Wildlife Research Report ADF&G/DWC/WRR–2018–2

Mountain Goat Resource Selection in the Haines–Skagway Area: Implications for Helicopter Skiing Management

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April 2018

Alaska Department of Fish and Game Division of Wildlife Conservation

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Kevin S. White

Dave Gregovich

Division of Wildlife Conservation
Alaska Department of Fish and Game
802 3rd Street
Douglas, Alaska 99824

Alaska Department of Fish and Game
Division of Wildlife Conservation
P. O. Box 115526
Juneau, Alaska 99811

Funding for this research was provided by the Pittman–Robertson Federal Aid in Wildlife Restoration Act (AKW-10 Project 12.01), State of Alaska Fish and Game funds, and the Bureau of Land Management. Hunters are important founders of the modern wildlife conservation movement. They, along with trappers and sport shooters, provided funding for this publication through payment of federal taxes on firearms, ammunition, and archery equipment, and through state hunting license and tag fees.

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This Wildlife Research Report was reviewed and approved for publication by Susannah Woodruff, Research Coordination for Region I, Division of Wildlife Conservation.

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This document should be cited as:

White, K. S., and D. Gregovich. 2018. Mountain goat resource selection in the Haines–Skagway area: Implications for helicopter skiing management. Alaska Department of Fish and Game, Wildlife Research Report ADF&G/DWC/WRR-2018-2 Juneau.

Cover Photo: Mountain goats in tree line wintering habitat, Takshanuk Ridge. ©2018 ADF&G. Photo by Kevin White (via remote camera).

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Abstract

Environmental variation plays an important role in influencing resource selection of wildlife and, by extension, design of wildlife conservation strategies. In northern ecosystems, snow influences distribution of mountain ungulates, resulting in variation in distribution and elevational wintering strategies. For species such as mountain goats (*Oreamnos americanus*) that are particularly sensitive to human and industrial disturbance, spatial delineation of critical habitat is needed to inform land and wildlife management decisions. We combined mountain goat GPS location (mountain goats, n = 64; GPS locations, n = 114,674) and remote sensing data in a GIS framework in order to develop resource selection function (RSF) models. Specifically, we developed seasonal- and wintering strategy-specific RSF models to delineate critical mountain goat habitat and inform helicopter tourism-based land management analyses and decision making. Our 3,620 km^2 study area, located near Haines and Skagway, Alaska, was characterized by a transitional coastal-interior climate. We identified 3 distinct elevational wintering strategies used by mountain goats—low/forest, medium/tree line and high/alpine—that broadly tracked the coastal to interior gradient. Low elevation wintering was more common near the coast, whereas high elevation wintering was more common in the interior. Aside from elevational differences, mountain goat resource selection patterns were similar throughout the study area with respect to season and wintering strategy such that animals selected steep, rugged areas in close proximity to cliffs. For each of 9 discrete geographic localities within our study area we determined the predominant wintering strategy or strategies used and delineated habitat based on the appropriate model or models. The resulting winter habitat delineations were used to determine that, depending on the area, 11% to 62% of existing mountain goat habitat was located within areas approved for helicopter skiing. Variation in mountain goat habitat and ski area overlap is partially related to whether mountain goats utilize low versus higher elevation wintering habitats, and also to the proportion of a given area allocated to helicopter skiing. Ultimately, we demonstrate how statistically rigorous RSF models based on extensive mountain goat GPS location and remote sensing data can be used in combination with information about human uses to parameterize socio-ecological trade-offs associated with making controversial land management decisions.

Key words: Alaska, helicopter skiing, mountain goat, *Oreamnos americanus*, resource selection function, snow.

Introduction

Environmental variation plays an important role in influencing resource selection of wildlife and, by extension, design of wildlife conservation strategies. In high latitude environments the distribution, depth, and density of snow is often the most important abiotic driver of population dynamics, particularly for ungulates. In the case of mountain ungulates, such as mountain goats and sheep, snow influences forage availability (Fox 1983, White et al. 2009), energetic costs of locomotion (Dailey and Hobbs 1989), distribution (Lowrey et al. 2017), survival (White et al. 2011), and ultimately population demography (White et al. 2017).

Consequently, such species exhibit diverse strategies to cope with the challenges associated with living in snowy environments, such as reducing daily movement and activity patterns (White 2006, Richard et al. 2014), constricting home range sizes (Lovari et al. 2006, Poole et al. 2009, Richard et al. 2014), and conducting seasonal migrations to confined areas or habitats with reduced snow (Fox et al. 1989, Poole et al. 2009). In some cases, snow exerts significant selective pressure and can lead to development of behavioral ecotypes, as is the case for mountain goats that winter at high or low elevations in response to local snow climates (Herbert and Turnbull 1977). Nonetheless, the effects of snow can usually be only partially mitigated and northern ungulates are typically in a negative energy balance during winter (Mautz 1978, Parker et al. 2009). From a wildlife conservation perspective, identifying and protecting areas used during the critical winter season are necessary for promoting population productivity and sustainability, particularly in areas where anthropogenic impacts are significant.

Among North American large mammal species, mountain goats are particularly sensitive to human disturbance (Côté 1996). Mountain goats exhibit heightened sensitivity to aerial disturbance such as helicopters and fixed-wing aircraft (Foster and Rahs 1983, Côté 1996, Goldstein et al. 2005, Cadsand 2012, Côté et al. 2013). This heightened sensitivity may have arisen as an adaptation to predation risk occurring from aerial predators such as golden eagles (Hamel and Côté 2009). Indeed, Frid and Dill (2002) have described human disturbance as a form of predation risk that can lead to deleterious individual and population level effects. Disturbance responses have been documented in previous studies and involve reduction of foraging behavior and assimilation of nutritional resources, increase in movement rates and energetic expenditure, and spatial displacement from critical habitats (Foster and Rahs 1983, Côté 1996, Goldstein et al. 2005, Cadsand 2012, Côté et al. 2013, Richard and Côté 2015, White and Gregovich 2017). Ultimately, such responses are expected to result in negative effects on population demography (i.e., decreased reproduction and recruitment), as documented by Joslin (1986). As such, identification and mitigation of human-caused aerial disturbance has been identified as an important conservation concern for the species throughout its range in western North America (Hurley 2004).

Helicopter supported recreational tourism has emerged in many places of North America as a significant form of industrial scale disturbance in otherwise remote and undeveloped landscapes (Hurley 2004). For example, the Juneau Icefield, a world class tourism destination located in Southeast Alaska, receives more than 20,000 summer helicopter landings annually (Jessica Schalkowski, U.S. Forest Service [USFS], Juneau, AK, personal communication). Thus, the exposure of wildlife species to human disturbance in such settings can be significant. However, the character of disturbance and the ability to mitigate it through policy depend on the context of tourism activities. For example, helicopter overflight activities that follow predictable routes to a few designated low-impact landing sites can be readily mitigated using wildlife habitat buffer distance guidelines and timing windows (sensu Hurley 2004). Other types of helicopter supported recreation, such as helicopter skiing, are logistically complex and require many more routes, and landing spots; such operations are unpredictable, because they depend on weather conditions, and make spatially extensive use of landscapes between landing sites. Helicopter skiing also involves the additive negative effects of actual skiing activities, which can result in additional disturbance and habitat displacement (Neumann et al. 2010, Courtemanch 2014). Consequently, regulation and management of helicopter tourism in order to mitigate disturbance of wildlife species is a complicated conservation problem that requires context and site-specific prescriptions. In this regard, acquisition of empirical knowledge about wildlife species' ecological requirements and responses is critical for devising data-based solutions to land management challenges. Such information is crucial for parameterizing the cost-benefit trade-offs that occur in oftentimes emotionally charged and controversial socio-economic settings.

In this study we used an extensive mountain goat Global Positioning System (GPS) location data set combined with remote sensing data in a geographic information system (GIS) framework to develop resource selection function (RSF) models in order to characterize mountain goat resource selection patterns during winter and summer. Because mountain goats exhibit unique morphological adaptations for living in steep, rugged terrain, we predicted that a suite of landscape features associated with steep and rugged terrain would be critical determinants of mountain goat distribution during all seasons. However, we also predicted that during winter mountain goat distribution would be variable and track coastal-interior snow climate gradients. Specifically, we predicted that animals near the coast would winter at low elevation whereas those in colder, drier interior sites would winter at high elevation. Ultimately, our goal was to integrate knowledge about spatial variation in wintering strategies and develop site-specific RSF models in order to map mountain goat winter habitat and inform conservation decisions associated with regulating helicopter skiing.

Study Area and Methods

STUDY AREA

Mountain goats were studied in a 3,620 km^2 area located in a mainland coastal mountain range located in the vicinity of the small, rural communities of Klukwan, Haines, and Skagway, Alaska (Fig. 1; Haines–Skagway). The configuration of the study area was intended to enable collection of field data across a representative array of habitat complexes inhabited by mountain goats during both summer and winter. The area is largely undeveloped, yet industrial disturbance activities associated with timber harvest, mining, and helicopter tourism currently and historically have impacted certain areas. Both summer and winter helicopter tourism occurs in the study area; however, activities are temporally and spatially segregated. For example, summer tourism is based out of Skagway and primarily involves flightseeing and landings at a few designated sites. Permitted annual summer landings varied from 100 to 4,100 between 1993 and 2017, but have declined significantly since 2010 as helicopter tourism operators have shifted to nearby USFS lands (Jesse Hankins, Bureau of Land Management (BLM), Glennallen, Alaska, personal communication).

