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Space Use Analyses Suggest Avoidance of a Ski Area by Mountain Goats

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ABSTRACT The development of recreational activities imposes growing anthropogenic pressure on wilderness areas worldwide. Because anthropogenic disturbances may modify wildlife use of habitat, space use studies may be useful to identify wildlife response to recreational activities. Mountain goats (*Oreamnos americanus*) are highly sensitive to anthropogenic disturbances and are thus likely to modify their space use in response to recreational activities. From 2011 to 2013, we studied space use of mountain goats in Jasper National Park, Canada, one of the most popular wilderness areas in North America, and assessed how it was influenced by an alpine ski area. Comparison of predicted use from habitat selection models and observed use defined by global positioning system collar data revealed ski area avoidance. The immediate surroundings of the ski area were, however, not avoided by mountain goats, but the presence of a natural salt lick <1 km from the ski area may have contributed to the observed mountain goat use of these areas. Ski activities have the potential to exclude mountain goats from habitat with otherwise high probability of use. Thus, we recommend that future ski area developments generally consider the behavior of species sensitive to anthropogenic disturbances and that construction should not occur in habitat essential for sensitive species like mountain goats. © 2015 The Wildlife Society.

KEY WORDS Canada, disturbance, Jasper National Park, *Oreamnos americanus*, resource selection function.

The growing popularity of outdoor recreational activities has contributed to the expanding anthropogenic pressure on wilderness areas worldwide (Knight and Gutzwiller 1995, Buckley 2004) and inevitably increased the demand for supporting infrastructure. National parks and other types of protected areas committed to recreational opportunities and wilderness protection are facing potential conflicts between the 2 mandates (Hammit and Cole 1987, Cole and Knight 1991, Liddle 1997). It is thus important to understand the effects of recreational activities on wilderness to successfully manage protected areas.

Human disturbance has consequences for wildlife, whether it be direct habitat destruction (Czech et al. 2000), indirect habitat loss through displacement (Bender et al. 1998), or habituation (Geist 1978, Hammit and Cole 1987, Knight 2009). Repeated disturbance may cause animals to avoid affected areas spatially (i.e., animals move to a different area following disturbance), or temporally (i.e., animals avoid an area when the disturbance is occurring and return when the disturbance has ended; Hamr 1988, Yarmoloy et al. 1988, Lusseau 2004, Wakefield and Attum 2006). This avoidance of anthropogenic activities or structures often results from

prey species perceiving people as a predation risk (Frid and Dill 2002). The spatially and temporally varying level of predation risk perceived by animals results in a landscape of fear (Laundré et al. 2001) that influences animal behavior and space use. Some recreational activities modify natural landscapes of fear and change wildlife behavior and space use (Rosner et al. 2014).

Recreational activities related to ski areas are mostly indirect disturbances mediated by habitat alteration: service roads, tree removal (for ski runs), chair lift installation, infrastructure development, soil compaction, variation in the duration of the period of snow cover, and changes in vegetation (Morrison et al. 1995, Rixen and Antonio 2013). Ski area maintenance activities occurring at any time of the year and avalanche control activity during winter may represent sources of direct wildlife disturbance. Direct impacts on wildlife may also result from recreational activities occurring within or close to the ski areas. For example, in Europe, chamois (*Rupicapra rupicapra*) fled when approached by downhill skiers (Hamr 1988). Disturbances occurring during winter may induce costly displacement to wildlife at a time when energy reserves and resources are limited. As such, most species attempt to conserve energy by limiting their movements and spatial range (Hammit and Cole 1987).

Mountain goats *(Oreamnos americanus)*, in comparison to other North American ungulates, are particularly sensitive to

