

Mountain Goat Resource Selection in Relation to Mining-related Disturbance, near the Kensington Mine, Southeast Alaska

Kevin S. White, David P. Gregovich



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Cover Photo: Photograph of a radiocollared adult female mountain goat (LG022) on a ridge east of the Kensington Mine, Lion Head Mountain, Alaska, October 2005. ©2005 ADF&G. Photo by Kevin White.

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Abstract

Industrial development can have important direct and indirect effects on wildlife populations. Resource selection function (RSF) modeling provides a powerful tool for assessing the effects of industrial development on spatial use patterns of wildlife. Among North American large mammal species, mountain goats (*Oreamnos americanus*) are particularly sensitive to human disturbance. In this study mountain goat seasonal resource selection patterns were examined using Global Positioning System (GPS) radio collar ($n = 79$ individuals) and remote sensing data in a Geographic Information System (GIS) framework across a 491 km² regional mountain range in Southeast Alaska, 2005–2015. The resulting global RSF model was then applied across a limited spatial extent centered on an industrial mining site in order to assess whether mining activity altered expected spatial use patterns at different distances from the mine. Using a quasi treatment-control experimental framework we examined the occurrence of spatially explicit mine disturbance thresholds. In general, resource selection modeling indicated that mountain goats selected for steep, rugged terrain in close proximity to cliffs in areas with high solar exposure; and they selected for lower elevations in winter than in summer. Mountain goat selection for rugged terrain and proximity to cliffs was stronger in winter than summer. RSF model applications indicated that mountain goat use of predicted habitat in close proximity to the mine was lower than expected at distances up to 1,800 m in winter and 1,000 m in summer. Because lower elevation winter habitat is closer to mining activity than summer habitat, 42% of winter habitat within the analysis area was affected by mining activity. The resulting net loss of functional winter habitat carrying capacity is likely to have long-term negative implications for the local mountain goat population. In places where mining is proposed, development should avoid areas within 1,800 m on mountain goat winter habitat. In places where mining is already occurring within disturbance thresholds (such as this study), long-term monitoring and more detailed field studies should be conducted to more fully understand population-level consequences of disturbance and identify practicable mitigation measures that have a high probability of success.

Key words: Disturbance, habitat selection, mining, mountain goats, *Oreamnos americanus*, resource selection function, RSF, Southeast Alaska

Introduction

Industrial development can have important direct and indirect effects on wildlife populations (Joslin 1986, Berger and Daneke 1988, McDonald and McDonald 2002, Hurley 2004, Sawyer et al. 2006, Ciuti et al. 2012, Northrup et al. 2015, Cristescu et al. 2016). Although direct mortality associated with industrial development is a chief concern, indirect effects are likely to be more widespread even if more difficult to detect analytically. In this context, Frid and Dill (2002) provide a useful conceptual framework to address indirect disturbance related effects. Specifically, they suggested that disturbance can be viewed as a form of predation risk. Similar to the “landscape of fear” concept (Laundre et al. 2001, 2010), spatial variation in disturbance can be expected to alter selection pressure, individual fitness and population dynamics. Consequently, understanding how human and industrial disturbance alter animal behavior and resource use across a given landscape can provide important insights about anthropogenic effects on wildlife populations as well as the appropriate management responses to such threats.

Resource selection modeling provides a powerful tool for assessing the effects of industrial development on spatial use patterns of wildlife (McDonald and McDonald 2002, Northrup et al. 2015, Cristescu et al. 2016). Resource selection function (RSF) models integrate information about use and availability of ecologically relevant habitat characteristics in order to quantitatively predict the relative probability of use across a given landscape. Such models are based on ecological theory and posit that animals distribute themselves across a given landscape in ways that maximize their fitness (Sutherland 1996). Thus, RSF modeling provides a robust framework for describing habitat-use relationships and distribution of critical habitats in natural and human-altered environments.

Among North American large mammal species, mountain goats (*Oreamnos americanus*) are particularly sensitive to human disturbance (Cote 1996). Previous studies have documented negative effects of human and industrial disturbance on mountain goat foraging behavior, movement patterns and population dynamics (Foster and Rahe 1983, Joslin 1986, Cote 1996, Goldstein et al. 2005, Cote et al. 2013, St-Louis et al. 2013, Richard and Cote 2015). In this context carefully understanding and, potentially, mitigating human and industrial disturbance in areas inhabited by mountain goats is important for ensuring sustainable mountain goat populations. Nonetheless, significant threats associated with industrial development exist throughout the range of the species (Festa-Bianchet and Cote 2008) and, in many cases, knowledge is lacking to adequately predict site- and context-specific responses needed to inform decision making.

In this study we examined mountain goat seasonal resource selection patterns using GPS radio collar and remote sensing data in a GIS framework across a 491 km² regional mountain range in Southeast Alaska. We then applied the resulting global RSF model across a limited spatial extent centered on an industrial mining site to assess whether mining activity altered expected spatial use patterns across a continuum of different distances from the mine. Using a quasi treatment-

control experimental framework we examined the occurrence of spatially explicit mine disturbance thresholds to provide guidance for future management, monitoring and mitigation.

Study Area

Mountain goats were studied in a ~491 km² area located in a mainland coastal mountain range east of Lynn Canal, a marine fjord located between Juneau and Haines in Southeast Alaska (Fig. 1). The study area was located in the Kakuhan Range oriented along a north-south axis and bordered on the south by Berners Bay (58.76N, 135.00W) and on the north by the Katzeihin River (59.27N, 135.14W). Approximately 300-600 mountain goats inhabited the study area (2005-2011; White et al. 2012b). Mountain goats in this area migrate seasonally between alpine habitats in summer and lower elevation forested sites in winter (White 2006, White et al. 2012b)

The Kensington Mine, a hard rock gold mine, is located at the southern end of the study area, immediately south of Lions Head Mountain in the Johnson, Slate and Sherman creek watersheds. A majority of aboveground mining activity occurs in 4 principal locations situated between 200–300 meters in elevation. The overall mine “footprint” comprises 56.6 km² of patented claims; a significant amount of activity is at low elevation (<300 m) and underground. This study occurred during both the construction and production phases of the mine and possible sources of disturbance to mountain goats in the vicinity included blasting, heavy equipment operation, helicopter operation, and vehicle traffic. Mining activity occurred during all months of the year, though exploration activity was more frequent during late-spring and summer.

Elevation within the study area ranges from sea level to 2,070 m. This area is an active glacial terrain underlain by late cretaceous-paleocene granodiorite and tonalite geologic formations (Stowell 2006). Specifically, it is a geologically young, dynamic and unstable landscape that harbors a matrix of perennial snowfields and small glaciers at high elevations (i.e. >1,200 m) and rugged, broken terrain that descends to a rocky, tidewater coastline. The northern boundary of the area is defined by the Katzeihin River, a moderate volume (~1,500 cfs; USGS, unpublished data) glacial river system that is fed by the Meade Glacier, a branch of the Juneau Icefield.

The maritime climate in this area is characterized by cool, wet summers and relatively warm snowy winters. Annual precipitation at sea level averages 1.4 m and winter temperatures are rarely less than -15°C and average -1°C (Haines, AK; National Weather Service, Juneau, AK, unpublished data). Elevations at 790 m typically receive ~6.3 m of snowfall, annually (Eaglecrest Ski Area, Juneau, AK, unpublished data). Predominant vegetative communities occurring at low-moderate elevations (<460 m) include Sitka spruce (*Picea sitchensis*)-western hemlock (*Tsuga heterophylla*) coniferous forest, mixed-conifer muskeg and deciduous riparian forests. Mountain hemlock (*Tsuga mertensiana*) dominated ‘krummholtz’ forest comprises a subalpine timberline band occupying elevations between ~460–760 meters. Alpine plant communities are composed of a mosaic of relatively dry ericaceous heathlands and moist meadows dominated by sedges, forbs and wet fens. Avalanche chutes are common in the study area and bisect all plant community types and often terminate at sea level.

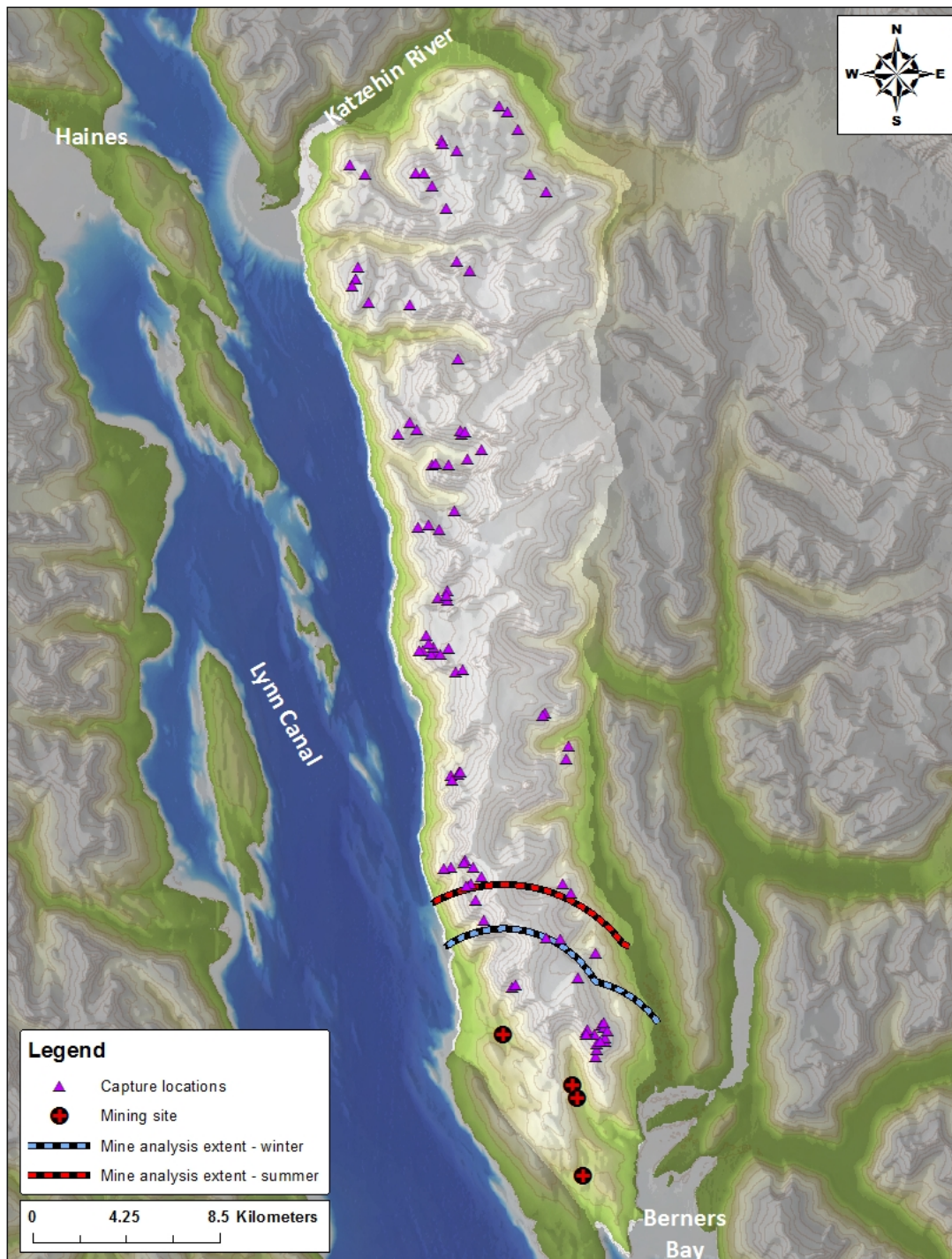


Figure 1. Map depicting the geographical extent of the study area used to develop the “global” summer and winter RSF models, Lynn Canal, AK. The light blue and red lines delineate the winter and summer extents used in the mine proximity analyses (based on the 95th percentile movement distances of mountain goats that spatially overlapped with the mine). The purple triangles indicate the mountain goat capture locations, and the red crosses depict mine activity sites.