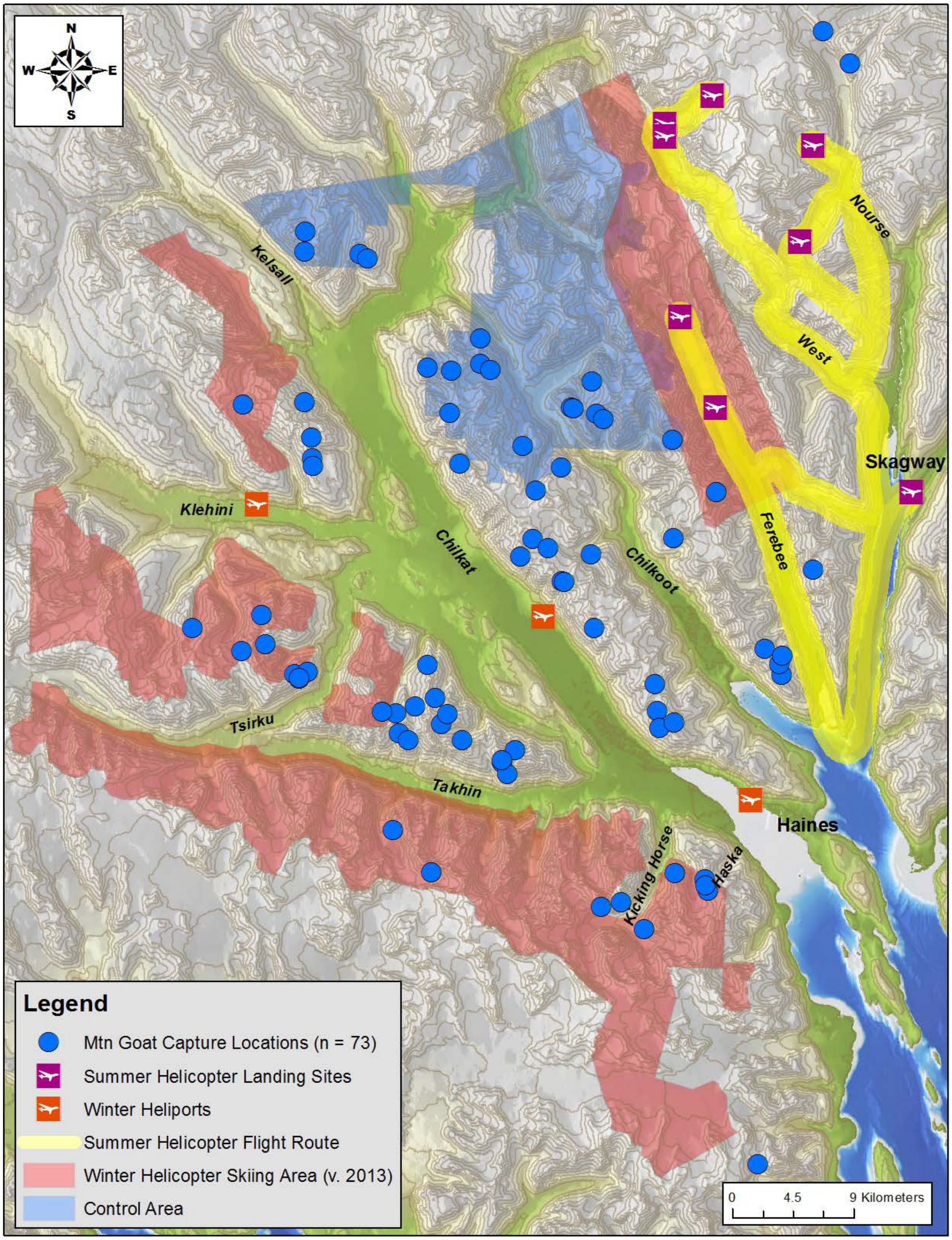

Figure 1. Map illustrating the study area, mountain goat capture locations, and summer and winter tourism management zones where mountain goat resource selection was studied during 2010–2016 in the Haines–Skagway area, Alaska.

Winter helicopter tourism, on the other hand, consists of helicopter skiing and is based out of Haines and the upper Chilkat Valley.

Helicopter skiing occurs across a broad geographic area (948 km^2) and involves helicopter landings and skiing across an extensive array of undesignated sites. The land ownership mosaic is diverse and consists of land managed by federal, state, borough, Alaska Native, and non-Native private interests. Depending on the location, helicopter landings and skiing are managed and permitted by the Bureau of Land Management (BLM, federal land) and by the Haines Borough (state land). During 2017, approximately 2,600 skier days were permitted on lands managed by the Haines Borough (Alekka Fullerton, Haines Borough, Haines, Alaska, personal communication) and 300 landings were permitted on BLM lands in the Chilkat and Ferebee river valleys (Jesse Hankins, BLM, Glennallen, AK, personal communication).

The area is characterized by a transitional coastal-interior climate and experiences cool, wet summers and moderately snowy winters at sea level. Total annual rainfall in Haines averages 1.6 m and winter temperatures are rarely less than -15°C and average -1°C (Haines, Alaska; National Weather Service, Juneau, Alaska). Total annual snowfall at sea level in Haines averages 4.7 m whereas the Haines Customs station (elevation = 260 m) typically receives 6.2 m of snowfall. Predominant vegetative communities occurring at low and moderate elevations (<460 m) include Sitka spruce (*Picea sitchensis*) and 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 m. 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. Large mammals inhabiting the area include mountain goats (1,000–1,500; White et al. 2014), moose, brown and black bears, wolves, coyotes, and wolverines.

STUDY APPROACH

Mountain goat GPS location data were collected from individual animals and integrated with remote sensing data to develop season-specific RSF models. Since animals exhibited variation in elevational distribution during winter, clustering analyses were used to identify whether discrete elevation-based wintering strategies existed. Individuals were then assigned to a given wintering strategy, based on average winter range elevation. Wintering strategy-specific RSF models were then derived using GPS location data for all animals who used each specific wintering strategy. Predominant wintering strategies were identified and mapped for each of 9 discrete geographic zones within the study area. In cases where multiple wintering strategies were used in a given area resulting habitat maps were a mosaic of multiple RSF models. Spatial relationships between delineated mountain goat winter habitat and helicopter skiing zones approved by the Haines Borough were then quantified using GIS to demonstrate the efficacy of the approach for land management decision-making.

Mountain Goat Capture

Mountain goats were captured using standard helicopter darting techniques and immobilized by injecting 2.4–3.0 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 (White et al. 2014). Following handling, 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. 2012). The Alaska Department of Fish and Game, Division of Wildlife Conservation Institutional Animal Care and Use Committee approved all capture procedures.

GPS Data

Telonics TGW-3590 and TGW-4590 GPS radio collars (1.4 kg; Telonics, Inc., Mesa, AZ) were deployed on all 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 or mortality. Location data were post-processed and filtered to remove geographically "impossible" points and two-dimensional (2D) locations with PDOP (position dilution of precision) values greater than 10, following D'Eon et al. (2002) and D'Eon and Delparte (2005).

RSF Model Development

RSF models (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 (following White and Gregovich 2017). In addition, since our study area occurs in a transitional coastal-interior snow climate and mountain goats were expected to exhibit variation in elevational distribution during winter (sensu Herbert and Turnbull 1977) we also developed separate wintering strategy-specific RSF models. Our approach for identifying, and ultimately modeling, different wintering strategies involved implementing k-means clustering analysis (based on average winter altitude by individual mountain goat and year) to determine the number of elevation-based wintering strategies. This analysis resulted in identification of 3 distinct elevational wintering strategies used by mountain goats—low, medium, and high (Figs. 2 and 3). GPS location data for each individual animal were then coded based on wintering strategy and used to develop wintering strategy-specific RSF models.

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" versus "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 km^2, a density determined to reliably describe resource availability patterns in our study area based on simulation analyses (sensu Northrup et al. 2013). The study area was geographically defined based on seasonal and annual movement distances and spatial deployment of GPS radio collars such that each pixel in the study area could have been encountered and selected by mountain goats. 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). Vegetative covariates were not used, because 1) existing land cover maps did not have adequate resolution and accuracy, and 2) the terrain variables considered previously enabled development of highly predictive RSF models (White and Gregovich 2017). Correlations between all covariate combinations ($r > 0.6$) were examined and only covariates that were not correlated were used in the model. These data were then analyzed using logistic regression (GLM function, stats package, ver. 2.13.1, R Development Core Team 2017) 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.

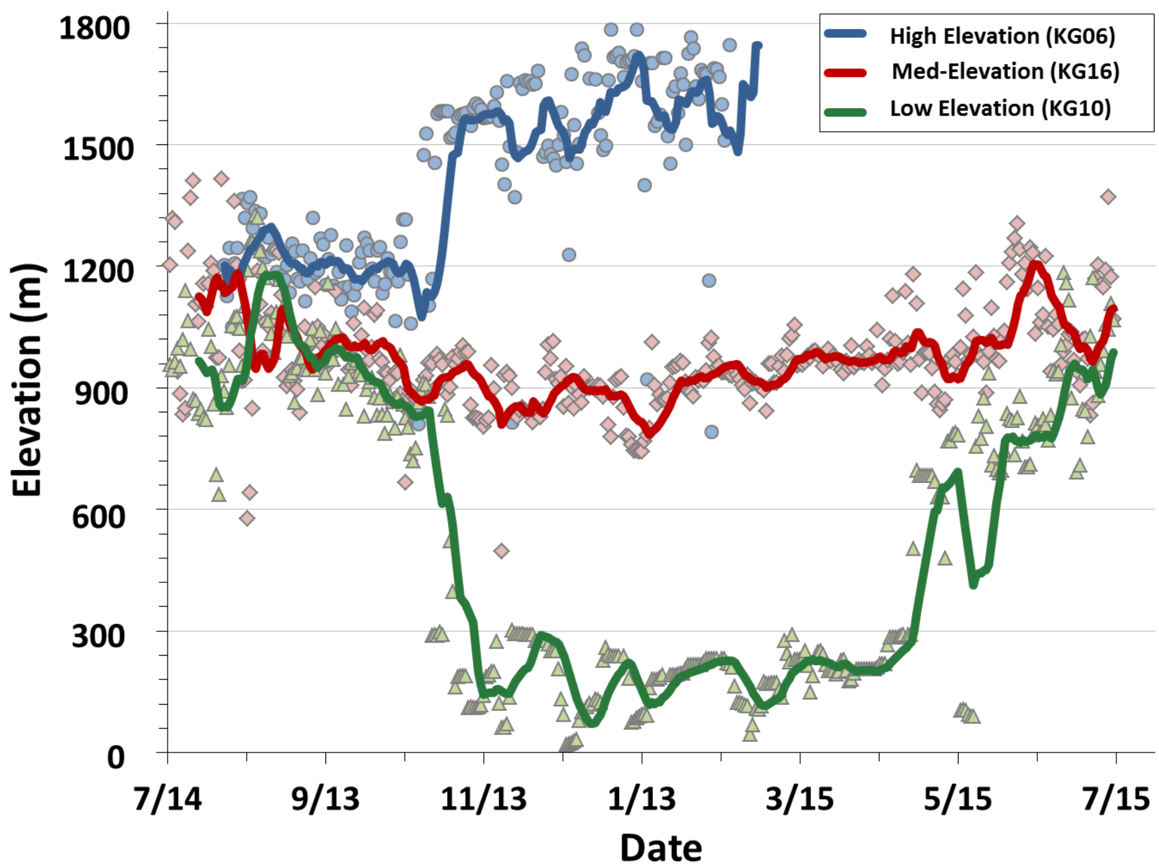

Figure 2. Seasonal variation in mountain goat elevational distribution, Haines–Skagway, Alaska. GPS location data are plotted over a biological year for 3 individual radiocollared mountain goats (KG06, KG16, and KG10), illustrating the different wintering strategies used by mountain goats during the study.

