Habitat Selection by Mountain Goats in South Coastal British Columbia

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Abstract: We analyzed data from 18 Global Positioning System collars from 2001 to 2003 in southwestern coastal British Columbia to improve understanding of mountain goat (*Oreamnos americanus*) habitat use and its relation to forestry operations. We described seasonal home ranges, movements, and winter habitat selection patterns to predict winter habitat use in similar geographic areas. Seasonal periods were determined for individual goats by observing shifts in elevation use. We used a Geographic Information System (GIS), digital forest cover mapping, and a 25-m raster digital elevation model (DEM) to determine habitat selection at 2 different scales. At a broad scale of selection, we pooled locations from 18 goats and conducted chi-square analyses. At a fine scale of selection, we used logistic regression to determine resource selection functions (RSF) for 15 individual goats. We used an information theoretic approach (Akaike's Information Criterion) to select the most likely models from an *a priori* set of candidate models to determine biological factors driving coastal winter habitat selection. We averaged selection coefficients from individual RSFs in a second-stage analysis to develop predictive maps of relative likelihood of use across the study area. Use of younger forests was greater than expected, particularly among male goats, and was largely associated with previously-burned stands 20 to 40 yr old. However, use of mature and old forests was relatively high for both sexes and was higher for males (42%) than for females (29%). Presence data was best fit by global models. Selection coefficients of RSFs were relatively consistent but variable for forest volume. At the fine scale, males were consistently associated with higher forest volume and older forest age. Females were more often associated with older forest age yet with lower forest volume.

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British Columbia has the greatest area of natural mountain goat habitat in North America and supports over half of the world's population of mountain goats (Krausman 1997). The species is classified provincially as yellow-listed (of management importance) because of its regional importance and special management interest. Mountain goats exhibit behaviours associated with 2 ecotypes in British Columbia, one associated with drier snow conditions in the interior and another associated with wetter coastal climates. The coastal ecotype winters at relatively lower elevations and has been associated with old forests and steep slopes (Hebert and Turnbull 1977, Schoen et al. 1980, Fox 1983, Smith 1994). One of the main management concerns for coastal populations is associated with forest harvest trends. As practices such as heli-logging allow harvest of marginal habitats at higher elevations, this may conflict with goat habitat.

Our objectives were to learn more about movement patterns and seasonal habitat use by goats in southern coastal British Columbia. Further, we wanted to determine the characteristics of winter habitats selected by goats, predict goat habitat use on the landscape, and relay information to coastal forest managers. Our goals included determining seasonal home ranges of collared goats, movement patterns, and use of habitat categories and attributes, particularly within forested habitats. We also created a multivariate model to allow wildlife managers to predict seasonal use of winter goat habitat and identify driving factors in goat habitat selection. Given that the province is finalizing legislated ungulate winter range for mountain goats, this information is beneficial in designing such areas.

Study area

The study area, centered near Bute and Toba Inlets of the Sunshine Coast Forest District (SCFD) of British Columbia, was situated approximately 200 km northwest of Vancouver on the southern mainland coast (Figure 1), west of Vancouver Island. These fiord inlets consist of steep sidewalls and extend up to 25 km inland to glaciated areas. Typical drainages range from approximately 4 to 10 km wide, peak to peak, and elevations ranged from sea level to approximately 2700 m. Logged areas occurred in lower valley positions of most drainages. The study area was situated in the southern portion of the North Pacific Range ecosection, where the following biogeoclimatic zones occurred: the Coastal Western Hemlock Zone, Mountain Hemlock Zone and Alpine Tundra (Green and Klinka 1994). Forests occurred in montane and submontane ecosystems. Forest types consisted mainly of Douglas-fir (*Pseudotsuga menziesii*) and western red cedar (*Thuja plicata*) in the drier subzone variants, western hemlock (*Tsuga heterophylla*) and amabilis fir (*Abies amabilis*) in the cooler, wetter variants, and mountain hemlock (*Tsuga mertensiana*) and amabilis fir in the Mountain Hemlock Zone.

Methods

Global Positioning System (GPS) collaring: We attempted to randomly select animals from within independent social groups. However, safe capture sites limited the selection procedure; steeper coastal headwalls, particularly associated with the northern shores of the Toba Inlet, were excluded from potential capture sites. Using aerial net gunning from helicopter, crews captured 24 mountain goats from November 2 to 6, 2001 and on September 11, 2002 in 12 different drainages.

We used two types of GPS collars: model G2000 (Advanced Telemetry Systems, Inc., Isanti, Minnesota, USA) on 11 female and 4 male goats, and model 2200R (Lotek Wireless Inc., Newmarket, Ontario, Canada) on 6 female and 3 male goats. The former collar fix schedules were designed to permit 2 yr of observations at a

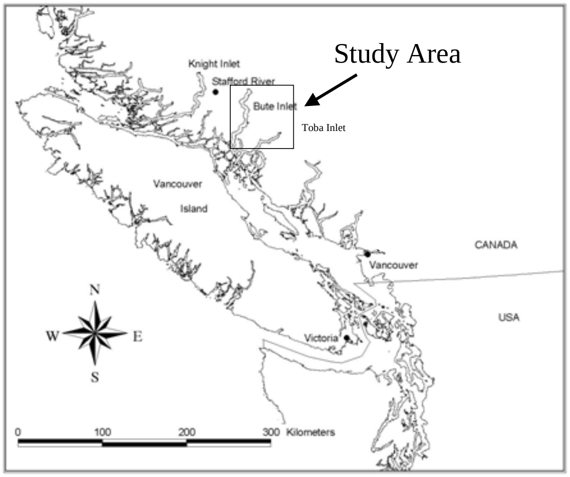

Figure 1. **Approximate location of study area near Bute and Toba inlets, B.C.**

fix-attempt rate of 3 locations per day, while the latter were designed to allow 1 yr of observation at 8 fix-attempts per day. GPS data from another 4 mountain goats in adjacent Stafford Valley (Taylor 2002) were used for range size determination and to assess potential risk of harvest related to slope. To ensure accuracy of locations, we discarded all GPS locations with positional dilution of precision (PDOP) greater than 10. GPS fix-rate bias can lead to inaccurate or incorrect habitat selection interpretations (Moen et al. 1996, 1997; Rempel et al. 1995; Dussault et al. 1999, 2001; Taylor 2002; Frair et al. 2004) but may not pose large problems for studies in environments with less-variable fix likelihood (D'Eon et al. 2002). We used three-dimensional and two-dimensional fix locations to maintain large sample sizes and minimize GPS fix-rate bias (Taylor 2002) based on testing GPS collar performance, modeling fix-rate with GIS over the landscape, and applying correction weights to each goat location, as described in Taylor et al. (2004).

