A pilot study of potential effects of human recreation activity on Abert's squirrel (*Sciurus aberti*) and dusky grouse (*Dendragapus obscurus*) in Boulder County

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Abstract

Many protected land networks, including Boulder County Parks and Open Space (BCPOS) and Boulder Open Space and Mountain Parks (OSMP), operate under a dual mandate to provide public access for outdoor recreation while also protecting natural resources. However, there is growing evidence that recreation activity can negatively affect wildlife communities, and land and wildlife managers are seeking solutions to balance the benefits of outdoor recreation for human communities with its impacts on species and ecosystems. We conducted a pilot study of the potential effects of recreation on Abert's squirrel (*Sciurus aberti*) and dusky grouse (*Dendragapus obscurus*). The objectives of the study were to: (1) Test the effectiveness of survey methods for the target species; and (2) Examine relationships between the types and intensity of recreation use and target species detections. We selected 24 sampling locations in a factorial design among permitted activities (mountain biking and hiking, or hiking only), domestic dog policy (off-leash, on-leash, or excluded), and variation in recreation use intensity. We surveyed for Abert's squirrels using feeding-sign surveys, we surveyed for dusky grouse using dropping counts and acoustic monitoring, and we monitored recreation activity using remotely-triggered cameras. Detections of Abert's squirrels were positively associated with the density of large trees and negatively associated with the density of Douglas fir (*Pseudotsuga menziesii*). We did not find evidence for an effect of permitted activities, domestic dog policy, or recreation use intensity on Abert's squirrels. However, dusky grouse were detected less frequently in recreation areas where mountain bikes are permitted and in areas with greater visitation levels by cyclists, and we were unable to identify another characteristic of the sampling locations (e.g., vegetation characteristics) that could explain these relationships. Thus, we recommend that BCPOS and OSMP continue to monitor the potential effects of recreation on dusky grouse in future years. To do so, we recommend altering the research design to focus on sampling locations with habitat characteristics associated with dusky grouse (e.g., mixed conifer forests), switch from a plot-based to a point-transect survey design, employ acoustic monitoring as a primary survey method, and increase the total number of sampling locations. We also recommend that dusky grouse surveys be paired with community-level surveys for other species groups (e.g., point counts for passerine birds) to identify additional species that may be sensitive to recreation disturbance, and to account for possible interactions among species. Results of this research would help to balance the recreation and conservation goals of protected lands by informing ongoing management of recreation and supporting decisions regarding designated use of new acquisitions.

Introduction

Many protected land networks, including Boulder County Parks and Open Space (BCPOS) and Boulder Open Space and Mountain Parks (OSMP), operate under a dual mandate to provide public access for outdoor recreation while also protecting native wildlife species and their habitats. Outdoor recreation provides many important human health (Frumkin 2001) and economic benefits (Goodwin 1996) to local communities, and the common assumption is that these activities have little or no impact on wildlife communities. However, this assumption is called into question by a growing scientific literature that links recreation activity to declines in wildlife abundance or density (Reed & Merenlender 2008), changes in spatial or temporal habitat use (George & Crooks 2006), increased physiological stress (Arlettaz et al. 2007), reduced reproductive success (Finney et al. 2005), and altered behavior (Geoffroy et al. 2015).

We conducted a pilot study of the potential effects of human recreation activity on two species in Boulder County: Abert's squirrel (*Sciurus aberti*) and dusky grouse (*Dendragapus obscurus*). Abert's squirrel has been listed as an indicator species for Boulder County, and a prior study found that small mammal activity, including tree squirrels (*Sciurus spp.*), was significantly lower near trails that permit dogs (Lenth et al. 2008). In addition, there is anecdotal evidence that dusky grouse may be displaced by recreation activity at lower elevations in Boulder County (BCAS 2015).

Although no prior studies have focused specifically on Abert's squirrel or dusky grouse, some research has investigated the effects of recreation on similar species. For example, responses of tree squirrels to recreation disturbance are typically greater in rural than in urban areas (Engelhardt & Weladji 2011) and may increase when humans are accompanied by domestic dogs (Cooper et al. 2008). Among grouse species, probability of occurrence and detections are significantly reduced near park entrances and hiking trails (Immitzer et al. 2014, Moss et al. 2014), and capercaillie (*Tetrao urogallus*) flush greater distances in areas with a higher intensity of recreation activity (Thiel et al. 2006).

To address the gap in our knowledge regarding the potential effects of recreation on Abert's squirrel and dusky grouse in Boulder County, the overall goal of our pilot study was to collect the information needed to design a longer-term observational experiment to assess the relationships between varying types and intensities of recreation activities and the occupancy, relative densities, or activity levels of the target species. Specifically, our objectives were to:

1) Test the effectiveness of survey methods for detecting the relative densities or activity levels of the target species; and
2) Relate variation in target species detections to permitted activities (mountain biking and hiking, or hiking only), domestic dog policy (off-leash, on-leash, or excluded), and variation in recreation use intensity.

Methods

Study design

We worked closely with BCPOS and OSMP staff to identify appropriate sampling locations on properties managed by both agencies. Sampling locations for both species were stratified in a factorial design among properties that do and do not permit mountain bikes, among properties that permit dogs to be off-leash, permit dogs but require them to be on-leash, or exclude dogs, and including properties that are closed to public access for recreation (Table 1).

Table 1. Factorial design of sampling locations among types of permitted recreation activities.

	Dogs off-leash	Dogs on-leash	No dogs	Closed
Bikes	• Flatirons Vista South 1 (OSMP) • Flatirons Vista South 2 (OSMP)	• Betasso Preserve 1 (BCPOS) • Betasso Preserve 2 (BCPOS) • Walker Ranch 1 (BCPOS) • Walker Ranch 2 (BCPOS)	• Bitterbrush, Hall Ranch (BCPOS) • Nelson Loop, Hall Ranch (BCPOS) • Wapiti, Heil Ranch (BCPOS) • Wild Turkey, Heil Ranch (BCPOS)	
No bikes	• Mesa Trail (OSMP) • Ranger Trail (OSMP) • Shanahan Ridge (OSMP)	• Bear Canyon Trail (OSMP) • Bear Creek West Ridge Trail (OSMP) • Eldorado Canyon Trail (OSMP) • Green Bear (OSMP)	• Button Rock, Hall Ranch (BCPOS) • Goshawk Trail (OSMP) • Long Canyon Trail (OSMP) • Nighthawk, Hall Ranch (BCPOS)	• Eldorado Canyon (OSMP) • Heil Ranch (BCPOS) • Walker Ranch (BCPOS)

We consulted with agency staff members to ensure that the selected locations represented a gradient of expected intensity of recreation use. To represent the habitat associations of Abert's squirrels and dusky grouse, sampling locations were located in both Ponderosa pine (*Pinus ponderosa*) and mixed conifer forest habitats (CPW 2015). In addition, to the extent possible, we sought to minimize variation in other habitat characteristics (e.g., proximity to water) and possible sources of human disturbance (e.g., forest thinning) that could influence detections of the target species among sampling locations.

