MODELING CORE WINTER HABITAT AND SPATIAL MOVEMENTS OF COLLARED MOUNTAIN GOATS

Bienn. Symp. North . Wild Sheep
and Goat Counc. 14:65-86

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Abstract: A total of 6,337 winter locations from 10 GPS collared mountain goats during three winter seasons (January 1 to April 30, 2000 to 2002) were used to determine winter movements, winter habitat selection, and derive a core winter habitat algorithm for mountain goats in the Taku River drainage. Collared mountain goats moved on average 20.41 ±1.24m/hr in the 2000 season, and 34.03 ±1.24m/hr in the 2001/2002 seasons. Winter home range sizes of GPS collared mountain goats ranged from 0.24km^2 for a winter season to 3.9km^2 for a period from February 14 to April 30 using a 95% adaptive kernel home range methodology. A total of 322 aerial telemetry locations from 16 to 18 radio collared mountain goats over three winter seasons in the study area were used to determine the average distance between center points of Jennrich-Turner (1969) bivariate normal home range areas for each individual in multiple years. Mountain goats used winter habitats that had center points that were on average 1284 ±703m to 1878 ±1045m distances apart in multiple years. A total of 774 mountain goat observation locations were taken during a helicopter survey in the study area on March 9-11, 2000. Mountain goats were observed at elevations ranging from 400m to 2200m (average 1264m). Habitat selection tests were used to test expected (5° slope classes, 20° aspect classes, and forest canopy height classes) against observed habitat proportions from winter GPS collar locations. Slope steepness, aspect classes, and non-forested habitats were selected for. An exponential relationship was found for the number of GPS collar locations verses distance from slopes from 45° to 60° steep at 100m intervals. A GIS algorithm was developed to identify core winter habitats for mountain goats based upon GPS collar findings in the study area. The derived model was tested against the 322 VHF aerial telemetry locations and against the 774 winter survey locations for validity. Significant differences between expected proportions from modeled habitats verses observed proportions from both VHF telemetry locations and winter survey locations were found. The derived model correctly identified 82.82% of all winter mountain goat, GPS locations.

INTRODUCTION

Repeated helicopter and fixed-wing aircraft over-flights and or direct interactions with people are well documented to adversely impact mountain wildlife populations by creating energetic costs to animals (Wilson and Shackleton, 2001; Frid, 1999; Stockwell et al., 1991; Côté, 1996; Sutherland, 1996; Gill et al. 1996; Maier et al. 1998; White et al. 1999; Macarthur et al., 1982). Understanding wildlife behaviours and identifying critical seasonal habitats can contribute to a sustainable management strategy that integrates the conservation of wildlife species with human resource development and land use. The objectives of this study were to measure spatial movements made by collared mountain goats, define winter habitat selection by collared mountain goats, and develop an algorithm that would identify core winter habitat areas selected by mountain goats in the Taku river drainage of north-west British Columbia.

STUDY AREA

This study was conducted in the Coastal Mountains of northwest British Columbia, Canada (58° 40' – 59° 15' N, 133° 45' - 133° 59' W). The study area is found approximately 60km to 100km distance from the coast of the Pacific Ocean near Juneau, Alaska. This area encompasses a variety of ecological parameters between interior N.W. British Columbia and coastal S.E. Alaska. The study area is located in the Boundary and the Teslin Plateau ecosections as identified by the British Columbia biogeoclimatic ecosystem classification system (Meidinger and Pojar, 1991). It encompasses the Englemann Spruce-Subalpine Fir, Sub Boreal-Spruce, and Alpine tundra ecozones in the Teslin Plateau ecosection and the Coastal Western Hemlock, Mountain Hemlock, and Alpine Tundra ecozones in the Boundary ecosection. In general, the Alpine Tundra ecozone occurs above 1400m elevations in the study area.

Winter temperatures can drop to -40°C with snow accumulations often reaching depths greater than 4.0m. Snow arrival is often dependent upon topographic relief but generally snow arrives in October or early November and remains into the following May or June. The area is frequented by strong up-flow winds that are most common from the south or southwest direction, resulting from pressure differences between coastal and interior climates.

An inventory of late-winter mountain goat abundance conducted in March 2000 for this study area reported a minimum population estimate of 890 mountain goats with an overall density of 0.45 mountain goats per square kilometer (Keim, 2001).

Although there is an application for a mine and access road development inside the study area, there currently is little to no human development. Currently, the only human caused impacts to mountain goats result from aerial and or riverboat travel most commonly used for wilderness recreation (including big-game hunting, fishing, and helicopter skiing) and reconnaissance inventory for resource development.

METHODS

Data Acquisitions

Data on mountain goat habitat use was acquired in three separate methods: VHF radio collar tracking, GPS collar tracking, and a winter helicopter survey.

For the first two, mountain goats were captured from a Hues 500 helicopter using a net gun and wildlife-capture team. This was done during winter when snow accumulations aided capture technique. Mountain goats were captured in a variety of habitat areas across the study area. A total of 19 mountain goats were fitted with VHF radio collars and 11 mountain goats were fitted with Lotek GPS_2000 model GPS collars (Lotek GPS_2000 manual, 1999). Mountain goats fitted with VHF radio collars were monitored for three consecutive winter seasons (January 1 to April 30, 2000 - 2002). Bi-monthly fixed-wing telemetry flights were conducted during the first year commencing in January 2000. Monthly telemetry flights were conducted during the second two years. Telemetry locations were taken using a GPS unit and observations for location, group size, and habitat features were recorded during each telemetry flight.

GPS collars were programmed to attempt to acquire GPS locations 6 times per day at four-hour intervals for one year. Each collar was equipped with a blow-away mechanism (Lotek, 1999) that was set to trigger on a fifty-two week clock. Data could be acquired only after the collar was retrieved from the field. On January 1-4, 2000 the first set of 5 GPS collars were deployed on mountain goats. These collars attempted to acquire GPS locations at 0:00, 4:00, 8:00, 12:00, 16:00, and 20:00 hours (Keim, 2001b). On February 4, 2001 a second set of 6 GPS collars were deployed on 6 additional mountain goats. These collars attempted to acquire GPS locations at 3:00, 7:00, 11:00, 15:00, 19:00 and 23:00 hours.