Methods

MOUNTAIN GOAT CAPTURE

Mountain goats were captured using standard helicopter darting techniques and immobilized by injecting 3.0–2.4 mg of carfentanil citrate, depending on sex and time of year (Taylor 2000), via projectile syringe fired from a Palmer dart gun (Cap-Chur, Douglasville, GA). During handling, all animals were carefully examined and monitored following standard veterinary procedures (Taylor 2000) and routine biological samples and morphological data were collected. Following handling procedures, the effects of the immobilizing agent were reversed with 100 mg of naltrexone hydrochloride per 1 mg of carfentanil citrate (Taylor 2000; White et al. 2012b). The State of Alaska Animal Care and Use Committee approved all capture procedures.

GPS DATA

Telonics TGW-3590 and TGW-4590 GPS radio collars (Telonics, Inc., Mesa, AZ) were deployed on most animals captured. GPS radio collars were programmed to collect location data at 6-hour intervals (collar lifetime: 2–3 years). Complete datasets for each individual were remotely downloaded (via fixed-wing aircraft) at 8-week intervals or downloaded manually following collar release. Location data were post-processed and filtered for “impossible” points and 2D locations with PDOP (i.e. position dilution of precision) values greater than 10, following D’Eon et al. (2002) and D’Eon and Delparte (2005).

RSF MODEL DEVELOPMENT

Resource selection function (RSF) models (i.e. Boyce et al. 2002) were developed using mountain goat GPS location data and remote sensing covariate data layers in a GIS framework in order to describe ecological relationships and identify where important seasonal habitats occurred in the study area. Mountain goat resource selection was analyzed separately for the winter (December 15–14 April) and summer (15 June–30 September) seasons, based on previously described differences in seasonal altitudinal distribution (White 2006, White et al. 2012b).

A resource selection function can be defined as: a model that yields values proportional to the probability of use of a given resource unit (Boyce et al. 2002). Specifically, we employed a logistic regression-based “used” vs “available” study design to estimate resource selection patterns at the population-level (i.e. 1st-order selection, Johnson 1980). In order to estimate resource availability in the study area, we randomly selected locations throughout the study area at a density of 100 locations per km², a density determined to reliably describe resource availability patterns in our study area based on simulation analyses (sensu Northrup et al. 2013). Mountain goat GPS locations (i.e. “used”) and “available” locations were then intersected (using GIS) with a suite of biologically relevant remote sensing data layers (Table 1). These data were then analyzed using logistic regression (GLM function, stats package, Program R, ver. 2.13.1) to derive selection coefficients for each covariate by individual animal. With the exception of the

“distance to cliffs” variable both linear and quadratic terms were used to describe selection functions for each variable.

Table 1. Variables used for modeling mountain goat resource selection, Lynn Canal, Southeast Alaska

Variable ¹	Definition	Source data
Elevation	Elevation (m)	IfSAR DEM
Slope	Slope (degrees)	IfSAR DEM
Distance to escape terrain	Distance to areas with slope > 50 degrees	IfSAR DEM
Solar radiation (Jan 1)	Solar radiation calculated for January 1	IfSAR DEM ²
Solar radiation (August 1)	Solar radiation calculated for August 1	IfSAR DEM ²
VRM	Vector ruggedness measure	IfSAR DEM ³

¹Variables were standardized for by subtracting the mean and dividing by the standard deviation: Elevation, $y = (x - 805.2831)/459.3702$; Slope, $y = (x - 27.4894)/14.9201$; Distance to escape terrain, $y = (x - 175.3112)/195.2089$; Solar radiation (Jan 1), $y = (x - 12.7190)/9.4410$; Solar radiation (Aug 1), $y = (x - 3742.861)/900.9018$; VRM, $y = (x - 0.0188)/0.0243$

²Calculated using the solar radiation algorithm in ArcGIS 10 (Fu and Rich 2002)

³Calculated using methods described in Sappington et al. (2007)

The median inter-individual coefficient value (and confidence interval) was computed for each covariate (i.e. the “two-stage” modeling framework; Fieberg et al. 2010) and stratified by season (winter vs. summer). The median coefficient values were used because they are more robust to skewness in inter-individual coefficient value distributions than mean values. Covariates were considered significant if confidence intervals did not overlap zero. Significant coefficient values were then multiplied by respective covariate remote sensing data layers in GIS using the following equation:

$$w(x) = \exp(\beta_1 x_1 + \beta_2 x_2 + \dots + \beta_n x_n) \quad (1)$$

Where, $w(x)$ represents a resource selection function (RSF) that is proportional to the probability of use of variables $x_1 + x_2 + \dots + x_n$. The resulting output was then used to generate a continuous raster surface representing relative probability of mountain goat use across the landscape. In addition, we calculated the contrast validation index (CVI; Hirzel et al. 2006, Fedy et al. 2014) in order to objectively identify mountain goat critical habitat. The CVI method employs an optimization routine to generate a binary classification that maps the area containing the greatest

number of use locations in the smallest footprint of predicted habitat. The predictive performance of RSF models was validated using k-fold cross validation (Boyce et al. 2002).

MINE PROXIMITY ANALYSIS

If an RSF model is robust (i.e. as determined via k-fold cross-validation) then the amount of mountain goat use should be positively correlated with the RSF value within a given spatial extent. Thus, to examine the effects of mine activity on mountain goat resource selection patterns, we divided the proportion of mountain goat GPS locations (“observed”) by the expected proportional use (“expected”) within buffers spaced at 200 m intervals from mining activity sites.

Calculation of buffer-specific selection ratios (i.e. observed/expected) allowed for assessment of the extent to which mountain goats selected predicted habitat at different distances from the mine. This analysis assumes that mountain goats will select resources similarly in all areas, but that access, or use, of resources was altered by proximity to the mine. As described above, predicted habitat represents the additive relative probability of use of multiple independent variables, conditional on the terrain characteristics (i.e. elevation, distance to escape terrain, etc.) within a given 5-m² pixel. Thus, our analysis focused on examining whether mine proximity alters selection of habitat patches rather than testing whether selection functions for given independent variables vary with respect to mine proximity. While the latter subject can be informative (i.e. Cristescu et al. 2016) it was not the focus of our analyses.

Observed use was calculated by dividing the number of GPS locations within each buffer by the total number of locations in all buffers (maximum buffer extent was based on the 95% percentile of all locations; i.e. 4,800 m and 6,800 m for winter and summer, respectively). Expected proportional use was based on the RSF volume within each buffer divided by total RSF volume of all buffers, weighted by the simulated random distribution of GPS locations across the analysis area (i.e. to account for spatial displacement of the mine and capture site locations; Appendix A). [This approach is conceptually similar to previously described methods used to weight locations in RSF models based on habitat-specific GPS error probabilities (Wells et al. 2011, Webb et al. 2013)]. The resulting “observed/expected” selection ratios were used to assess whether mountain goats used areas near the mine differently than areas further away (i.e. distances where mine effects would not be expected—a quasi “treatment-control” framework). This approach also descriptively enabled detection of threshold distances of putative mine disturbance. Selection ratios within each buffer were also compared to the median selection ratio (for all buffers) to derive buffer-specific relative selection ratios, a potentially more intuitive metric for evaluating mountain goat response to mine developments. Thus, thresholds were defined as the distance at which selection ratios were no longer negative, relative to the median value for all distances from the mine.

Individual mountain goats selected for this analysis included only animals whose 95% percentile movement distances overlapped with mine development. This ensured that only animals that were potentially exposed to mine activity and inhabited areas within a distance approximate to the diameter of their home range were considered in analyses. (In practice, animals considered

for the analysis were captured on ridges or alpine bowls immediately above the mine, or in close proximity—i.e., 2–4 km away). This approach also ensured that the distribution of animals and associated GPS locations were roughly homogenous throughout the analysis area, and that all animals considered for analysis would have access to suitable habitats both near and far from the mine.

Results

MOUNTAIN GOAT CAPTURE AND HANDLING

Mountain goats were captured during August–October 2005–2015. Overall, 118 animals were captured using standard helicopter darting methods; complete GPS location data sets were compiled from 79 individual animals (the remainder of animals were either deployed with VHF collars or GPS collars have not yet released).

RESOURCE SELECTION MODELING

GPS location data collected from 70 individual animals (total locations = 49,141) were used to derive summer RSF models. For winter modeling, GPS location data from 75 individual animals were used (total locations = 53,569) to develop RSF models.

Overall, resource selection was modeled using 5 terrain variables (Tables 1 and 2). In general, mountain goat selection patterns for most terrain variables were different during winter and summer. Slope was the only variable for which seasonal selection patterns did not differ substantially; however, solar radiation metrics were not strictly comparable between seasons (Table 2). Overall, mountain goats selected for areas close to cliffs with moderately steep, rugged slopes that had moderate-high solar exposure. Within this context, mountain goats selected for low elevation areas during winter and moderate-high elevation areas during summer. Mountain goats selected for more rugged areas (i.e. high VRM) and distances closer to cliffs during winter, as compared to summer. K-fold cross validation results indicated that resource selection models accurately predicted actual use patterns of GPS-marked mountain goats (Table 3).

Table 2. RSF model coefficients used for predicting mountain goat resource selection in Lynn Canal, Southeast Alaska.

Model variable	Winter			Summer		
	Coefficient	LCI	UCI	Coefficient	LCI	UCI
Elevation	-7.513	-10.293	-6.399	1.290	0.859	1.988
Elevation ²	-3.248	-4.170	-2.639	-4.296	-4.797	-3.714
Distance to escape terrain	-3.332	-4.107	-2.732	-0.926	-1.144	-0.705
Slope	0.481	0.356	0.653	0.602	0.412	0.773
Slope ²	-0.243	-0.354	-0.154	-0.441	-0.515	-0.384
Solar radiation (Jan 1)	1.377	0.933	1.552	--	--	--
Solar radiation (Jan 1) ²	-0.901	-1.344	-0.516	--	--	--
Solar radiation (Aug 1)	--	--	--	0.344	0.253	0.442
Solar radiation (Aug 1) ²	--	--	--	-0.096	-0.182	-0.006
VRM	0.669	0.481	0.804	0.231	0.170	0.297
VRM ²	-0.251	-0.318	-0.203	-0.029	-0.066	-0.016

Table 3. K-fold cross-validation results describing predictive performance of summer and winter RSF models developed for predicting mountain goat resource selection in Lynn Canal, Southeast Alaska.