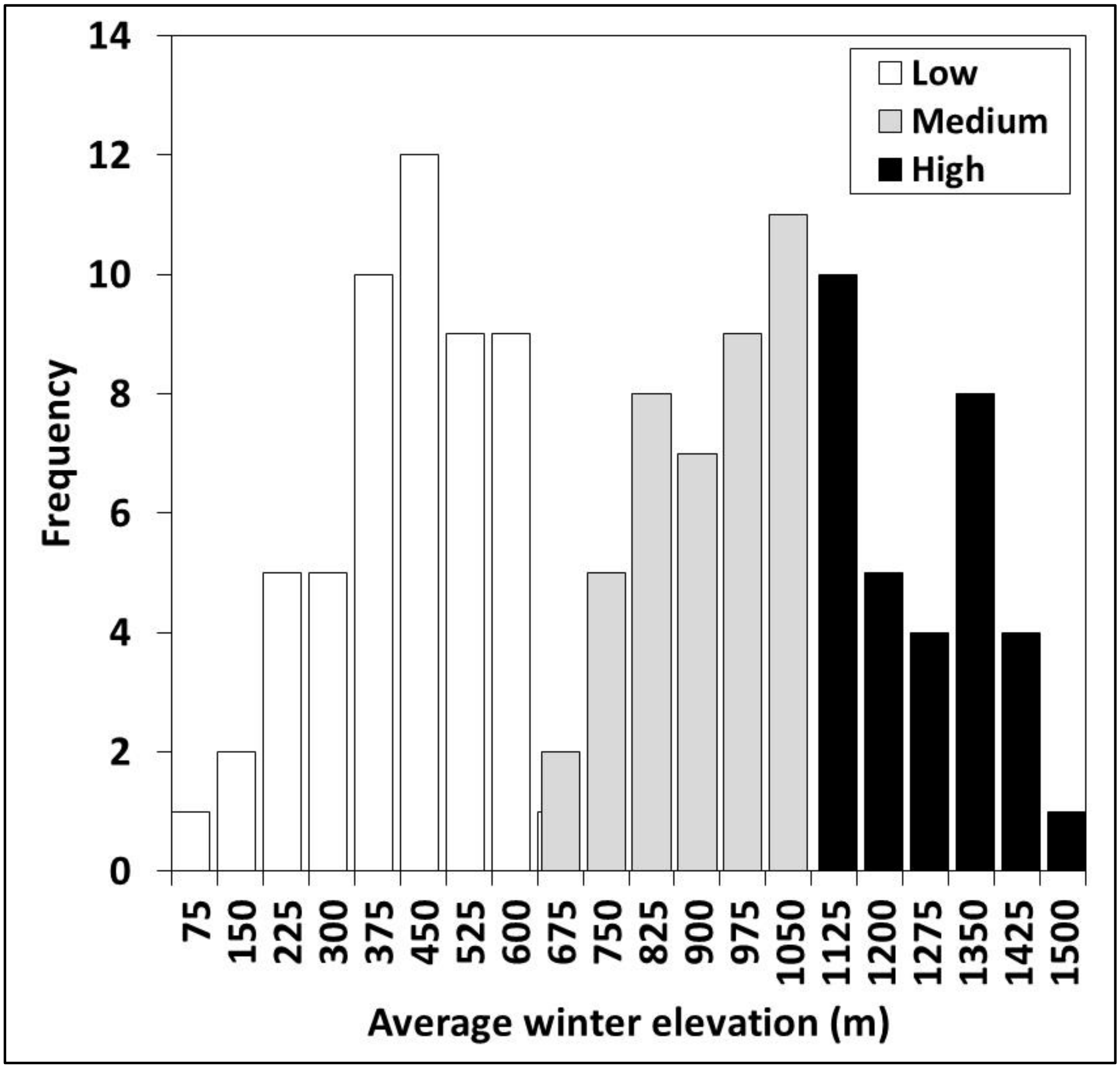

Figure 3. Histogram summarizing average winter elevation for GPS radiocollared mountain goats in the Haines–Skagway area, Alaska during 2010–2016. Mountain goat wintering strategy classifications were based on k-means clustering analyses (*n* = 3).

Table 1. Variables used for modeling mountain goat resource selection, Haines–Skagway, Alaska.

Variable[a]	Definition
Elevation	Elevation (m)
Slope	Slope (degrees)
Distance to cliffs	Distance to areas with slope > 40 degrees
Solar radiation (Jan 1)[b]	Solar radiation calculated for January 1
Solar radiation (August 1)[b]	Solar radiation calculated for August 1
VRM[c]	Vector ruggedness measure
TPI	Topographic Position Index

[a] Variables were standardized for by subtracting the mean and dividing by the standard deviation: elevation, y = (x – 987.3345)/532.7045; slope, y = (x – 23.2200)/14.4476; distance to cliffs, y = (x – 293.0284)/539.8905; solar radiation (1 Jan), y = (x –1.1314)/0.6516; solar radiation (1 Aug), y = (x – 6.2802)/1.3891; VRM, y = (x – 0.0299)/0.0371; TPI, y = (x + 0.00025)/4.3011

[b] Calculated using the solar radiation algorithm in ArcGIS 10 (Fu and Rich 2002).

[c] Calculated 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) and wintering strategy (low vs. medium vs. high). 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:

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

Where, w(x) represents a resource selection function (RSF) that is proportional to the probability of use of variables $x_1 + x_2 + \ldots + x_n$. 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 important mountain goat 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). In order to enhance our understanding of model validation dynamics, we simulated k-fold cross validation routines 100 times using stratified random draws of used and withheld data. To illustrate the degree of variation in k-fold cross validation (i.e., an additional index of model validation reliability) we calculated median and 95% lower and upper confidence limits.

RSF Model Mapping and Applications

Following delineation of important habitat using the CVI method (Fedy et al. 2014), we clipped out all areas considered non-habitat, such as ocean, lakes, and glaciers (National Hydrographic Database, NOAA Coastline). In addition, habitat patches were removed that were less than 0.017 km^2 (17 ha) in size, as patches smaller than this size were not selected by mountain goats (Appendix A). The study area was then subdivided into 9 discrete areas based on local geographic features (e.g., rivers, glaciers, coastline) and the proportion of GPS radiocollared individuals that used each wintering strategy in each area was determined. Specifically, for each discrete geographic area, mountain goat winter GPS locations were intersected with each wintering strategy model in GIS and it was determined what proportion of locations were correctly classified by each model. This output was then used to determine which model(s) best described mountain goat winter distribution for a given geographic area. Mountain goat winter habitat was then delineated for each of the 9 areas based on which wintering strategies (and associated RSF models) were utilized. If multiple wintering strategies were used in a given area, then the associated winter RSF model delineations were overlaid and ultimately merged into a single multi-model delineation. Finally, mountain goat winter habitat delineations were overlaid with approved helicopter skiing areas in the Haines Borough (v. 2013) in order to determine 1) how much mountain goat habitat was located within each approved area, and 2) what proportion of total mountain goat habitat was located within approved helicopter skiing areas.

Results

MOUNTAIN GOAT CAPTURE AND HANDLING

Mountain goats were captured during August–October 2010–2016. Seventy-two animals were captured using standard helicopter darting methods (males = 42, females = 30; Appendix B, Fig. 1). Complete GPS location data sets (i.e., <100 locations per season) were compiled for 64 individual animals (males = 36, females = 28).

RESOURCE SELECTION MODELING AND VALIDATION

GPS location data (n = 64,672) collected from 64 mountain goats were used to derive summer RSF models. For winter RSF modeling, GPS location data (n = 50,002) collected from 57 animals were used; however, sample sizes varied depending on the wintering strategy model (low, n = 29 individuals, GPS locations = 19,751; medium, n = 28, GPS locations = 17,461; high, n = 20, GPS locations = 12,790). Overall, resource selection was modeled using 6 terrain variables (Table 1). In general, mountain goats selected for mid-slope or ridgetop areas in close proximity to cliffs, on moderately steep, rugged slopes that had moderate–high solar exposure (Table 2, Fig. 4). However, variation in selection with respect to season (summer vs. winter) and wintering strategy (low vs. medium vs. high) was evident, especially in regard to elevation. Specifically, quadratic RSF functions describing mountain goat relative probability of use with respect to elevation indicated that distributions of animals using low versus high wintering strategies did not overlap; however, animals using the medium wintering strategy significantly overlapped both the low and high strategies (Table 2, Fig. 4).

Table 2. RSF model coefficients used for predicting mountain goat resource selection during winter and summer in the Haines–Skagway area, Alaska. Three separate winter models were derived based on elevational wintering strategies used by mountain goats in the study area.

