HABITAT USE AND MOVEMENTS OF MOUNTAIN GOATS AS DETERMINED BY PROTOTYPE GPS COLLARS, ROBSON VALLEY, BRITISH COLUMBIA

KIM G. POOLE, Timberland Consultants Ltd., Fish and Wildlife Division, P.O. Box 171, Nelson, British Columbia, V1L 5P9

DOUGLAS C. HEARD, BC Ministry of Environment, Lands and Parks, Omineca-Peace Region, 3rd Floor, 1011 4th Ave., Prince George, British Columbia, V2L 3H9

Abstract: Conventional aerial telemetry on ungulates living in mountainous terrain is often restricted by poor weather, the requirement for daylight, and the high costs and dangers associated with repeated aircraft flights. In late July 1997 we deployed 2 prototype global positioning system (GPS) collars on adult nanny mountain goats (*Oreamnos americanus*) living in the Robson Valley in east-central British Columbia. The collar's GPS receiver was programmed to determine its location every hour. About every 2 weeks we located the goats from a fixed-wing aircraft using the collar's VHF transmissions. The GPS function of the collars on goats 9701 and 9705 lasted 24 and 49 days and provided 163 and 917 locations, respectively. The collar on goat 9705 had a higher daily observation rate than 9701 (78.9% vs. 26.9%; $P <$ 0.001), lower mean positional dispersion of precision (PDOP) (3.6 ± 0.05 vs. 4.2 ± 0.17; $P =$ 0.0002), and proportionately more 3D vs. 2D fixes (and presumably more precise locations; 66.7 vs. 30.1%; $P = 0.001$). These differences may have been related to the position of the goats relative to steep cliffs and satellites. Goats 9701 and 9705 ranged over 400 and 800 m in elevation, respectively. Comparing 6 hour periods during the day, goat 9705 was at lower elevations from midnight to 0600 hr (2068 ± 11.5 m vs. 2127-2176 m during 600 – midnight; P < 0.001), moved less from noon to 1800 hr (196 ± 14.4 m/hr) and more from 1800 to 2400 hr (253 ± 18.7 m/hr; $P = 0.049$). Goat 9701 showed no daily pattern of elevation use or movement rates. The hourly movements of goat 9705 provided an index of the disturbance caused by both capture and aerial relocations. Goat 9705 moved about 70% farther in the 24 hours after aerial relocations (mean hourly movement 232 ± 27.7 m/hr) compared with presumably undisturbed periods before relocations (137 ± 12.3 m/hr; $P = 0.002$), and over 3 times further in the period after capture and collaring (474 ± 96.2 m/hr) compared to undisturbed periods ($P= 0.002$). Although mean elevation and slope of GPS and aerial telemetry locations did not differ for either goat ($P > 0.17$), the range in elevation determined from aerial telemetry was only 62% of the range using GPS positions and the range in slope only 19-49%. Less than 9% of GPS positions put goats in commercial forests [primarily lodgepole pine (*Pinus contorta*) and subalpine fir (*Abies lasiocarpa*)]. Although the locations obtained using GPS collars are likely biased by habitat, e.g., vegetation and terrain, this paper provides examples of how GPS technology could benefit a host of studies, including research into disturbance, examination of movement rates or night-time habitat use, and documentation of rarely used habitats.

INTRODUCTION

Conventional aerial telemetry using very high frequency (VHF) transceivers has been used in many studies to obtain information on mountain goats (*Oreamnos americanus*) (e.g., Singer and Doherty 1985, Haynes 1992, Hopkins et al. 1992, Festa-Bianchet et al. 1994, Smith 1994). However, telemetry on ungulates living in mountainous terrain is often restricted by poor weather, the requirement for daylight, and the high costs and dangers associated with repeated aircraft flights (Heimer 1994). Resultant data thus may be biased by sampling only portions of the day or during good weather. Given the cost and difficulty in relocating animals where ground access is restricted, location sample sizes in these studies tend to be less than ideal. The fright and hiding responses by goats to aircraft noted by researchers (summarized in Côté 1996) also brings into question the impact of aerial relocations on goat behaviour.

Use of global positioning system (GPS) technology for automated tracking of large animals may permit researchers to study interactions of animals with their habitat at a level of detail not previously attained. GPS-collar performance has been field tested in various boreal forest types and on moose (*Alces alces*) in Ontario, Minnesota and Alaska (Rempel et al. 1995, Moen et al. 1996, 1997, Rempel and Rodgers 1997). Earlier GPS collars were not suitable for mountain goat or mountain sheep (*Ovis* spp.) sized animals because of high mass (1.8 kg; Moen et al. 1996). However, recent technological changes have enabled development of GPS collars <1.0 kg in mass, more suitable for mid-sized mammals.