We assigned locations for each goat into 1 of 2 seasons (winter or non-winter), dependent upon whether the animal was in a high- or low-elevation portion of its home range. From our Digital Elevation Model (DEM), we recorded the elevation associated with each goat location and calculated the weekly mean elevation per animal per year. Weekly means were averaged, and 3-wk running means calculated. Individual winter periods were determined from the largest weekly shifts in the range of weekly-elevation shifts.

We used ArcGIS 8.3, ArcView 3.2 (Environmental Systems Research Institute, Inc.) and custom-developed scripts for GIS analysis. MELP KID (ArcView 3.2 extension, BC Ministry of Environment, Lands and Parks) was used to convert geographic co-ordinates (datum 186 World Geodetic System 1984) and UTM (North American Datum 1983 (NAD 83), zone 10) projections to BC Albers Standard Projection (datum NAD 83, BC Ministry of Sustainable Resource Management). Range data for goats were analyzed with the ArcView extension Animal Movement (Hooge et al. 2002). We used base topographic layer data from 1:20 000 BC terrain resources information management files (TRIM). We created a triangular irregular network DEM using ArcGIS 8.3 and mass points as an input, followed by raster conversion. To analyze topographic attributes, we used 6 terrain variables derived from DEM: elevation, slope, slope position, distance to escape terrain, terrain ruggedness, and insolation (solar loading). From 1:20,000 forest cover inventory data (Ministry of Forests 1995), we used 5 forest cover variables including biogeoclimatic variant, habitat class (Table 1), leading species, net primary forest stand volume, and forest crown closure. We produced a 25-m grid cell raster for each variable and spatially linked values with GIS to all winter goat locations.

Table 1. Definitions of codes used in chi-square tables.

Forested habitat variable	Description
Other	No typing available, non-sufficiently restocked forest
NPF	Non-productive forest
Early	Forest (<40 yr)
Young	Forest (40-80 yr)
Mature, open	Forest (81-250 yr, <50% crown closure)
Mature, dense	Forest (81-250 yr, >50% crown closure)
Old, open	Forest (>250 yr, <50% crown closure)
Old, dense	Forest (>250 yr, >50% crown closure)

We estimated escape terrain on the landscape by deriving polygons based on DEM slopes greater than 50° (119%), consistent with a coastal habitat model from Alaska (Smith 1994). The ArcView script nearfeat.avx was used to determine distance (m) from goat locations and available locations to nearest edge of an escape-terrain polygon. We used the script shortwavc.aml to calculate insolation, or amount of potential (clear-sky) direct solar radiation for a given raster cell over a given time period (Kumar et al. 1997), and accounting for hill shading at hourly intervals. We calculated mean daily insolation (kj/m^2/day) for 3 time periods (November-December, January-March, and April-May) and then selected the period which best fit mountain goat presence data, using a data-dredging technique (highest R^2 value).

Because we were most interested in mountain goat habitat selection in relation to forestry, we focused analyses on habitat use during winter. We conducted 2 main analyses at different scales. In the first analyses, we determined habitat selection at Johnson's (1979) second order of selection by analyzing goat selection of winter ranges from the study area. We obtained a census of available units by systematically sampling from a 50-m grid of the study area defined by determining the minimum convex polygon from all goat locations. We conducted modified chi-square tests (Neu et al. 1974) for all variables. We pooled animals by sex, and used Bonferroni confidence intervals (Byers and Steinhorst 1984) to determine habitat categories significantly selected. We briefly report on the most important findings from this analysis; additional details are provided in Taylor et al. (2004).

In the second analyses, we assessed finer habitat selection at Johnson's (1979) third order of selection by using stand selection within individual goat home ranges. We calculated multivariate logistic regression resource selection functions (RSF) for individual goats (Manly et al. 2002) to predict relative likelihood of goat use. We obtained a census of availability by systematically sampling from 25-m raster cells within each goat's 95% adaptive kernel range. Goat locations were weighted for low values of GPS fix likelihood. A GPS location was classified as 1 for dependent variable presence and 0 for available location.

We created an *a priori* set of candidate models (Taylor et al. 2004) associated with different biological requirements of goats, including security from predators, thermoregulation, and snow avoidance, and from previous models from the literature (Smith 1994, Gross et al. 2002). To maintain a high number of locations per variable, we kept the number of model parameters to a minimum. Before creating candidate models, we tested for multi-collinearity of input variables and did not use more than 1 variable in 1 model when Pearson's correlation values were greater than 0.7 (Tabachnick and Fidell 1996). Forest variables including age, crown closure and volume, and topographic variables including slope position and elevation were collinear.

We then used Akaike's Information Criterion (AICc; Burnham and Anderson 1998) based on maximized log-likelihood values to select the model most likely to best fit the presence data. Analyses were conducted for 8 females and 7 males. We ordered models in relation to fit and calculated weights of evidence suggesting which model was the best inference. We also used AIC weights to compare model weights relative to one another. From individual RSF models (first-stage analysis), we made inferences to the population of goats (second stage analysis), by averaging *B* coefficients across individuals (Manly et al. 2002). This enabled us to calculate an average RSF model per cohort (males and females). To assess accuracy of RSFs, we estimated standard error of coefficients across all models using n-1 degrees of freedom and standard deviation of n individual estimates (Manly et al. 2002).

To approximate potential harvest risk, we determined the amounts of old and mature forests present within the winter ranges of 22 goats. We then used GIS to link the slope classes associated with these forests. Although many factors (including market economics, terrain stability, soil moisture, and site regenerative ability) determine the potential harvest of forests, slope class is one of the major factors associated with forest operability in coastal environments.

Results

General goat movement patterns

Eighteen complete datasets gathered from 24 collared goats included 4496 annual female observations and 5199 annual male observations, and 2430 male winter observations and 2605 female winter observations. Seven goats died of natural causes and 2 of capture myopathy. Of the natural mortalities, 2 females died as a result of avalanches and wolverine tracks and scat were observed at 2 other mortality sites.

