MODELING RESOURCE SELECTION OF MOUNTAIN GOATS IN SOUTHEASTERN ALASKA: APPLICATIONS FOR POPULATION MANAGEMENT AND HIGHWAY DEVELOPMENT PLANNING

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Abstract: Mountain goats (*Oreamnos americanus*) are among the most culturally and economically important large mammal species in Alaska. Due to their low population growth rates and relatively high degree of sensitivity to natural and anthropogenic disturbance, resource management decisions must be carefully evaluated to ensure sustainable populations. In this study we combined data collected from 124 GPS radio-marked mountain goats and remote sensing data layers in a GIS-based resource selection function (RSF) modeling framework. Modeling output was used to characterize the spatial distribution of mountain goat habitat in an area subject to construction of an all-season highway. We characterized the extent to which the proposed highway overlapped with predicted mountain goat wintering habitat in order to assess the need for and recommend appropriate modifications of mountain goat population management strategies and highway mitigation methods. We determined that the proposed highway would transect 25.3 km of predicted high-to-moderate-use mountain goat wintering areas. In the event the proposed highway is constructed we propose specific changes to existing mountain goat hunting regulations and management strategies and provide recommendations for how highway design, construction, maintenance, and use can be implemented to reduce deleterious effects to local mountain goat populations.

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Key words: southeastern Alaska, disturbance, habitat modeling, highway, Lynn Canal, mountain goat, *Oreamnos americanus*, resource selection.

Mountain goats (*Oreamnos americanus*) are among the most culturally and economically important large mammal species in Alaska. Consequently, mountain goats are carefully managed to account for a broad array of human uses and considerations including subsistence and sport hunting, wildlife viewing, and native customary uses involving blanket weaving and handicrafts. Effective management of mountain goats requires field-based data and an empirical understanding of factors that influence population dynamics such as winter severity, human harvest, disease or industrial disturbance. Ideally, model-based frameworks informed by field data are used to predict specific outcomes or qualitative assessments of proposed management actions.

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However, in many cases basic knowledge about population biology and resource selection are lacking, particularly in relation to risk factors, and studies are needed to articulate appropriate management responses to natural and anthropogenic changes to the environment.

Mountain goats have very specialized habitat requirements, a conservative life-history strategy and low population growth rates relative to other ungulates (Fox et al. 1989, Festa-Bianchet and Côté 2006). These characteristics likely contribute to the species' sensitivity and apparent vulnerability to industrial development activities. Past studies have documented negative impacts of industrial development activities that include temporary range abandonment, alteration of foraging behavior, and population decline (Chadwick 1973, Foster and Rahs 1983, Joslin 1986, Côté 1996, Côté and Festa-Bianchet 2003, Hurley et al. 2004). Thus, in the context of proposed development activities, acquisition of knowledge about mountain goat resource selection patterns and distribution represents a key preliminary source of information needed to assess the extent to which industrial development has potential to affect a given population.

Southeastern Alaska is a maritime region sparsely populated by small cities and rural communities, and connected by a network of state ferries and, in a few cases, roads. Juneau (population = 31,000), the capital of Alaska, is located 110 km south of the small rural community of Haines and the continental highway system. The state of Alaska (Department of Transportation and Public Facilities) has proposed the construction of an 83.6 km all-season highway from the Juneau road system to the Katzehin river flats (i.e. the Juneau Access Highway Improvements Project), a project that would substantially shorten the existing 4.5 hour ferry ride required for Juneau residents to access the continental highway system in Haines. The proposed highway alignment traverses steep, rugged, and largely inaccessible terrain along the shore of Lynn Canal and Berners Bay. Substantial portions of the proposed highway corridor transect expected mountain goat winter habitat. As such, activities associated with construction, maintenance and use of the proposed highway are expected to affect local populations and require altered mountain goat management strategies.