anthropogenic disturbances (Geist 1978, Gordon and Reynolds 2000, Festa-Bianchet and Côté 2008). Cases of mountain goat habituation are known but rare (Singer 1978, Penner 1988, Gordon and Reynolds 2000, Côté et al. 2013). In most cases, disturbance impacts are thought to be additive for mountain goats and result in significant changes of behavior, space use, and population dynamics (Foster and Rahs 1983, Joslin 1986). Mountain goats appear to change their spatial distribution and increase alertness when facing various anthropogenic activities: aircraft flights (Côté 1996, Gordon and Reynolds 2000, Côté et al. 2013), seismic exploration (Joslin 1986), industrial development (Foster and Rahs 1983), road traffic (Singer 1978), all-terrain vehicles (St-Louis et al. 2013), and human confrontation (Foster and Rahs 1983). Buffer areas of 1.5 km to 2.0 km have been used to limit the impact of helicopter and industrial activities on mountain goats (Foster and Rahs 1983, Côté 1996, Mountain Goat Management Team 2010, Cadsand 2012). The impacts of non-motorized recreational activities on mountain goats are, nevertheless, poorly understood (Mountain Goat Management Team 2010). It has been reported elsewhere that humans on foot generally induce stronger reactions from animals than motorized vehicles, possibly because foot traffic is less predictable (Papouchis et al. 2001, Stankowich 2008). Any recreational activity occurring in areas inaccessible to motorized traffic may result in disturbance potentially causing displacement of mountain goats (Mountain Goat Management Team 2010). Therefore, where recreation and mountain goat habitat overlap, it is important to understand the relationship between them for managed coexistence (Foster and Rahs 1983, Côté et al. 2013, St-Louis et al. 2013).

Mountain goats are generalist herbivores (Laundré 1994). They spend the majority of their time close to escape terrain (Haynes 1992, Gross et al. 2002) and are generally associated with mid to high elevations especially in summer, when they take advantage of forage availability and the relative refuge from predators above treeline. Natural salt licks are used to supplement nutrition (Ayotte et al. 2008), and trails used by mountain goats to access the licks are considered important components of their habitat and ecology (Hebert and Cowan 1971, Hengeveld et al. 2003). Mountain goats show strong fidelity to specific licks and access trails, and demonstrate traditional use over successive generations (Hengeveld and Caldwell 2004). Inability or unwillingness to access a lick could result in a deficiency of essential resources, possibly leading to decreased fitness and eventually decreased population viability (Gosling 2003).

Based on habitat selection models, global positioning system (GPS) collar data, and behavioral observations, we studied the effects of an existing alpine ski area on mountain goat space use by comparing their use of suitable habitat within and outside the ski area. We could not evaluate the reaction of mountain goats toward skiers, but we evaluated the reaction of mountain goats toward hikers. This should be a conservative indication of how they would react to skiers because skiers move with greater speed, which usually induces stronger reactions (Frid and Dill 2002).

STUDY AREA

Marmot Basin is the only downhill ski area in Jasper National Park and is located on Marmot Mountain (53.80°N, 118.08°W), approximately 10 km south of the town of Jasper, west central Alberta, Canada. Marmot Mountain is part of the Trident Range that approximately delimited the population range of the marked mountain goats, covering approximately 125 km^2 (Fig. 1). We focused our analyses on the inner study area that surrounded Marmot Mountain. We used this area to compare mountain goat habitat use within the ski area and its surroundings. We defined the study area by following the valleys surrounding Marmot Mountain.

The region is at the interface of the subarctic and humid continental climates and is divided in 3 ecosystems: montane, subalpine, and alpine. The climate is generally dry; in July, average temperatures in the valley are around 15°C, whereas they are around −10°C in January. The Jasper National Park covers 10,878 km^2, which is largely undeveloped outside the town site. Other large ungulates, such as bighorn sheep (*Ovis canadensis*), moose (*Alces alces*), elk (*Cervus elaphus*), caribou (*Rangifer tarandus*), white tail deer (*Odocoileus virginianus*), and mule deer (*Odocoileus hemionus*), are present in the park. The predator community in the area is largely intact and included wolves, brown bears (*Ursus arctos*), black bears (*Ursus americanus*), cougar (*Puma concolor*), wolverine (*Gulo gulo*), coyotes (*Canis latrans*), and golden eagle (*Aquila chrysaetos*). The ski area has been in operation since 1964 and receives around 220,000 visitors/year, between mid-November and early-May. It covers 678 ha ranging from 1,698 m to 2,612 m above sea level, with its lowest elevation about 700 m above the valley floor. Treeline occurs at around 1,950 m in this region. The Whistlers Creek mineral lick is located in a narrow valley <1 km to the north of the ski area (Fig. 1) just below the tree
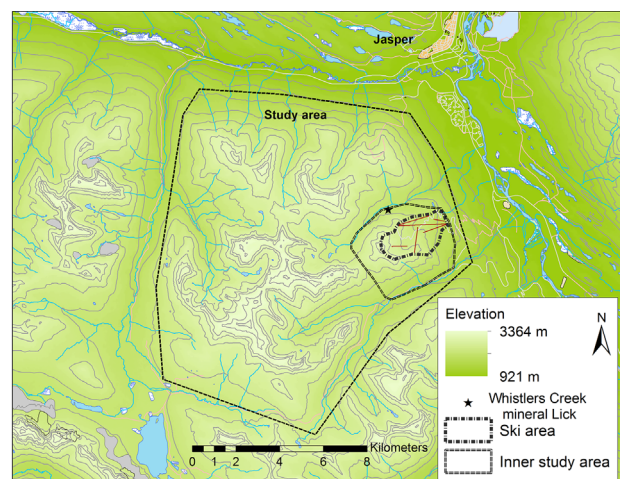