Individual fix success differed widely during the winter. Overall winter fix success for 6 goats with Lotek collars ranged from 13.2% to 60.5% and averaged 37.8%, and for 12 goats with ATS collars ranged from 10.8% to 42.4% and averaged 25.4%.

We observed a distinct shift in elevation use by goats (Figure 2). Although they generally remained at high or low elevations during a given seasonal period, goats shifted between low and high elevation within a relatively short period from the second week of May to the first week of June (weeks 18 and 23; Figure 3). Goats descended to lower elevation habitats during a slightly longer period from the first week of November to the second week of December (weeks 44 and 51; Figure 3).

Movements along valleys during winter ranged from 0.9 to 5.5 km for females (average 2.3 km) and 1.4 to 4.3 km for males (average 2.8 km). Complete annual movements for 7 females ranged from 2 to 6 km, and for 6 males from 3 to 10 km. Except for elevation shifts and movements associated with rutting, where male goats moved up to 6 km from

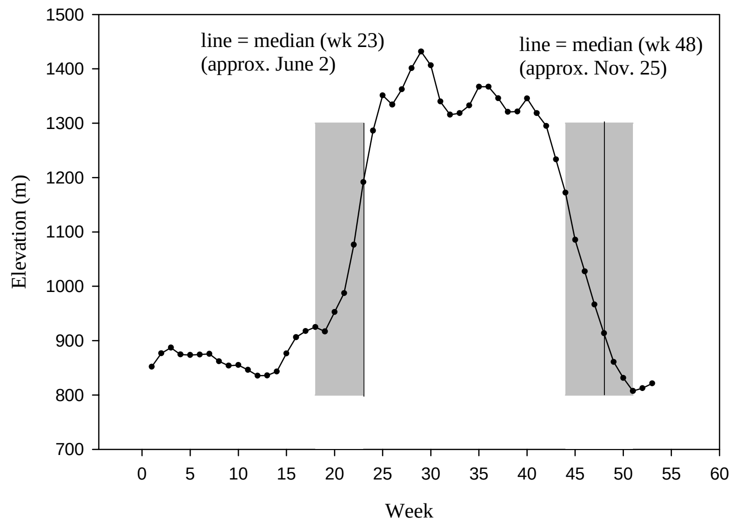

Figure 2. Three-wk running mean of elevation used by goats in coastal British Columbia. (Shift period in grey)

November to December, goat habitat use remained in close proximity (~2 km) to winter habitats. Females with kids did not move from typically-used winter areas. Few goats crossed into other drainages. Consistent seasonal trends in shifts of aspect were not observed, and most seasonal ranges were located on southerly aspects.

Neither winter nor annual range size differed by sex (t = -1.367, p = 0.183; t = -1.926, p = 0.069). Mean winter range size was 140 ha for females and 271 ha for males. Seventy-five percent of winter ranges were less than ~184 ha for females and 270 ha for males (Figure 4). Mean annual range size was 295 ha for females and 544 ha for males. Seventy-five percent of annual ranges were less than ~440 ha for females and 800 ha for males (Figure 4). Some of the mean differences were likely attributable to greater male movements during the rutting period.

GPS datasets with complete winter data for two years were available for 6 individuals (4 females and 2 males). Overlap of winter ranges both years was high; 3 of 4 females (Figure 5) and 2 of 2 males (Figure 6) exhibited nearly identical use from one winter to the next. In some cases forest polygons in which goats showed high site fidelity were only several hundred meters wide.

Tests of the 2 types of collars showed that Lotek and ATS GPS collars differed markedly in fix-rate bias (different likelihood of receiving a location from a given fix attempt), depending on the GPS-fix environment (forest and terrain characteristics). To ensure that our selection analyses were properly interpreted, we independently corrected fix-rate bias for each collar type (Taylor et al. 2004).

Broad scale winter habitat selection - chi-square analyses

Positive habitat selections occurred when use exceeded availability. We present selection analyses only for those variables later included in final multivariate models; further analyses are presented in Taylor et al. (2004).

Forty-two percent of male goat use occurred in mature or old forest, compared

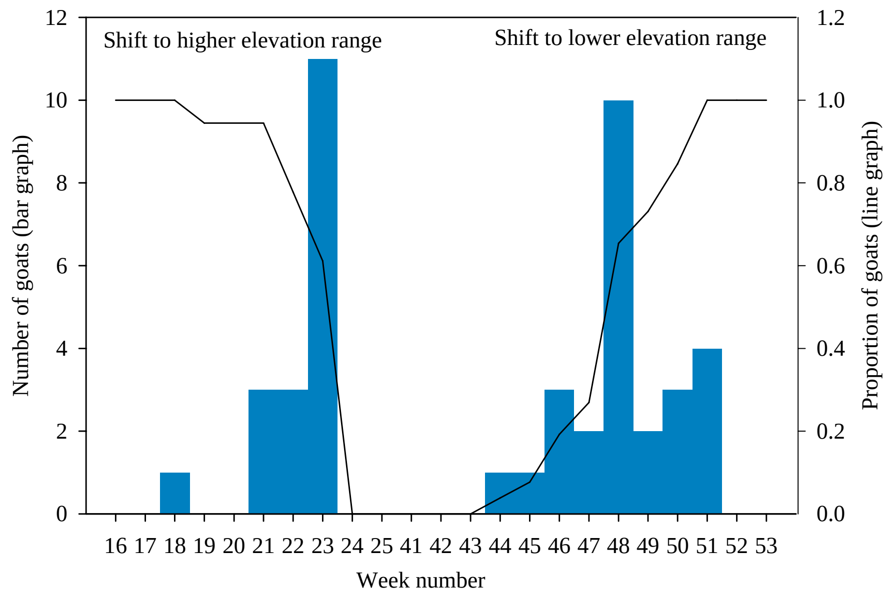

Figure 3. Elevation shifts by mountain goats in coastal British Columbia.
By wk 48, 70% of goats shifted to lower elevation and 10 goats shifted that wk.