Set	Winter		Summer	
	r_s	P -value	r_s	P -value
1	0.98	0.000	1.00	0.00
2	0.83	0.006	1.00	0.00
3	0.99	0.000	1.00	0.00
4	0.84	0.004	1.00	0.00
5	1.00	0.000	1.00	0.00
Average	1.00	0.000	1.00	0.00
Overall	0.91	0.000	0.98	0.00

MINE PROXIMITY ANALYSIS

To assess the relationship between distance to the mine and mountain goat selection patterns, we used GPS location data collected from 18 mountain goats in summer (total locations = 14,910) and 17 mountain goats in winter (total locations = 15,386). These were individuals whose 95th percentile movement distance encompassed the mine. Most animals were captured within 2–4 km of the mine (Fig. 2 and 3). The analysis extent, as determined by the 95th percentile of mountain goat GPS locations, was 4,800 m (from the mine) for winter and 6,800 m for summer. As expected, mountain goats exhibited more constrained movement during winter than summer (i.e. White et al. 2012b). During the study, about 20–100 animals occupied the area in the vicinity of the mine (White et al. 2012b, K. White, ADF&G, unpublished data). The proportion of marked animals in the local population varied between 5% and 20% annually over the course of the study.

Visual examination of mapped GPS locations and predicted mountain goat winter habitat clearly reveals an absence of winter mountain goat GPS locations in habitat patches situated in close proximity to the mine (Fig. 2). Selection ratio analysis results provide more quantitative detail and indicate that selection ratios were lower than the median for all 9 buffers between 0–1,800 m from the mine (Fig. 4a–4b, Appendix C). In contrast at distances beyond 2,000 m from the mine, selection ratios were above the median in 86% of the cases (12 of 14 buffers; Fig. 4a–4b, Appendix B). Consequently, the relative selection ratio analyses indicated that mountain goats were avoiding winter range habitats at distances up to a 1,800 m threshold from mine activity centers.

Examination of summer habitat relationships indicated that selection ratios were consistently below the median for all 5 buffers between 0–1,000 m from the mine (Fig. 5a–5b, Appendix C). Substantial variation (but of more limited amplitude) existed in selection ratios in the 18 buffers between 1,200–4,600 m from the mine (Fig. 5a–5b, Appendix C). However, selection ratios in all 11 buffers between 4,800–6,800 m from the mine were substantially larger than the median (Fig. 5a–5b, Appendix C). Thus, the results indicate that mountain goats tended to avoid summer habitats between 0 to 1,000 m from the mine, exhibited limited evidence for selection or avoidance of habitats at moderate distances, but strongly selected for habitats 4,800–6,800 m from the mine.

The CVI method enabled quantitative determination of critical summer and winter habitats by defining RSF value cut-points that optimize the amount of observed locations within a minimum amount of area. The winter CVI analyses yielded a RSF cut-point value of 19.97 and included 85.5% of the observed mountain goat locations (Appendix D). The summer CVI analyses identified a RSF cut-point value of 0.16 and included 86.4% of mountain goat locations (Appendix E). Subsequent mapping of critical habitat indicated that much less predicted summer habitat occurs in close proximity to the mine, as compared to winter habitat (Fig. 6, Appendix F). This occurs because mountain goats select for high elevation habitats in summer and lower elevation habitats in winter (Table 2). Thus, summer habitats are more spatially separated from the low elevation mining sites, as compared to winter habitats. For example, 327.6 hectares of

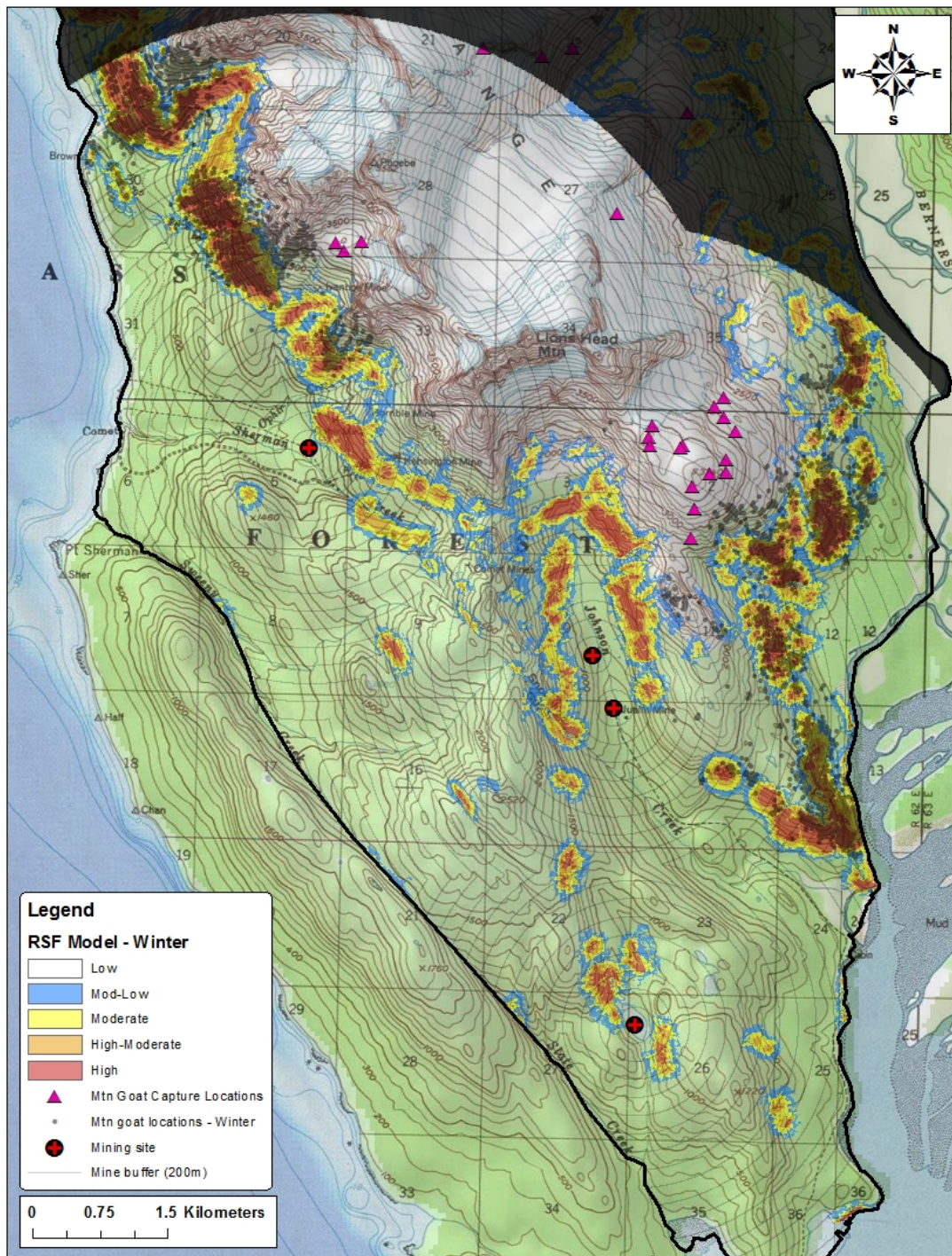


Figure 2. Map depicting mountain goat use of predicted winter habitat in the vicinity of the Kensington Mine, Lynn Canal, Southeast Alaska. Winter mountain goat GPS locations (grey dots) and capture sites (purple triangles) are plotted along with mine activity centers (red crosses) and 200 m concentric buffers (grey lines). RSF model predictions, which describe the relative probability of use, are color-coded based on the quantile distribution of RSF scores.

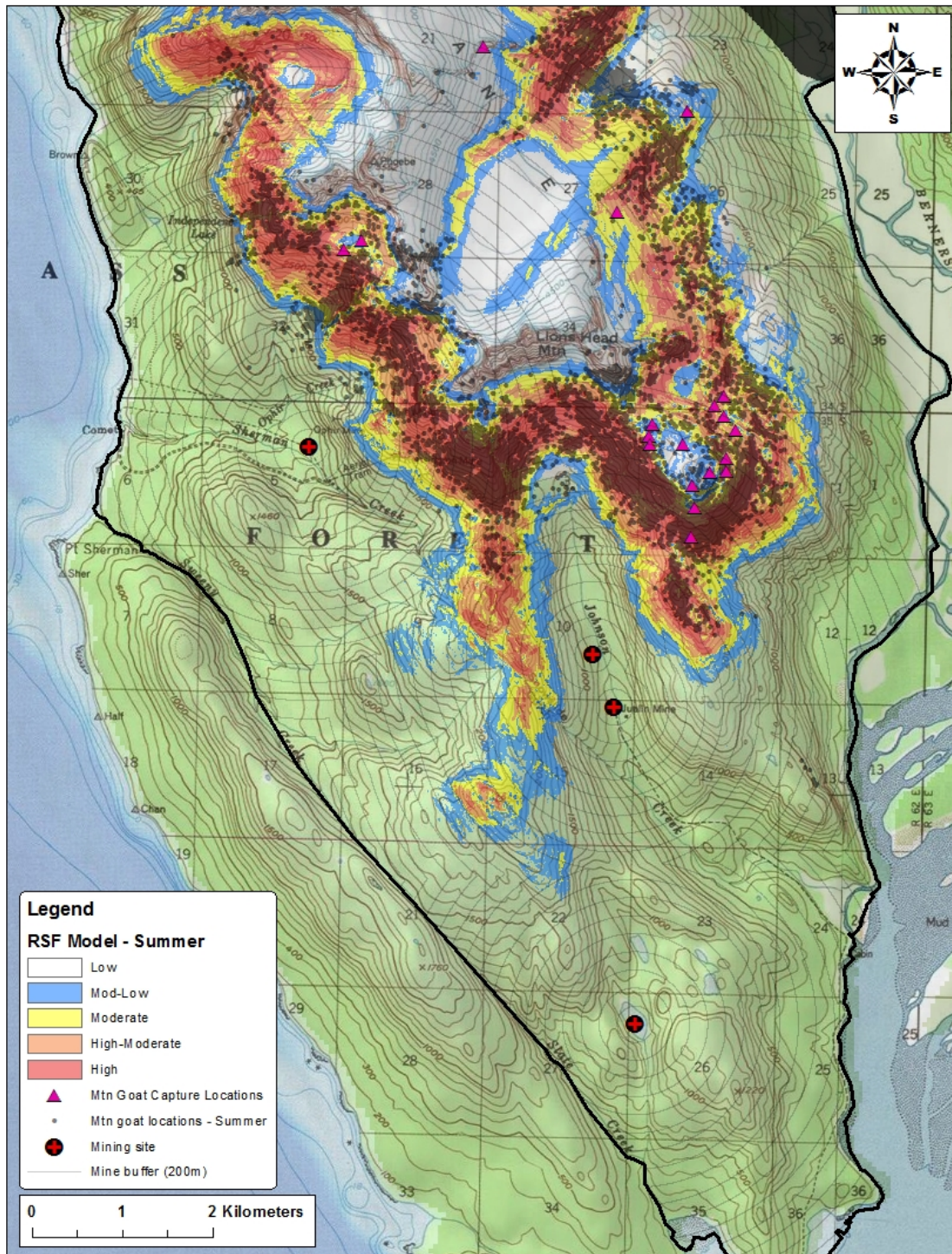


Figure 3. Map depicting mountain goat use of predicted summer habitat in the vicinity of the Kensington Mine, Lynn Canal, Southeast Alaska. Summer mountain goat GPS locations (grey dots) and capture sites (purple triangles) are plotted along with mine activity centers (red crosses) and 200-m concentric buffers (grey lines). RSF model predictions, which describe the relative probability of use, are color-coded based on the quantile distribution of RSF scores.