Figure 1. Study area and location of the Marmot Basin ski area where we followed mountain goat space use from summer 2011 to summer 2013, Jasper National Park, Alberta, Canada. Topography and elevation are represented by 100-m contour lines and graduated colors. Straight lines within the ski area are chairlifts. We used the inner study area around Marmot Mountain to compare mountain goat habitat use within the ski area and its close proximity.

line at 1,915 m. The ground at the lick is covered with grasses and forbs and is surrounded by white spruce (*Picea glauca*), Engelmann spruce (*Picea engelmannii*), and subalpine fir (*Abies lasiocarpa*) subalpine forest. Two camera traps mounted at the lick during May–September over 4 summer seasons (2010–2013) resulted in 40,000 pictures of mountain goats. The cameras recorded 179 visits representing 436 individual observations of marked and unmarked mountain goats. The lick is not available for mountain goats in winter because of the high snow cover that limits mountain goat movements and blocks access to the ground vegetation around the lick.

We defined seasons using expert knowledge and a literature review of mountain goat movements and activity. Because we were interested in mountain goat space use, we accounted for variables influencing space use when defining season. Because snow is one of the main variables influencing mountain goat space use in winter (White 2006, Poole et al 2009, Richard et al. 2014*b*), we determined that the beginning of summer would correspond to the period when snow was receding in the area. We defined summer as 1 May–14 October and winter as 16 December–30 April. We excluded mid-October to mid-December to avoid recordings during the rut.

METHODS

Captures and GPS Data
We captured and marked 8 individual mountain goats with GPS collars (GPS PLUS Iridium collars, VECTRONIC Aerospace GmbH, Berlin, Germany) and ear tags from 2011 to 2013: 5 females ≥3 years and 3 males ≥4 years (Table 1). We captured 2 of the females on the same occasion and considered them to be from the same group at that time. The GPS data and field observations later revealed that all marked females shared very similar spatial distribution and had frequent social interactions. Our sample size represented approximately half of the individuals using Marmot Mountain (Richard et al. 2014*a*). Also, because mountain goats are highly gregarious, each recorded location point may represent a small group of animals. We used the Whistlers Creek lick site for captures with self-triggered Stevenson style wooden box traps. Before handling, we immobilized mountain goats with an intramuscular injection of xylazine hydrochloride (Rompun, Bayvet Division, Etobicoke, Ontario, Canada) at a dosage of 5 mg/kg. Following handling procedures, we reversed the effect of

xylazine by intramuscular injection of 0.9–1.2 mg of idazoxan (RX 811059, Reckitt and Colman, Kingston-upon-Hull, United Kingdom; Haviernick et al. 1998). All captured animals were hobbled and masked to minimize outside stimuli and animals received supplemental oxygen during handling. All capture and handling procedures were approved by the animal care committee of Université Laval, Québec and Parks Canada.

The GPS collar recording schedule varied according to seasons with location points recorded every 3 hours in summer and every 6 hours in winter. We defined the population home range by the 95% minimum convex polygon (MCP) of the complete dataset of mountain goat GPS location points.