Locations taken from GPS collars were tested for an overall GPS fix rate for each collar using the formula:

Fix Rate = total fixes acquired / total fix attempts

An average fix rate ± standard error (SE) was determined for all 10 GPS collars.

Locations taken from GPS collars were also tested for missed or lost GPS fixes through an analysis of the average ±SE number of hours between GPS fix acquisitions and the range of the number of hours between GPS acquisitions (the difference in hours between fix acquisitions should be no less than 4 hours).

Late-winter mountain goat observations and subsequent GPS locations acquired during a helicopter inventory for the study area in March 2000 were also utilized for habitat use and habitat selection analysis for model verifications. Keim (2001), describes methodologies used during this winter mountain goat inventory.

Winter Home Range Size

Winter locations (January 1 to April 30) collected from 10 GPS collars were imported to point files for home range analysis in the Animal Movement Version 2.0 (Spatial Analyst) extension of Arc/View 3.2 (Hooge and Eichenlaub, 1997). Home range analysis was completed using a 95% probability, adaptive kernel method (Worton, 1989). These same adaptive kernel home ranges were used to identify patch habitat selection within winter home ranges.

Hourly Movements

GPS winter locations with a four-hour interval between consecutive locations were utilized for analysis of hourly movements. The distance (m) between consecutive locations was determined using an extension to Spatial Analyst 2.0 in Arc/View 3.2. The rate of movement (m/hr) was then determined between consecutive locations. The average hourly movements and SE were identified for movements made during different periods of the day (0:00 to 4:00, 3:00 to 7:00, 4:00 to 8:00, 7:00 to 11:00, 8:00 to 12:00, 11:00 to 15:00, 12:00 to 16:00, 15:00 to 19:00, 16:00 to 20:00, 19:00 to 23:00, 20:00 to 24:00, and 23:00 to 3:00) in the winter by GPS collared mountain goats.

Winter Home Range Re-use in Multiple Years

Winter locations collected from 16 to 18 VHF radio collared individuals (12 females: 6 males or 11 females: 5 males) were utilized to determine the distance between multiple winter home range habitat areas and home range re-use in three multiple winter seasons (2000, 2001, and 2002). A home range analysis was completed for each individual for each winter season using Animal Movement Version 2.0 (Spatial Analyst) extension of Arc/View 3.2. The Jennrich-Turner (1969) Bivariate Normal Home Range method was used to calculate the center point of each home range area. The distance between the center points of winter home ranges in multiple years among individuals was then determined. The average distance between the center points of home range areas was then determined for the three winter seasons. Visual comparisons of the calculated Jennrich Turner Bivariate Normal Home Range Areas were then compared for home range overlap by each individual in three multiple winter seasons (2000 vs. 2001, 2000 vs. 2002, and 2001 vs. 2002).

Identifying Patch Habitat Selection within Winter Home Ranges

Habitat selection tests were conducted for each GPS collared individual based upon GPS locations within habitat proportions of identified 95% adaptive kernel home range areas. Habitat proportions included categorized 5° slope classes, 20° aspect classes, and forest cover height classes as available within each 95% adaptive kernel home range area. Slope and aspect classes were determined from a digital elevation model (DEM) of 20m-pixel size. Forest cover age class data was determined from 1:20,000 forest-cover mapping for the province of British Columbia, Canada. Significant difference in use between habitat proportions was determined using a log-likelihood chi-square test (Manly et al, 1993). If a significant difference of use was determined, significant selection for or against a particular habitat proportion was then determined by comparing expected habitat use (as determined from habitat proportion areas within the 95% adaptive kernel home range areas) against observed habitat use (GPS collar locations) using a Bonferroni correction (Manly et al, 1993) with a 95% confidence limit.

Slopes between 45° and 60°, were considered "deemed escape terrain" (steep slopes with rocky outcrops utilized as security cover) for mountain goats. The distance to "deemed escape terrain" was tested with GPS mountain goat locations using an exponential regression analysis for the number of locations verses the distance to "deemed escape terrain" in 100m increments.

Generating the Model Algorithm

A model algorithm for mapping core winter mountain goat habitats was generated using a weighted-overlay grid from the model builder extension in Arc/View 3.2 (Environmental Research Institute Inc., 1999). Algorithm variables included; distance to escape terrain, slope, aspect, and elevation. Each variable was weighted, with the total of all variables measuring 100%.

Each variable consisted of internal values ranked on a scale from one to five. The model output scored core winter mountain goat habitats from 0 (unsuitable habitat) to 5 (optimal habitat) over the entire study area in a grid layout.

Model Verifications

The effectiveness of this model was tested against 322 winter VHF radio collar telemetry locations (from three winter seasons and 18 individuals) and 774 winter mountain goat survey observations (Keim, 2001) in two separate habitat selection tests. A standardized selection ratio for the scored habitats was determined based upon analysis for both VHF radio collar locations and survey observations using methods from Neu et al (1974). Significant difference in use between habitat proportions was determined using a log-likelihood chi-square test (Manly et al, 1993). If a significant difference in use was determined, significant selection for or against a particular habitat proportion was then determined by comparing expected habitat use against observed habitat use. Habitat proportions were measured based upon the habitat model scores (areas of each) within a study area defined by a minimum convex polygon (MCP) home range method (Mohr, 1947) compiled around (1) all VHF telemetry locations and (2) all survey observations using the Animal Movement Version 2.0 extension of Arc/View 3.2 (Hooge and Eichenlaub, 1997). Observed habitat use was measured from (1) VHF telemetry locations and (2) survey observation locations using a Bonferroni correction (Manly et al, 1993) with a 95% confidence limit.

RESULTS

Data Acquisitions

A sum of 322 aerial telemetry locations were collected from 19 VHF radio collared mountain goats (12 females: 7 males) during three winter seasons. Locations from 18 of the 19 VHF radio collared mountain goats were used for determining winter home range reuse in multiple years. All 322 aerial telemetry locations were used for model verification.