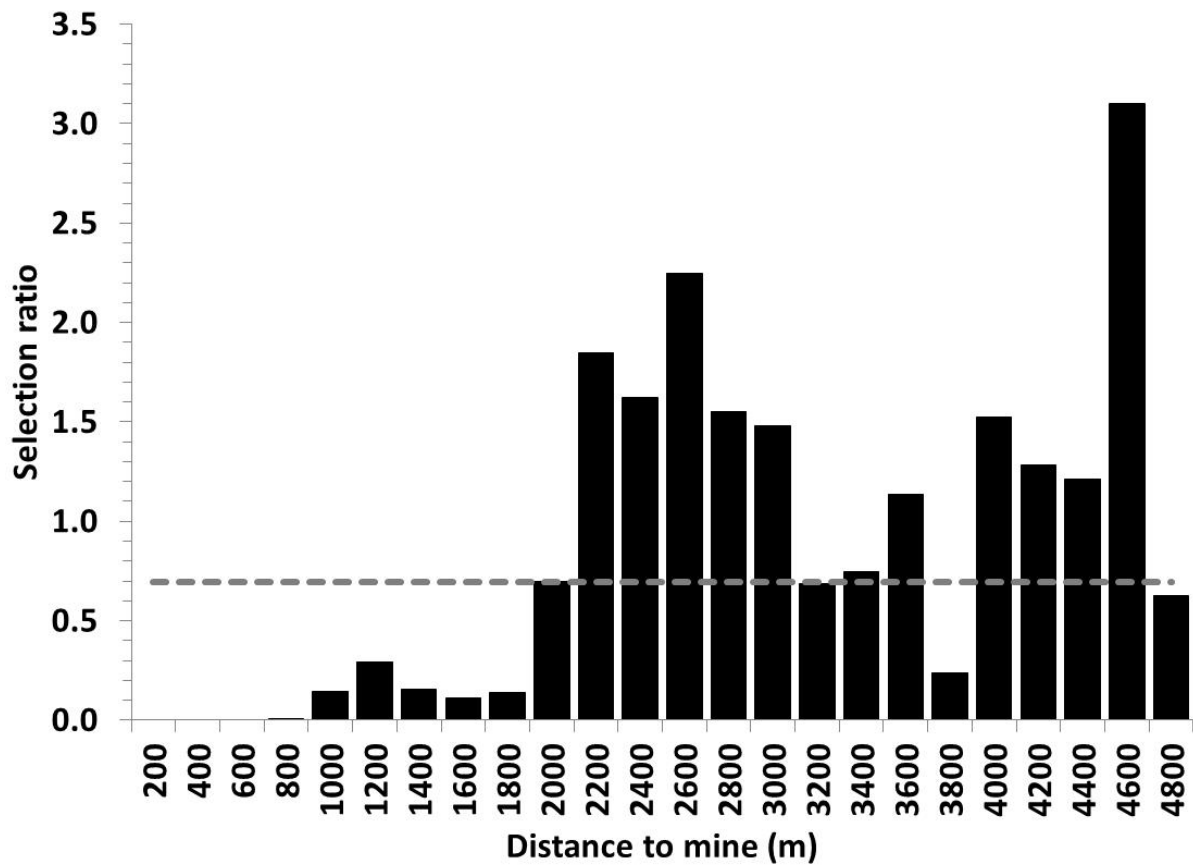


Figure 4a. The relationship between winter mountain goat selection (i.e. observed/expected use) and distance from the mine, calculated within concentric 200 m interval buffers radiating away from mine activity, Lynn Canal, Southeast Alaska.

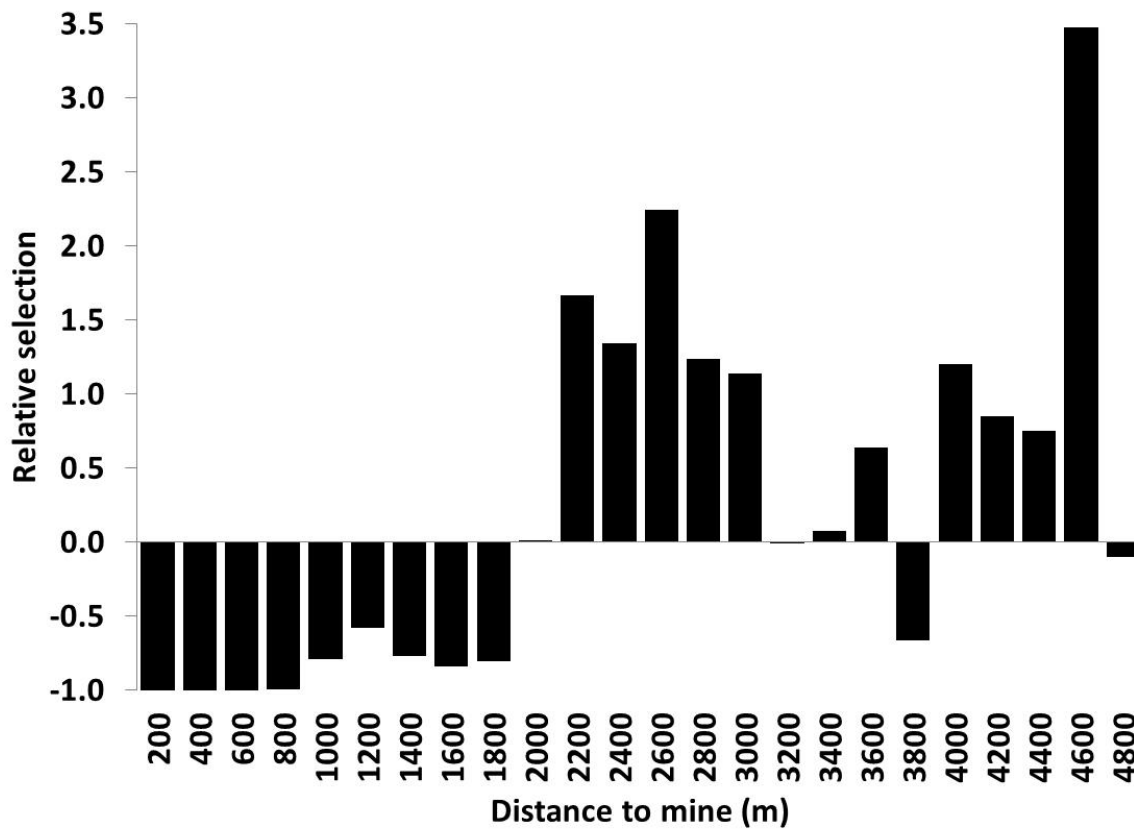


Figure 4b. The relationship between winter mountain goat selection (i.e. observed/expected use), relative to median selection (0.69) for the analysis extent, and distance from the mine, calculated within concentric 200-m interval buffers radiating away from mine activity, Lynn Canal, Southeast Alaska.

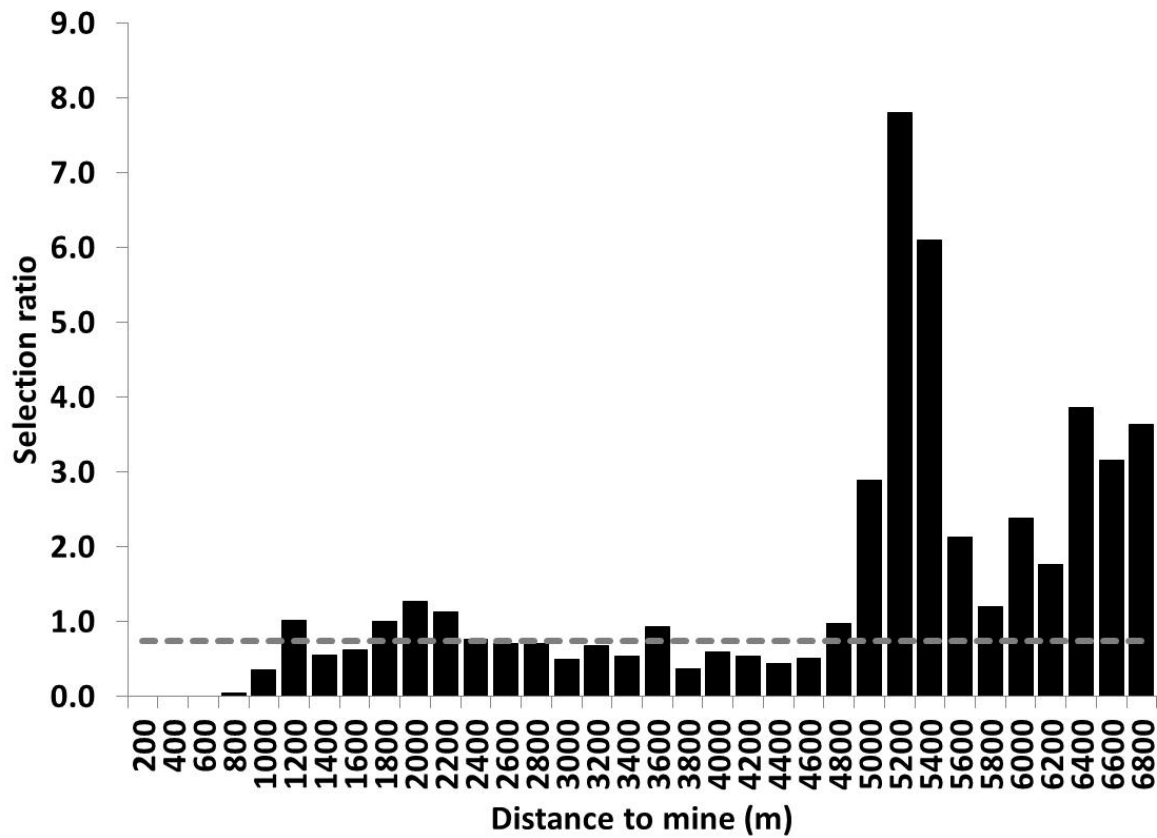


Figure 5a. The relationship between summer mountain goat selection (i.e. observed/expected use) and distance from the mine, calculated within concentric 200-m interval buffers radiating away from mine activity, Lynn Canal, Southeast Alaska.