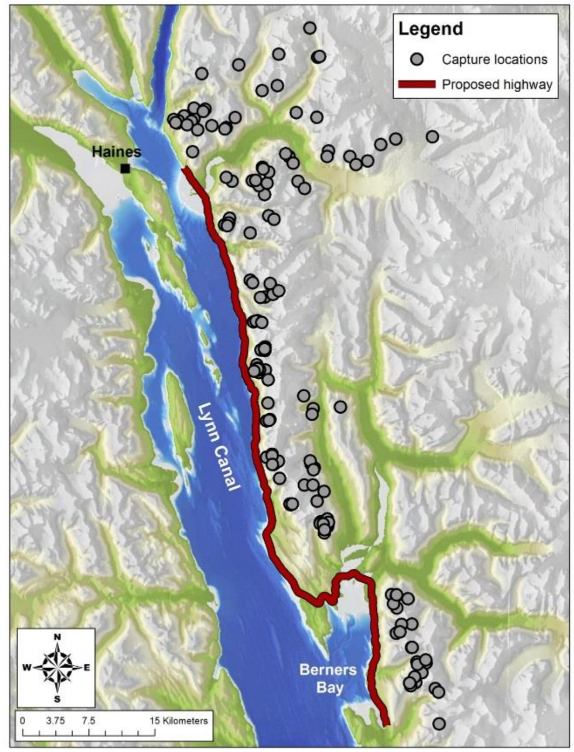

Fig. 1. Locations of mountain goats captured and subsequently monitored in the study area, 2005-2011.

The intent of this study was to combine mountain goat GPS location data with remote sensing data layers in a resource selection function (RSF) modeling framework to quantitatively characterize mountain goat habitat in the vicinity of the proposed highway development area. Assessment of the extent of overlap between the proposed highway corridor and mountain goat habitat will then be used to identify appropriate highway mitigation methods and explore the degree to which existing mountain goat management strategies need to be modified.

STUDY AREA

Mountain goats were studied in an approx. 1,077 km^2 area located in a mainland coastal mountain range east of Lynn Canal, a marine fjord located near Haines in southeastern Alaska (Fig. 1). The initial study area was oriented along a north-south axis and bordered in the south by Berners Bay (58.76N, 135.00W) and by Dayebas Creek (59.29N, 135.35W) in the north. Because winter elevational distribution differed between areas east of Berners Bay (hereafter "East Berners") and in Lynn Canal (Lions Head, Mt. Sinclair and Mt. Villard), the study area was further subdivided for resource selection function analyses.

Elevation within the study areas ranges from sea level to 1,920 m. This area is an active glacial terrain underlain by late cretaceous-paleocene granodiorite and tonalite geologic formations (Gehrels 2000). 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. above 1,200 m) and rugged, broken terrain that descends to a rocky, tidewater coastline. The northern part of the area was bisected by the Katzehin River, a moderate volume (approx. 42 m^3/second; US Geological Service, 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 140 cm, and winter temperatures are rarely less than -15° C and average -1° C (Haines, AK; National Weather Service, Juneau, AK, unpublished data). Elevations at 79 m typically receive approx. 635 cm of snowfall, annually (Eaglecrest Ski Area, Juneau, AK, unpublished data). Predominant vegetative communities occurring at low-moderate elevations (<450 m) included Sitka spruce (*Picea sitchensis*)-western hemlock (*Tsuga heterophylla*) coniferous forest, mixed-conifer muskeg, and deciduous riparian forests. Mountain hemlock (*Tsuga mertensiana*)-dominated 'krummholtz' forest comprised a subalpine timberline band occupying elevations between 450–760 m. Alpine plant communities were composed of a mosaic of relatively dry ericaceous heathlands and moist meadows dominated by sedges and forbs and wet fens. Avalanche chutes were common in the study area and bisected all plant community types and often terminated at sea-level.

METHODS

Mountain Goat Capture and Collar Deployment

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. 2012). All capture procedures were approved by the State of Alaska Animal Care and Use Committee.

GPS Location Data

Telonics TGW-3590 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. 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).

Habitat Selection, Activity and Movement Patterns

Wintering Strategies and Elevational Distribution

GPS locations were intersected with the NASA Shuttle Radar Topography Mission (SRTM) digital elevation model (http://srtm.usgs.gov/index.php) using Geospatial Modeling Environment (http://www.spatialecology.com/gme) in order to determine elevation for each GPS location. Average daily elevation was then estimated for each individual animal and summarized by individual animal, sex and day in order to estimate sex-specific average daily

Table 1. Remote-sensing covariates used to derive mountain goat resource selection functions, 2005-2011, Lynn Canal, AK.