A total of 6,337 locations were collected from 10 of the 11 GPS collared mountain goats (7 females: 3 males) during three winter seasons. One GPS collar malfunctioned and did not record GPS locations. For the 2000 winter season (January 1 to April 30) 2723 locations were collected from 5 GPS collared females. During the 2001 winter season (data could only be collected from February 12 to April 30) 2,151 GPS locations were collected from 2 females and 3 males. During the 2002 winter season (data could only be collected from January 1 to March 13) 1,463 GPS locations were collected from the same 2 females and 3 males studied in 2001.

On average ±SE GPS collars had a GPS fix rate of 0.81 ±0.01. The average ±SE number of hours between GPS fixes taken was 7.8 ±0.2 hours (range: 4 – 56).

A total of 774 mountain goat observations during a late winter mountain goat inventory were collected from helicopter on March 9 to 11, 2000 (Keim, 2001). Observation locations were utilized to verify the habitat model and elevation data for mountain goat observations was used for model generation.

Winter Home Range Size

The 95% probability adaptive kernel home range estimates in the 2000 winter season (January 1 to April 30) for the 5 GPS collared females (range: n= 313 – n=702) averaged 0.56 ± 0.23 km^2 (range: 0.24–0.82 km^2).

The 95% probability adaptive kernel home range estimates for the five GPS collared mountain goats in the 2001 winter season averaged ±SE 1.56 ±1.20km^2 measured during 75 ±2 days (Table 1).

Table 1. Mountain goat 95% probability adaptive kernel home range estimates derived from GPS collar data, 2001.

Sex	Area (km^2)	n	Timeframe
F	0.47	444	2/14/01 – 4/30/01
F	0.85	421	2/12/01 – 4/30/01
M	1.63	435	2/13/01 – 4/30/01
M	0.96	441	2/14/01 – 4/30/01
M	3.9	410	2/14/01 – 4/30/01

The 95% adaptive kernel home range estimates ranged from 0.01 to 3.60km^2 (Table 2)

Table 2. Mountain goat 95% probability adaptive kernel home range estimates derived from GPS collar data, 2002.

Sex	Area (km^2)	n	Timeframe
F	0.78	253	1/1/02 – 3/13/02
F	3.60	313	1/1/02 – 3/13/02
M	2.02	363	1/1/02 – 3/13/02
M	0.01	293	1/1/02 – 2/25/02
M	0.11	241	1/1/02 – 2/27/02

Hourly Movements

In the 2000 year, 2,376 sessions were obtained for measuring hourly movements, mountain goats moved on average ±SE 20.41 ±1.45m/hr. In the 2001 and 2002 years 3,219 sessions were obtained for measuring hourly movements, mountain goats moved on average ±SE 34.03 ±1.24m/hr (Figure 1).

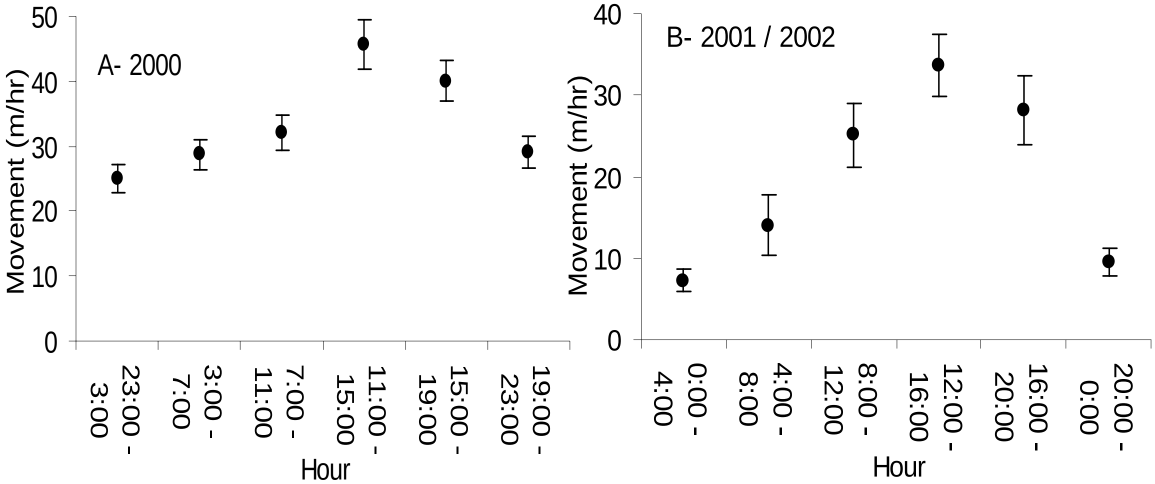

Figure 1. Average ± SE rates of movement (m/hr) measured between locations taken at 4-hour intervals of the day. All locations were acquired from GPS collared mountain goats (n=5 for A / n=5 for B) in the winter seasons of A, 2000 and of B, 2001 and 2002.

Winter Home Range Re-use in Multiple Years

Winter home range center points were compared among 16 (11 females: 5 males) to 18 (12 females: 6 males) VHF radio collared mountain goats (50 home range center points) during three separate winter seasons (Table 3). In 48 of the 50 comparisons, individual mountain goats had overlapping winter home range areas in multiple years.

Table 3. Average distances ± SE between the center points of Jennrich-Turner Bivariate Normal home range areas of individual mountain goats in multiple winter seasons.

Years	N	Average distance ± SE
2000 – 2001	18	1284 ± 703m
2000 – 2002	16	1486 ± 585m
2001 – 2002	16	1878 ± 1045m

Identifying Patch Habitat Selection within Winter Home Ranges

A total of 10 GPS collared mountain goats were tested for selection of slope, aspect, and forest cover classes. There was a significant difference found between habitat proportions available and use of habitat proportions in 9 of the 10 mountain goats tested against 5° slope classes (X^2= 32.2, 7.4, 175.3, 30.7, 187.6, 622.2, 422.5, 53.8, 253.1, 272.7 / df= 9, 12, 13, 13, 13, 13, 9, 14, 14, 14 / P=0.05) (Table 4). A significant difference was found between habitat proportions available and habitat proportions used in 9 of the 10 mountain goats tested against 20° aspect classes (X^2= 47.4, 18.8, 128.9, 34.4, 214.6, 125.3, 169.6, 192.2, 234.3, 331.7 / df= 9, 12, 13, 13, 13, 13, 9, 14, 14, 14 / P= 0.05) (Table 5). It was only possible to test for significant selection of forest cover habitats in 6 of the 10 mountain goats because the remaining 4 mountain goats did not have identifiable forest cover in their 95% probability adaptive kernel home range areas. There was a significant difference in habitat proportions available and habitat proportions used in 4 of the 6 mountain goats tested against forest cover classes (X^2= 6.0, 8.7, 60.3, 2.75, 12.5, 20.4 /df= 2 / P= 0.05). For selection tests for or against forest cover habitat types, never was an identifiable forested habitat selected for.