Resource Selection Analyses
We calculated a resource selection function (RSF) with a presence-availability design (Boyce et al. 2002, Fortin et al. 2008) to characterize mountain goat habitat selection. We used a logistic regression comparing characteristics of used versus random location points to predict the relative probability of use within the study area. The ski area covered about 4% of the population range, and about 0.55% of the used location points were within the ski area. All of the ski area above 1,900 m was available to all individuals and was included in the population home range. We nevertheless excluded random location points within the ski area because they could be perceived as unavailable by mountain goats because of disturbance. We could not identify any factors, other than the ski area activities, that could limit the availability of the ski area to mountain goats, and mountain goats regularly used other aspects of Marmot Mountain. As such, areas within and outside the ski area were equally available to mountain goats, and their probability of use could be compared. Out of the approximately 25,000 locations obtained by GPS collars, we removed all data with improbable elevations or with a dilution of position (DOP) ≥10 (∼3% of the location points) occurring as a result of poor satellite coverage (D'Eon and Delparte 2005). After data screening we based the analyses on 23,434 valid location points from 8 individuals (Table 1). We performed RSF analyses separately for summer and winter to account for changes in environmental conditions. For summer, we had 17,397 points from 8 individuals (5 F and 3 M), and we had 6,037 points from 6 individuals (4 F and 2 M) for winter. For

Table 1. Monitoring of collared mountain goats between 2011 and 2014 on Marmot Mountain, Jasper National Park, Alberta, Canada. Percentage of successful global positioning system locations represent the percentage of valid locations remaining after data screening.

ID	Sex	Age at capture	Monitoring start	Monitoring end	Duration (days)	% of successful locations	No. of locations in winter analyses	No. of locations in summer analyses
562	M	5	15 Jun 2011	10 Jul 2014	1,122	94.7	1,486	3,907
565	F	6	5 Aug 2011	1 Sep 2014	1,123	97.1	1,442	4,141
444	F	6+	5 Aug 2011	20 Jun 2013	686	98.0	1,015	2,282
559	M	6	19 Jun 2012	24 Jul 2012	36	99.6	0	280
556	F	6	7 Jul 2012	7 Dec 2012	154	91.2	0	1,309
557	F	5	21 Jul 2012	1 Sep 2014	772	99.0	1,032	3,006
561	F	3	8 Aug 2012	18 Feb 2013	195	99.6	512	684
568	M	4	9 Jul 2013	1 Sep 2014	419	99.7	550	1,788
					Total: 4,507	$\bar{x}$: 97.4	Total: 6,037	Total: 17,397

each season, we selected randomly an equal number of available location points within the annual population home range but outside the ski area to use in the analyses.

We included individual identity and year of observation as random effects in all models to account for individual and annual variability in habitat selection. Topographical (physical) characteristics of the landscape are known to be most useful for characterizing mountain goat habitat (Gross et al. 2002, Poole et al. 2009), and our collared mountain goats spent the majority of their time in the alpine where vegetation is very sparse. As such, we could not find any data representing vegetation cover types relevant to mountain goat use, and we included only abiotic and topographical variables in the RSF analyses. We derived all abiotic characteristics of the landscape from digital elevation model (DEM; ASTER global digital elevation model) data with 24-m cell size (Table 2). For each grid cell, we calculated the distance to the nearest escape terrain (m), which we defined as slopes of $\geq 40°$ or $\geq 84\%$ (Poole et al. 2009, Shafer et al. 2012). Solar radiation can be used as a proxy for snow depth and snow density (Pomeroy et al. 1998), which influence mountain goat space use (Taylor et al. 2006, Poole et al. 2009, White et al. 2012). We calculated solar radiation using the area solar radiation function in ArcGIS (Environmental Systems Research Institute, Inc., Redlands, CA), which gives the amount of solar radiation in watts that would have reached each cell seasonally given there were only sunny days. We produced grids of slope, curvature (range: −30 to 36) and aspect (4 cardinal directions and flat areas) using the DEM surface tool (Jenness 2004) in ArcGIS. Because mountain goats are associated with broken terrain, we also added a ruggedness index (range: 0.9–15.9) representing the standard deviation of curvature in a 100-m radius around each grid cell (Poole et al. 2009). In the models, we estimated aspect effects using flat areas as reference. We did not use solar radiation and aspect in the same model as they were closely related. The same was the case for curvature and ruggedness because the latter was calculated using the curvature values. We centered elevation values to the average elevation in the study area (2,104 m) and used squared centered elevation to allow a non-linear relation with elevation,

which we expected because mountain goats in the area use elevations between 2,000 m and 2,500 m (Richard et al. 2014a). This improved interpretability of the coefficients because the estimate of the linear term represents the linear effect (higher vs. lower elevation use), whereas the estimate for the quadratic term represents the effects of extremes values (use vs. avoidance of very high or very low elevation; Schielzeth 2010). Both estimates should be interpreted independently. We selected 7 predictive variables: distance to escape terrain, solar radiation, curvature, ruggedness, aspect, centered elevation, and squared centered elevation, and biologically meaningful interactions among these variables that could influence mountain goat habitat selection (calculated at a resolution of 24×24 m) to develop an a priori set of candidate models based on literature and field observations (see Supplementary Table S1, available online at www.wildlifejournals.org). Although mountain goats are sexually segregated, males and females used similar habitat and the inclusion of sex did not improve model performance.