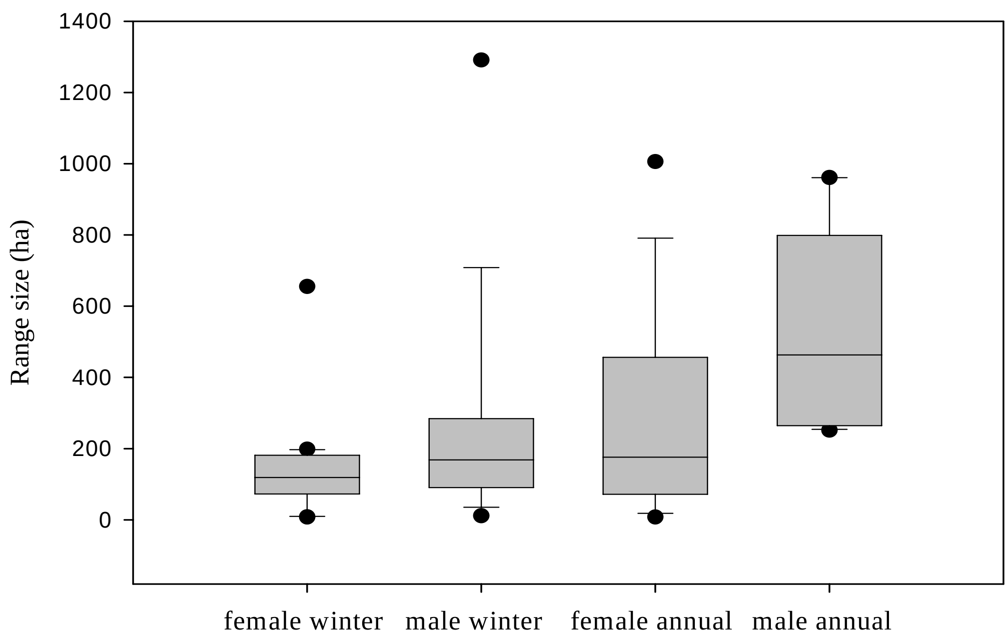

Figure 4. Seasonal and annual mountain goat home ranges in coastal B.C., November 2, 2001 to August 25, 2003. Each box outlines the 25th , 50th , and 75th percentile (lower, upper, and median lines, respectively) Whiskers indicate 10th and 90th percentiles. Black points represent outliers.

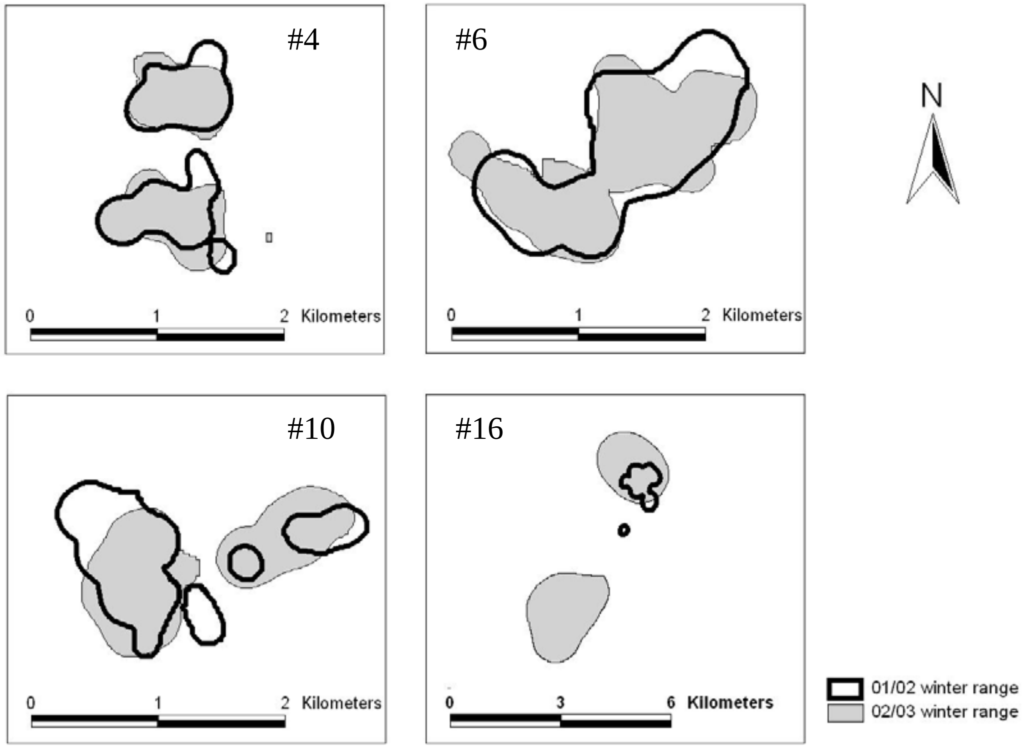

Figure 5. Winter home ranges of 4 female mountain goats in coastal B.C., 2001/2002 and 2002/2003.

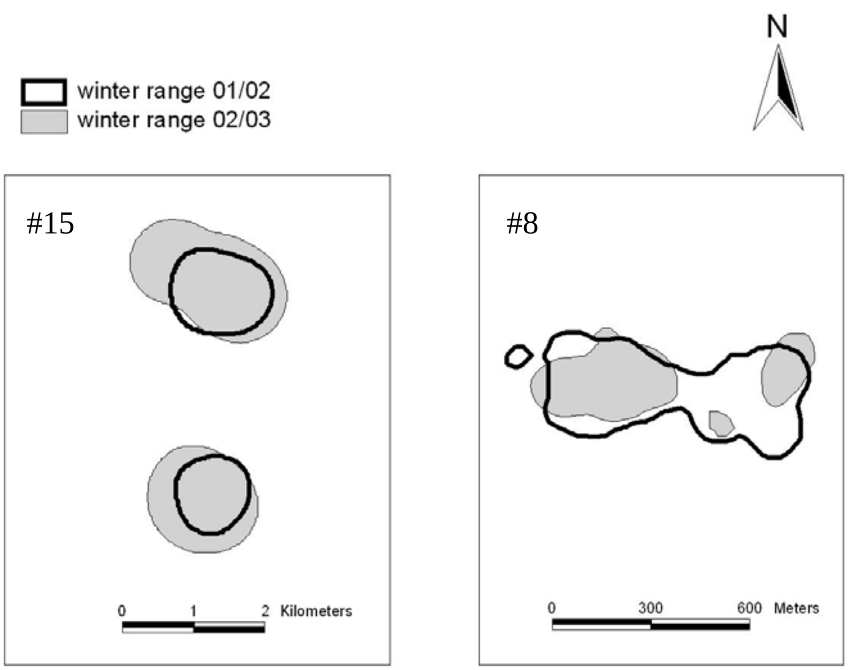

Figure 6. Winter home ranges of 2 male mountain goats in coastal British Columbia. Movements likely associated with rut were removed.