We selected a total of 24 sampling locations that met these criteria (Figure 1, Figure 2). Half (n=12) were located on properties managed by BCPOS, and half (n=12) were located on properties managed by OSMP (Table 1). Thirteen sampling locations were selected primarily for surveys of Abert's squirrels, seven were selected primarily for surveys of dusky grouse, and four were selected for surveys of both target species.

Figure 1. Map of sampling locations in the northern portion of the study area.

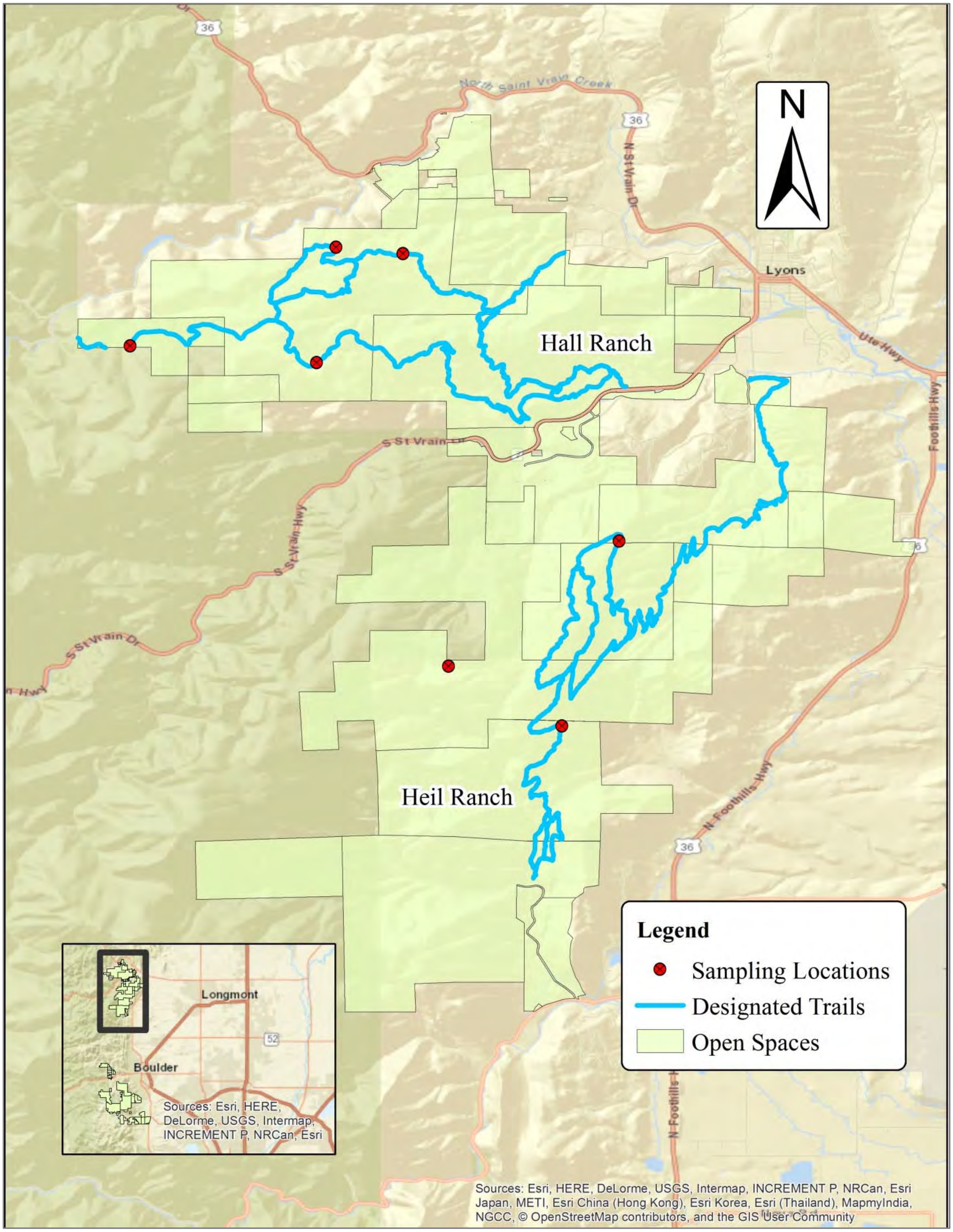
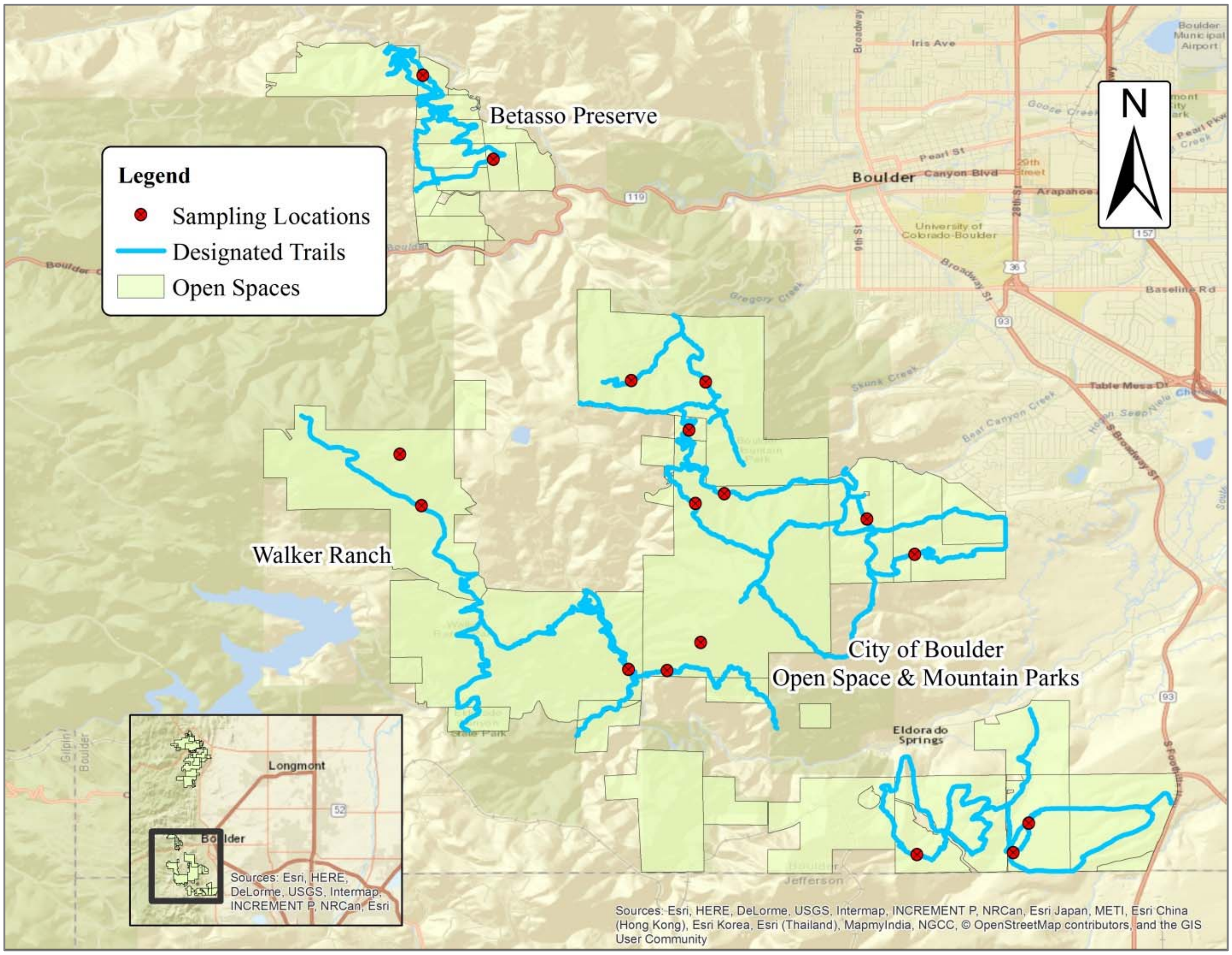