We then assessed the strength of competing models based on Akaike's Information Criterion and parsimony (AIC; Anderson and Burnham 2002). We performed a k-fold cross validation on the best model for each season to evaluate predictive strength (Boyce et al. 2002). The k-fold cross validation represents a Spearman's rank correlation, thus correlation values closer to 1 represent a higher prediction success. For each season, we repeated the cross validation 10 times, and we calculated an average correlation score with standard deviation. Because mountain goats showed high site fidelity, GPS data suffered from autocorrelation. Generalized estimating equations (GEE) are often used to obtain robust standard errors in the presence of autocorrelation (Fortin et al. 2005). In our case, the autocorrelation was such that we could not identify time lags when autocorrelation stopped, which is necessary to perform GEE. Nevertheless, effect sizes are robust to this and therefore valid, whereas standard error and P-values are underestimated (Nielson et al. 2002). We conducted spatial analyses in ArcGIS and R (version 2.12.2, www.r-project.org, accessed 20 May 2011), which was also used for statistical analyses.

Table 2. Seasonal resource selection function results for 3 males and 5 females (summer) and 2 males and 5 females (winter) mountain goats in the Trident Range area, Jasper National Park, Alberta, Canada, 2011–2013.

Variables[a]	Effect	Winter			Effect	Summer		
		SE	2.5% CI	97.5% CI		SE	2.5% CI	97.5% CI
Intercept	−1.012	0.222	−1.447	−0.577	−1.920	0.150	−2.214	−1.626
Ruggedness	0.434	0.030	0.375	0.492	0.393	0.016	0.361	0.425
Solar radiation (W/m^2)	4.28E−06	3.53E−07	3.59E−06	4.97E−06	1.56E−06	1.24E−07	1.32E−06	1.80E−06
Elevation (m)	0.001	0.001	0.000	0.003	0.004	0.001	0.003	0.006
Elevation^2	−1.86E−05	6.77E−07	−1.99E−05	−1.73E−05	−1.96E−05	3.95E−07	−2.03E−05	−1.88E−05
Distance escape (m)	−0.020	0.001	−0.022	−0.018	−0.005	1.89E−04	−0.005	−0.004
Elevation × distance escape	2.59E−05	4.49E−06	1.70E−05	3.47E−05	−8.72E−06	1.15E−06	−1.10E−05	−6.47E−06
Elevation × solar radiation	1.38E−08	1.87E−09	1.02E−08	1.75E−08	5.89E−09	5.63E−10	4.79E−09	6.99E−09
Elevation × ruggedness	−0.001	1.38E−04	−1.26E−03	−7.18E−04	−6.96E−04	7.02E−05	−8.33E−04	−5.58E−04

[a] Ruggedness represents the standard deviation of curvature in a 100-m radius around each grid cell. Elevation values are centered to the average elevation in the study area (2,104 m).

To quantify mountain goat use of the ski area, we measured the number of locations recorded by GPS collars in areas of high probability of use within and outside the ski area on Marmot Mountain. Because all collared individuals used the west, northwest, and southwest faces of Marmot Mountain, which are surrounding the ski area, we assumed that habitat with high probability of use located within and outside the ski area was available to all individuals. We assigned high probability of use to cells having a seasonal RSF prediction ≥ 0.7. We then summed the number of GPS locations within these areas of high probability of use and reported their densities (km^2) for both parts of Marmot Mountain (ski area vs. others).