Variable	Definition	Source Data
Elevation	elevation (meters)	SRTM DEM[1]
Slope	slope (degrees)	SRTM DEM[1]
Distance to escape terrain	distance to areas with slope > 40 degrees	SRTM DEM[1]
Solar radiation (Jan 1)	solar radiation calculated for January 1	SRTM DEM[2]
Solar radiation (August 1)	solar radiation calculated for August 1	SRTM DEM[2]
VRM	vector ruggedness measure	SRTM DEM[3]

[1]Calculated using the Spatial Analyst Extension in ArcGIS 10
[2]Calculated using the solar radiation algorithm in ArcGIS 10 (Fu and Rich 2002)
[3]Calculated using methods described in Sappington et al. (2007)

elevation. These data were then used to describe seasonal patterns in distribution, specifically to determine when animals conducted altitudinal migrations between summer and winter ranges.

Habitat Selection and Modeling

Resource selection function (RSF) models (i.e. Boyce 2002) were developed using mountain goat GPS location data and remote sensing covariate data layers in a GIS framework in order to describe where important winter and summer habitats occurred in the study area. 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. first-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 30 locations per km^2, a density determined to reliably describe resource availability patterns in our study area (D. Gregovich, Alaska Department of Fish and Game (ADFG; unpublished data). 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. In a few cases variable coefficients calculated for individual animals resulted in extreme values (i.e. <3 standard deviations of the mean), apparently due to unusual individual selection patterns. Such individuals were considered outliers and systematically removed from analyses. This procedure was necessary to ensure that models accurately represented selection patterns of a majority of animals and that final model coefficients were not unduly influenced by animals exhibiting atypical behavior.

The average inter-individual coefficient value (and confidence interval) was computed for each covariate (ie. the "two-stage" modeling framework; Fieberg et al. 2010) and stratified by season (winter vs. summer) and study area (East Berners vs. Lynn Canal). Stratification by study area was deemed appropriate because animals in the East Berners study area wintered at slightly higher elevations than those along Lynn Canal. Covariates considered to be significant were evaluated by examining whether confidence intervals for a given covariate included 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) represented a RSF that was proportional to the probability of use of variables $x_1 + x_2 + \ldots + x_n$. The resulting output was then categorized (using the quantile function in ArcGIS10) to characterize areas across the study area that differed in their relative probability of use by mountain goats. The predictive performance of RSF models was validated using k-fold cross validation (Boyce et al. 2002).

RESULTS

Mountain Goat Capture and Collar Deployment

Mountain goats were captured during August–October 2005–2011. Overall, 159 animals (75 females and 84 males) were captured including 7 re-capture events. One hundred and thirty-five animals were fitted with Telonics GPS radio-collars, and 23 animals were fitted with conventional (i.e. non-GPS) VHF-only collars. Analyses were based on data collected from 124 GPS radio-marked mountain goats; adequate data were not collected from the 11 remaining GPS collar deployments. Data collected from the 23 VHF-collared animals were not included in analyses.

GPS System Performance

Overall, 193,681 GPS locations were acquired from the 124 GPS collars included in analyses. This comprised 83% of the total possible GPS fixes attempted (n = 233,497), an acceptable fix success rate. Field testing during 2006 indicated that location dispersion (an index of accuracy) was lowest in open habitats (median = 20.1 m, mean = 28.3 ± 3.0 m, n = 11), intermediate in cliff habitats (median = 46.8, mean = 50.7 ± 15.4 m, n = 3) and highest in forested habitats (median = 40.6 m, mean = 69.7 ± 15.1 m, n = 11). Because remote sensing data layers used for habitat modeling are typically refined to 30 m resolution, these levels of accuracy are acceptable for routine applications.

Wintering Strategies and Elevational Distribution

Nearly 95% of the mountain goats monitored with GPS radio-collars wintered in low-elevation forested habitats. Typically, migration from low elevation winter ranges to alpine summer range commenced in mid-May; females tended to initiate migrations approx. 2 weeks earlier than males on average (Fig. 2). Migration from summer range to winter ranges typically commenced in mid-October and coincided with the first annual significant alpine snowfall event (Fig. 2).