	Winter–Low Elevation			Winter–Medium Elevation			Winter–High Elevation			Summer		
Variable	β	LCI	UCI	B	LCI	UCI	β	LCI	UCI	β	LCI	UCI
Elevation	-27.08	-41.96	-14.35	-1.79	-3.39	-0.84	4.05	2.22	9.32	1.50	0.91	1.98
Elevation^2	-12.82	-17.01	-9.16	-3.73	-6.97	-2.57	-6.87	-7.73	-4.21	-5.47	-6.14	-4.83
Dist. cliffs	-35.56	-41.20	-30.67	-27.45	-30.88	-20.43	-19.58	-30.84	-6.42	-8.08	-10.26	-6.93
Slope	0.36	0.10	0.48	0.56	0.05	1.13	0.73	0.08	2.05	0.51	0.37	0.69
Slope^2	--	--	--	-0.23	-0.36	-0.03	-0.51	-0.95	-0.20	-0.28	-0.34	-0.22
Solar (Jan)	--	--	--	1.11	0.61	1.80	1.30	0.51	3.02	--	--	--
Solar (Jan)^2	--	--	--	-0.40	-0.65	-0.10	-0.32	-0.61	-0.08	--	--	--
Solar (Aug)	--	--	--	--	--	--	--	--	--	0.44	0.30	0.64
Solar (Aug)^2	--	--	--	--	--	--	--	--	--	--	--	--
VRM	3.01	2.40	3.67	1.16	0.66	1.69	0.93	0.02	1.17	0.44	0.32	0.66
VRM^2	-1.09	-1.62	-0.70	-0.29	-0.52	-0.19	-0.22	-0.39	-0.10	-0.14	-0.16	-0.10
TPI	0.37	0.26	0.67	0.46	0.39	0.67	0.66	0.49	0.95	0.16	0.13	0.19
TPI^2	-0.05	-0.07	-0.04	-0.03	-0.06	-0.01	-0.05	-0.09	-0.04	--	--	--

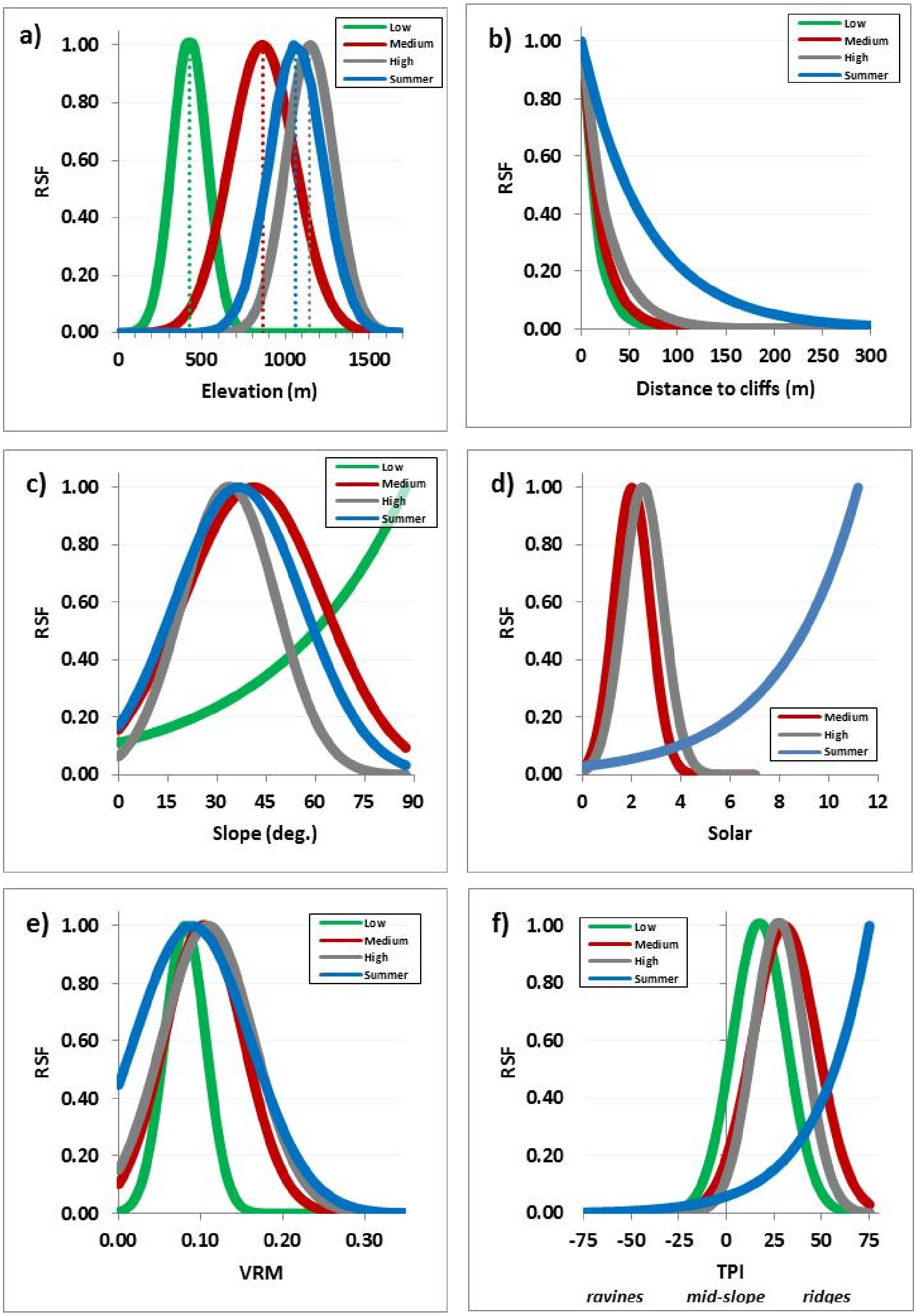

Figure 4. Relationship between mountain goat relative probability of use (RSF) and a) elevation, b) distance to cliffs, c) slope, d) solar radiation, e) terrain ruggedness (VRM), and f) topographic position (TPI). RSF values were standardized between 0 and 1.

Summer RSF functions for elevation were very similar to, and largely overlapped with, the high wintering strategy (Table 2, Fig. 4). Within the seasonal and wintering strategy constraints on elevational distribution, mountain goats exhibited strong selection for areas in close proximity to cliffs; however, this relationship was stronger during winter than during summer. For example, during summer, models predicted an increasing probability of use for areas closer to cliffs (i.e., escape terrain) provided areas were within 250 m to cliffs (Table 2, Fig. 4). During winter, the same relationship existed except the distance threshold declined to 50–100 m, depending on wintering strategy (Table 2, Fig. 4). Topographic Position Index (TPI) analyses indicated strong selection for ridge features during summer, whereas during winter mountain goats selected more broadly for mid-slope and ridge features.

K-fold cross validation results indicated that all resource selection models accurately predicted actual use patterns of GPS-marked mountain goats (Table 3). The overall strong predictive performance of our models (i.e., high r_s values), was considered to be very reliable due to the limited variation in k-fold cross validation results via our simulation analyses. For example, median r_s values for all models considered (r_s = 0.85–1.0) exhibited very limited intra-model variation (95% CL ± 0.0–0.3).

Table 3. K-fold cross-validation results describing predictive performance of summer and winter RSF models developed for predicting mountain goat resource selection in the Haines–Skagway area, Alaska. K-fold cross validation was simulated 100 times using stratified random draws; median and 95% lower and upper confidence limits are reported.

	Spearman rank correlation (r_s)		
Model	median	LCL	UCL
Winter - low	0.94	0.93	0.95
Winter - medium	0.98	0.97	0.98
Winter - high	0.85	0.82	0.86
Summer	1.00	1.00	1.00

RSF MODEL MAPPING AND APPLICATIONS

We observed spatial variation in mountain goat wintering strategies throughout the study area (high = 25%, medium = 34%, low = 41%; Fig. 5). In only 22% (2/9) of the geographic areas did mountain goats use a single wintering strategy. In the remaining 78% (7/9) of the areas, mountain goats used either 2 or 3 wintering strategies. In general, winter habitat was more spatially limited than summer habitat (Figs. 6 and 7). In winter, the low elevation wintering strategy was most common near the coast and least common in the northernmost areas with the strongest interior climatic influence; however, substantial localized variation was evident (Fig. 7).

Overall, 24% (225 km^2) of the approved helicopter skiing area is composed of mountain goat winter habitat, and represents 33% of the total amount of mountain goat habitat in the geographic areas where helicopter skiing occurs (Table 4, Fig. 8). However, substantial geographic variation occurs such that the amount of winter mountain goat habitat within approved helicopter skiing areas varies from 11% to 62%, depending on the area of consideration.

Discussion

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 Alaska (Fox et al. 1989, White et al. 2012, White and Gregovich 2017) and elsewhere (Festa-Bianchet and Côté 2008, Poole et al. 2009). This occurs because mountain goats are habitat specialists and exhibit unique morphological and behavioral adaptations that enable them to efficiently utilize steep, rugged terrain. This is a strategy expected to correlate with reduced predation risk and, during winter, increased forage access and lower energetic costs because snow depths are lower in these areas due to snow shedding characteristics of steep terrain). Yet, while terrain characteristics can be considered a key prerequisite for predicting mountain goat habitat, the strength of selection for certain terrain features can vary seasonally. Similar to earlier research conducted in the nearby Lynn Canal study area (White and Gregovich 2017) and interior British Columbia (Poole et al. 2009), mountain goats selected more strongly for areas closer to escape terrain (i.e., cliffs) during winter than during summer. Such fine-scale seasonal variation in selection for habitat features associated with cliffs suggests 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 microsites. 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 due to their increased mobility in snow-free conditions.