A total of 6,337 winter locations from 10 GPS collared mountain goats were used to measure distances (in 100m intervals) from 45 to 60° slopes (Figure 2). On average ±SE mountain goat GPS collar locations were 100 ±1.3m (range: 0 – 700m) from 45 to 60° slopes, measured in 100m intervals.

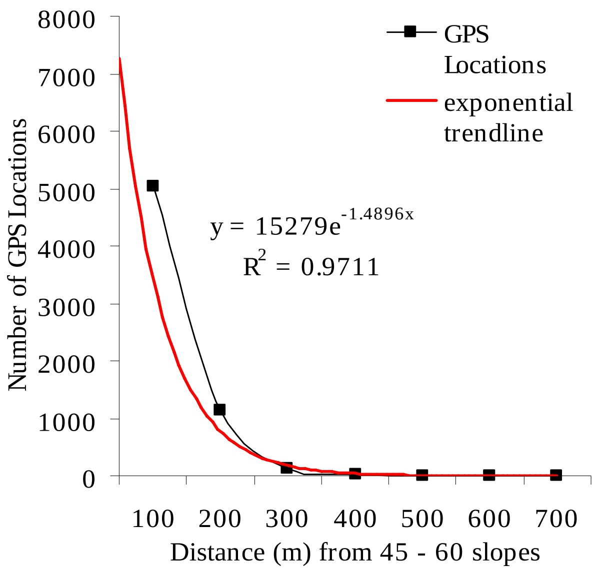

Figure 2. An exponential regression analysis for the number of locations from GPS collared mountain goats to 45 - 60° slopes measured at 100m intervals.

Mountain goats were observed at elevations ranging from 400m to 2200m with an average elevation of 1264m in the late-winter helicopter survey (Keim, 2001) (Figure 3).

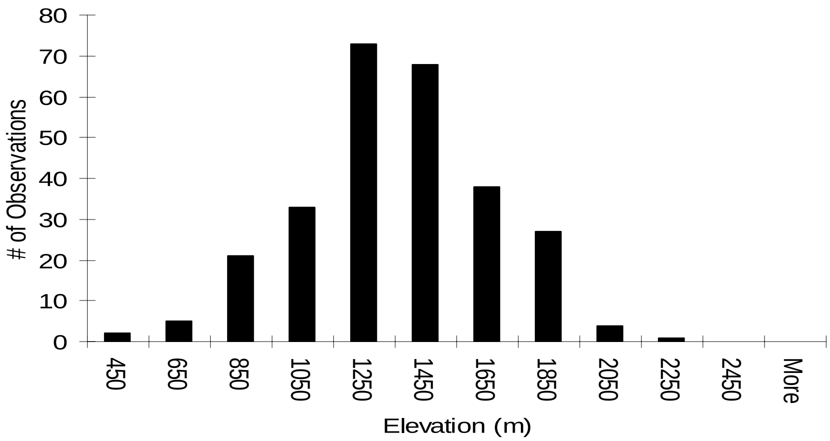

Figure 3. A frequency distribution table for elevations of mountain goat group observations in a late-winter helicopter inventory survey (Keim, 2001).

Table 4. Summary of the number of GPS collared mountain goats having expected proportion of habitat use less than observed proportion of habitat use ±Bonferroni correction (habitat type selected for), expected proportion of habitat use equal to observed proportion of habitat use ±Bonferroni correction (habitat type not selected for or against), and expected proportion of habitat use greater than observed proportion of habitat use ±Bonferroni correction (habitat type selected against) for 5° slope-classifications between 0° and 80°.

Slope Class	0 To 5°	5 To 10°	10 To 15°	15 To 20°	20 To 25°	25 To 30°	30 To 35°	35 To 40°	40 To 45°	45 To 50°	50 To 55°	55 To 60°	60 To 65°	65 To 70°	70 To 75°	75 To 80°
Expected proportion < Observed proportion	0	0	0	1	0	1	1	0	3	4	7	4	2	1	0	0
Expected proportion = Observed proportion	2	3	3	2	2	3	3	7	5	6	3	3	1	3	1	0
Expected proportion > Observed Proportion	3	2	4	6	8	6	6	3	2	0	0	1	1	0	0	0

Table 5. Summary of the number of GPS collared mountain goats having expected proportion of habitat use less than observed proportion of habitat use ±Bonferroni correction (habitat type selected for), expected proportion of habitat use equal to observed proportion of habitat use ±Bonferroni correction (habitat type not selected for or against), and expected proportion of habitat use greater than observed proportion of habitat use ±Bonferroni correction (habitat type selected against) for 20° aspect-classifications between 0° and 360°.

Aspect Class	0 To 20°	20 To 40°	40 To 60°	60 To 80°	80 To 100°	100 To 120°	120 To 140°	140 To 160°	160 To 180°	180 To 200°	200 To 220°	220 To 240°	240 To 260°	260 To 280°	280 To 300°	300 To 320°	320 To 340°	340 To 360°
Expected proportion < Observed proportion	0	0	0	0	0	0	2	2	2	3	2	3	3	4	2	0	0	0
Expected proportion = Observed proportion	1	1	1	1	1	5	4	5	4	4	7	4	3	2	1	2	0	1
Expected proportion > Observed Proportion	1	3	4	6	6	4	3	2	3	3	1	3	3	2	3	3	2	1

