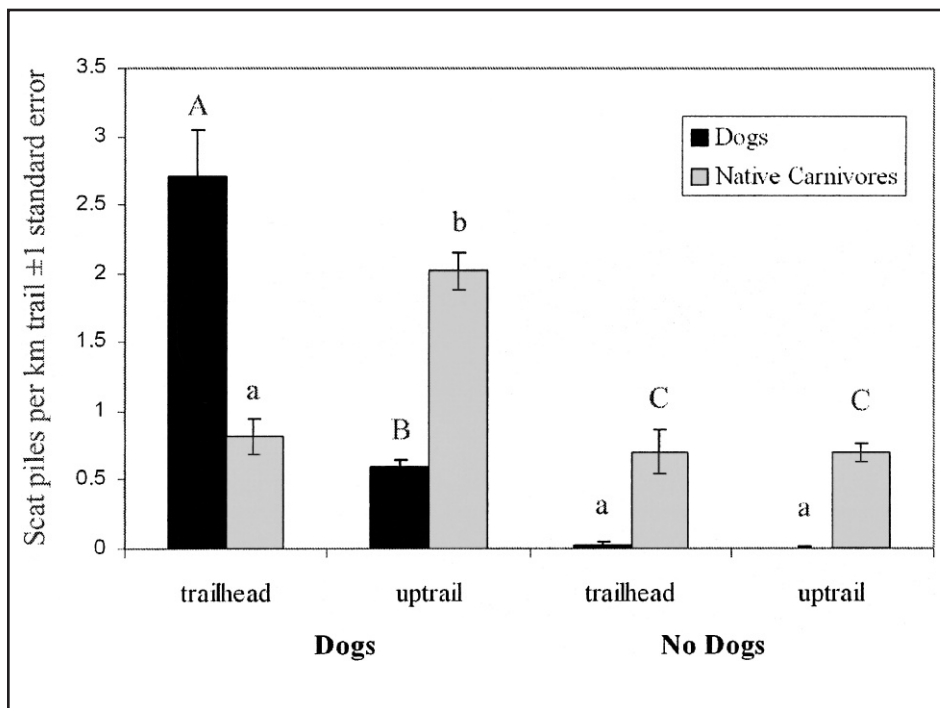

Figure 4. On-trail scat densities by dog policy, within 1 km of trailheads or uptrail, for dogs and combined native carnivores, including coyotes, red foxes, grey foxes, bobcats and mountain lions. Different letters above columns indicate significant differences (p < 0.1) for dogs (capital letters) and 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.
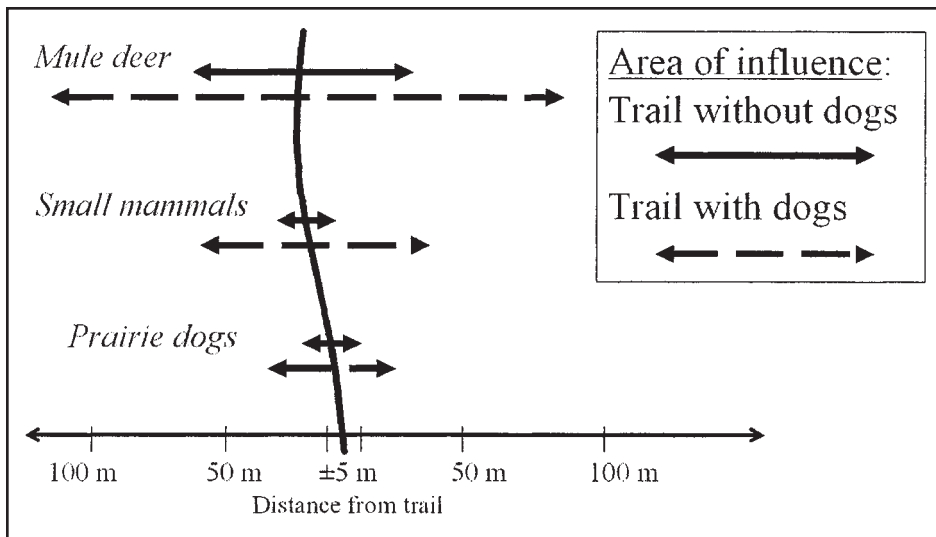
Policies regulating types of recreational use in protected areas should be considered within a regional context, considering both the relative ecological and recreational values of an area. The types of recreational uses allowed on trails influences the rates of recreational visitation and their associated 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.

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.

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