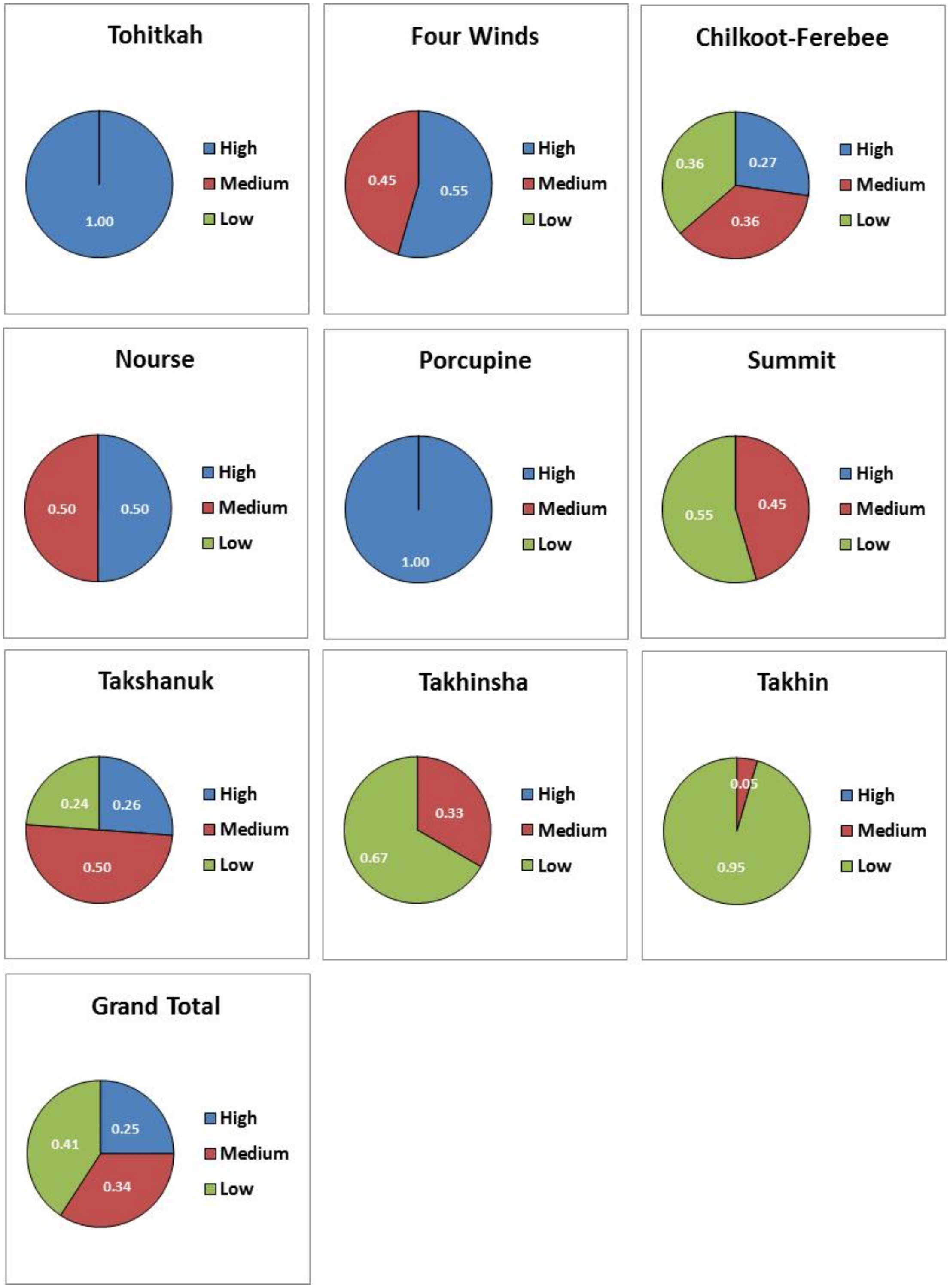

Figure 5. Proportion of GPS radiocollared mountain goats using low, medium, or high elevation wintering strategies in each of 9 different geographic areas, Haines–Skagway, Alaska, 2010–2017.

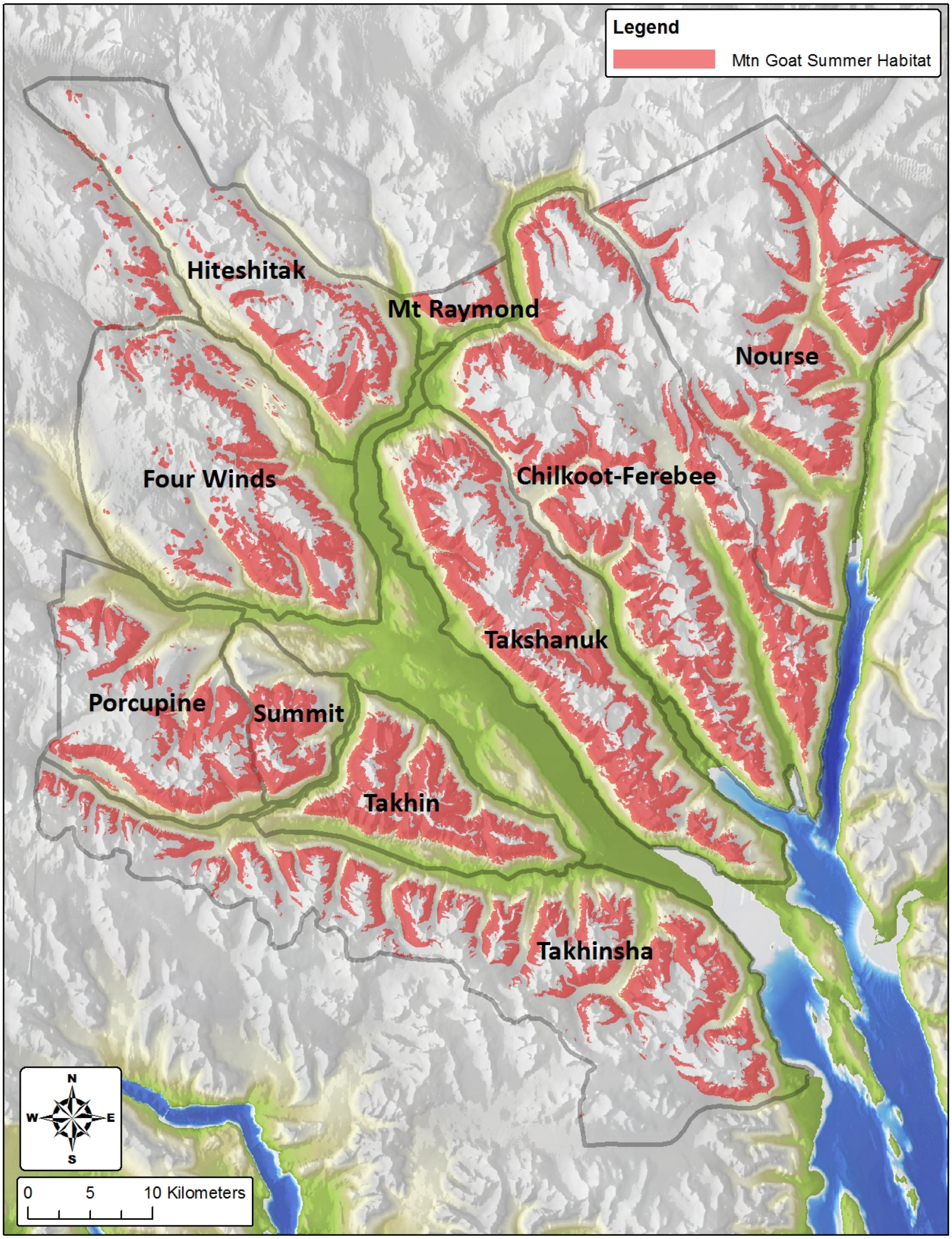

Figure 6. Map delineating mountain goat summer habitat, Haines–Skagway, Alaska, and identifying the geographic areas for which collected data were analyzed.

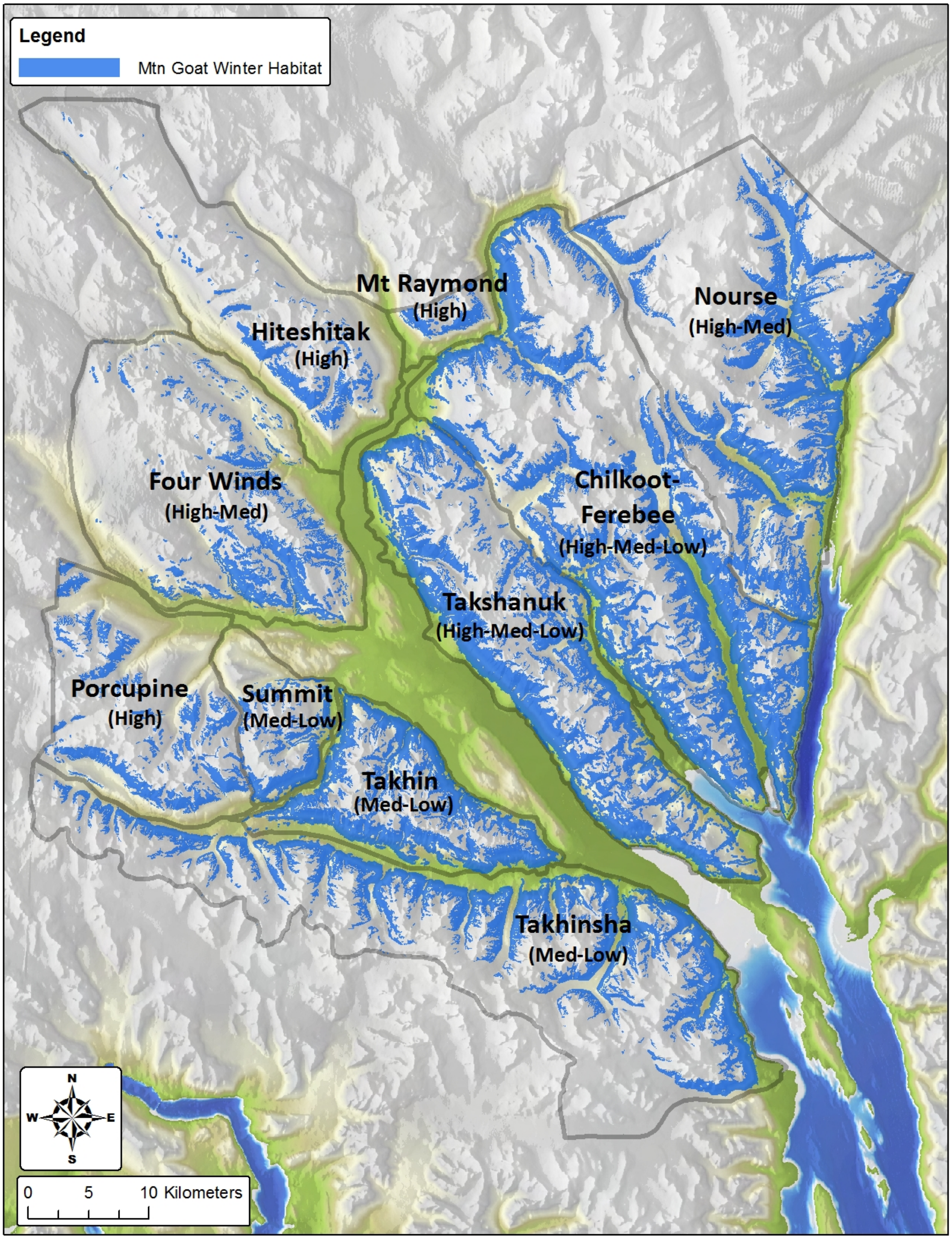

Figure 7. Map delineating mountain goat winter habitat, Haines-Skagway, Alaska, the geographic areas for which data were analyzed, and mountain goat wintering strategies identified in those areas.