MODEL ALGORITHM

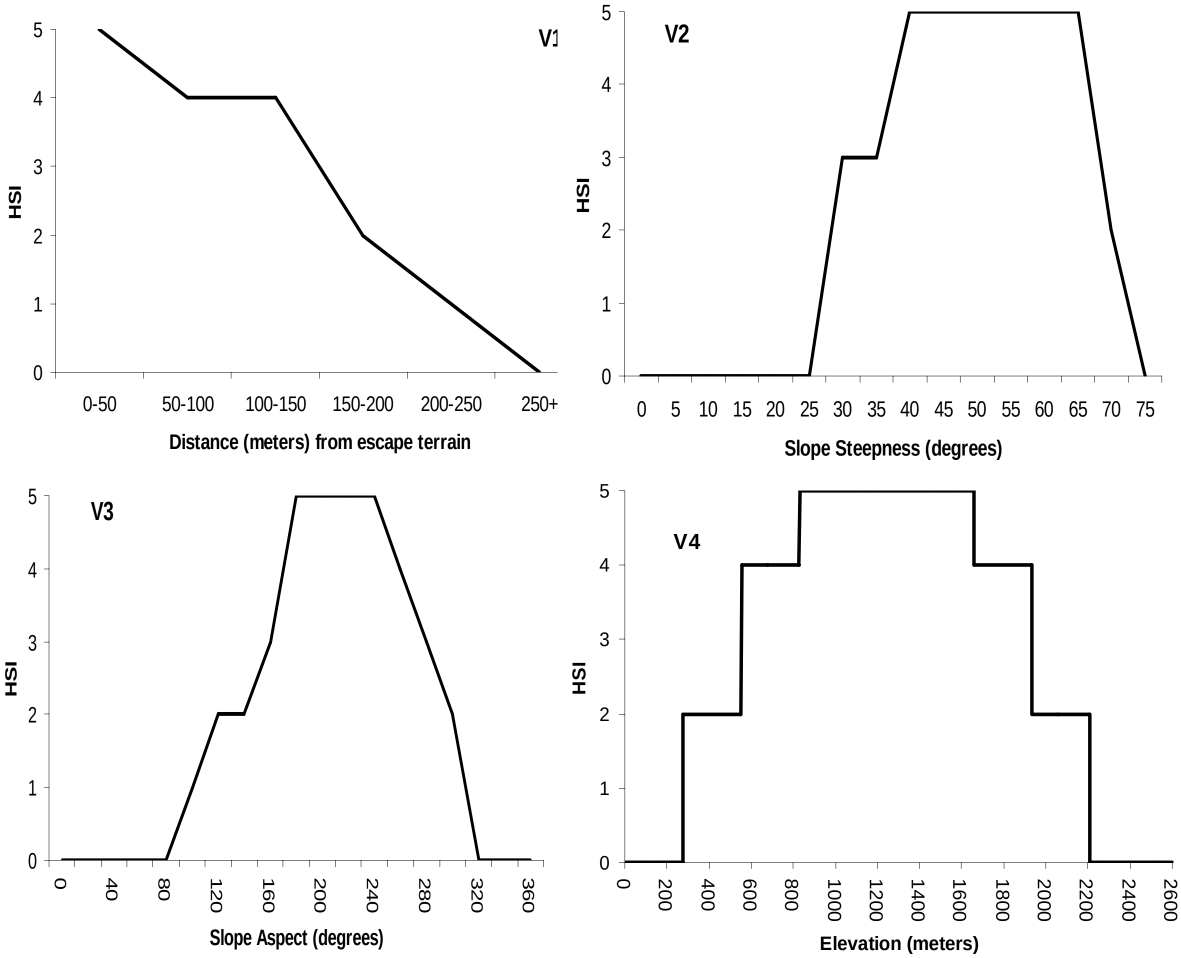

Figure 4. Graphical relationships between habitat variables and habitat suitability values for the mountain goat winter range habitat model.

(Winter Mountain Goat Habitat)
Habitat Suitability Index = (V1 x 0.35) + (V2 x 0.25) +(V3 x 0.25) + (V4 x 0.15)

The HSI algorithm predicts winter mountain goat habitat on a scale between 0 and 5. Habitats predicted to have an HSI value greater than or equal to 3 are defined as suitable winter mountain goat habitat.

For V1 “escape terrain” is defined at slope steepness between 45° and 60°.

All habitat variables (V1 to V4) were identified using data from a digital elevation model as a raster in a GIS with 25m-pixel resolution.

A minimum continuous winter habitat area of 5.0 hectares was used as a final step.

Core winter mountain goat habitat is defined within an elevation range of 278m to 2209m ASL, on aspects facing between 100° and 300°, on slopes that are between 20° and 65° steep, and in areas that are no further than 400m from slopes that are between 45° and 60° steep (Figure 4). Core winter mountain goat habitats within these boundaries are ranked on a scale from 1 (poor habitat) to 5 (optimal habitat) in a GIS grid at 60m-pixel resolution.

Model Verifications

Two separate data sets were used to test and verify the core winter mountain goat habitat model (1. VHF collared mountain goat winter telemetry locations 2. Locations from a winter mountain goat inventory survey from helicopter).

In the first test, 322 winter mountain goat VHF collar telemetry locations over three separate winters were tested for significance (X^2= 148.13, P= 0.05) to the model in an area of 1,357km^2. A standardized selection ratio was used to define which habitat classes were most or least selected for (higher proportions are most selected for, relative to the selection ration value (Table 6).

Table 6. The standardized selection ratio of each habitat class plus expected and observed habitat proportions found within the MCP home range area of all winter telemetry locations.

Winter habitat Value (0-5)	Expected Habitat Proportions (% Area)	Observed Habitat Proportions (*)	Standardized Selection Ratio
0	0.80	0.39 ± 0.07	0.04
1	0.00	0.00 ± 0.00	0.00
2	0.02	0.04 ±0.03	0.12
3	0.07	0.12 ±0.05	0.13
4	0.09	0.30 ±0.07	0.26
5	0.02	0.15 ±0.05	0.45
Total	1.0	1.0	1.0

* Observed proportion of telemetry locations within each habitat area ±Bonferroni correction.

VHF collared mountain goats selected for model classes 4 and 5 (observed proportions ±Bonferroni correction > expected proportions), against model class 0 and 1 (observed proportions ±Bonferroni correction < expected proportions), and neither for or against (observed proportions ±Bonferroni correction = expected proportions) model classes 2 and 3 (Figure 5).