Figure 2. Map of sampling locations in the southern portion of the study area.



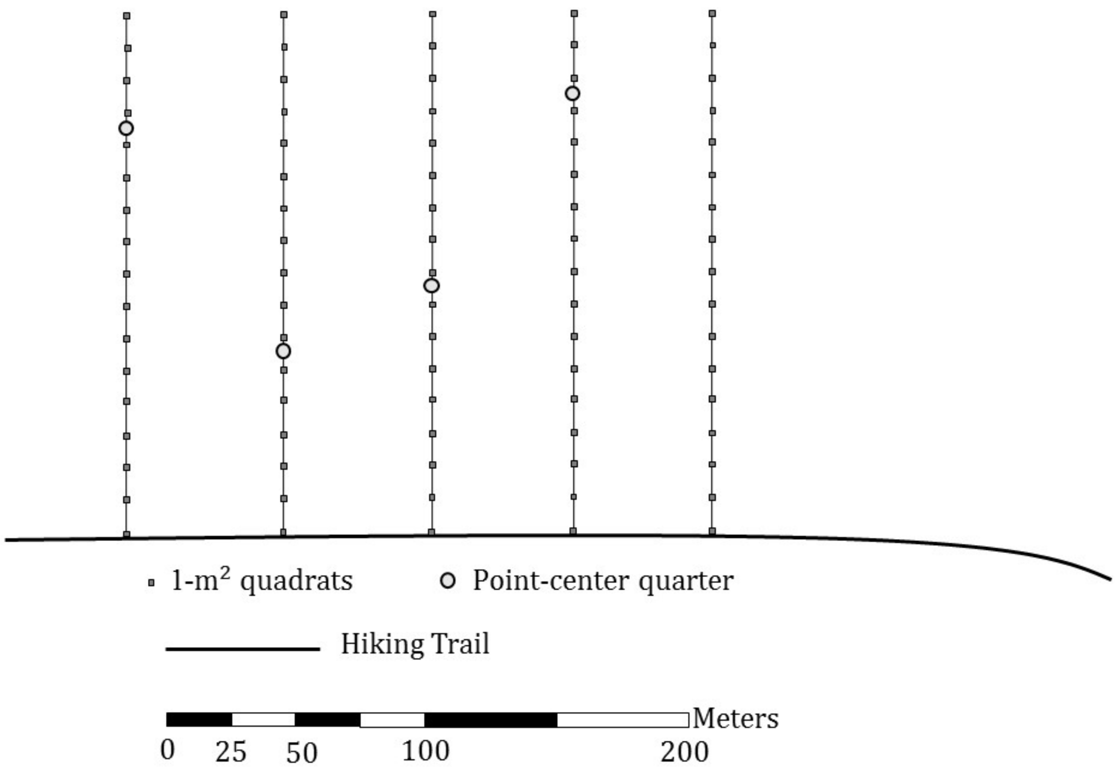
Abert's squirrel surveys

We surveyed for Abert's squirrels using feeding-sign surveys. Feeding-sign surveys are an established method of surveying for tassel-eared squirrels, and the density of winter feeding sign has been shown to be a reliable index of overall population density (Dodd et al. 1998). In addition, feeding-sign surveys are also used by BCPOS in an ongoing study of the effects of forest thinning on the quality and use of habitat by Abert's squirrels (BCPOS 2013). Due to the timing of the availability of funding for this project, our feeding-sign surveys continued beyond the optimal time period identified in prior studies (Worden & Kleier 2012); however, they were a sufficient means to assess the general spatial distribution of Abert's squirrels in relation to recreation activity.