Resource Selection Modeling

Mountain goat resource selection was analyzed separately for the winter and summer seasons based on previously described differences in seasonal altitudinal distribution (Table 2a, 2b). Overall, resource selection was modeled using five terrain variables (Table 2b), with the exception of the East Berners summer model which included three terrain variables (Table 2a). In general, mountain goat selection patterns for most terrain variables were similar during winter and summer; elevation was the only variable for which seasonal selection patterns differed substantially (Table 2a, 2b). Overall, mountain goats selected areas close to cliffs with moderately steep, rugged slopes that had moderate-high solar exposure. Within this context, mountain goats selected low elevation areas during winter and moderate-high elevation areas during summer. Interestingly, mountain goats tended to winter at slightly higher elevations in the East Berners study area relative to the Lynn Canal study areas. In the Lynn Canal area steep rugged terrain often continuously extended from alpine areas to sea level. Whereas, on the east side of Berners Bay steep terrain often terminated at mid-elevation upland areas of moderate slope and less commonly extended to sea level.

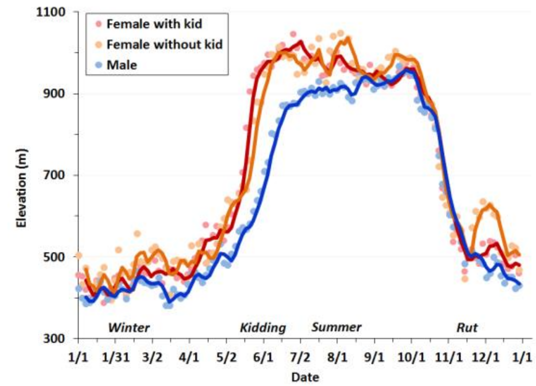

Fig. 2. Elevation distribution on GPS radio-marked mountain goats (n = 124) in relation to time of year, Lynn Canal, AK, 2005-2011. Elevation was calculated by summarizing daily mean values, by individual, and based on GIS estimates via the SRTM digital elevation model.

Despite these general patterns in resource selection it is important to note that individual variation in resource selection was detected such that some individual animals demonstrated resource selection patterns that differed from the majority of animals. For example, the few marked animals in the upper Meade Glacier and Antler

Table 2. Resource selection function (RSF) coefficients for remote-sensing variables used to derive RSF models for mountain goats in the a) East Berners area, Alaska, 2006-2011 and b) Lynn Canal area, Alaska, 2006-2011.

a)

	Winter			Summer		
Variable	Coefficient	LCI	UCI	Coefficient	LCI	UCI
elevation	-2.812129	-4.650915	-0.973344	2.161979	1.764804	2.559154
elevation^2	-2.556290	-3.365947	-1.746633	-2.427439	-2.883036	-1.971843
cliffs	-5.235536	-7.275517	-3.195555	-2.436600	-3.431124	-1.442076
slope	-0.653048	-0.949059	-0.357037	--	--	--
slope^2	-0.233425	-0.441483	-0.025367	--	--	--
solar (Jan 1)	1.376696	0.586528	2.166864	NA	NA	NA
solar (Jan 1)^2	-0.438847	-0.861545	-0.016149	NA	NA	NA
solar (Aug 1)	NA	NA	NA	0.266072	-0.072772	0.604916
solar (Aug 1)^2	NA	NA	NA	-0.265269	-0.429749	-0.100790
VRM	0.173776	-0.174946	0.522499	--	--	--
VRM^2	-0.310421	-0.516873	-0.103968	--	--	--

b)

	Winter			Summer		
Variable	Coefficient	LCI	UCI	Coefficient	LCI	UCI
elevation	-7.424985	-8.805059	-6.044912	1.606339	1.167352	2.045325
elevation^2	-2.946404	-3.644584	-2.248223	-3.326321	-3.640783	-3.011859
cliffs	-1.843572	-2.158784	-1.528361	-0.651351	-0.833230	-0.469473
slope	1.190326	0.974464	1.406187	0.599884	0.413313	0.786455
slope^2	-0.363247	-0.445018	-0.281475	-0.367023	-0.445540	-0.288505
solar (Jan 1)	0.541136	0.235795	0.846477	NA	NA	NA
solar (Jan 1)^2	-0.883769	-1.089006	-0.678532	NA	NA	NA
solar (Aug 1)	NA	NA	NA	0.221452	0.059737	0.383167
solar (Aug 1)^2	NA	NA	NA	-0.221750	-0.325468	-0.118032
VRM	0.722373	0.563777	0.880968	0.233641	0.151278	0.316004
VRM^2	-0.272687	-0.330349	-0.215025	-0.052771	-0.070885	-0.034657

Lake areas wintered at high elevations, a phenomenon that was probably linked to local climate and/or inaccessibility of low elevation forested winter ranges. Consequently, as described previously, it is important to recognize that our models represent "average" resource selection patterns and may not be representative for every animal and specific locality in the study area.