Table 4. Summary of the amount of mountain goat winter habitat in different geographic areas in regards to the amount of terrain approved for helicopter-skiing, Haines – Skagway, Alaska.

		Total area			Approved ski terrain			Mountain goat habitat
Area	Wintering strategies	Size (km^2)	Habitat (km^2)	%	Size (km^2)	Habitat (km^2)	Proportion	% impacted
Takhinsha	Med-Low	622	170	27	483	106	0.22	62
Chilkoot-Ferebee	High-Med-Low	694	286	41	205	65	0.32	23
Porcupine	High	270	49	18	115	20	0.17	40
Four Winds	High-Med	427	64	15	69	17	0.25	26
Summit	Med-Low	90	25	27	48	8	0.16	32
Takhin	Med-Low	182	95	52	28	10	0.37	11
Nourse	High-Med	564	189	33	0	0	--	0
Takshanuk	High-Med-Low	404	181	45	0	0	--	0
Hiteshitak	High	327	27	8	0	0	--	0
Mt Raymond	High	39	8	21	0	0	--	0

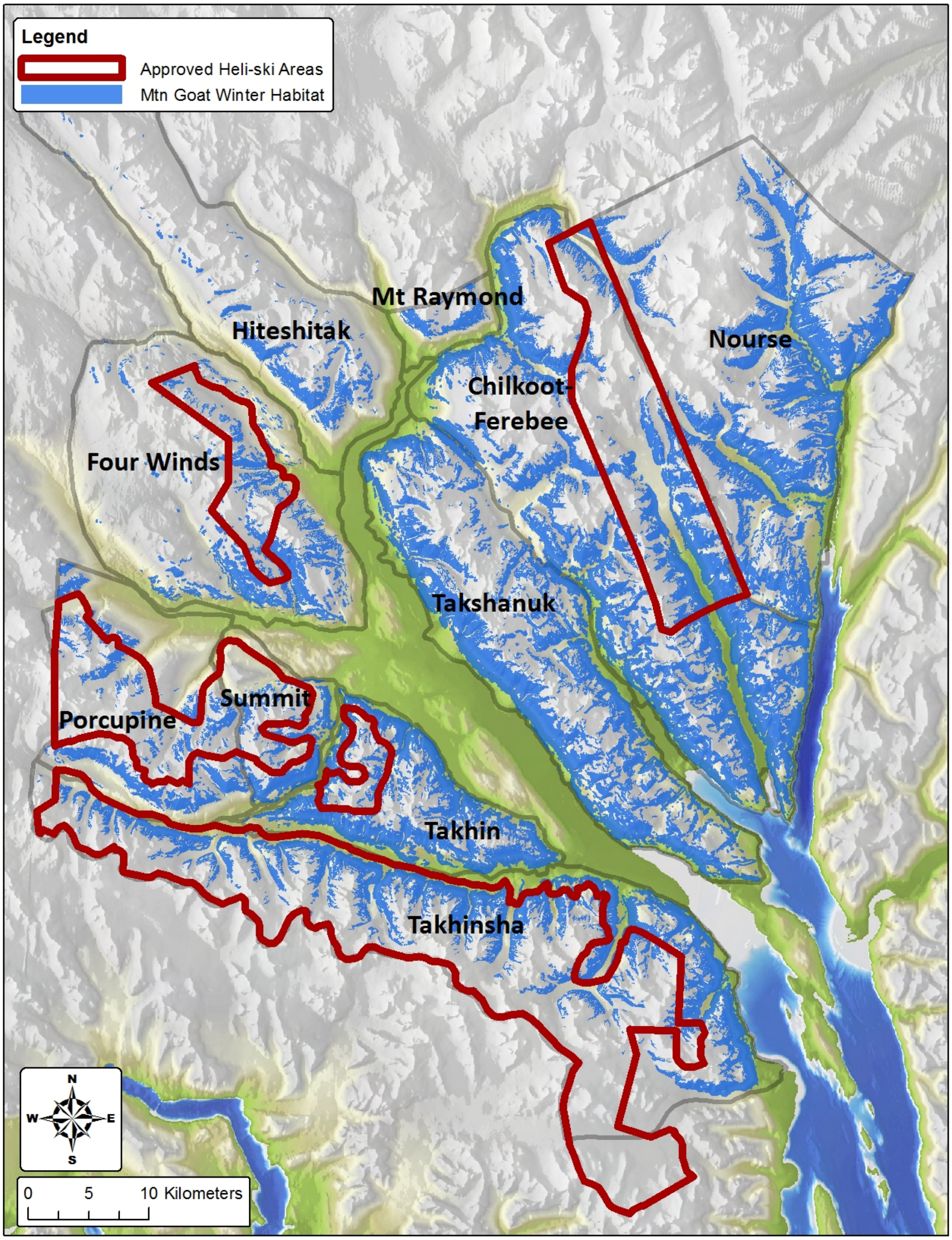

Figure 8. Map depicting the location of approved helicopter skiing areas and mountain goat winter habitat, Haines–Skagway, Alaska. The ski area boundaries were approved by the Haines Borough in 2013.

Snow can exert strong effects on ungulate forage availability (Fox 1983, White et al. 2009), energetic costs of locomotion (Dailey and Hobbs 1989), survival (White et al. 2011), and ultimately distributional patterns (Lowrey et al. 2017). During snow-free summer months, mountain goats utilize steep, rugged terrain in high elevation alpine and subalpine areas. However, during winter, localized variation in snow characteristics and accumulation patterns constrain the availability of suitable wintering sites. At a broad scale, snow conditions tracked a coastal to interior gradient in our study area but varied due to local topographic complexity at finer scales.

As a result, we documented substantial spatial variation with respect to mountain goat distribution during winter as shown by the 3 discrete mountain goat wintering strategies (i.e., low, medium [tree line] or high elevation), or ecotypes (sensu Herbert and Turnbull 1977), that broadly correlated to local variation in winter snow climate. For example, mountain goats in close proximity to coastal areas (characterized by heavy, wet snowpacks) tended to winter in lower elevation forested habitats more often than animals distant from the coast. In colder, drier, and more interior areas near the Canadian border, mountain goats commonly wintered at medium to high elevations in windswept subalpine and alpine terrain. Nonetheless, substantial spatial variation in wintering strategies was evident such that individuals used different strategies even in the same general geographic area, or in relatively close geographic proximity. The occurrence of multiple strategies in a given area may reflect individual responses to small-scale variability in snowpack conditions or, alternatively, suggest that in certain areas the benefits of using one strategy may not be significantly more advantageous than another. Overall, the diversity of wintering strategies is notable and contrasts with the nearly exclusive use of low elevation wintering habitats in the nearby (within 5–20 km) Lynn Canal study area (White 2006, White et al. 2012, White and Gregovich 2017), an area with a stronger maritime influence.

Management Applications

The elevational distribution of mountain goats during winter has important implications for mitigation of helicopter skiing disturbance. In areas where mountain goats winter at low elevation little potential exists for spatial overlap, and associated disturbance of mountain goats by helicopter skiing activities is unlikely. However, in areas where mountain goats use medium and high elevation wintering strategies disturbance risk is higher as helicopter skiing occurs at similar elevations. For example, depending on the geographic area, from 11% to 62% of mountain goat winter habitat is within one or more areas currently approved for helicopter skiing (Table 4). Such levels of apparent impact have the potential to exert negative effects on local mountain goat populations. Previous research has shown that helicopter overflights can elicit stress responses and alter movement patterns of mountain goats at distances up to 1,500–2,000 m away (Côté 1996, Côté et al. 2013), and responses may persist for up to 48 hours after the cessation of disturbance (Cadsand 2012). In addition, mountain goats avoid areas where extensive skiing activity occurs, even when ski access is non-motorized (Richard and Côté 2015).

Given these considerations, it is important to minimize the extent of spatial overlap between mountain goats and helicopter skiing activity whenever possible. In cases where helicopter skiing is already occurring, mitigation measures can be implemented to limit the exposure of mountain goats to disturbance. These measures could include timing windows (i.e., limiting activity during biologically critical periods) or limits on the number of landings (sensu Hurley 2004). In such cases, it is also very important to carefully monitor affected mountain goat populations in order to detect and implement management responses to changes in a timely manner.

Characterizing the spatial distribution and intensity of use of helicopter skiing activity is important for accurately determining the extent of overlap and projected impacts and to evaluate existing and proposed management actions. In our study area land managers annually permit up to 2,900 skier days, yet, unlike other areas in North America (Andrus 2005), helicopter ski runs and landing sites are not currently delineated or monitored. Consequently, it is unclear what proportion of mountain goat habitat within approved areas is actually impacted by helicopter skiing activities. Approved helicopter skiing areas consist of extensive blocks of land that likely include areas that are not suitable or desirable for helicopter skiing (i. e., old-growth forest, river valleys). In addition, at smaller spatial scales, winter habitat selection patterns by mountain goats tend to target areas with relatively low snowfall (in comparison to the surrounding landscape) to avoid increased energetic costs of locomotion and foraging (due to snow burial of food resources) as well as steep slopes that exhibit relatively high probabilities of shedding snow (i.e., avalanche). Consequently, at such spatial scales, overlap between mountain goat winter habitat and the best quality and safest skiing terrain may be less than expected a priori (yet is currently unknown). In other areas of North America partnerships between backcountry users and government agencies have enabled fine-scale mapping of recreational activities in order to facilitate data-based land and wildlife management decision making (Andrus 2005, Cadsand 2012, Olson et al. 2017, Squires et al. 2018). Implementation of a similar approach in our study area will be critical for future quantification of spatial overlap and, ultimately, evaluation of socio-ecological trade-offs needed to inform management decisions.