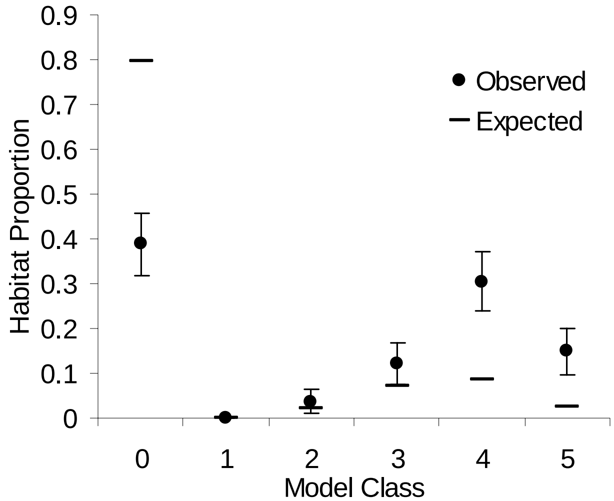

Figure 5. Observed VHF collared mountain goat telemetry locations ±Bonferroni correction and expected habitat proportions (% Area) verses winter habitat model classes (0 – 5).

In the second test, 774 late-winter mountain goat observations were tested for significance (X^2= 575.92, P= 0.05) to the model in an area of 3,031km^2. A standardized selection ratio was used to define which habitat classes were most or least selected for (higher proportions are most selected for, relative to the selection ration value (Table 7).

Table 7. The standardized selection ratio of each habitat class plus expected and observed habitat proportions found within the MCP home range area of all winter survey observations.

Winter habitat Value (0-5)	Expected Habitat Proportions (% Area)	Observed Habitat Proportions (*)	Standardized Selection Ratio
0	0.80	0.31 ±0.04	0.02
1	0.00	0.00 ±0.00	0.00
2	0.02	0.07 ±0.02	0.20
3	0.07	0.09 ±0.03	0.08
4	0.09	0.35 ±0.04	0.25
5	0.02	0.19 ±0.04	0.44
Total	1.0	1.0	1.0

* Observed proportion of observed locations within each habitat area ±Bonferroni correction.

The locations of mountain goat survey observations showed selection for model classes 2, 4, and 5; against model class 0; and neither selected for or against model classes 1 and 3 (Figure 6).

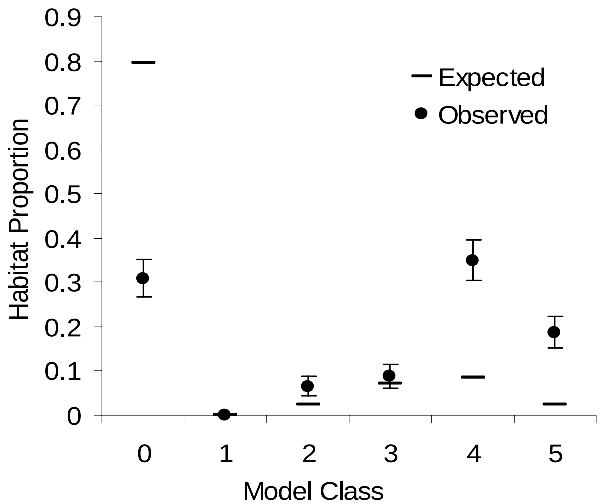

Figure 6. Observed mountain goat survey locations ±Bonferroni correction and expected habitat proportions (% Area) verses winter habitat model classes (0 – 5).

In this model for the Taku study area, habitat classes greater than or equal to 3 were considered suitable mountain goat habitats. As a validation measure, the proportion of the winter GPS collar mountain goat data set found to be located in suitable habitats (HSI classes 3, 4, and 5) was measured for accuracy. The HSI model, using classes 3, 4, and 5 as suitable winter range habitat in the Taku study area, correctly validated 0.83 of the winter GPS collar locations.

DISCUSSION

Data Acquisitions

The GPS tracking studies provided spatial and temporal data on individual mountain goats at an intensity that is difficult, if not impossible, to acquire by conventional radio tracking and observation methodologies.

At a spatial scale, conservative measures on the accuracy of GPS collar locations have found GPS locations to be accurate to at least 65.5m of the actual location (Moen et al, 1997). However, the effects of topographic relief and canopy cover on GPS collars, is well acknowledged (Moen et al 1997, Moen et al 1996, Rodgers et al 1996, Rempel et al 1995). In environments with increased canopy cover and/or increased topographic relief the ability for GPS collars to acquire satellites is reduced. Thus, it is inferred that a positional bias may result for GPS tracking habitat use and habitat selection studies towards open-canopy and or relatively flat habitats (low variability in topographic relief). Given the results of GPS collar performance in this study, there appears low potential for positional bias for several reasons:

1) GPS collars acquired a location at 81 ± 1% of timed fix attempts. Therefore, the only potential for positional bias would result from the remaining 18 to 20% fixes not acquired.
2) The time interval between GPS fix acquisitions was small, averaging 7.8 ±0.2 hours with a maximum interval between locations being 56 hours (14 consecutive GPS fix attempts). Thus, data gaps (times periods

when GPS fixes were not acquired) are both infrequent and short in duration.

3) GPS study animals made minimal movements, on average less than 25m per hour and had home range areas less than $3.9km^2$ during winter season measurements.
4) The reasons for loss of GPS fixes may result from a number of other random events including animal positioning relative to GPS antenna, or a physical loss of available satellites.

Given the high rate of GPS acquisition, the infrequent and short duration of GPS acquisition gaps, and the short distance of movements mountain goats made within a relatively confined home range area any positional habitat bias is low in stature and probably lost due to sample size in this study.

At a temporal scale, GPS collars in this study acquired locations at a rate of approximately 5 per day, providing more than an adequate sample size for habitat selection and home range analysis on individual mountain goats. The drawback of GPS-collar tracking in this study was not the sample size of locations acquired per individual but rather, the small sample size in the number of individuals (only 10 GPS study animals during three winter seasons).