Model validation results indicated that resource selection models accurately predicted actual use patterns of GPS-marked mountain goats (Table 3a, 3b). The Lynn Canal models tended to perform better than models for East Berners. Since the Lynn Canal models were developed with substantially more mountain goat GPS location data it is not surprising that the Lynn Canal models more accurately predicted actual use patterns than the East Berners models. The winter model for East Berners was characterized by the lowest performance (though validation results still indicated a significant relationship between actual and predicted use). This occurred because the model tended to under-represent use in some areas (i.e. areas with low RSF scores were used more than predicted). Consequently, the winter modeling output for the East Berners area should be considered a conservative representation of actual mountain goat winter use and distribution in this area.

DISCUSSION

Elevational Distribution

Along the Pacific coast, mountain goats exhibit elevational migrations from alpine summer range to low-elevation, forested winter ranges where snow depths are relatively reduced (Herbert and Turnbull 1977, Fox et al. 1989). This pattern

Table 3. Resource selection function (RSF) model validation results for the a) Lynn Canal area, and b) East Berners area, relative to season. Cross-validated Spearman-rank correlations (r_s) between RSF bin ranks and area-adjusted frequencies for individual and average model sets reported below provide an indication of the extent to which RSF models accurately predicted actual use of iteratively withheld data from GPS-marked animals.

a) Lynn Canal

	Winter		Summer	
Set	r_s	*P*-value	r_s	*P*-value
1	0.99	<0.001	0.99	<0.001
2	1.00	<0.001	1.00	<0.001
3	0.99	<0.001	0.99	<0.001
4	1.00	<0.001	0.99	<0.001
5	0.96	<0.001	1.00	<0.001
Average	0.77	0.014	0.99	<0.001

b) East Berners

	Winter		Summer	
Set	r_s	*P*-value	r_s	*P*-value
1	0.66	0.044	0.99	<0.001
2	0.88	0.002	0.61	0.066
3	0.19	0.608	0.96	<0.001
4	0.79	0.010	0.99	<0.001
5	0.94	<0.001	0.96	<0.001
Average	0.77	0.014	0.99	<0.001

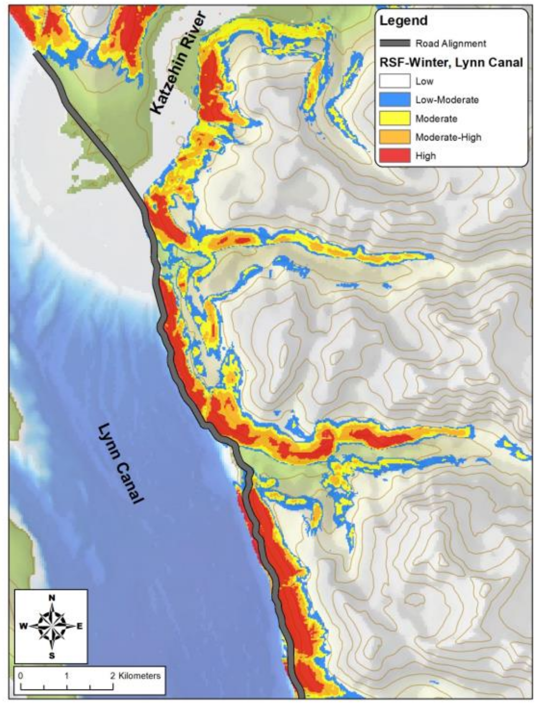

Fig. 3. Resource selection function modeling output describing mountain goat winter range in the Lynn Canal area. The area juxtaposes the proposed highway alignment and predicted mountain goat winter habitat. The map encompasses an area near the Katzehin river mouth, near the northern terminus of the proposed highway and is included for illustrative purposes.