Forestry activities are increasing in the mountains surrounding the Robson Valley in east-central British Columbia (BC). To better manage and mitigate potential conflicts between the forestry industry and mountain goats, we initiated a study in 1997 to examine low-elevation forest use by goats in the Robson Valley, including seasonal variations in forest use and identification of mineral licks of importance to goats (Poole 1998). Specific objectives during 1997 included testing 2 prototype GPS collars, which we report on here.

STUDY AREA

The Robson Valley mountain goat study area flanks the Rocky Mountain Trench, which separates the Rocky Mountains to the east and the Cariboo Mountains to the west (centred on McBride at 53°22'N, 120°15'W). The area consists of a number of biogeoclimatic zones: Sub-Boreal Spruce (SBS) and Interior Cedar-Hemlock (ICH) zones in the Trench, through the Englemann Spruce-Subalpine Fir (ESSF) zone to the Alpine Tundra (AT) zone with increasing altitude. Treeline generally is at 1900-2150 m. Climate varies with elevation. In the Trench and valley edges hybrid white spruce (*Picea glauca* x *engelmannii*), subalpine fir (*Abies lasiocarpa*), western hemlock (*Tsuga heterophylla*), and western redcedar (*Thuja plicata*) are the dominant trees, with extensive stands of lodgepole pine (*Pinus contorta*) due to frequent fire disturbances (MacKinnon et al. 1992). Higher up the mountainsides spruce, subalpine fir and lodgepole pine dominate, with scattered stands of whitebark pine (*Pinus albicaulis*) at the highest elevations. Douglas-fir (*Pseudosuga menziesii*) trees are found throughout the area. In the AT zone conifers are only present in stunted krummholz forms.

METHODS

Capture and collaring

We tested prototype GPS collars developed by and in co-operation with Advanced Telemetry Systems (ATS, Isanta, Minnesota). The collars weighed 950 g, and were equipped with a VHF transmitter. The collar's GPS receiver was programmed to determine its location every hour and store the locations in the collar's on-board memory. The collars stored horizontal position, date, time, positional dilution of precision (PDOP), satellite data, fix mode [2- or 3-dimensional (2D or 3D)], and the time required to obtain a fix. Horizontal dilution of precision (HDOP), which relates to the expected quality of the position estimate based on satellite configuration geometry (Rempel et al. 1995, Moen et al. 1996), was not obtained. PDOP cannot at present be used to censor locations prone to higher error because there is apparently no correlation between PDOP and accuracy, however, it is possible that the PDOP information could be incorporated into a filtering scheme in the future (N. Christensen, ATS, personal communication). The collars operated in auto 2D/3D mode, meaning that if signals from ≥4 satellites were obtained a 3D fix (latitude, longitude, and elevation) was taken, otherwise if only 3 satellite signals were obtained a 2D fix (latitude and longitude) was taken using the elevation obtained from the last 3D fix (Rempel et al. 1995). 3D locations generally have less location error than 2D locations (median error 45.5 vs. 65.5 m, respectively, Rempel et al. 1995; mean error 43 vs. 83 m, respectively, Moen et al. 1996). The collars generally attempted to acquire a fix for ≤96 seconds. If unsuccessful, a maximum of 2 retry attempts was made at 15-minute intervals for that programmed GPS interval. GPS collars were removed from the animals by a remotely fired mechanism after the collars signalled that battery power was too low for GPS function. Data required for differential correction were not collected in the current version of the collar, but will be available in future models (C. Kochanny, ATS, personal communication).

We captured goats with a hand-held netgun using a Hughes 500 helicopter. The maximum duration of pursuit was set at 5 minutes; generally animals initially were pushed slowly to terrain appropriate for capture, and were run for <1 minute prior to netting. Each animal was then hobbled, blindfolded, and fitted with horn guards prior to processing. We aged captured goats by counting the number of distinct horn annuli plus the fainter kid annuli formed at 6 months of age (Stevens and Houston 1989). We affixed numbered, orange Allflex eartags to each ear. We released captured goats generally within 20 minutes of netting.

We located the goats using standard aerial telemetry procedures (Mech 1983, Kenward 1987) about every 2 weeks from a Cessna 337 using the collar's VHF transmissions. Flights were often scheduled late in the evening and early the following morning to save ferrying costs and maximize the likelihood of locating goats at mineral licks (Singer and Doherty 1985). Goat locations were recorded using the aircraft's GPS. The general habitat of the location was also recorded.