Following the methods of Dodd et al. (1998) and Worden and Kleier (2012), we established 4-ha plots adjacent to the trail at each sampling location, with five parallel 200-m transects spaced 50 m apart and oriented perpendicular the nearest trail (Figure 3). In each plot, we established a total of 85 1-m^2 quadrats, placed every 12.5 m along the parallel transects, to survey for feeding sign. In our proposal, we had recommended altering the shape of the survey plots to be two parallel 500-m transects perpendicular to the nearest trail, in order to additionally investigate the possible effects of proximity to trail on species detections. However, during the study design process we determined that the 500-m transects were prohibitively long to establish due to steep slopes and potential confounding effects (i.e., proximity to trails, roads, or other human disturbances).

We recorded the presence of evidence of feeding by Abert's squirrels within or touching each quadrat. Evidence of feeding included bracts and cores of cones, terminal bundles of needles, and short twigs with outer bark removed (Dodd et al. 1998). We also recorded visual observations of Abert's squirrels detected during the feeding-sign surveys.

Figure 3. Plot design for surveys of Abert's squirrel feeding sign surveys and dusky grouse droppings.



Dusky grouse surveys

We surveyed for dusky grouse using two methods: dropping counts and acoustic monitoring. Counts of droppings, or feces, are a common method of surveying for grouse species (Immitzer et al. 2014, Moss et al. 2014) and require less intensive effort than other methods such as pointer-dog surveys and playback surveys (e.g., Evans et al. 2007). As grouse species defecate regularly, droppings are appropriate indicators of habitat use (Immitzer et al. 2014), and the density of droppings can also provide a reliable index of actual population density (Evans et al. 2007). We used the same plot design as for the Abert's squirrel feeding-sign surveys to conduct dropping counts (Figure 3). We recorded the presence of groups of three or more fibrous pellets within a 1-m strip along each 200-m transect. We also recorded visual observations of dusky grouse detected during the dropping counts.

In addition to dropping counts, we conducted a preliminary test of the effectiveness of acoustic monitoring as a survey method for dusky grouse. Acoustic surveys for hooting, fluttering, or drumming are a common method of surveying for grouse species, and a prior study demonstrated that counts of fluttering male spruce grouse (*Dendragapus canadensis*) heard by a human observer provided a reliable index of male density (Keppie 1991). However, to our knowledge, passive acoustic monitoring has not previously been tested as a possible alternative to active listening surveys for grouse.

At eight of the sampling locations where we conducted dropping counts, we installed one acoustic monitor (SongMeter SM4, Wildlife Acoustics) and set it to record sound from 30 minutes before dawn until 60 minutes after dawn, and from 60 minutes before dusk until 30 minutes after dusk. In the CSU Listening Lab, a student research assistant listened to the first 10 seconds of every two minutes from the collected recordings and visually inspected daily spectrograms to identify and record audible dusky grouse calls (Lynch et al. 2011). Using positive identifications of target species sounds, the student also identified acoustic measurement parameters that could be used to develop an automated detector for dusky grouse activity using sound analysis software (e.g., RavenPro; Brown et al. 2013).

Vegetation surveys

We recorded vegetation characteristics that may influence the occurrence and density of the target species at all sampling locations. Following the methods of Dodd et al. (2003) and Worden and Kleier (2012), we randomly selected one point on four transects in each plot (Figure 3). We used the point-centered-quarter method to measure tree density and basal area at the four selected points, and we assigned trees to size classes according to diameter at breast height (dbh): small, 0-20 cm; medium 20.1-50 cm; and large >50 cm (Worden & Kleier 2012). We used a spherical densiometer to measure canopy cover. At sampling locations for dusky grouse, we also recorded the presence of understory species that provide important forage for grouse (e.g., Vaccinium spp; CPW 2015).

Recreation use surveys

We used remotely-triggered cameras to measure the types and intensity of recreation use occurring at the sampling locations. In a prior study, we found that remotely-triggered cameras were the most efficient and cost-effective technique currently available for counting visitors to recreation areas (Reed et al. 2014). We installed remotely-triggered cameras (Bushnell TrophyCam with infrared flash) along the target trail and set them to record continuously day and night for a minimum of 14 days at each location. In sites officially closed to recreation access, we installed cameras along fire roads or unofficial trails.

We analyzed the collected photos to obtain an estimate of visitation by activity type. We subsampled the collected photos as needed to obtain a continuous 14-day sample at each study site, and we viewed each photo to count the number of individual hikers, mountain bikers, equestrians, and domestic dogs. We also noted whether dogs were leashed and recorded the direction of travel for each group of visitors. We calculated separate estimates of total mean daily visitation and daily visitation by hikers, bicyclists, equestrians, and dogs for each sampling location.

Statistical analyses

We conducted a two-factor analysis of variance (ANOVA) to assess variation in detections of Abert's squirrels and dusky grouse by permitted activities (mountain biking and hiking, or hiking only) and domestic dog policy (off-leash, on-leash, or excluded) (Zar 1999). Using these data, we conducted a statistical power analysis to determine the sample size necessary to detect effects of permitted activities or domestic dog policy, if they exist, in future studies. We also used two-sample t-tests and linear regression models to assess variation in target species detections in relation to vegetation characteristics and recreation use intensity. Finally, we examined correlations among explanatory variables to aid in interpretation of pilot study results and inform the design of future studies.

Results

Abert's squirrel surveys

We detected Abert's squirrel feeding sign at 18 of the 24 sampling locations (75%), in a mean of 4.79 (range: 1-13) quadrats per plot. Abert's squirrel feeding sign was detected at 11 sampling locations (85%) selected primarily for surveys of Abert's squirrel, at three locations (43%) selected primarily for dusky grouse, and at four locations (100%) selected for surveys of both target species. We did not find a relationship between the frequency of detections of Abert's squirrel feeding sign and distance to the nearest trail (R^2=0.003, p=0.847).

Dusky grouse surveys

We detected dusky grouse using droppings at eight of the 24 sampling locations (33%), in a mean of 1.38 (range: 1-12) quadrats per plot. Dusky grouse droppings were detected at five sampling locations (71%) selected primarily for surveys of dusky grouse, at two locations (15%) selected primarily for Abert's squirrel, and at one location (25%) selected for surveys of both target species. We also observed live dusky grouse at seven of the eight sampling locations (88%) where we detected grouse droppings. We did not find a relationship between the frequency of dusky grouse detections and distance to the nearest trail (R^2=0.022, p=0.574).