Field Observations

To estimate the use of Marmot Mountain by uncollared individuals and the behavioral response of mountain goats toward hikers, we conducted surveys of mountain goats by hiking within the study area. Except from 1 backcountry hiking trails (~20 hikers per week during summer) located at the southern limit of the study area, our surveys were conducted away from any maintained trails. Over 3 field seasons (2011–2013), we spent 152 observation-days within the Trident Range area and recorded 277 mountain goat groups (839 individual observations). Mountain goat herds are sexually segregated and form distinct nursery (F with young) and bachelor groups (adult M) for most of the year except during the rut (Festa-Bianchet and Côté 2008). We used binoculars and spotting scopes to recorded group size, location, composition, and activity for each observation, and multiple locations could be recorded for the same group in a single day. Observation time of a group usually lasted between 30 and 90 minutes (range: 5–480 min). To limit disturbance, we generally tried to avoid approaching mountain goats, but when encounters occurred within 1 km, we recorded the distance, and animal reactions to our presence according to 4 ordinal classes: 1) notice our presence but do not modify its previous behavior; 2) look at us regularly, if feeding, continue to feed while moving away slowly, if bedded, stay bedded; 3) alert, look at us continuously and intensively, if away from escape terrain, move away, if in escape terrain, stand and stay alert; and 4) run away. We measured distances using a laser range finder (Bushnell Elite 1500, Bushnell Performance Optics, Overland Park, KS) with a 1-km detection range. Hiking group size varied from 1 to 3 peoples, but 2 people were present for most encounters. We compared reaction class between sex and according to distance between observers and mountain goats using a linear model.

RESULTS

The best RSF model was the same for both seasons and contained the ruggedness index, total solar radiation for the season, centered elevation linear and squared effect, and distance to escape terrain. The best model also included 3 interactions involving centered elevation in interaction with distance to escape terrain, solar radiation, and ruggedness (see Supplementary Tables S2 and S3, available

online at www.wildlifejournals.org). Mountain goats consistently used rugged terrain and stayed close to escape terrain throughout the year but more so during winter. Collared individuals remained almost exclusively above tree line throughout the year but avoided the highest elevations. Mountain goats generally used higher elevations in summer than in winter. Mountain goats preferred areas with more solar radiation, especially in winter (Table 2). The k-fold cross validation revealed that both seasonal RSF models predicted mountain goat space use correctly and precisely. For both models, we obtained an average Spearman's rank correlation of 0.99 between predicted and observed data, and the standard deviation of the mean correlation was 0.01 for the winter RSF and 0.003 for the summer RSF.

Comparison of RSF predictions and actual space revealed that mountain goats avoided the ski area (Fig. 2). During summer, males visiting Marmot Mountain were found twice as often (locations/km^2) in areas of high probability of use outside the ski area compared to within the ski area, whereas females were 9 times more often outside the ski area compared to within the ski area (Table 3). During winter, the
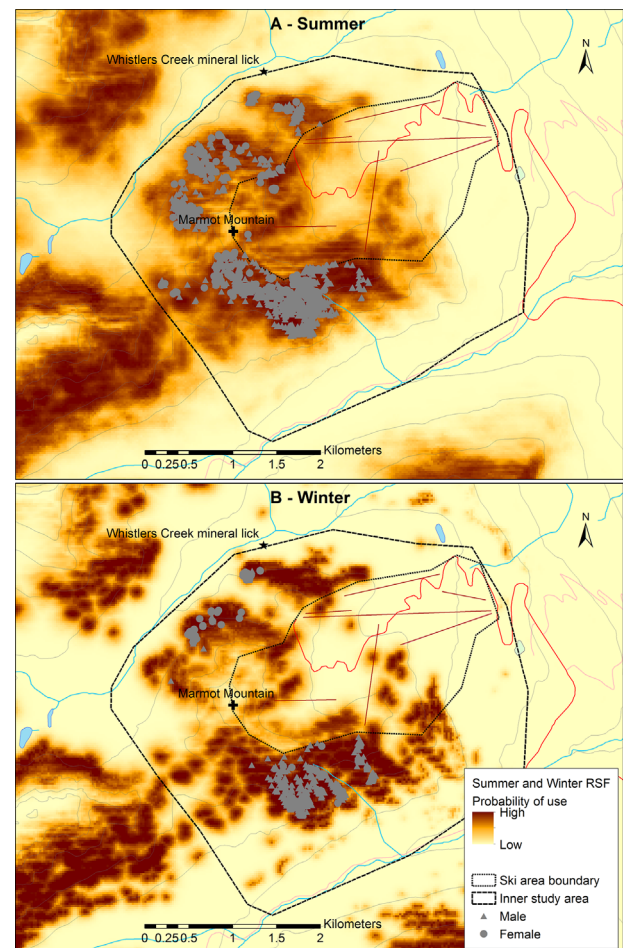