GIS analyses

Aerial relocation and GPS fix data were imported into a geographic information system (GIS) for mapping and spatial analysis. All data were standardized to the NAD83 datum. Using the GIS with forest cover and TRIM base maps, the following habitat parameters were examined for each goat relocation and GPS fix: elevation, average location aspect (in 90° intervals centred on the four cardinal directions), slope, and the forest cover attribute of the polygon. Forest cover mapping in the study area classified polygons into 3 broad attribute descriptors: non-productive, meaning the area is not capable of supporting commercials forests (e.g., alpine, alpine forest, or rock); non-forest, meaning that the area is not currently forested but is capable of supporting commercial forests (e.g., a logged area that is not sufficiently restocked); or commercial forest. Where applicable, the leading tree species, projected age and height class of the stand also were examined.

Data summarisation and analyses were performed using SAS software (SAS Institute Inc. 1988). Non-parametric tests were used when data were not normally distributed. Statistical tests were considered significant at $P < 0.05$. Means are presented with associated standard errors (SE).

RESULTS

We placed GPS collars on 2 nannies on 26 July 1997. We estimated goats 9701 and 9705 to be 6 and 5 years old, respectively. No obvious capture-related injuries were detected. We relocated goats 9701 and 9705 by aircraft 10 and 13 times, respectively, between 31 July and 10 November; the GPS function was working for 4 and 7 of those relocations, respectively. The 2 GPS collars were removed in October and November.

The GPS function of the collars on goats 9701 and 9705 lasted 24 and 49 days and provided 163 and 917 fixes, respectively (Table 1). The GPS success and fix quality differed markedly between collars. The collar on goat 9705 had a higher mean daily observation rate compared with 9701 ($t = 14.6$; $P < 0.0001$), lower mean PDOP ($t = 3.8$; $P = 0.0002$), and proportionately more 3D versus 2D fixes (and therefore presumably more precise locations; $\chi^2 = 78.4$; 1 df; $P = 0.001$)(Table 1). There was no relationship between PDOP and distance moved from the previous location for goat 9701 ($P = 0.82$); for goat 9705 the relationship was significant but explained almost none of the variation ($r^2 = 0.01$, $P = 0.003$). Mean distance moved between fixes was similar for 2D and 3D modes for goat 9701 ($t = 0.49$, $P = 0.62$), but was greater for 2D mode compared with 3D mode for goat 9705 ($t = 2.37$, $P = 0.02$; 2D mode 259 ± 14.3 m; 3D mode 219 ± 8.8 m).

Table 1. GPS collar data from mountain goats in the Robson Valley. The collars were programmed to take a GPS location every hour. PDOP is the positional dilution of precision.

Goat no.	Days functioned	No. locations	Fixes/day 0 (SE)	Observation rate (%)	PDOP 0 (SE)	% 3D fixes
9701	24	163	6.5 (0.86)	26.9	4.2 (0.17)	30.1
9705	49	917	18.9 (0.43)	78.9	3.6 (0.05)	66.7

Over a 24-day period goat 9701 used about 1.5 km of each of 2 parallel ridges spaced 1 km apart (Fig. 1). Most of the fixes were on the west slopes of the ridges, although occasionally ridgelines and valley bottoms were used. The movement between ridges was made 6-7 August, 12 days after collaring.

Goat 9705 moved about 5.5 km after capture and collaring, and spent 5 days along 1 cliff system northwest of the capture area (Fig. 2). Subsequently (and immediately after the first aerial relocation) the goat returned to the capture area where it spent the remaining 6 weeks of the GPS collar's life along a 5.5 km stretch of mountainside.

Goats 9701 and 9705 ranged primarily over 400 and 800 m in elevation, respectively. Goat 9705 was initially at a lower elevation for the first 5 days after collaring, but returned to higher elevation closer to the original capture area. Comparing 6 hour periods during the day, goat 9705 was at lower elevations from midnight to 0600 hr compared with other time periods (ANOVA $F = 15.6$, 3,913 df, $P < 0.001$; Table 2). Goat 9701 showed no daily pattern of elevation use ($F = 1.8$, 3,158 df, $P = 0.16$).

Table 2. Mean elevation (m) over 6-hour periods and totaled for goats 9701 and 9705, as determined by GPS collars.