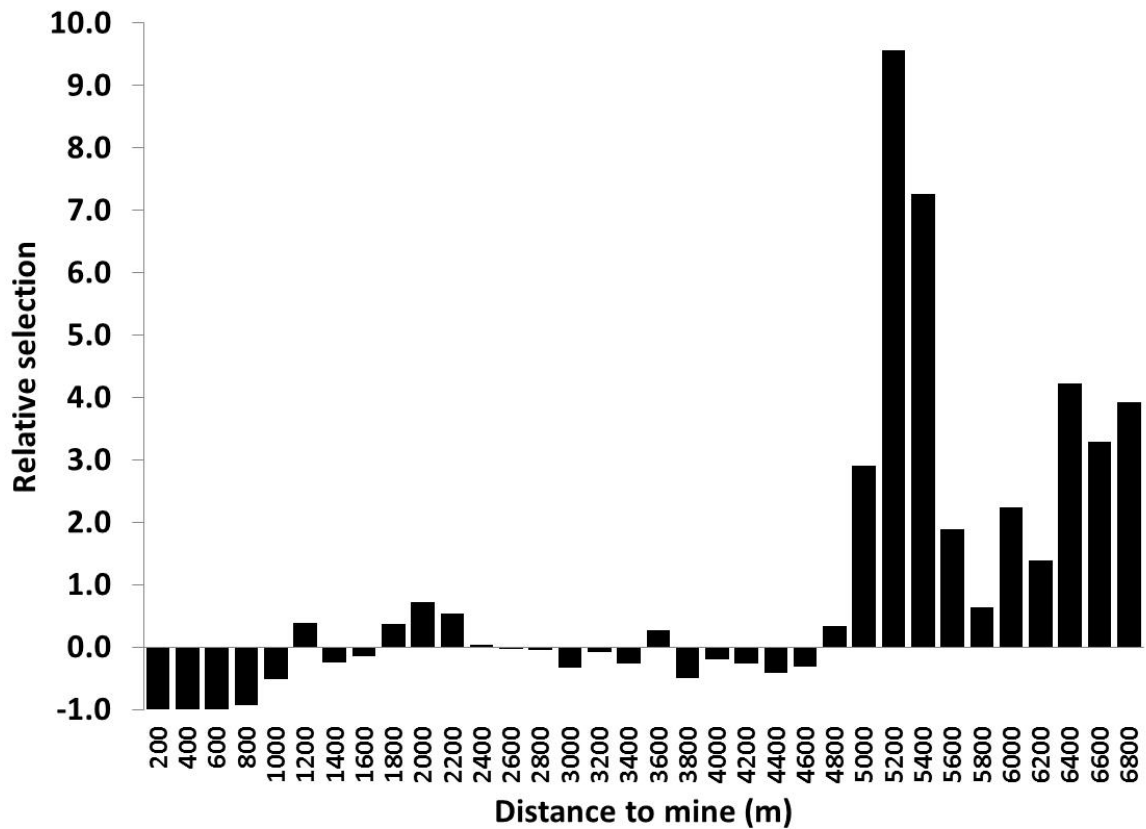


Figure 5b. The relationship between winter mountain goat selection (i.e. observed/expected use), relative to median selection (0.72) for the analysis extent, and distance from the mine, calculated within concentric 200-m interval buffers radiating away from mine activity, Lynn Canal, Southeast Alaska.

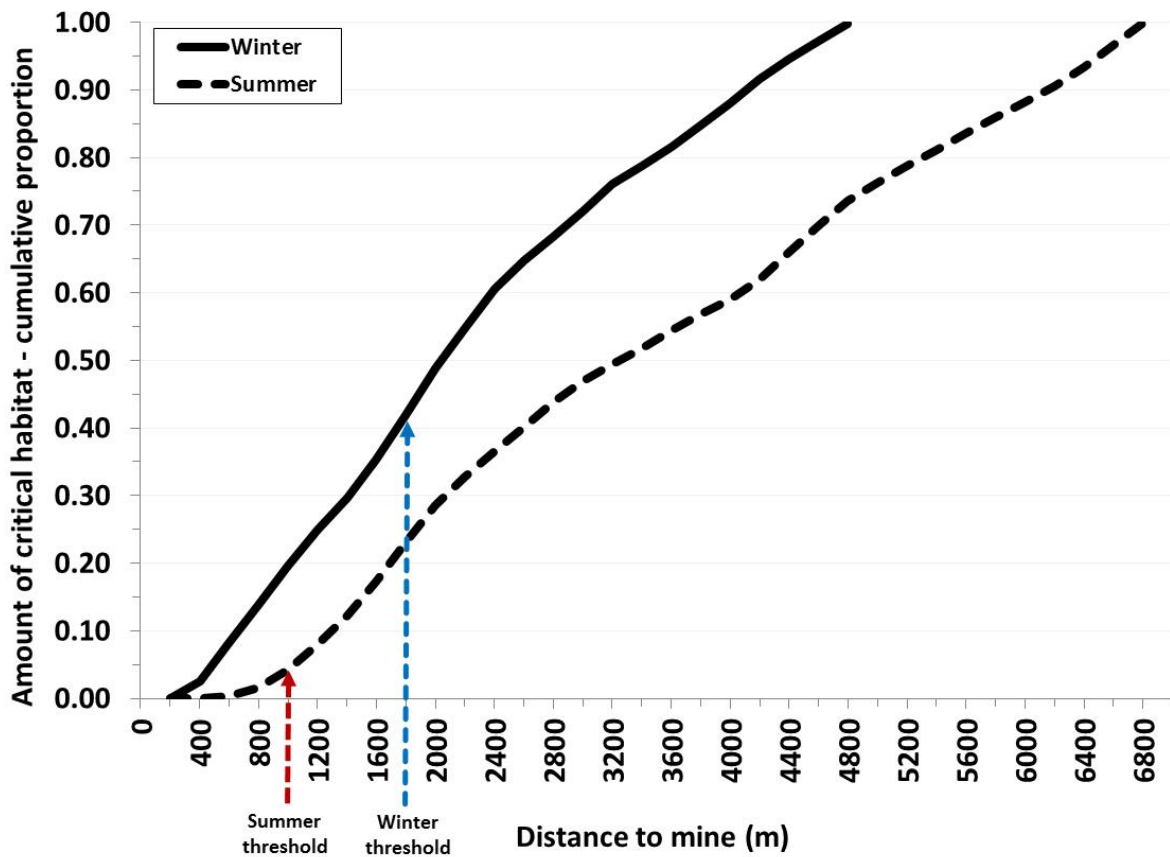


Figure 6. The relationship between cumulative proportion of winter and summer habitat, within 200-m buffers, and proximity to the Kensington Mine, Lynn Canal, Southeast Alaska. Summer and winter disturbance thresholds are depicted and based on observed vs expected use of predicted habitat.

winter habitat, and 45.7 ha of summer habitat was predicted at distances between 0–1,000 m from the mine.

In order to further examine mine effects on mountain goat habitat up to the 1,800 m mine distance threshold, buffer-specific selection ratios were multiplied by the amount of predicted critical habitat in each buffer to estimate the amount of habitat actually used and compared to the amount that was available. At distances between 0–1,800 m from the mine, 694.5 hectares of high value winter habitat was predicted yet only 0.4% (2.8 ha) of such habitats were actually used. For comparison, 642.6 ha of summer habitat were located within 1,800 m, of which 69.9% (449.7 ha) were used.

Discussion

MOUNTAIN GOAT RESOURCE SELECTION

Our analyses describe a strong affinity of mountain goats for areas with steep, rugged terrain in close proximity to cliffs, a pattern previously described for the species in southeastern Southeast Alaska (Fox et al. 1989, White et al. 2012a) and elsewhere (Festa-Bianchet and Cote 2008). In fact, terrain characteristics can be considered a key prerequisite for predicting mountain goat habitat, irrespective of season. However, during winter, mountain goat selection is further constrained to include lower elevation habitats that are typically vegetated with closed-canopy conifer forest. Such habitats have reduced snow depths (Kirchhoff and Schoen 1987) and thus greater forage availability (Fox 1983, White et al. 2009) and reduced costs of locomotion (Dailey and Hobbs 1989). Nonetheless, snow shedding characteristics of steep terrain also reduce snow depth resulting in use of non-forested habitats in some cases (particularly if sites are characterized by high solar radiation). In locations where steep terrain continuously extends from high elevation summer range to sea level, such as along Lynn Canal, mountain goats will winter at extremely low elevations, including on cliffs immediately above the high tide line.

Mountain goats selected more strongly for rugged terrain (high VRM) and distances closer to cliffs during winter, as compared to summer. The detection of these differences in resource selection patterns differs from an earlier RSF analyses conducted in this area (which did not detect seasonal differences in selection for VRM or distance to cliffs; White et al. 2012a). The primary difference between the two analyses relate to the resolution of the digital elevation model (DEM) used to develop the terrain variables used in RSF analyses. The White et al. (2012a) analyses used a 24 m pixel DEM (SRTM), whereas the current analysis used a substantially higher resolution 5 m pixel DEM (IfSAR). Thus, the higher resolution IfSAR DEM enabled detection of finer-scale patterns in selection than was possible with the coarser-grained SRTM DEM. Fine-scale seasonal variation in selection for habitat features associated with escape terrain suggest that the perceived risk of predation may be higher in winter than summer. Locomotory impedance caused by deep winter snow is likely to limit the ability of mountain goats to escape attacks by wolves and could exert strong selection pressure for enhanced use of rugged habitats near cliffs, even if food resources are less available in such micro-sites. Whereas during summer, mountain goats may be able to stray farther from rugged terrain and cliffs to

access a broader array of foraging sites and still avoid a net increase in predation-risk because they have increased mobility in snow-free conditions.

MINE PROXIMITY ANALYSES

Our analyses indicate that mining activity altered mountain goat behavior and, specifically, selection of predicted winter and, to a lesser extent, summer habitat. In particular, mountain goat selection of wintering habitats within 1,800 m of mining activity was substantially lower than expected. This finding is consistent with previous studies suggesting that mountain goats are sensitive to disturbance associated with helicopter overflights at distances up to 2,000 m (Cote 1996, Goldstein et al. 2005, Cote et al. 2013). While helicopter overflights represent one type of disturbance associated with mining activity in our study area other potential types of disturbance include blasting, heavy equipment, and mill site machinery operation. Because blasting and mechanized human travel have also been documented to alter mountain goat behavior and population dynamics (Joslin et al. 1986, St Louis et al. 2013), it is unclear what types of disturbance were most relevant to the observed patterns of habitat avoidance. As such, we concluded that the cumulative disturbance associated with mining activity is responsible for the observed pattern. In the future, detailed efforts to link temporal and site specific disturbance factors to mountain goat movement patterns and habitat selection could provide a more detailed understanding of the effects of different types of disturbance and associated distance thresholds. Other factors capable of influencing mountain goat habitat selection patterns such as predator abundance or snow climate are unlikely to explain the observed pattern. Snow depth is unlikely to vary at such a small geographic scale (i.e. within 2,000 m) and, due to “human shield” effects (sensu Berger 2007), predator activity is likely reduced in close proximity to mine and human activity.