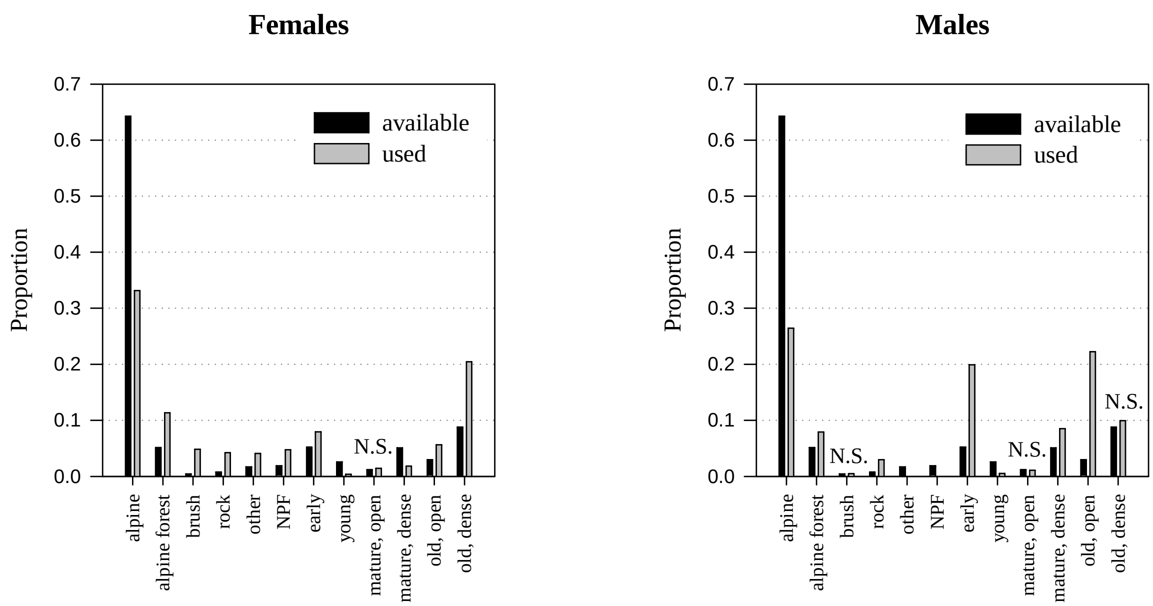

Figure 7. Selection of habitat classes by female and male mountain goats

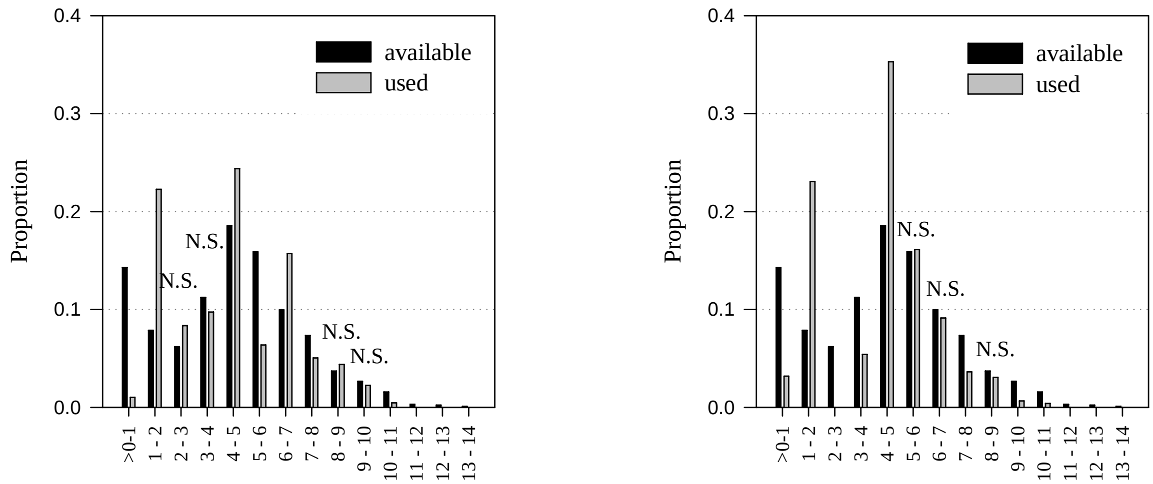

Figure 8. Volume classes selected by female and male mountain goats (in 100's m3/ha)

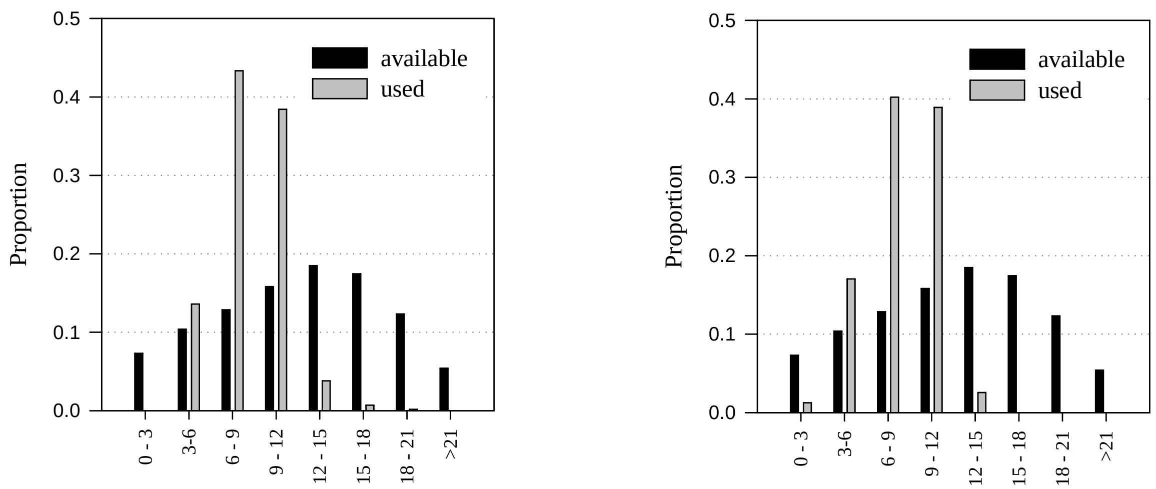

Figure 9. Elevation classes selected by female and male mountain goats (in 100 m's)