Land management decisions need to incorporate information about trade-offs associated with proposed uses in order to have socially and politically acceptable outcomes. In the case of helicopter skiing management, the economic benefits of helicopter skiing activity are commonly balanced against impacts on wildlife habitat and populations, local property values, non-motorized backcountry activities, commercial snowmachine operations, and personal aesthetic considerations. In order to maximize the social resilience of decisions, it is important to use a decision-making framework that is data-based and relies on a quantitative determination of the costs and benefits of each proposed action (Nielsen et al. 2006, Squires et al. 2018). In this regard, development of reliable mountain goat RSF models based on extensive GPS location data and rigorous statistical analyses will provide valuable tools for quantifying spatial overlap and impacts of helicopter skiing on mountain goat populations (Figs. 9 and 10). While this represents a significant advance in our ability to parameterize wildlife-based costs of helicopter skiing activities in specific areas, further effort is required to quantify other non-wildlife related costs and, importantly, benefits of helicopter skiing, before an optimal decision-making framework can be implemented.

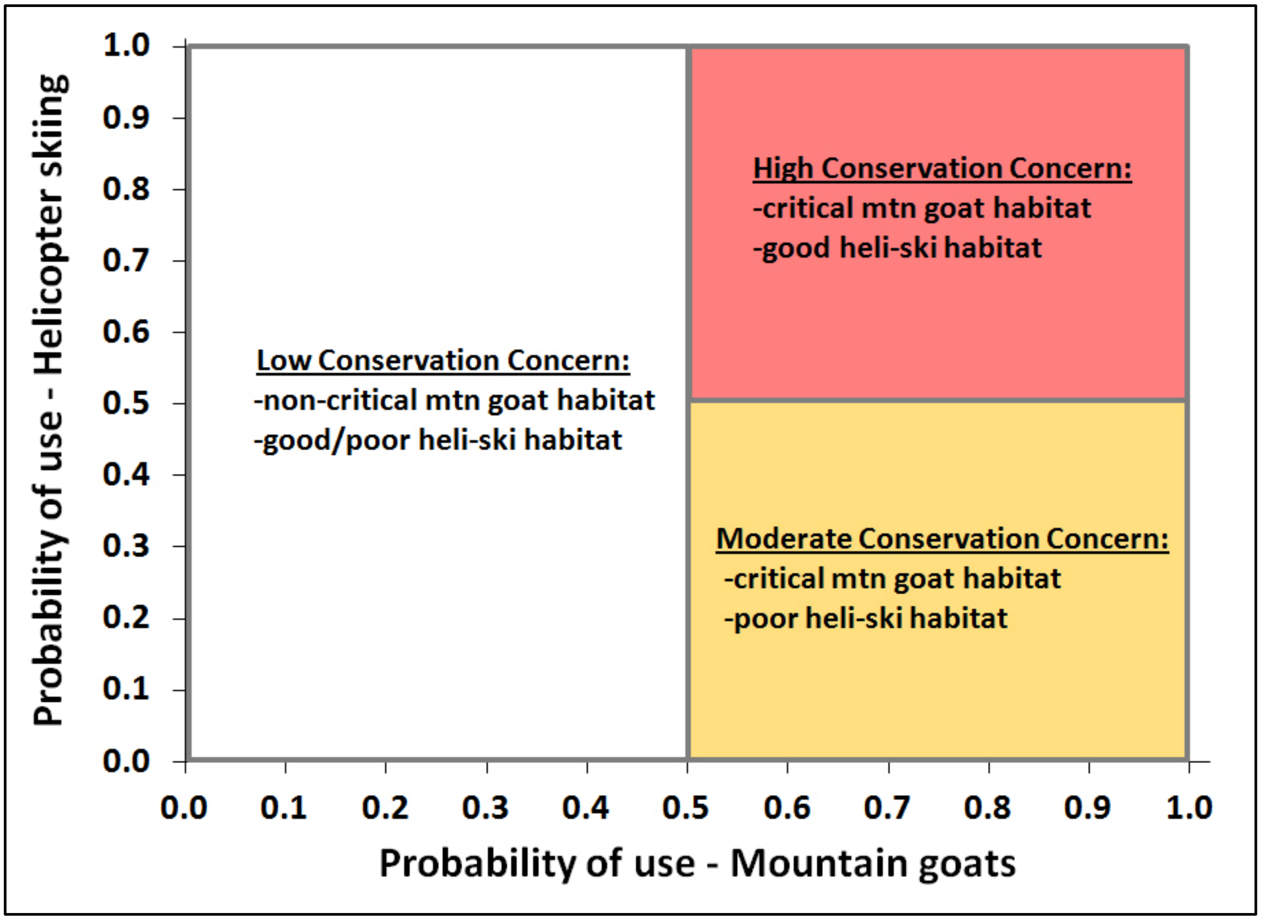

Figure 9. Conceptual framework illustrating how helicopter skiing and mountain goat habitat conservation trade-offs can be quantified to assist in decision-making processes.

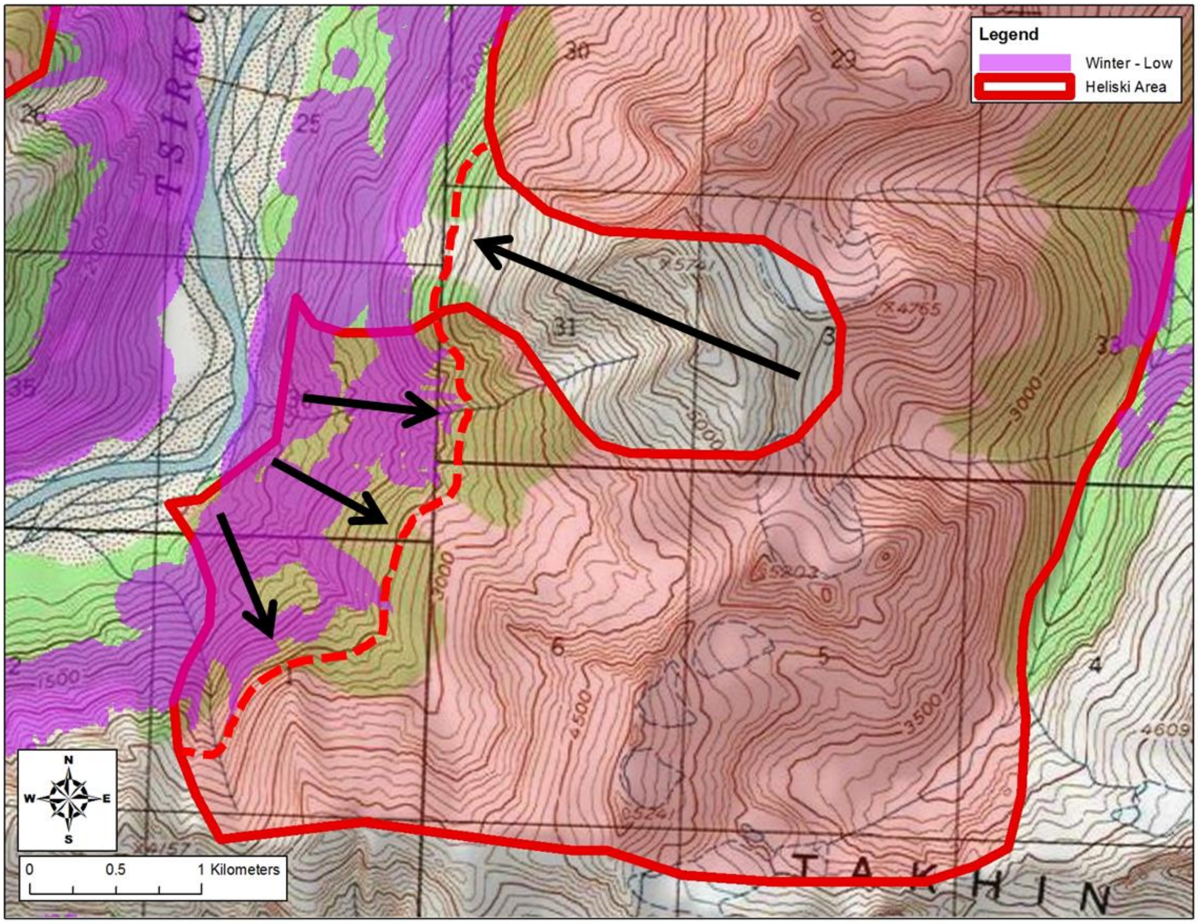

Figure 10. Map illustrating the juxtaposition of mountain goat winter habitat (i.e., low elevation wintering strategy) and a helicopter skiing area. In this example, the black arrows indicate the direction that helicopter skiing boundaries can be shifted to maximize mountain goat habitat conservation and not change the amount of area available for helicopter skiing.

Acknowledgments

This project was funded by the State of Alaska Department of Fish and Game and the Bureau of Land Management. Rod Flynn (ADF&G), Sandy O'Brien (ADF&G), David Thomson (ADF&G) and Sandee Smith (BLM) coordinated project funding. Jeff Jemison, Yasaman Shakeri, Anthony Crupi, Neil Barten, Chad Rice, Carl Koch, Stephanie Sell, Ryan Scott, Susannah Woodruff, Ben Williams, Jamie Womble, Jamie King, Ben Kirkpatrick, Dana Van Burg, Mark Battian, Mike Van Note, Raphael McGuire and Thomas McGuire provided assistance with field or related activities. Lynn Bennett, Chuck Schroth and Pat Valkenburg provided fixed-wing aerial support. Mitch Horton, Eric Main, Christian Kolden and Andy Hermansky (Temsco Helicopters) provided safe and reliable helicopter capture services.