Mountain goats appear to be less tolerant of using habitats within the 1,800 m distance threshold during winter than in summer (though summer habitat use was, on average, less than expected). Richard and Cote (2015) documented this pattern of increased aversion to habitats associated with human disturbance during winter, as compared to summer, in an Alberta mountain goat population. In that study, seasonal differences in mountain goat use of disturbed areas was largely attributed to corresponding differences in the amount of activity during winter vs. summer. However, in our study area mining activity does not exhibit a similar pattern of seasonal fluctuation. Instead, seasonal nutritional and energetic constraints are likely to be the key determinants of mountain goat response to mining activity in this study. During winter, mountain goats experience severe energetic and nutritional challenges associated with availability and quality of food resources and, perhaps more importantly, high costs of locomotion in deep snow (Fox 1983, Dailey and Hobbs 1989, Fox et al. 1989, White et al. 2009). Consequently, mountain goats exhibit an extremely conservative bioenergetic strategy during winter that is characterized by restricted movement (White 2006, Richard et al. 2014). Indeed, most mountain goat mortality occurs in late winter (White et al. 2011) and in our study area was most often associated with malnutrition (White et al. 2012b). Thus, mountain goats are expected

to be less tolerant of habitats prone to disturbance during winter than they are in summer, given the high costs of moving away from acute disturbances during winter.

The spatial distribution and relative abundance of mountain goat habitat relative to mine proximity has important implications for the carrying capacity of local populations. Because of the severe nutritional and energetic constraints that occur during winter, mountain goat populations are generally considered to be limited by availability of winter habitat (Fox et al. 1989). Further, because of the more strict winter habitat selection patterns, as compared to those in summer, mountain goat winter habitat is less abundant across a given landscape. In this study, winter habitat was 1.7 times less abundant than summer habitat. In addition, because available winter habitat occurs at lower elevation than summer habitat, it is closer to low elevation mining sites (Fig. 6). For example, the amount of habitat within 1,000 m of the mine is about 7.2 times higher for winter (327.6 ha) than for summer (45.7 ha). When referenced with the previously described season-specific mine disturbance threshold distances, 42% of the overall winter habitat available to mountain goats in our analyses area was within the 1,800 m winter disturbance threshold whereas only 1.6% of available summer habitat was within the 1,000 m summer disturbance threshold (Fig. 6). Consequently, by negatively influencing use of available wintering habitats in close proximity to the mine, mining activity has substantially reduced the functional winter range carrying capacity for the local mountain goat population.

Management Implications and Recommendations

Based on our analyses, industrial projects such as mining that involve blasting, heavy equipment operation and helicopter overflights should be situated at distances greater than 1,800 m from mountain goat winter habitat in order to avoid impacts on local mountain goat populations. However, given that mining activity is already occurring within 1,800 m of a significant portion (42%) of the available winter range in our study area it is important to closely monitor demographic and other effects on the locally affected population. Mountain goats that had access to areas within the disturbance distance thresholds also ranged as far as 4,800 m in winter and 6,800 m in summer from the mine site. Thus, the “disturbance shadow” extended a significant distance from the actual mining activities. Within this spatial extent we expect mining effects, such as the significant reduction of functional winter range carrying capacity, to have the most acute population level effects. However, it is also critical to monitor animals at distances far beyond the predicted range of disturbance effects in order to document baseline ecological conditions for comparison. And, perhaps more importantly, monitoring should occur both before and after disturbance.

In this study area, pre-development field data was collected during an earlier mine planning phase (1990–1994; Robus and Carney 1995) but, unfortunately, mine site developments shifted to a different watershed and the earlier data no longer represented a suitable pre-development baseline. During the current phase of development, pre-development baseline data collection opportunities were not available. Future project planning efforts should prioritize pre-development baseline data collection, to the extent possible.

In this study, total winter snowfall during 6 of the last 10 winters has been above average (National Weather Service, Juneau, Alaska). As a result, local and regional mountain goat populations have declined (White et al. 2012b). Yet, the extent to which functional reduction of winter range carrying capacity near the mine has exacerbated local population declines is unclear. Nonetheless, populations are currently expected to be below winter range carrying capacity. Given the predicted net reduction of functional winter range in proximity to the mine it will be critical to continue monitoring local populations to assess whether the rate of future demographic recovery is slowed by mining effects, relative to other nearby (but non-affected) areas.

There are other benefits to maintaining a long-term monitoring program. Continued collection of high-resolution mountain goat GPS location data is important to assess whether mountain goat use of wintering habitats within disturbance thresholds increases (i.e. habituation to mining disturbances) or decreases (i.e. sensitization) over time. Such data is also valuable for assessing whether currently affected wintering habitats are re-colonized once mining activity ceases. Long-term data collection also allows for expanded analytical opportunities such as investigating whether use patterns and disturbance thresholds differ for males vs. females or between mild vs. severe winters. For example, larger sample sizes could allow for statistical assessment of whether females are more strongly affected by disturbances, than males—a likely scenario given previous observations (i.e. Festa-Bianchet and Cote 2008). Finally, compilation of spatial and temporal records relating to mining activities can offer more detailed insights into what types of disturbance are most relevant and provide opportunities to understand habitat use-disturbance relationships in more detail. For example, examination of mountain goat movement responses to acute disturbances (*sensu* Cadsand 2012) could provide a deeper understanding of why mountain goat use of wintering habitats near the mine are not being used as expected.

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Appendices

Appendix A. Calculating expected use.

The expected proportion of mountain goat locations in a given buffer can be based on the amount of RSF volume in the buffer divided by the total. This relationship logically assumes that mountain goats should spend more time in buffers with higher quality habitat (i.e. high RSF volume), than in buffers with lower quality habitat. However, the distribution on mountain goat locations in any given buffer is also related to where mountain goats were captured and the animals' central tendency movement patterns. For example, the further a given animal was captured from the mine site the less of a chance it would have had to spend time in high quality habitat patches within buffers near the mine. Thus if a capture site location and central tendency movement patterns are not accounted for selection ratios might underestimate the actual use of buffers near the mine, particularly if capture sites are relatively far away from the mine sites.

To account for this possible bias, the expected proportion of mountain goat locations in a given buffer (i.e. based on RSF volume) was weighted based on the distance a given animals' capture site was from the mine and its associated central tendency movement distribution. Specifically, the distance from capture site was calculated for each GPS location collected for a given animal, and stratified by season. Exactly emulating the resulting individual-based distance to capture site frequency distribution, points with a random azimuth were then plotted (i.e. radiating in random directions from the capture site but simulating the central movement tendency and movement capabilities of a given animal). The distance to the mine was then calculated for each point. The procedure was conducted for each individual animal, by season. For each season, all animal locations were then pooled and assigned to each 200 m distance to mine buffer. The proportion of simulated locations in each buffer was then used to weight the expected proportion of locations in a given buffer (i.e. based on RSF volume). Thus the resulting expected proportion was weighted based on the RSF volume in a given buffer and the expected proportion of animal locations in the buffer based on the capture location, central movement tendency and number of locations each individual contributed to the data set. Use of this weighting procedure limited bias associated with spatial displacement of capture sites relative to the mine and resulted in a more conservative assessment of mine effects on mountain goat spatial use patterns. That is, the chance of performing a Type 1 error (i.e. incorrectly predicting an effect that does not exist) is lower using this method than would be the case if using non-weighted expected proportions of use.

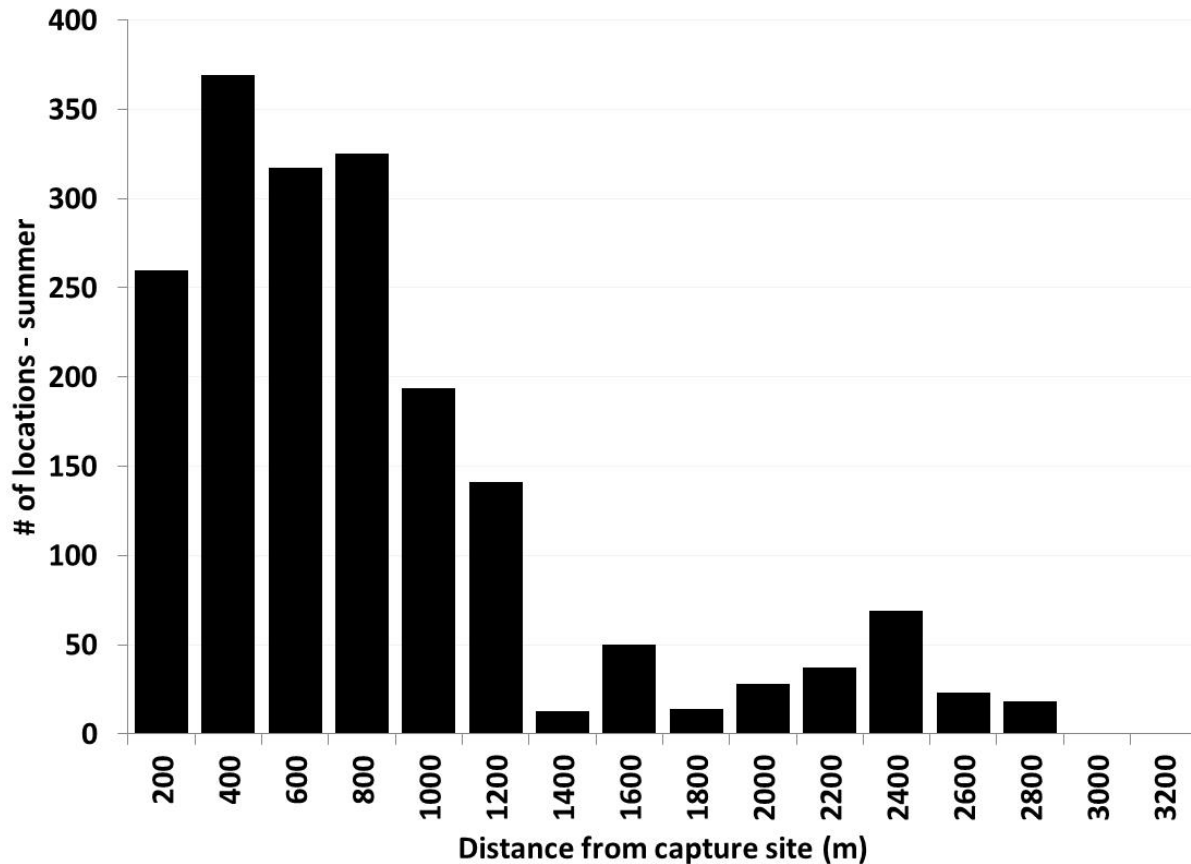


Figure 1. Example frequency distribution relating the number of GPS locations to the distance from the capture site for LG141 (adult male) during the summer season. LG141 was captured 1957 m from the mine site. To derive a theoretical distribution of LG141 relative to the mine, samples with a random azimuth were drawn from this “distance to capture site” distribution and coded based on distance to the mine. The resulting distribution reflects the locations LG141 could have visited in the analysis area as a function of its capture site location and movement tendencies.