Consequently the GPS tracking study was complimented with conventional aerial telemetry tracking data from 18 additional collared mountain goats and habitat use data from an intensive mountain goat helicopter survey involving 26.6 hours of helicopter survey time during three consecutive late-winter days (Keim, 2001). Unfortunately due to costly telemetry flying expenses, data acquisition from radio collared mountain goats provided only a small sample size for individual mountain goats during the winter seasons (5 to 10 locations per individual per season). Thus insufficient data was available to measure trends in animal movements from radio collared individuals.

In combination (the data acquired from GPS tracking studies, mountain goat survey observations, and the radio telemetry locations) winter habitat selection and animal movement findings determined from an intensive GPS collar study were testable over a broad scale of individuals within the study area.

Winter Home Range Size

Mountain goat studies in S.E. Alaska have found annual home range areas between 10 to $20km^2$ with winter home range areas that are much smaller in scale (as small as $0.2km^2$) and more distinct in habitat characteristics (Schoen and Kirkoff, 1982 and Smith, 1982). Similarly, winter home range areas in the Taku drainage were found to be significantly less than the 10 to $20km^2$ annual home range areas found in Alaska, and measured in area as small as $0.47km^2$ in the late winter season. Geist (1971) interpreted that with wide forage acceptance, mountain goats have the ability to compensate with a narrow habitat preference. It is my interpretation that mountain goats tend to minimize energetic costs in the winter by increasing resting bouts, decreasing movements, and increasing foraging time. Consequently, in the winter mountain goats strategically place themselves into specific (and small) core habitat locations that have the necessary habitat attributes to aid in minimizing energetic costs during the winter.

Hourly Movements

Winter mountain goat movements tended to peak during mid-day to late-afternoon in this study and did not exceed a measured average rate of movement greater than 46m per hour. Fox (1978) observed mountain goat behavior and found average daily movement to be 15 to 30m.

In this study there are several potential sources of error in the hourly movement measurements that were not quantified. First, hourly movements were reduced from measured distances between two points measured four hours apart. Second, errors in point locations could potentially be as far as 65.5m. Lastly, the distance between point measurements does not consider topographic relief.

However, given the observed data and the potential errors considered it would be safe to interpret that; on average, studied mountain goats did not exceed rates of movements greater than 100 to 150m per hour (as a conservative measure), mountain goats tended to be most active during the day from 11:00 to 16:00 and least active from 23:00 to 4:00, and movements as measured (including winter home range areas) indicate that studied mountain goats tend to be relatively inactive during the winter season. Schoen and Kirkoff (1982) and Fox (1978) have made similar observations on winter movements by mountain goats.

Winter Home Range Re-use in Multiple Years

Schoen and Kirkoff (1982) studied a mountain goat population just across the Canada / USA border from this study area for 3 consecutive years and found a winter home range site fidelity rate near 0.66. The average ±SE distance between home range center points was measured for 18 to 16 VHF collared mountain goats in three consecutive winters. Unfortunately, winter home range areas were measured from only 5 to 10 telemetry locations per season. However, the average distances between the center points of these 5 to 10 locations for each individual in multiple years provide an indication of individual presence to similar winter habitat areas in multiple years. Studied mountain goats were found in winter habitats at distances of closest proximity in the winters of 2000 / 2001 (1284 ±703m) and were found in winter habitats at distances of farthest proximity during the winters 2001 / 2002 (1878 ±1045m). In 48 of 50 visual comparisons individual winter mountain goat home range areas overlapped in multiple years. Studied mountain goats tended to re-use, to some degree, core winter habitat areas in multiple years.

Identifying Patch Habitat Selection within Winter Home Ranges

Habitat selection within winter home range areas defined from GPS collar data was tested against variables for slope steepness, aspect direction, and forest cover height class. Preferences were found for slope steepness, and aspect direction. No preference was discovered for forested habitats, however non-forested habitats were selected for over forested habitats by four of the ten mountain goats tested.

Habitat selection tests for GPS collar study animals found selection, by at least one individual, on slopes between 15° and 70° steep. Core habitat selection by collared mountain goats was most frequent on slopes between 35° and 70° steep. The greatest level of selection for the 10 mountain goats was found for slopes between 50° and 55° steep. Core winter mountain goat habitats were most strongly associated on slopes between 45° and 60° steep. An exponential relationship was observed between mountain goat locations and distance to 45° and 60° slopes, for which 80% of all winter locations were found within a 100m distance of such slopes. Previous studies and winter mountain goat habitat modeling have identified slopes greater than 50° steep (and most often between 50° and 65°) to be deemed escape terrain (Pollard, 2000; Demarchi and Johnson, 1998; Smith, 1983; Schoen and Kirkoff, 1982; and Smith, 1981) and the most critical component for identifying winter mountain goat habitats. Mountain goats tend to adopt a strategy of passive avoidance as a means to avoid predators. This infers a selection of habitats where the risk of encountering potential predators is reduced. For mountain goats the resulting habitat is steep rocky terrain (escape terrain). Smith (1986) concluded that mountain goats utilized areas within 0.8km of deemed escape terrain in establishing their home ranges. Demarchi and Johnson (1998) recorded 95% of their mountain goat track locations were observed within less than 50m of deemed escape terrain.

Habitat selection tests for GPS collar study animals found selection, by at least two individuals, on aspects facing between 120° and 300° direction. The prevailing aspect direction was to the south-southwest (180° to 240°) directions. Other studies on mountain goats have observed a trend of habitat selection on mountain slopes facing a southerly direction (Demarchi and Johnson, 1998; Smith, 1983; Schoen and Kirkoff, 1982; and Smith, 1981). In the northern hemisphere, southern aspects receive the greatest amount of solar radiation. Solar radiation can directly impact metabolic rates of mountain goats in the winter by maintaining homeostasis at a time when the seasonal climate may provide for low body temperatures requiring behavioural or physical response factors (shivering, panting or moving) which may contribute to energy loss and imbalance. These behavioural and physical activities can also divert from otherwise important activities, as foraging, and further decrease an animal's metabolic rate. Indirectly, southerly aspects also offer a longer growing season and greater rates of snowmelt than do northerly aspects. In the Taku drainages the prevailing wind direction is from the southwest, providing a mechanism to clear (create wind-swept) southwest facing ridges and slopes of snow. Decreased duration and depth of snow cover results in greater mobility and improved access to forage for longer periods of the year and thus potentially optimizes energy conservation by mountain goats.