We detected probable dusky grouse calls using acoustic monitoring at five of the eight sampling locations (63%) where acoustic monitors were installed. All five locations were also locations where dusky grouse were detected using dropping counts. Probable male dusky grouse calls, or hoots, appeared as a single frequency band between 100-600 Hz and had a brief duration of 0.2-0.5 seconds (Figure 4a). Probably female calls had a broadband signature up to 5000 Hz and had a variable duration ranging from 0.1-2 seconds (Figure 4b). Based on these observations, we recommend parameters for future development of band-limited energy detectors for automated detection of each type of call (Table 2).

Figure 4. Spectrograms of probable (a) male and (b) female dusky grouse calls.

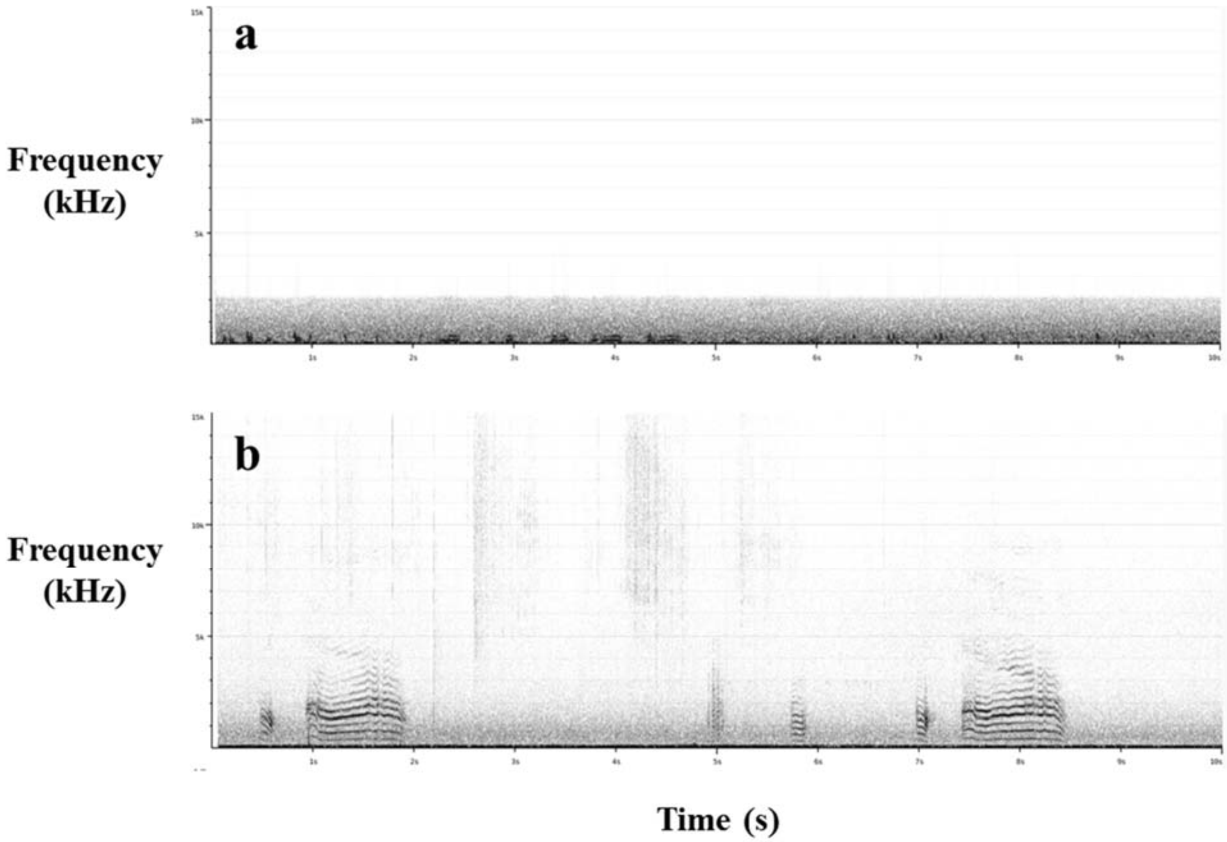


Table 2. Recommended parameters for development of band-limited energy detectors for automated detection of male and female dusky grouse calls.

	Male	**Female**
Minimum frequency (Hz)	100	100
Maximum frequency (Hz)	600	5000
Minimum duration (s)	0.01	0.1
Maximum duration (s)	0.3	2
Minimum separation (s)	0.5	0.1

Vegetation surveys

Overall, vegetation characteristics of the sampling locations were highly variable. However, locations selected primarily for surveys of Abert's squirrels had greater total tree density, greater density of small and medium trees, and greater density of Ponderosa pines than did locations selected for dusky grouse or for surveys of both target species. Sampling locations selected primarily for surveys of dusky grouse had greater density of Douglas fir (*Pseudotsuga menziesii*), greater total basal area, and greater basal area of Douglas fir than did locations selected for Abert's squirrels or for surveys of both target species (Table 3).

The total density of trees per sampling location was strongly and positively correlated with the density of medium trees (r=0.98) and the density of Ponderosa pines (r=0.97). The total basal area per sampling location was strongly and positively correlated with the basal area of Douglas fir (r=0.95) (Appendix 1).

Table 3. Vegetation characteristics of sampling locations selected primarily for surveys of Abert's squirrel, dusky grouse, or both target species. Mean (±SE) values are given for percent canopy cover, tree density, and basal area.