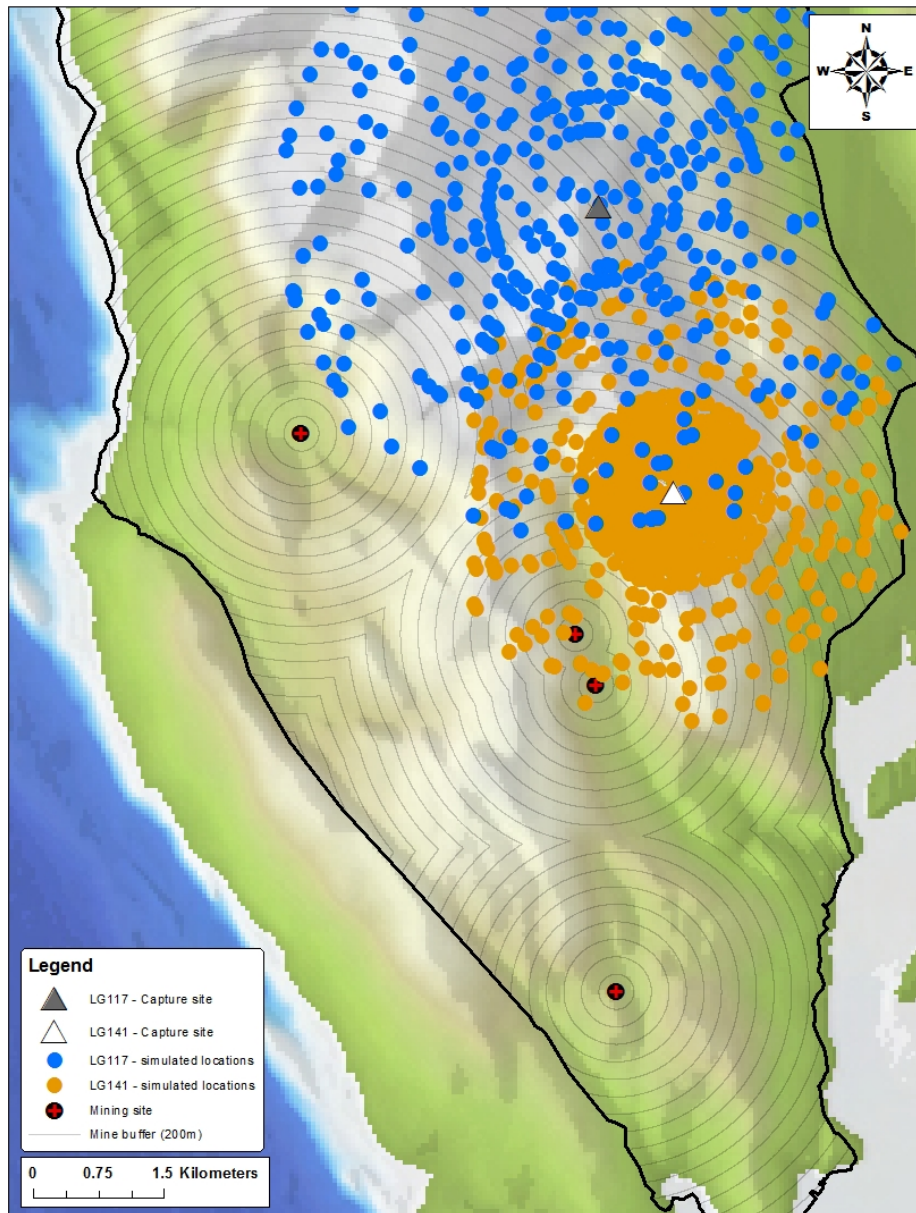


Figure 2. Map depicting simulated summer locations around capture sites for LG141 and LG117. Simulated locations are based on the frequency distribution of distances moved from capture site (i.e. Figure 1) and plotted based on random azimuth. The map illustrates how areas closer to capture locations would be weighted more heavily than areas further away (LG141). And, how individuals captured further away from the mine would be expected to have lower use of areas near the mine (i.e. LG117). The weighted expected proportion calculation (exp_w) takes into consideration animal capture location, central tendency movement patterns and the number of locations each individual contributed to the data set in order to enable an unbiased prediction of the number of locations that should be expected in a given area based on the RSF volume.

Appendix B. Summary statistics describing mountain goat winter resource selection characteristics in each 200 m interval mine proximity buffer, Lynn Canal, Southeast Alaska.

Buffer interval	Buffer area (ha)	No. of locations	Mean RSF	Exp _{RSF}	Exp _{sim}	Exp _w	Obs _{GPS}	Obs/exp	Relative selection
200	50.4	0	0.28 ⁻²	0.00	0.00	0.00	0.00	0.00	-1.00
400	145.1	0	3.48 ⁻²	0.03	0.01	0.01	0.00	0.00	-1.00
600	215.8	0	5.19 ⁻²	0.06	0.02	0.03	0.00	0.00	-1.00
800	290.2	1	2.80 ⁻²	0.05	0.02	0.03	0.00	0.00	-1.00
1000	364.1	76	1.68 ⁻²	0.03	0.04	0.03	0.00	0.14	-0.79
1200	420.5	172	1.33 ⁻²	0.03	0.05	0.04	0.01	0.29	-0.58
1400	479.9	133	1.24 ⁻²	0.03	0.07	0.05	0.01	0.16	-0.77
1600	539.8	102	1.30 ⁻²	0.04	0.07	0.06	0.01	0.11	-0.84
1800	596.8	149	1.31 ⁻²	0.04	0.07	0.07	0.01	0.14	-0.80
2000	598.4	914	1.63 ⁻²	0.06	0.07	0.08	0.06	0.70	0.01
2200	541.5	2001	1.56 ⁻²	0.05	0.06	0.07	0.13	1.85	1.67
2400	490.1	2531	2.83 ⁻²	0.08	0.06	0.10	0.16	1.62	1.34
2600	438.0	1943	1.96 ⁻²	0.05	0.05	0.06	0.13	2.25	2.25
2800	387.6	1569	2.55 ⁻²	0.06	0.05	0.07	0.10	1.55	1.24
3000	350.4	2104	4.01 ⁻²	0.08	0.05	0.09	0.14	1.48	1.14
3200	324.2	596	2.72 ⁻²	0.05	0.05	0.06	0.04	0.69	-0.01
3400	281.9	201	0.95 ⁻²	0.02	0.05	0.02	0.01	0.74	0.08
3600	250.4	184	0.68 ⁻²	0.01	0.05	0.01	0.01	1.14	0.64
3800	248.7	69	1.57 ⁻²	0.02	0.04	0.02	0.00	0.24	-0.66
4000	245.2	457	2.39 ⁻²	0.03	0.03	0.02	0.03	1.52	1.20
4200	228.9	872	5.65 ⁻²	0.07	0.03	0.04	0.06	1.28	0.85
4400	216.6	360	3.10 ⁻²	0.04	0.02	0.02	0.02	1.21	0.75
4600	217.8	838	2.89 ⁻²	0.04	0.02	0.02	0.05	3.10	3.48
4800	222.9	114	2.11 ⁻²	0.03	0.02	0.01	0.01	0.62	-0.10

Definitions: Buffer interval = maximum distance to the mine for each concentric 200-m buffer;
of locations = number of mountain goat GPS locations within a given buffer;
Mean RSF = mean RSF value (5-m² pixel size) within a given buffer;
exp_{RSF} = expected proportion of use based on RSF volume within a given buffer;
exp_{sim} = expected proportion of use based on simulated locations radiating from capture site;
exp_w = weighted expected proportion of use based on exp_{RSF} and exp_{sim};
obs_{GPS} = proportion of GPS locations within a given buffer
obs/exp = obs_{GPS}/exp_w; relative selection = selection ratio (obs/exp) for a given buffer relative to the median selection ratio (0.69) for the total extent.

Appendix C. Summary statistics describing mountain goat summer resource selection characteristics in each 200 m interval mine proximity buffer, Lynn Canal, Southeast Alaska.

Buffer interval	Buffer area (ha)	# of locations	Mean RSF	exp _{RSF}	exp _{sim}	exp _w	obs _{GPS}	obs/exp	Relative selection
200	50.4	0	0.00	0.00	0.00	0.00	0.00	0.00	-1.00
400	145.1	0	0.01	0.00	0.01	0.00	0.00	0.00	-1.00
600	215.8	0	0.09	0.00	0.01	0.00	0.00	0.00	-1.00
800	290.2	2	0.29	0.01	0.01	0.00	0.00	0.05	-0.93
1000	364.1	42	0.54	0.02	0.02	0.01	0.00	0.35	-0.52
1200	420.5	334	1.01	0.04	0.02	0.02	0.02	1.02	0.39
1400	479.9	449	1.34	0.05	0.04	0.05	0.03	0.55	-0.26
1600	539.8	736	1.39	0.06	0.05	0.08	0.05	0.62	-0.15
1800	596.8	1528	1.13	0.06	0.07	0.10	0.10	1.01	0.37
2000	598.4	2455	1.22	0.06	0.08	0.13	0.16	1.27	0.73
2200	541.5	2169	1.31	0.06	0.08	0.13	0.15	1.13	0.54
2400	490.1	1010	1.24	0.05	0.07	0.09	0.07	0.77	0.04
2600	438.0	850	1.19	0.04	0.07	0.08	0.06	0.71	-0.04
2800	387.6	698	1.18	0.04	0.07	0.07	0.05	0.71	-0.04
3000	350.4	279	1.02	0.03	0.05	0.04	0.02	0.49	-0.33
3200	324.2	276	0.86	0.02	0.05	0.03	0.02	0.68	-0.08
3400	281.9	173	0.88	0.02	0.04	0.02	0.01	0.54	-0.26
3600	250.4	248	0.98	0.02	0.03	0.02	0.02	0.94	0.27
3800	248.7	67	0.81	0.02	0.03	0.01	0.00	0.37	-0.50
4000	245.2	88	0.84	0.02	0.02	0.01	0.01	0.59	-0.20
4200	228.9	88	1.22	0.02	0.02	0.01	0.01	0.54	-0.27
4400	216.6	112	2.16	0.04	0.02	0.02	0.01	0.44	-0.41
4600	217.8	121	2.47	0.05	0.01	0.02	0.01	0.51	-0.31
4800	222.9	171	1.68	0.03	0.01	0.01	0.01	0.98	0.33
5000	227.8	278	1.02	0.02	0.01	0.01	0.02	2.89	2.91
5200	208.9	682	1.27	0.02	0.01	0.01	0.05	7.80	9.56
5400	201.2	471	1.34	0.02	0.01	0.01	0.03	6.10	7.26
5600	197.8	190	1.75	0.03	0.01	0.01	0.01	2.13	1.88
5800	197.7	119	1.59	0.03	0.01	0.01	0.01	1.21	0.64
6000	198.7	154	1.17	0.02	0.01	0.00	0.01	2.39	2.24
6200	197.6	116	1.35	0.02	0.01	0.00	0.01	1.76	1.39
6400	196.3	335	1.52	0.03	0.01	0.01	0.02	3.86	4.22
6600	194.5	248	1.48	0.02	0.01	0.01	0.02	3.16	3.28
6800	195.8	421	1.61	0.03	0.01	0.01	0.03	3.64	3.92

Definitions: Buffer interval = maximum distance to the mine for each concentric 200-m buffer;

of locations = number of mountain goat GPS locations within a given buffer;

Mean RSF = mean RSF value (5-m² pixel size) within a given buffer;

exp_{RSF} = expected proportion of use based on RSF volume within a given buffer;

exp_{sim} = expected proportion of use based on simulated locations radiating from capture site;