contrasts with mountain goat populations in colder, drier (generally interior) climates where mountain goats typically winter at high elevations on windblown slopes. In our study area, nearly all animals exhibited migrations to low elevation habitats between 300–450 m, on average (Fig. 2). In some instances, particularly along Lynn Canal, mountain goats spent considerable time below 150 m, including several cases where animals wintered in close proximity to high tide line. In contrast, in a few isolated instances (n = 7) mountain goats in specific locations wintered at high elevations. This was likely linked to colder, drier and windier climates in these areas and/or restricted access to warmer, less snowy coastal wintering habitats. Nonetheless, nearly 95% of the mountain goats monitored with GPS radio-collars in this study wintered in low elevation forested habitats.

Resource Selection Modeling

Our analyses described 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) and elsewhere (Festa-Bianchet and Côté 2007). 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 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 reduces 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

Table 4. Proportion of the proposed highway that transects mountain goat winter habitat in the Lynn Canal and East Berners areas, Lynn Canal, AK, 2005-2011. Resource selection function (RSF Categories) were binned using the quantile function in ArcGIS 10 and intended to represent biological meaningful delineations for management and planning purposes.

		Lynn Canal		East Berners	
RSF Bin	RSF Category	km of road	Proportion	km of road	Proportion
0	Not Habitat	14.2	0.22	1.0	0.05
1	Low	19.4	0.31	18.5	0.92
2	Low-Moderate	4.6	0.07	0.5	0.03
3	Moderate	5.2	0.08	0.1	0.00
4	Moderate-High	8.4	0.13	0.0	0.00
5	High	11.7	0.18	0.0	0.00
Total		63.5	1.00	20.1	1.00

above high tide line (Fig. 3). In eastern Lynn Canal, 25.3 km of the highway alignment intersected areas in the "moderate" to "high" RSF categories (Table 4). However, in other localities, such as east of Berners Bay, steep terrain did not consistently extend to sea level, and mountain goats winter at slightly higher elevations, on average.

MANAGEMENT IMPLICATIONS AND RECOMMENDATIONS

Human Access

The construction of the Juneau Access highway would result in increased human access to areas determined to be high value mountain goat habitats. Increased human access (i.e. recreational and industrial) will increase the potential for disturbance of mountain goats, particularly in low-elevation wintering habitats. However, perhaps more importantly, large numbers of hunters from Juneau (population: 31,000) will be afforded unprecedented access to high quality mountain goat range. Such access will result in difficulties managing harvest quotas under existing (registration hunt) regulations; similar to outcomes resulting from construction of the Skagway-White Pass highway (30 km north of the present study) in the 1970s (Ryan Scott, ADFG, pers. obs.). Following road construction, hunting opportunities in this area should be regulated using more restrictive limited-entry drawing hunts in order to avoid overharvest. In addition, smaller more geographically distinct hunt areas should be created to avoid localized depletion of mountain goats. Regulations should also take the timing of winter migration into account, as animals will be particularly vulnerable in overwintering areas near the road corridor. Finally, a specific management strategy should be considered for areas in the vicinity of Haines in order to respect and to maintain traditional harvest patterns.

Post-construction Highway Effects

As described above, findings from this study documented spatial overlap of the Juneau Access highway corridor and high value mountain goat wintering habitat. In such areas the probability of lethal and sub-lethal (i.e. Frid and Dill 2002) highway effects on mountain goats will increase following highway construction. Such effects should be carefully documented and explicitly integrated into mountain goat harvest strategies. For example, coordination between the ADFG and law enforcement agencies will be required to accurately document mountain goat-vehicle collisions and reduce harvest quotas accordingly. In order to assess the extent to which sub-lethal effects alter population size and productivity future studies are recommended that compare the existing baseline data to comparable data collected during and after construction of the highway. Such studies would help wildlife managers determine how the highway affects mountain goat habitat use and population dynamics and, ultimately, ensure that local mountain goat populations are managed in a manner that explicitly incorporates sub-lethal effects.