Figure 2. Mountain goat (A) summer (3 M and 5 F) and (B) winter (2 M and 5 F) location points and predicted relative probability of use around Marmot Basin, Jasper National Park, Alberta, Canada, 2011–2013, based on resource selection functions (RSF). Straight lines within the ski area are chairlifts and the tortuous line is an access road.

ski area was never used by mountain goats, whereas areas of Marmot Mountain located outside the ski area were used regularly (Table 3). Males were more often present on Marmot Mountain than females, accounting for 67.7% of all location points recorded there over 2 winters. Additionally, only 5 of the 277 observations of mountain goat groups were within the ski area. These were 5 male groups of 1 or 2 individuals located within 50 m of the ski area boundary.

When we were within 1 km of mountain goats and moving, they always reacted to our presence. We recorded 26 encounters within 1 km: 16 male groups and 10 female groups that were used in this analysis. The distance between observers and mountain goats varied from 15 m to 830 m, but mountain goat reactions did not vary according to distance within this range ($\beta(x) = 0.0008$, SE $= 0.001$, $t = 0.836$, $P = 0.41$). A linear model showed that the average reaction class for nursery groups or lone females was 3.5 (SE $= 0.27$, $t = 12.69$, $P < 0.001$), significantly higher than for males whose reaction class averaged 2.1 (SE $= 0.35$, $t = -3.91$, $P = <0.001$). From direct observations and collar data, Marmot Mountain was the only access route used by mountain goats to reach the Whistlers Creek lick.

DISCUSSION

The GPS and observational data indicated limited use of the ski area by mountain goats despite relatively frequent use of similar habitats close to the ski area. Even when mountain goats moved across the ski area boundary they did not venture far. Although RSF analyses based on topographical traits of the landscape predicted a high probability of use for the highest elevation and steepest parts of the ski area, these cliffs and rugged terrain were used less than expected. Our data suggest that mountain goat space use in and around the Marmot Basin Ski Area was related to factors other than topography alone.

In winter, when human activity in the ski area was high, mountain goats completely avoided areas of high probability of use within the ski area but continued to use the rest of Marmot Mountain. During summer, mountain goats were located within the ski area, but areas of high probability of use within the ski area were used 2 and 9 times less often than outside the ski area by males and females, respectively. During summer, human activity within the ski area is constant and greater than in surrounding areas but limited to maintenance and occurs at a low level. This suggests either that summer activity is sufficient to limit mountain goat use

of the ski area or that mountain goats avoid the area year round as a consequence of high disturbance during winter.

Areas of high probability of use by mountain goats within the ski area were about 25% smaller in winter than in summer. They were not often used by recreationists, but they were located directly above ski runs and subject to regular avalanche control activities. Overall, mountain goats' habitat selection remained largely constant from summer to winter, highlighting their high fidelity to rugged alpine habitat. Habitat selection observed around Marmot Mountain appears similar to other Rocky Mountain goat populations (Gross et al. 2002, Poole et al. 2009). Use patterns by the mountain goat population in the vicinity of the ski area suggest that either physical modification of the landscape, or the level of risk perceived by mountain goats resulting from anthropogenic activities occurring almost year round may be altering space use.

Physical modifications related to the ski area (tree removal, soil leveling, snow-making infrastructure) can lead to the observed space use patterns especially in summer. Changes in vegetation cover could influence resource availability for mountain goats. Although most of the changes occurred at elevations below preferred mountain goat habitat, a service road and chair lift infrastructure do impact vegetation cover in the upper section of the ski area that is more suitable for mountain goats. The presence of cleared ski runs also provides resources for grizzly bears (*U. arctos*), an important mountain goat predator (Festa-Bianchet and Côté 2008) that was regularly observed in the ski area during early summer (J. H. Richard, Université Laval, personal observation). In other studies, mountain goat habitat use is more influenced by predator avoidance than forage availability (Hengeveld et al. 2003). Disturbances linked to predation risk that either reduce access to escape terrain or increase local predator density could influence mountain goat space use in this setting. Proximity of anthropogenic disturbance may conversely lower predation risk to habituated wildlife if predators themselves are sensitive to human disturbance (Sutherland 2007). In our study area, however, interactions are complex with grizzly bears absent during winter. Wolves are either deterred or facilitated by anthropogenic factors depending upon the intensity of factors (Hebblewhite and Merrill 2008, Musiani and Boitani 2010).