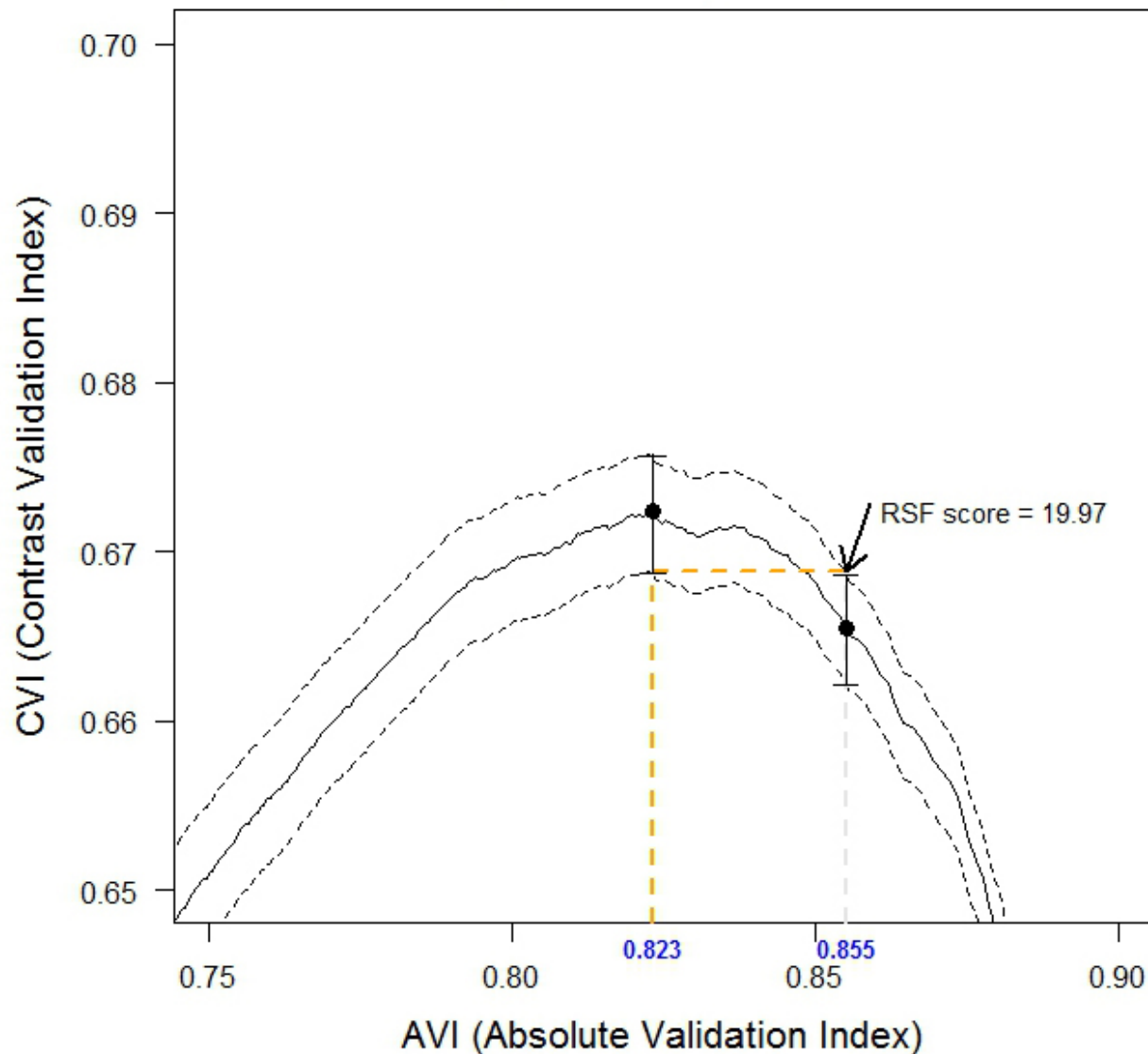
exp_w = weighted expected proportion of use based on exp_{RSF} and exp_{sim};

obs_{GPS} = proportion of GPS locations within a given buffer obs/exp = obs_{GPS}/exp_w;

relative selection = selection ratio (obs/exp) for a given buffer relative to the median selection ratio (0.74) for the total extent

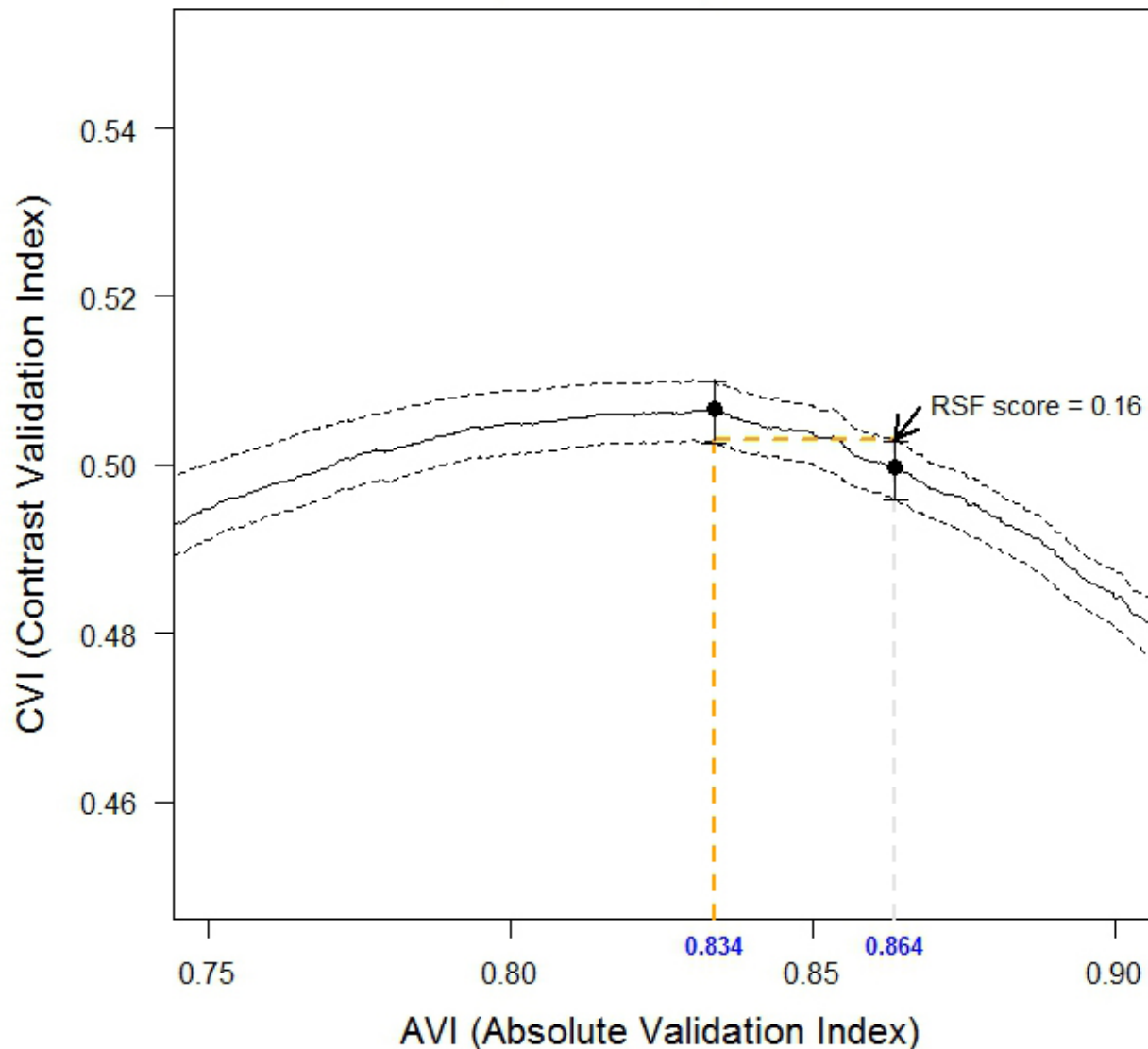
Appendix D. Graphical depiction of the relationship between CVI and AVI used to determine the RSF value cut-point for delineating mountain goat winter habitat.

AVI represents the proportion of GPS locations encompassed at a given CVI value. The analyses indicated that 85.5% of GPS locations were encompassed with areas of the RSF surface coded with values greater than 19.97. Methods used are described by Fedy et al. (2014).



Appendix E. Graphical depiction of the relationship between CVI and AVI used to determine the RSF value cut-point for delineating mountain goat summer habitat.

AVI represents the proportion of GPS locations encompassed at a given CVI value. The analyses indicated that 86.4% of GPS locations were encompassed with areas of the RSF surface coded with values greater than 0.16. Methods used are described by Fedy et al. (2014).



Appendix F. Summary statistics describing the amount of mountain goat critical habitat and mean RSF score in concentric 200-m interval buffers around the mine, Lynn Canal, Southeast Alaska.

Buffer interval	Buffer area (ha)	Summer			Winter		
		Critical habitat (ha)	Critical habitat (cumulative prop.)	Mean RSF score	Critical habitat (ha)	Critical habitat (cumulative prop.)	Mean RSF score
200	50	0	0.00	0.00	3	0.00	0.28 ⁻²
400	145	0	0.00	0.01	43	0.03	3.48 ⁻²
600	216	8	0.00	0.09	91	0.08	5.19 ⁻²
800	290	37	0.02	0.29	93	0.14	2.80 ⁻²
1000	364	74	0.04	0.54	97	0.20	1.68 ⁻²
1200	421	104	0.08	1.01	87	0.25	1.33 ⁻²
1400	480	117	0.12	1.34	80	0.30	1.24 ⁻²
1600	540	141	0.17	1.39	93	0.35	1.30 ⁻²
1800	597	161	0.23	1.13	108	0.42	1.31 ⁻²
2000	598	150	0.29	1.22	114	0.49	1.63 ⁻²
2200	542	119	0.33	1.31	101	0.55	1.56 ⁻²
2400	490	104	0.37	1.24	94	0.61	2.83 ⁻²
2600	438	99	0.40	1.19	69	0.65	1.96 ⁻²
2800	388	102	0.44	1.18	59	0.68	2.55 ⁻²
3000	350	88	0.47	1.02	62	0.72	4.01 ⁻²
3200	324	70	0.49	0.86	66	0.76	2.72 ⁻²
3400	282	66	0.52	0.88	45	0.79	0.95 ⁻²
3600	250	70	0.54	0.98	46	0.82	0.68 ⁻²
3800	249	67	0.57	0.81	53	0.85	1.57 ⁻²
4000	245	62	0.59	0.84	55	0.88	2.39 ⁻²
4200	229	83	0.62	1.22	60	0.92	5.65 ⁻²
4400	217	111	0.66	2.16	47	0.95	3.10 ⁻²
4600	218	109	0.70	2.47	44	0.97	2.89 ⁻²
4800	223	102	0.74	1.68	42	1.00	2.11 ⁻²
5000	228	75	0.76	1.02	--	--	--
5200	209	69	0.79	1.27	--	--	--
5400	201	67	0.81	1.34	--	--	--
5600	198	69	0.84	1.75	--	--	--
5800	198	65	0.86	1.59	--	--	--
6000	199	61	0.88	1.17	--	--	--
6200	198	63	0.90	1.35	--	--	--
6400	196	79	0.93	1.52	--	--	--
6600	195	93	0.97	1.48	--	--	--
6800	196	93	1.00	1.61	--	--	--