Hebert and Turnbull (1977), described southern interior and coastal mountain goat ecotypes in British Columbia. They described coastal winter ranges, within 30 – 50km distance of the ocean, to be characterized and restricted by mature forest canopy cover overhanging steep bluff areas. They believe heavy coastal snow with high water content, restricted winter mountain goat movement to and from these coastal winter habitat ranges. They described southern interior (East Kootenay) mountain goat ranges to include the Englemann Spruce-Subalpine Fir biogeoclimatic zone and up to snow free ridge tops at 2,135+m elevation.

More recent mountain goat habitat work in areas with similar proximity to the Pacific Ocean as the Taku study area have identified mature forest canopy as a crucial component to mountain goat winter ranges (Pollard, 2000; and Demarchi and Johnson, 1998). All mountain goat habitat studies in near by S.E. Alaska have identified mature forest canopy as a crucial component to mountain goat winter ranges (Smith, 1983; Schoen and Kirkoff, 1982; and Smith, 1981).

In three consecutive years of study in the Taku watershed area, I did not at any time observe winter mountain goat habitat use in mature forest canopy cover. Habitat selection data from GPS collar studies found no selection for any forest cover types and in fact, found selection against forest cover by 4 of 10 collared GPS mountain goats. Habitat use occurred only in non-forested habitats, forest cover height class 1 (0.4-10.4m), and forest cover height class 2 (10.5-19.4m) for all 28 collared mountain goats (GPS and VHF) in the study. This said, it is important to realize that collared mountain goats in this study were captured during winter months in locations that were accessible by helicopter. It is quite possible that a bias resulted in mountain goats studied towards individuals that select high elevation, non-forested winter habitats. Further, the sightability of mountain goats under forest canopy is very low and it is possible that mountain goats using mature forest canopy habitats (especially closer to the coast) were not observed during winter wildlife inventory surveys. It is still true however, that mountain goats in this study area utilized high elevation, alpine habitats, above tree line. I believe the strong outflow winds associated with coastal weather systems, as present in the Taku River drainage, provide for wind swept ridges that allow mountain goats to utilize higher elevation habitats in the winter.

Model Algorithm

All inputs to the model algorithm were based upon inventory data collected within the study area, and most often derived from habitat selection analysis of GPS collar tracking studies. The greatest weighted habitat component (0.35 on a scale to 1.0) of the model was the distance to 45° to 60° steep slopes. This factor probably results from a security factor that mountain goats utilize steep slopes to avoid predators. Slope and aspect habitat components were weighted as the second greatest components, each at a factor of 0.25. Elevation was the last habitat component and was weighted at a factor of 0.15, because although important it only appeared to provide a boundary that other habitat components had to be within. Any habitat value outside of the variable range for each habitat component was omitted from the algorithm for core winter mountain goat habitat. Forest cover neither added to, nor was omitted from the habitat value in the model algorithm.

Model verifications provided significant findings for and against modeled winter habitat values, on a scale of 0 to 5. The top two habitat values (4 and 5) when tested against both VHF radio collar locations and observed survey locations accurately identified potential core winter habitat areas preferred by wintering mountain goats. A habitat value of 5 provided for a standardized selection ratio of 0.44 and 0.45 in the habitat selection tests for the 6 habitat value classes. A habitat value of 4 provided for a standardized selection ratio of 0.25 and 0.26 in the habitat selection tests. Together habitat classes 4 and 5 identify winter mountain goat habitat selection with a selection ratio of 0.69 and 0.71 against survey observations and VHF radio collar observations, respectively. Interestingly, the habitat proportions for the analysis in both tests were identical in % area, even though they were different areas of measurement. Classes 4 and 5 represented 9% and 2% of the total area, respectively. In both selection tests and as expected, habitat value 0 was selected against and should be considered an area of unsuitable winter mountain goat habitat. Habitat value 0 made up 80% of the tested area. The testing of habitat value 1 was obviously not important for mountain goats because it occupied 0% of the land base tested. Habitats 2 and 3 were either found to contain the expected proportion of habitat use or to have a reasonably low level of habitat selection by mountain goats in the selection tests. These areas always had a standardized selection ratio below 0.2 for the 6 habitat classes. Habitat values 2 and 3 should be considered low value habitat classes, but when adjacent to habitat classes 4, and or especially 5, of greater value. In this Taku model habitat classes greater than or equal to 3 are considered suitable winter mountain goat habitat, correctly validated by 82.8% of all winter mountain goat GPS collar locations.

MANAGEMENT IMPLICATIONS

Winter mountain goat habitat relationships are identifiable and should be incorporated into the planning and management of winter recreational activities (in particular helicopter skiing), resource development, and flight paths for low flying aircraft. The data indicate that mountain goats in the Taku drainage area are abundant; are relatively inactive during the winter, moving on average only small distances within limited winter home range areas; are found to re-use winter habitats, to some degree; and are found to utilize specific and definable core winter habitat areas. The developed habitat model accurately identifies potential winter mountain goat habitats in the study area and is presumably applicable to nearby mountain goat populations in the Atlin, BC area. This model identifies potential mountain goat habitats at a fine scale (60m pixel resolution) and should be used in conjunction with broader scale mountain goat habitat indices and or winter habitat surveys that identify mountain goat habitat use by an experienced mountain-ungulate, wildlife biologist. The development of management guidelines for areas identified to be winter mountain goat habitat should be required before resource use is considered.

ACKNOWLEDGEMENTS

Data collected in this study resulted from inventory work conducted with, and funded by the British Columbia Ministry of Water, Land, and Air Protection in the Skeena Region for the Tulsequah Chief Environmental Review Assessment. I would like to personally thank Karen Diemert, Brian Fuhr, and Rick Keim for providing me with the opportunity to work with them on this project, and for giving me the opportunity to report findings from the Tulsequah Chief Wildlife Studies; Thank you all. I would like to especially give gratitude to biologist Norm MacLean for reigning in an unlimited number of technical errors and attitude distractions over the past several years. I would like to gratefully recognize the flying and aerial radio telemetry work conducted by Chris Moser of Atlin Air. Discovery Helicopters Ltd. provided the excellent flying services of pilots Norm Graham and Geoff Reed.

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