Alternatively, or perhaps additively, anthropogenic disturbances appear to influence mountain goat space use. Patterns of human use in the ski area and mountain goat disturbance

Table 3. Distribution of mountain goats from global positioning system (GPS) location points recorded in areas of high probability of use between 2011 and 2014 on Marmot Mountain, Jasper National Park, Alberta, Canada.

Season	Site	Areas size (km²)	No. of male GPS locations	No. of female GPS locations	Total no. of GPS locations	Male locations/km2	Female locations/km2	Total locations/km2
Winter	Ski area	0.28	0	0	0	0	0	0
	Rest of Marmot mountain	2.02	1,163	273	1,436	575.7	135.1	710.8
Summer	Ski area	0.40	118	11	129	296.5	27.6	324.1
	Rest of Marmot mountain	1.92	1,222	472	1,694	635.7	245.5	881.3

responses correspond to behavior that suggests a landscape of fear may be affecting mountain goats. Examples of disturbance resulting in animal space use alteration are common and mountain goats decreased their use of previously occupied habitat following disturbance (Gordon and Reynolds 2000). Similarly, Hamr (1988) reported that disturbance occurring in an alpine recreational area displaced chamois from quality foraging habitat for prolonged periods and altered home range use patterns. In Vail, Colorado, USA, elk use of the most developed part of a ski area was only 4% of pre-development levels (Morrison et al. 1995). In Elk Island National Park, Canada, elk and moose avoided areas with high levels of cross-country skiing during winter (Ferguson and Keith 1982). Elsewhere it has been reported that species sensitive to human presence may be displaced permanently (Knight and Gutzwiller 1995). Indeed, displacement to less desirable and often poorer areas may be as detrimental to wildlife populations as harassment or habitat changes (Hammitt and Cole 1987) due to reduced foraging efficiency (Knight and Gutzwiller 1995) and increased predation risk (Geist 1978, Lusseau 2004) decreasing fitness (Miller et al. 2001). But these effects are difficult to detect.

We were not able to assess mountain goat reactions to human encounters beyond 1 km, but ≤1 km, mountain goats detected and responded to human activity. This confirmed that mountain goats react to human presence from long distance as if that presence is a threat. Even in the absence of hunting in the park for over 100 years, mountain goats appear to relate human presence to predation risk. Stronger reactions by female mountain goats suggest that they were more sensitive to disturbance than males. Males generally appeared to be more tolerant to human presence and somewhat habituated to the high human activity on Marmot Mountain during winter. As such, behavioral response of mountain goats to human encounters supported results of spatial analysis, suggesting that the avoidance of the ski area is related to anthropogenic activities. Because the Whistlers Creek lick is often used by mountain goats of the area, we suggest that its presence in the proximity of the ski area could promote mountain goat habitat use just outside the ski area boundary. Mineral licks are considered essential components of the landscape (Dormaar and Walker 1996) and their distribution influences movement and space use of ungulate populations (Ayotte et al. 2006, Jokinen et al. 2014). As such, the presence of a key resource close to the ski area could at least partly explain why mountain goats that appeared to avoid the ski area seemed to have learned the boundaries of the ski area and continued using areas in proximity to it. Therefore, mountain goats may have been more tolerant to the activities of the ski area in summer than in winter because they needed to access the lick.

MANAGEMENT IMPLICATIONS

Developments and recreational activities occurring in alpine ski areas alter the space use of large mammals inevitably resulting in cumulative, detrimental consequences. In all areas where new developments or their expansion are being considered, and particularly in protected areas where wildlife protection is enshrined, mitigations should be developed and implemented. At Marmot Basin Ski area in Jasper National Park, we recommend excluding development and limiting recreational activity in a 1-km radius around the natural mineral lick and in core wintering habitat found directly next to the ski area boundary to favor long-term persistence of the local mountain goat population. This would facilitate undisturbed access to essential landscape features including a mineral lick and quality wintering habitat.

ACKNOWLEDGMENTS

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Associate Editor: Barbara Zimmermann.

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