	Abert's squirrel (*n*=13)	**Both species** (*n*=4)	**Dusky grouse** (*n*=9)
Canopy cover (%)	53.8 (6.1)	57.8 (4.9)	46.8 (7.1)
Total tree density (# ha^{-1})	636.7 (238.6)	465.5 (115.6)	536.9 (87.4)
Density by size class			
Small (<20 cm)	928.9 (315.7)	337.6 (150.8)	740.5 (166.5)
Medium (20-50 cm)	620.7 (254.5)	430.5 (104.4)	495.9 (111.7)
Large (>50 cm)	25.6 (12.3)	99.2 (99.2)	17.6 (17.6)
Density by species			
Ponderosa pine	630.6 (241.0)	377.8 (47.3)	471.0 (80.7)
Douglas fir	146.5 (58.4)	354.8 (208.2)	1211.5 (595.5)
Total basal area (m^2 ha^{-1})	33.9 (5.3)	64.2 (24.9)	76.6 (32.1)
Basal area by species			
Ponderosa pine	27.3 (4.8)	35.9 (9.1)	27.5 (6.2)
Douglas fir	6.6 (2.9)	28.3 (16.4)	39.1 (30.0)

Recreation use surveys

We identified recreational visitors from photos collected during a mean of 17.2 (range: 4.0-33.9) days of remote camera monitoring at each sampling location. We detected visitors at 23 of the 24 locations (96%), including two sites that were officially closed to public access (Table 4). Specifically, we detected hikers at 22 sampling locations (92%), bicyclists at 13 locations (54%), and equestrians at nine locations (38%). We detected domestic dogs at 18 of the 24 sampling locations (75%), including one site that was officially closed to public access and four sites that did not allow dogs.

Mean daily numbers of total visitors were strongly and positively correlated with mean daily numbers of hikers (r=0.87) and cyclists (r=0.83), and mean daily numbers of domestic dogs were strongly and positively correlated with mean daily hikers (r=0.88) and total visitors (r=0.78) (Appendix 1).

Table 4. Mean (±SE) daily numbers of hikers, cyclists, equestrians, total visitors, and domestic dogs in sampling locations by permitted activities (mountain biking and hiking, or hiking only) and domestic dog policy (off-leash, on-leash, or no dogs).

	Hikers	**Cyclists**	**Equestrians**	**Total visitors**	**Dogs**
Biking and hiking					
Off-leash (*n*=2)	60.09 (18.70)	13.46 (6.29)	0.27 (0.27)	73.81 (25.26)	12.39 (2.72)
On-leash (*n*=4)	87.05 (39.06)	66.02 (53.10)	0.14 (0.10)	153.21 (87.83)	12.35 (5.58)
No dogs (*n*=4)	18.90 (9.96)	38.02 (17.09)	1.72 (0.86)	58.64 (27.49)	0.13 (0.13)
Hiking only					
Off-leash (*n*=3)	135.98 (27.59)	0	0	135.98 (27.59)	17.36 (7.27)
On-leash (*n*=4)	49.11 (11.84)	0	0	49.11 (11.84)	4.21 (1.04)
No dogs (*n*=4)	18.81 (8.13)	0.06 (0.06)	0.97 (0.34)	19.84 (8.12)	0.28 (0.13)
Closed (*n*=3)	0.38 (0.38)	0.01 (0.01)	0	0.39 (0.38)	0.30 (0.30)

Statistical analyses

In a two-factor analysis of variance (ANOVA), detections of Abert's squirrel feeding sign did not vary by permitted activities or domestic dog policy (Figure 5). Specifically, we did not find statistically significant variation in detections of Abert's squirrels between recreation sites that allowed hiking only and sites that permitted mountain bikes ($F_{1,18}$=0.137, *p*=0.715), or among sites that permit dogs off-leash or on-leash or do not allow dogs ($F_{2,18}$=2.93, *p*=0.079). In addition, we did not find evidence for an interaction between the two factors ($F_{2,18}$=2.18, *p*=0.142). Given the differences observed in this study, the sample size (i.e., number of sampling locations) would need to be increased by three times in order for the ANOVA to have a power >0.9 of detecting an effect of domestic dog policy (off-leash, on-leash, or excluded) on Abert's squirrels.

Sampling locations where Abert's squirrel feeding sign was detected had a greater density of large trees (47.4±23.2 trees ha^{-1}) than locations where squirrels were not detected (0±0; t=2.04, *p*=0.028). In linear regression analyses, we found that detections of Abert's squirrel feeding sign increased with increasing density of large trees (R^2=0.269, *p*=0.009) and decreased with increasing density of Douglas fir (R^2=0.177, *p*=0.041). Sampling locations where Abert's squirrels were detected had greater visitation levels by equestrians (0.66±0.25 equestrians day^{-1}) than sites where they were not detected (0±0; t=2.66, *p*=0.008). Detections of Abert's squirrel feeding sign increased with increasing visitation levels by cyclists (R^2=0.179, *p*=0.039) and increasing total visitation levels (R^2=0.181, *p*=0.038) (Table 5). Correlations among explanatory variables are summarized in Appendix 1.

Figure 5. Mean (±SE) detections of Abert's squirrel feeding sign in sampling locations stratified by permitted activities (mountain biking and hiking, or hiking only) and domestic dog policy (off-leash, on-leash, or no dogs).

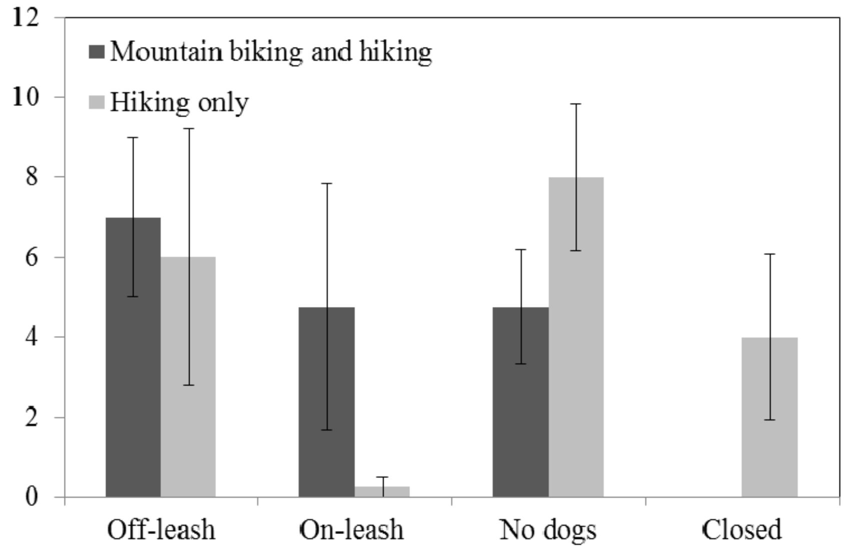
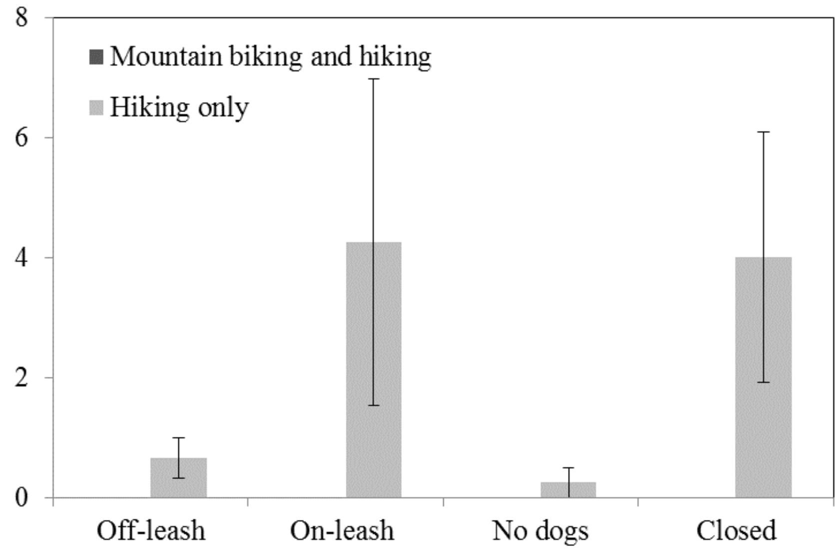