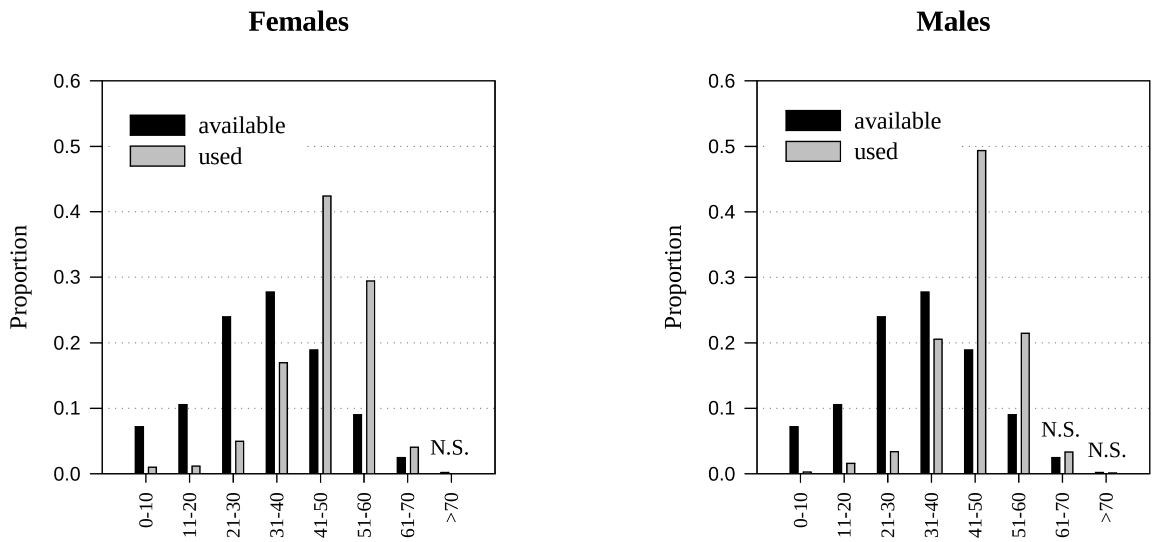

Figure 10. Slope classes selected by female and male mountain goats (in degrees)

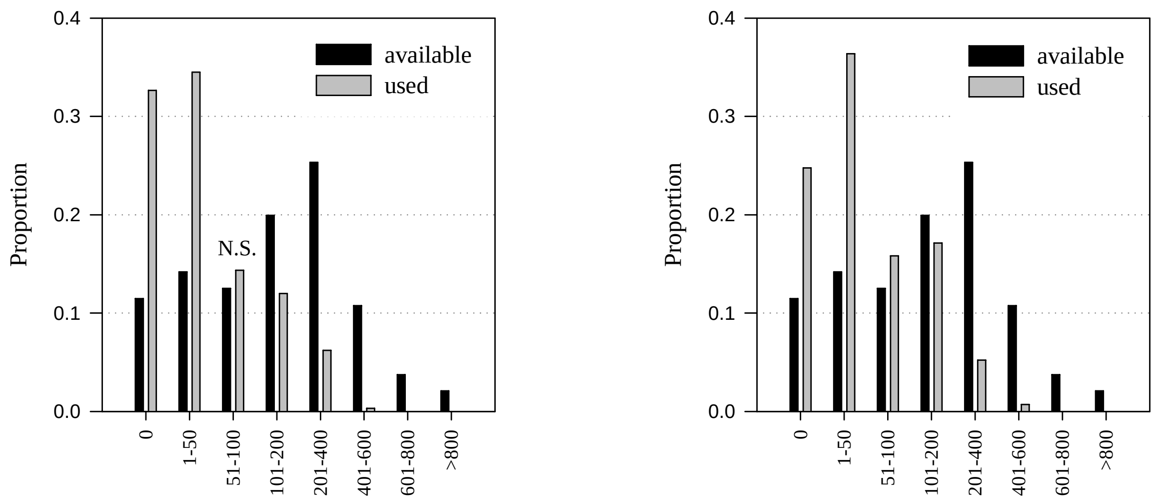

Figure 11. Selection for distance to escape terrain by female and male mountain goats (in m)

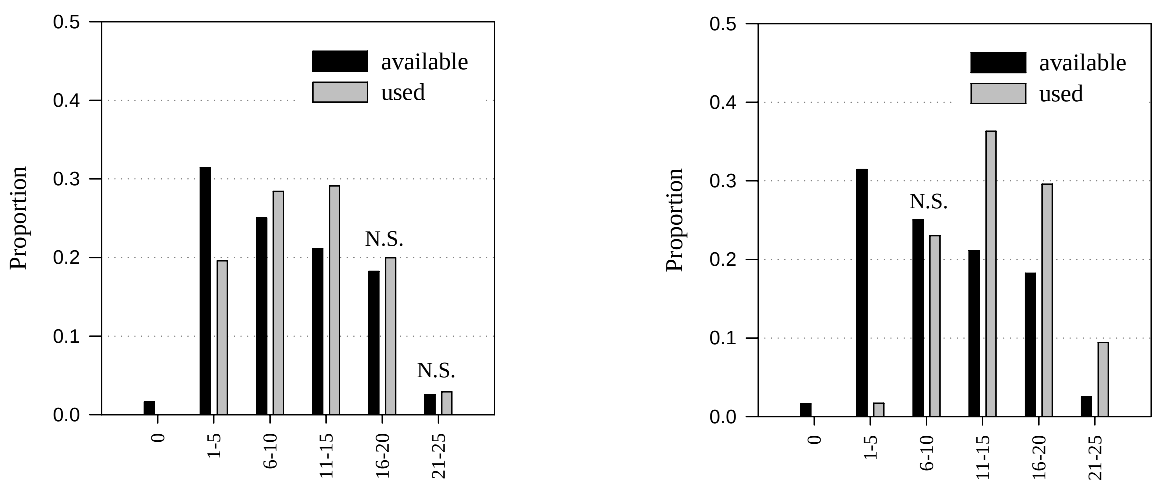

Figure 12. Selection for insolation by female and male mountain goats (in kj/m2/day)

to 29% of female goat use. When located in mature or old forests (>80 yr), females most frequently used old, dense forests (>250 yr) while males most frequently used old, open forests (Figure 7). Unexpectedly, 8% of female locations and 20% of male locations were observed in early forest (<40 yr). Mountain goats also made frequent use of alpine habitat (largely avalanche tracks). Although the rate of use was 33% for females and 26% for males, alpine habitat was used less than its large availability.