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Appendices

Appendix A. Patch size analysis

Mountain goat RSF models were used to delineate important habitat using the CVI method (Fedy et al. 2014). In order to maximize the precision of the resulting habitat delineation we conducted analyses to determine minimum patch size used by mountain goats. This approach was intended to further refine habitat maps by removing habitat patches that were small, potentially isolated, and not utilized by mountain goats. To accomplish this we calculated the proportional use of patches of each size used by mountain goats and compared these values to the availability of patch sizes. Availability was determined by randomly selecting points within a 1656 m buffer (i.e. the diameter of winter home range size; White 2006) surrounding used points. Patch size specific relative selection ratios [(used/available) – 1] were calculated to determine the minimum patch size used by mountain goats (i. e. positive values denote use greater than availability). Overall, we determined that mountain goats only selected for patches greater than 1.7 hectares in size (Fig. A1). Consequently, our final habitat delineations only included patches greater than this threshold size.

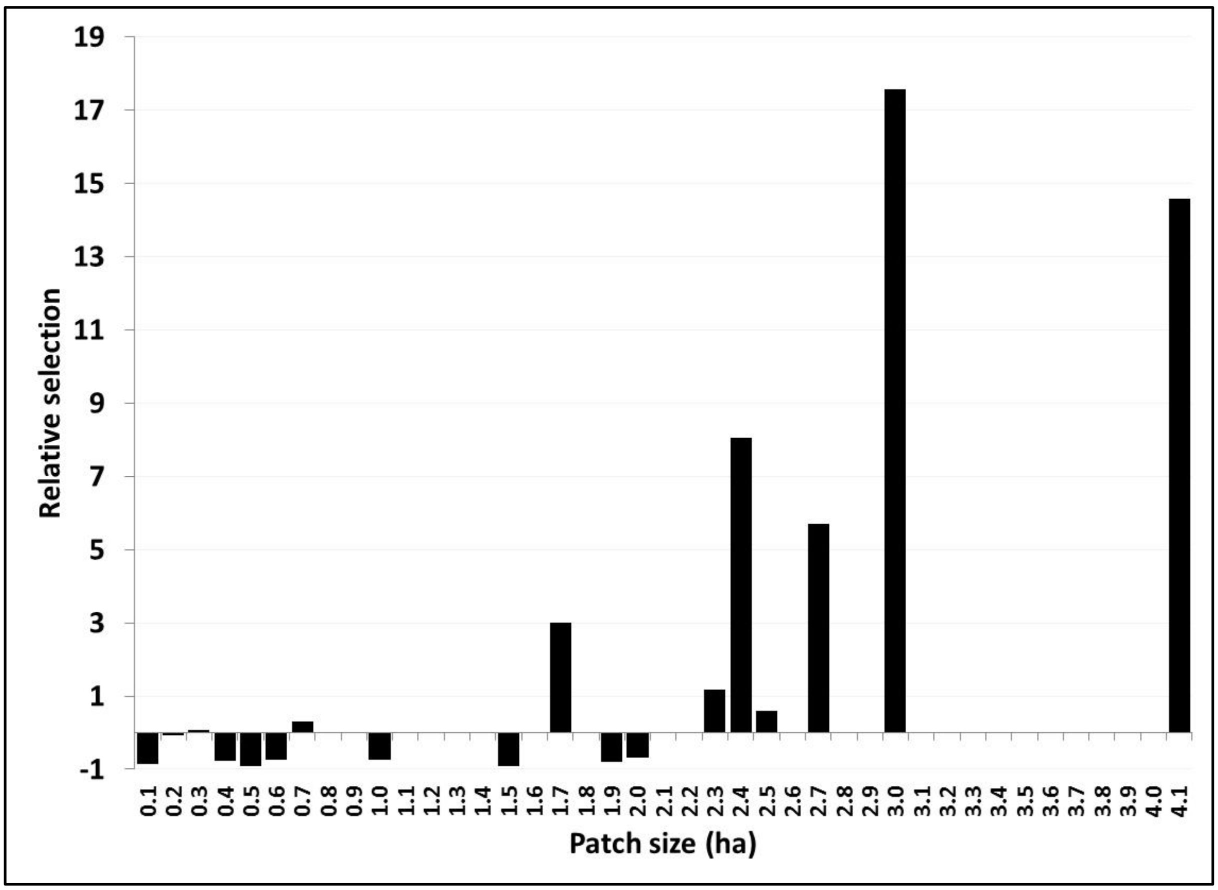

Figure A1. Relationship between patch size and relative selection by mountain goats during winter in the Haines–Skagway area, Alaska, 2010–2017.

Appendix B. Summary of mountain goats captured and deployed with GPS radio collars, Haines-Skagway, Alaska, 2010–2017.

ID	Sex	Age	Capture date	Days monitored	GPS locations	Status
KG001	F	8	8/4/10	1,044	2,808	Complete
KG002	M	6	8/4/10	137	526	Complete
KG003	F	6	8/4/10	2,372	5,405	Still Deployed
KG004	M	5	8/4/10	1,043	3,142	Complete
KG005	F	13	8/4/10	1,043	3,013	Complete
KG006	F	14	8/4/10	199	647	Complete
KG007	F	6	8/4/10	1,044	3,043	Complete
KG008	M	5	8/4/10	1,043	2,938	Complete
KG009	M	11	8/13/10	235	845	Complete
KG010	M	5	8/13/10	818	2,455	Complete
KG011	M	6	8/13/10	88	345	Complete
KG012	M	12	8/13/10	632	2,269	Complete
KG013	M	9	8/13/10	159	608	Complete
KG014	M	11	8/13/10	111	415	Complete
KG015	F	6	8/13/10	581	2,117	Complete
KG016	F	6	8/13/10	818	2,786	Complete
KG017	M	7	8/14/10	1,401	5,391	Complete
KG018	M	6	8/14/10	1,193	4,518	Complete
KG019	M	4	8/14/10	1,401	5,312	Complete
KG020	M	6	8/14/10	1,225	4,672	Complete
KG021	F	3	8/14/10	1,034	2,980	Complete
KG022	F	4	8/14/10	253	931	Complete
KG023	F	11	8/14/10	147	570	Complete
KG024	F	5	9/8/11	--	--	Collar Failure
KG025	M	5	9/8/11	1,010	2,291	Complete
KG026	M	4	9/8/11	1,010	2,759	Complete
KG027	M	6	9/8/11	215	1,207	Complete
KG028	M	7	9/8/11	--	--	Did Not Release
KG029	F	1	9/8/11	1,010	2,561	Complete
KG030	M	4	9/8/11	1,010	2,928	Complete
KG031	M	4	10/2/11	638	2,251	Complete
KG032	M	6	10/2/11	124	423	Complete
KG033	F	8	10/2/11	591	2,289	Complete
KG034	M	6	8/15/12	1,085	4,417	Complete
KG035	M	6	8/15/12	99	750	Complete
KG036	M	4	8/15/12	1,085	5,540	Complete
KG037	M	5	8/15/12	1,085	5,314	Complete

Appendix B (continued). Summary of mountain goats captured and deployed with GPS radio collars, Haines, Alaska, 2010–2017.

ID	Sex	Age	Capture date	Days monitored	GPS locations	Status
KG038	M	11	8/15/12	112	856	Complete
KG039	F	10	10/10/12	1,029	4,815	Complete
KG040	F	7	10/10/12	999	4,859	Complete
KG041	M	9	8/29/13	987	4,938	Complete
KG042	M	6	8/29/13	1,042	5,352	Complete
KG043	M	7	8/29/13	1,042	5,102	Complete
KG044	F	1	8/29/13	1,042	5,259	Complete
KG045	M	3	8/29/13	684	3,923	Complete
KG046	M	6	8/29/13	759	4,251	Complete
KG047	M	7	8/29/13	1,042	5,392	Complete
KG048	F	4	8/29/13	1,043	5,361	Complete
KG049	F	7	9/9/14	54	396	Complete
KG050	F	7	9/9/14	896	4,705	Still Deployed
KG051	M	6	9/9/14	896	4,502	Still Deployed
KG052	F	11	9/9/14	896	4,460	Still Deployed
KG053	F	7	9/9/14	443	2,712	Complete
KG054	F	11	9/9/14	896	4,599	Still Deployed
KG055	F	7	9/9/14	896	4,323	Still Deployed
KG056	M	2	8/21/15	291	1,427	Complete
KG057	F	6	8/21/15	279	1,584	Complete
KG058	M	5	8/21/15	326	1,910	Complete
KG059	F	5	8/21/15	550	3,405	Still Deployed
KG060	F	5	8/21/15	550	3,407	Still Deployed
KG061	M	5	8/21/15	550	3,402	Still Deployed
KG062	M	4	8/29/16	155	1,997	Still Deployed
KG063	F	9	8/29/16	155	2,020	Still Deployed
KG064	F	12	8/29/16	155	1,768	Still Deployed
KG066	M	4	8/29/16	155	2,264	Still Deployed
KG067	F	6	8/29/16	155	2,170	Still Deployed
KG068	M	1	8/8/17	--	--	No Data Yet
KG069	M	6	8/8/17	--	--	No Data Yet
KG070	F	4	8/8/17	--	--	No Data Yet
KG071	M	5	8/8/17	--	--	No Data Yet
KG072	M	8	8/8/17	--	--	No Data Yet
KG073	M	6	8/8/17	--	--	No Data Yet

Appendix C: Summary of the proportion of GPS radiocollared mountain goats using different wintering strategies by geographic area during 2010–2017, Haines–Skagway, Alaska.

Area	High	Medium	Low	Individuals	Locations
Tohitkah	1.00	0.00	0.00	7	4,126
Porcupine	1.00	0.00	0.00	2	939
Four Winds	0.55	0.45	0.00	11	7,112
Nourse	0.50	0.50	0.00	2	1,557
Chilkoot-Ferebee	0.27	0.36	0.36	11	6,629
Takshanuk	0.26	0.50	0.24	42	30,147
Summit	0.00	0.45	0.55	11	8,759
Takhinsha	0.00	0.33	0.67	12	7,021
Takhin	0.00	0.05	0.95	22	15,240
Total	0.25	0.34	0.41	120	81,530