Table 5. Results of linear regression analyses to variation in Abert's squirrel detections in relation to vegetation characteristics and recreation use intensity

	R^2	*p*	*B*(95% CI)
Canopy cover (%)	0.032	0.402	
Total tree density (# ha^{-1})	0.000	0.928	
Small (<20 cm)	0.000	0.970	
Medium (20-50 cm)	0.002	0.836	
Large (>50 cm)	0.269	0.009	0.025 (0.007 – 0.044)
Ponderosa pine	0.002	0.834	
Douglas fir	0.177	0.041	-0.0019 (-0.0036 – -0.0001)
Total basal area (m^2 ha^{-1})	0.091	0.152	
Ponderosa pine	0.010	0.648	
Douglas fir	0.140	0.071	
Total visitors (# day^{-1})	0.181	0.038	0.021 (0.001 – 0.040)
Hikers	0.093	0.148	
Cyclists	0.179	0.039	0.038 (0.002 – 0.073)
Equestrians	0.060	0.248	
Total dogs (# day^{-1})	0.106	0.121	

In a two-factor ANOVA, we found that detections of dusky grouse droppings also did not vary by permitted activities or domestic dog policy (Figure 6). Specifically, we did not find statistically significant variation in detections of dusky grouse among recreation sites that permit dogs off-leash or on-leash or do not allow dogs ($F_{2,18}$=1.89, *p*=0.180). However, variation in detections of dusky grouse between sites that allowed hiking only and sites that permitted mountain bikes approached statistical significance ($F_{1,18}$=3.97, *p*=0.062). We did not find evidence for an interaction between the two factors ($F_{2,18}$=1.94, *p*=0.173). Given the differences observed in this study, the sample size (i.e., number of sampling locations) would need to be increased by three times in order for the ANOVA to have a power >0.9 of detecting an effect of permitted activities (hiking or mountain biking) on dusky grouse. The number of sampling locations would need to be increased by four times to have a power >0.9 of detecting an effect of domestic dog policy (off-leash, on-leash, or excluded) on dusky grouse.

Figure 6. Mean (±SE) detections of dusky grouse droppings in sampling locations stratified by permitted activities (mountain bikes or hiking only) and domestic dog policy (off-leash, on-leash, or no dogs).



Sampling locations where dusky grouse droppings were detected had lower visitation levels by cyclists (0±0 cyclists day^{-1}) than locations were they were not detected (27.7±14.2 cyclists day^{-1}; t=1.95, p=0.035). In linear regression analyses, we did not find any significant relationships between vegetation characteristics or recreation use intensity and the number of dusky grouse detections among sampling locations. Correlations among explanatory variables are summarized in Appendix 1.

Discussion

Abert's squirrels were widespread across the pilot study area, and we detected their feeding sign frequently in the majority (75%) of sampling locations. As expected, detections of Abert's squirrels were correlated with the habitat characteristics of the study plots; specifically, Abert's squirrel feeding sign was positively associated with the density of large trees and negatively associated with the density of Douglas fir (Table 5). However, we did not find evidence for effects of permitted activities (hiking or mountain biking), domestic dog policy (off-leash, on-leash, or excluded), or variation in recreation use intensity on Abert's squirrels. The only relationships we observed were weakly positive associations between detections of feeding sign and visitation levels by equestrians, cyclists, and all visitors (Table 5). Rather than indicating a positive effect of recreation activity on Abert's squirrels, we suspect these results indicate that Abert's squirrels are habituated to recreation activity, as has been demonstrated for other tree squirrel species (Cooper et al. 2008, Englehardt & Weladji 2011), and that the positive associations between feeding sign and visitation levels are attributable to an artefactual correlation with some unmeasured characteristic of the sampling locations that positively influenced both squirrels and recreational visitors. It is also possible there are other effects of recreation use on Abert's squirrels that we were not able to detect using feeding-sign surveys, such as changes in temporal activity patterns, physiological condition, or interactions with other species (e.g., pine squirrels [*Tamiasciurus hudsonicus*]).

Dusky grouse were less common in the pilot study area, but we detected their droppings in the majority (71%) of sampling locations selected primarily for surveys of dusky grouse. Although we did not observe any statistically significant relationships between dusky grouse dropping counts and habitat characteristics, sampling locations selected primarily for surveys of dusky grouse had a greater density of Douglas fir and a greater basal area of Douglas fir than did locations selected for Abert's squirrels or locations selected for surveys of both target species (Table 3). We did find possible evidence for an effect of permitted activities and variation in recreation use intensity on dusky grouse. Specifically, dusky grouse droppings were not detected in any sampling locations that permitted mountain bikes (Figure 6) or had any level of visitation by cyclists. Although these relationships could be attributable to an artefactual correlation with another characteristic of the sampling locations that influenced both grouse and cyclists, we did not find any strong correlations between visitation levels by cyclists and other characteristics of the sampling locations (Appendix 1). Therefore, we recommend that the possible effects of recreation on dusky grouse warrants further study.