At the broad scale of analysis, we did not observe a strong linear trend between forest-stand volume and mountain goat use (Figure 8). The largest use occurred in average and below-average volumes, and goats did not use the lowest volume class.

Both sexes selected elevations between 300 m and 1200 m (Figure 9). Males and females positively selected slopes between 41° and 60° (Figure 10). Females also selected slopes from 61° to 70°. A clear relationship emerged between distance to escape terrain and habitat use by goats (Figure 11). Both sexes made positive selections for habitats within escape terrain polygons and within 50-m distance from these polygons. Males selected habitats within 100 m of escape terrain polygons; females showed neutral selection for these habitats. Goats were negatively associated with habitats greater than 100 m from escape terrain. The solar loading winter period between January and March best fit presence data of both sexes. Both females and males selected habitats associated with relatively high solar loading (Figure 12).

We analyzed location data to determine the disturbance factors associated with early forest (20-40 yr). Goats occurred in this forest category in 25 polygons originating from only 2 female and 2 male goats. The disturbance associated with 16 of these polygons (64%) was attributable to disturbance burns, 1 to a site preparation burn, 4 due to logging, and 4 unknown. The winter home ranges of 7 of the 18 goats included areas that had been logged, especially near the border of a home range. However, goats also occurred in logged areas of 2 home ranges where no wildfires occurred.

Fine scale habitat selection – logistic regression resource selection functions

Global models that included all variables were the favoured models for all 15 goats analyzed at the fine scale (Taylor et al. 2004). Selection for the global model was definitive for 12 of 15 goats (i.e., no competing models within evidence ratios; Burnham and Anderson 1998). For the remaining 3 goats, small weight of evidence ratios (1.2, 1.3, 17.4) indicated that snow interception was a plausible alternate model. Global models that included forest volume were more likely models for 10 of 15 goats, and 5 of 15 models favoured stand age instead of volume. Of the 10 volume models, 2 were nearly equivalent in stand age, where volume was 1.1x and 1.5x more likely to be the best model. Crown closure was much less likely to be the best model to predict presence.

Distance to escape terrain was an important factor in all models.

The most consistent trend in variable selection for global models was distance to escape terrain. In model #3B (Table 2, *and see* Taylor et al. 2004), the largest coefficients (positive) and log odds ratios were associated with insolation. Log odds ratios describe the change in likelihood of habitat use by mountain goats given a unit change of a particular variable (i.e., in model #3B, male goats are almost 3 times more likely to use a given habitat unit during winter when there is a 5 unit increase in insolation ($k^2/m^2/day$)). Relatively consistent trends also were observed with associations for lower elevations in goat annual ranges.

Coefficients for slope were relatively variable among individuals, but were more often observed as positive. Associations between goat presence and forest volume were less consistent. Males had positive associations with forest volume in 6 of 7 cases, while females had negative associations in 5 of 8 cases. However, negative associations tended to be in areas of burned habitats. Both sexes showed relatively consistent positive associations with forest age.

Data on forest volume were not available for all polygons throughout the study area. For this reason, and because evidence for model selection was equivocal between 3A and 3B, we used the global model that included forest age as a predictive tool. Although 5 of 8 female goats had positive associations with forest age, the high coefficients of the 3 females showing negative associations resulted in a negative average for the age variable. To account for the selection of forest age shown by the majority of females, and to map the likely forest use by goats, we removed these 3 females from the average RSF calculation.

On average, ~30 ha of old and mature forest were found within each goat winter home range. Based on slope class alone, 22% of old and mature forests had a high potential risk of harvest, whereas ~31% was greater than 100% slope and therefore considered at no harvest risk (Table 3). The remaining terrain was difficult to assign harvest risk without further information.

Discussion

This project is the first study of coastal mountain goats to analyze habitat selection for individual goats in a multivariate nature. Our datasets provided a high level of detail of goat movement patterns. Although many of our conclusions support previous concepts of goat habitat use, some unexpected results emerged. The development of a predictive tool for goat habitat will enhance the ability of managers to identify goat habitat throughout the landscape and to model habitat supplies under various disturbance scenarios. The refinement of our understanding of goat-habitat attributes should provide management direction and aid identification of winter range for mountain goats on the south coast of B.C..

Table 2. Resource selection function data from averaged winter resource selection function models for 12 mountain goats in coastal B.C. (Model #3B). For example, for every 25m distance from escape terrain, a landscape unit is 0.8 times as likely to be used by a mountain goat during winter.

		7 males			5 females		
Variable	Unit of change	Coefficient Average	Log odds ratio	Standard Error x	Coefficient Average	Log odds ratio	Standard Error x
Distance	25	-0.008	0.8	0.075	-0.008	0.8	0.200
Elevation	200	-0.003	0.5	0.600	-0.002	0.7	0.600
Slope	15	0.000	1.0	0.120	-0.002	1.0	0.090
Insolation	5	0.211	2.9	0.760	0.146	2.1	0.730
Age*	25	0.004	1.1	0.100	0.002	1.1	0.175
Constant		-2.651			-1.634		

*3 female mountain goats with negative forest age coefficients not included.

Table 3. Risk of harvest of old and mature forests in mountain goat winter home ranges in coastal B.C..