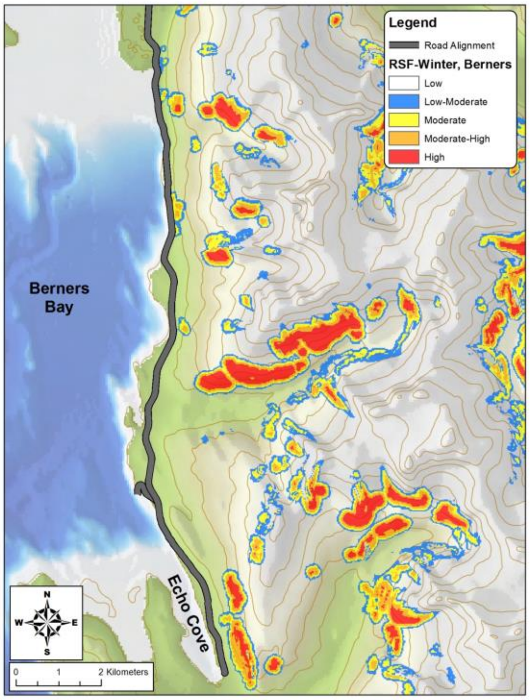

Fig. 4. Resource selection function modeling output describing mountain goat winter range in the East Berners area. The map encompasses an area east of Berners Bay, near the southern terminus of the proposed highway, and is included for illustrative purposes and juxtaposes the proposed highway alignment and predicted mountain goat winter habitat.

Mountain Goat-Vehicle Collisions

The Alaska Department of Transportation and Public Facilities (DOT/PF) has a stated interest in reducing or mitigating the likelihood of mountain goat-vehicle collisions along the Juneau Access highway, in the event it is constructed. Findings from this study indicated that highway alignment intersects areas of moderate-high mountain goat winter use (i.e. 25.3 km) along eastern Lynn Canal and, to a lesser extent, east of Berners Bay (Table 4, Figs. 3, 4). Consequently, to mitigate mountain goat-vehicle collisions DOT/PF should concentrate mitigation and design efforts in the eastern Lynn Canal and Berners Bay areas. Mountain goat-vehicle collision risk is only prevalent during the winter months (November–early May). During this season periods of reduced daylight and poor driving conditions may result in increased difficulty seeing and avoiding animals in low-light conditions. Appropriate design strategies for reducing mountain goat-vehicle collisions would involve, but are not limited to, "wildlife crossing" signage, reduced speed limits, structural design features (i.e. Singer et al. 1985, Clevenger and Huijser 2011) and adequate sight lines to enable drivers to see mountain goats that are in close proximity to the road (particularly relevant in conifer forest areas). Ultimately, fine-scale highway design that integrates field visits to identify traditionally used mountain goat trails, mountain goat GPS location data and geotechnical highway construction constraints is recommended in order to maximize efficacy of mountain goat-vehicle collision planning and mitigation. Such site-specific analyses was beyond the scope of the current study but is recommended via future collaboration between ADFG and DOT/PF.

Avalanche Control

Avalanche chutes are prevalent along the eastern side of Lynn Canal and Berners Bay and intersect the highway alignment in many areas. Human safety concerns require avalanche control activities upslope from the road corridor in areas adjacent to or currently used by mountain goats during winter. Avalanche control activities (ie. helicopter surveillance, blasting) will cause significant disturbance to mountain goats in such areas. Further, because mountain goats occasionally forage in avalanche chutes during winter (including during times of high avalanche danger) the likelihood exists for mountain goats to be killed in human-instigated avalanches that occur during routine control activities. Such direct mortalities could be mitigated if avalanche control crews examined avalanche chutes for the presence of mountain goats prior to blasting and adjusted avalanche control scheduling to occur during times when mountain goats were not present in avalanche paths.

Monitoring Efficacy of Recommendations

The above mentioned mitigation strategies are designed to reduce the impact of road construction, maintenance , and continued use on mountain goats, via direct mortality or indirect reduction in productivity. However, implementation success is uncertain based on limited previous study. Detailed post-development studies designed to determine effectiveness of site-specific mitigation prescriptions are recommended to ensure mitigation strategies are optimized for reducing mountain goat-vehicle collisions, overharvest, and mortality from avalanche control. Such monitoring studies could identify and remedy any site-specific issues, and could be used to inform future road building projects that potentially impact mountain goats and their habitat.

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