The methods employed in this pilot study, including feeding-sign surveys, dropping counts, acoustic monitoring, and remotely-triggered cameras, were effective for detecting the target species and for measuring recreation use intensity. However, we identified some limitations of the research design and recommend several modifications to increase the number of sampling locations and improve estimates of species habitat use. In the pilot study, we adapted a research design, which is currently employed by BCPOS to estimate the density of Abert's squirrel feeding sign in response to forestry treatments (Worden & Kleier 2012, BCPOS 2013) (Figure 3). We encountered three limitations of the using this research design to examine potential effects of recreational trails and activity levels on Abert's squirrels and dusky grouse. First, a high proportion of recreational trails were located within 200 m of another trail, and thus we had to exclude many potential sampling locations due to the close proximity of other (i.e., non-target) trails. Second, very steep slopes (>60% grade) within 200 m of recreational trails precluded safe surveys of some sampling locations and ultimately excluded entire trails from consideration, typically those trails located along narrow ridgelines or in steep-walled canyons. Finally, some sampling locations encompassed multiple aspects, leading to substantial variation in canopy cover and vegetation type within a single 4-ha plot. In addition to reducing possible areas available to sample, these limitations also introduce potential bias into the study.

Therefore, we recommend switching to a spatially-balanced point-transect survey method, which may be a more efficient and less biased research design to examine potential effects of recreation on dusky grouse and other sensitive species. Each point-transect would incorporate one or several large circular plots (e.g., 5-m radius). At each circular plot, counts of dusky grouse droppings would be recorded and/or an acoustic monitor would be installed. Distance to recreational trails and recreation activity levels could then be treated as continuous covariates in relation to the occurrence or relative density of the species of interest. In addition, this research design could accommodate sampling of other taxonomic groups (e.g., point counts for passerines). Finally, if researchers conduct surveys multiple times within a season, it would allow for estimation of the probability of detecting a species, which would improve estimates of species' habitat use and relationships to habitat characteristics, permitted activities, domestic dog policy, and recreation activity levels. In addition, this alternative research design could increase the number of sampling locations (3-4x) for the study to have sufficient statistical power (>0.9) to detect an effect of permitted activities on dusky grouse.

Conclusions

Providing public access for recreation while conserving wildlife species and other natural resources are important goals for BCPOS and OSMP, similar to most protected areas around the world. However, visitation of protected areas and participation in outdoor recreation are increasing rapidly in the U.S. (Cordell 2012) and globally (Balmford et al. 2015). At the same time, there is growing evidence that recreation activity can negatively affect wildlife species at the community, population, and individual levels. In a recent global systematic review of 274 published articles on recreation and wildlife, we found that nearly all studies (93%) documented at least one effect of recreation on wildlife, and the majority (60%) of those effects were negative (Larson et al. 2016). Moreover, studies of hiking and other non-motorized activities observed negative effects on wildlife 1.3 times more frequently than studies of motorized activities. Land and wildlife managers are seeking solutions to balance the benefits of outdoor recreation for human communities with its potentially negative effects on species and ecosystems (Hadwen et al. 2007).

In this pilot study, we did not find evidence for an effect of permitted activities, domestic dog policy, or recreation use intensity on Abert's squirrels. However, we detected dusky grouse less frequently in recreation areas where mountain bikes are permitted and in areas with greater visitation levels by cyclists, and we were unable to identify another characteristic of the sampling locations (e.g., vegetation characteristics) that could explain these relationships. Thus, we recommend that BCPOS and OSMP continue to monitor the potential effects of recreation on dusky grouse in future years. To do so, we recommend altering the research design to focus on sampling locations with habitat characteristics associated with dusky grouse (e.g., mixed conifer forests), switch from a plot-based to a point-transect survey design, employ acoustic monitoring as a primary survey method, and increase the total number of sampling locations. We also recommend that dusky grouse surveys be paired with community-level surveys for other species groups (e.g., point counts for passerine birds), to identify additional species that may be sensitive to recreation disturbance, and to account for possible interactions among species (e.g., turkeys [*Meleagris gallopavo*]). Results of this research would help to balance the recreation and conservation goals of protected lands by informing ongoing management of recreation and supporting decisions regarding designated use of new acquisitions.

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Appendix 1. Matrix of Pearson's correlation coefficients (*r*) between pairs of explanatory variables. Bold text indicates pairs of explanatory variables that are highly correlated with one another (|*r*|>0.7).

	Canopy	**TotalDensity**	**Density_Small**	**Density_Medium**	**Density_Large**	**Denisty_Pond**	**Density_Doug**	**BA_Total**	**BA_Pond**	**BA_Doug**	**HikersPerDay**	**BikersPerDay**	**HorsesPerDay**	**VisitorsPerDay**	**DogsPerDay**
Canopy	**1**	0.54	0.29	0.50	-0.14	0.48	0.24	0.40	0.57	0.25	0.15	-0.06	0.03	0.06	-0.04
TotalDensity		**1**	0.65	**0.98**	-0.20	**0.97**	0.07	0.28	0.66	0.07	-0.07	0.24	0.63	0.09	-0.23
Density_Small			**1**	0.57	-0.20	0.62	0.07	0.11	0.24	0.03	-0.08	0.24	0.37	0.09	-0.14
Density_Medium				**1**	-0.18	**0.98**	0.01	0.23	0.67	0.02	-0.06	0.23	0.64	0.09	-0.22
Density_Large					**1**	-0.19	-0.16	-0.17	-0.08	-0.16	0.14	0.12	0.14	0.16	0.14
Denisty_Pond						**1**	-0.06	0.18	**0.70**	-0.05	-0.08	0.24	0.65	0.09	-0.24
Density_Doug							**1**	**0.90**	0.12	**0.98**	0.12	-0.19	-0.25	-0.03	0.16
BA_Total								**1**	0.49	**0.95**	0.16	-0.13	-0.13	0.03	0.12
BA_Pond									**1**	0.19	0.11	0.08	0.28	0.12	-0.11
BA_Doug										**1**	0.14	-0.18	-0.25	-0.01	0.18
HikersPerDay											**1**	0.45	-0.15	**0.87**	**0.88**
BikersPerDay												**1**	0.29	**0.83**	0.43
HorsesPerDay													**1**	0.07	-0.26
VisitorsPerDay														**1**	**0.78**
DogsPerDay															**1**