Slope category (%)	Old + mature forest (%)	Harvest risk	Rationale in relation to slope class
<60	21.6	high	No terrain assessments required
60-80	21.7	moderate	Terrain field assessment required if terrain mapping not available
80-100	26.2	low	Terrain field assessment required if terrain mapping not available
>100	30.5	nil	Excessively steep slopes

The variability of forest cover types used by mountain goats during winter was unexpected. Some goats selected habitats previously considered marginal for snow interception (e.g., low crown closure) even when snow was relatively deep. During winter, second-growth forests associated with burns were used more frequently than expected, and in a few cases, clearcut habitats were used. Surprisingly, some goats did not use old or mature forest cover during the entire winter period. This area, as well as the majority of second growth habitats used by goats, consisted of forests 20-40 yr after burns. Although goats forage in clearcut habitats during summer (Gilbert and Raedeke 1992), our study is the first to document such use during winter. Similar findings were seen in ongoing research in Washington (C. Rice, Washington Department of Fish and Wildlife, personal communciation). This use likely coincides with low snow levels.

Burns provide short-term benefit to ungulates in the form of increased living vegetative biomass (Ruckstuhl et al. 2000) and nitrogen uptake by vegetation (Shaw and Carter 1990, McWhirter et al. 1992), and also may increase the proportion of palatable diet items over a longer period by preventing succession (Carlson et al. 1993). There are likely 2 reasons goats used burns in our study area: forage-related benefits and snow-free areas during winter.

Similar to previous studies (Fox and Smith 1988, Fox et al. 1989, Smith 1994), a moderate proportion of goat habitat was in mature and old forest, and the least movements often were in older forest stands. Use by male and female goats was positively associated with forest age, although females less than males. Although Smith (1994) described preference for greater forest volume by mountain goats, we found that use of volume classes varied. Goats made highest use of moderate to low volume classes; however, females and males had variable patterns associated with forest volume. Coefficients for selection of volume were positive for most males but slightly more than half of the females were negatively associated with higher volumes. Apparently forest volume is not the primary habitat selection feature.

Exclusive use of younger habitat types by some goats indicated they likely selected high forage availability during winter rather than direct forest stand attributes. One area in our study consisted of steep, snow-shedding, southerly-aspect slopes that provided access to winter forage outside of mature or old forest. This area had relatively snow-free conditions and high concentrations of goats. However, such snow-free areas might have little use during winters with heavier snowfall. Winter periods with heavy snowfall are a critical period for goat winter survival and may be associated with population declines (Joslin 1986).

Goats made little use of unburned logged habitats. Where these habitats occurred, they were frequently on the periphery of goat winter ranges. Such activity did not preclude use by goats, while areas associated with burns appeared to attract goats.

Abiotic variables such as elevation and aspect appeared to be consistent predictors of goat use. For example, goats were positively associated with habitats within 100 m of escape terrain, and use was mostly within 400 m. All individuals were negatively associated with distances away from escape terrain within their home ranges. Goats consistently use areas within 300 to 500 m of escape terrain during winter (Fox 1983, Fox et al. 1989, Poole and Mowat 1997).

When comparing AIC weights of candidate models, snow avoidance was a plausible model for few goats. In terms of biological requirements, no single function was enough to satisfy goat requirements in coastal habitats. Multiple requirements were necessary to provide adequate habitat. Security from predators, thermoregulation, and snow avoidance were all necessary components to fit goat use to winter habitat.

Fidelity for annual winter sites is relatively high (Smith and Raedeke 1982). However, site fidelity to the degree to which we observed was unexpected. Goats consistently used similar areas from one winter to the next. The average area of mature and old forest stands in the average goat winter home range was 30 ha. Our observations are consistent with other coastal studies that reported limited movements relative to other areas in the range of mountain goats (Smith and Raedeke 1982, Taylor and Brunt 2007). Relative to the coast, interior goat populations (Joslin 1986, Lemke 1999) have larger movements and more movements between drainages. This observation, coupled with the relatively short distances goats moved between elevation ranges, may aid managers in predicting winter use from summer home ranges.

Maintaining available snow interception canopy at various elevations adjacent to goat winter ranges may be important during winters with heavy snowfall. Because goats tended to make larger lateral movements (2-3 km) than vertical ones in winter, lateral connectivity also may be important. However, younger stands were used by goats in winter and were not especially restrictive to goat movements (Gordon and Reynolds 2000, this study). Because goats expend greater energy in deep snow packs (Daily and Hobbs 1989), use likely depends on stand age and snowpack condition.

Many factors are involved in determining risk to goat populations due to conflicts with forest harvest. For example, in our area, the harvest operability is lower in montane variants than lower elevation submontane variants (BC Ministry of Sustainable Resource Management 2002). Given goat affinity for escape terrain and high use of montane variants (Taylor and Brunt 2007, Taylor et al. 2004) the potential for harvest of forests preferred by goats may be relatively low. However, our analysis shows at least a low to moderate overlap between harvestable timber and goat winter range. Additional constraints such as the inability to regenerate forests on shallow soil veneers will lower the risk of some goat habitat being logged.

Management implications

Winters with heavier snowfall than our study period are an important consideration for goat habitat management in coastal areas. Considering that site fidelity was high and areas of mature and old forest used per goat were not large, it is important to maintain a relatively high proportion of forest in goat winter ranges in older structural stages. Canopy providing snow interception should be maintained near goat winter ranges at various elevations including the lower submontane variant. Sufficient goat habitat appears harvestable to merit some caution. In areas with low operability, goat habitat may be maintained naturally. However, in areas with higher operability, special attention should be made to ensure preferred winter habitat is maintained.

Goats use a wide variety of habitats during winter and some older forest will be maintained due to relatively high inoperability. Logging in the periphery of goat winter home ranges does not preclude range use and goats appear to make significant use of early forest habitats in burned areas. Logging small portions of goat winter home ranges through group selection or variable-density tree removal may provide more abundant summer forage and winter forage in lower snowfall years, particularly for good snow-shedding areas.

Given the limited monitoring of coastal population trends and understanding of the affects of canopy removal on goat populations, decisions to alter snow interception canopy should be considered in a cautionary and adaptive management context. The strategy should consider selecting some consistent altered and unaltered areas monitored before and after alteration. Ungulate winter ranges designed to protect goat habitat should consist of some areas in which limited harvest may occur, provided sufficient winter snow interception is maintained, and others in which no harvest should occur.

Future site-specific (on-the-ground) analyses would identify the linkage of site selection to resource requirements rather than just habitat features. We recommend further assessment of operability in mature and old forests used by goats in this study. Further research regarding benefits of burned habitats to goats in coastal areas also is warranted.

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