	Goat 9701			Goat 9705		
Time period (hr)	*n*	0	SE	*n*	0[a]	SE
2400-0600	39	1815	25.4	245	2068a	11.5
0600-1200	35	1787	18.8	230	2127b	12.1
1200-1800	34	1751	21.3	209	2176c	11.1
1800-2400	54	1814	20.0	233	2151bc	12.1
Total	162	1795	11.0	917	2129	6.0

[a] Means denoted by the same letter are not significantly different (Ryan's Q multiple range tests, $P < 0.05$)

Goat 9701 on average used steeper ground than goat 9705 (Mann-Whitney $U = 8.41$, $P = 0.0001$; Table 3). Goat 9701 used less steep slopes during the periods from 1800 to 0600 hr ($F = 10.74$, 3, 158 df, $P < 0.0001$); goat 9705 showed no pattern in slope use during the day ($F = 1.03$, 3, 913 df, $P = 0.38$).

Table 3. Mean percent slope over 6-hour periods and totaled for goats 9701 and 9705, as determined by GPS collars.

	Goat 9701			Goat 9705		
Time period (hr)	*n*	0[a]	SE	*n*	0	SE
2400-0600	39	78a	8.2	245	65	2.0
0600-1200	35	129 b	8.0	230	65	2.0
1200-1800	34	113 b	7.7	209	68	2.4
1800-2400	54	82a	6.0	233	69	1.9
Total	162	98	4.0	917	67	1.0

[a] Means denoted by the same letter are not significantly different (Ryan's Q multiple range tests, $P < 0.05$)

Aspect use differed between goats ($\chi^2 = 235.9$, 3 df, $P < 0.0001$; Table 4). West-facing slopes were heavily used by goat 9701 ($\chi^2 = 89.1$, 3 df, $P < 0.0001$) and south-facing slopes were used more often by goat 9705 ($\chi^2 = 42.1$, 3 df, $P < 0.0001$). Aspect use may have been a function of the structure of the mountain block inhabited by each goat. Goat 9701 lived on fairly steep-sided ridges aligned in a north-south direction, while goat 9705 lived on a more rounded block oriented in an east-west direction.

Table 4. Distribution (%) of aspect of locations for 2 goats wearing GPS collars, Robson Valley. Aspect based on 90° intervals centred on the 4 cardinal directions.

Goat no.	*n*	North	East	South	West
9701	162	12.4	13.6	0.6	73.5
9705	917	23.8	19.9	38.4	18.0

Distance moved between fixes differed among 6 hourly periods during the day for goat 9705 ($F = 2.6$, 3,751 df, $P = 0.049$) but not for goat 9701 ($F = 0.3$, 3,71 df, $P = 0.85$), where smaller sample size likely weakened the analyses (Table 5). Goat 9705 moved on average less distance during the period from noon to 1800 hr and further during the 1800 hr to midnight period.

Table 5. Mean distance (m) moved hourly over 6-hour periods and totaled for goats wearing GPS collars, Robson Valley[a].

	Goat 9701			Goat 9705		
Time period (hr)	*n*	0	SE	*n*	0[b]	SE
2400-0600	16	242	53.8	205	231ab	16.1
0600-1200	19	215	93.5	195	206ab	12.4
1200-1800	13	162	31.2	160	196a	14.4
1800-2400	27	195	28.1	195	253 b	18.7
Total	75	204	28.3	755	223	7.9

[a] Locations separated by <1:15 hr used for calculation of hourly movement rate.

[b] Means denoted by the same letter are not significantly different (Ryan's Q multiple range tests, $P < 0.05$)

The hourly movements of goat 9705 provided an index of the disturbance caused by both capture and aerial relocations. Twenty-four hour periods after capture and before and after aerial relocation were compared (Table 6). Goat 9705 moved about 70% further in the 24 hours after aerial relocations compared with presumably undisturbed periods before relocations ($t = 3.15$; $P = 0.002$), and over 3 times further in the period after capture and collaring compared to undisturbed periods ($t = 3.48$; $P = 0.002$). Three of 5 of the longest hourly movements recorded for goat 9705 were within the 24-hour periods after aerial relocations. Longer distance movements after aerial relocation were often not immediate, but occurred during the following dawn or dusk up to 12 hours after disturbance. Observation rate for goat 9701 was too low to examine hourly movement patterns.

Table 6. Mean distance (m) moved hourly by goat 9705 within 24 periods after capture, and before and after aerial relocations, as determined by GPS collar.

Period	n	0	SE
Capture	22	474.2	96.22
Before relocation	77	136.5	12.25
After relocation	107	232.1	27.68

Fifty-three percent (*n* = 162) of GPS fixes from goat 9701 were in the AT subzone, with the remainder in the ESSFmm1 (moist, mild) subzone/variant; GPS fixes for goat 9705 were 88% in AT and 12% in ESSFmm1 (*n* = 917).

Less than 9% of GPS fixes placed goats in commercial forests (Table 7). Almost 90% of fixes from both goats were in polygons with the alpine non-productive forest attribute. Forest cover polygons designated as alpine forest were comprised only of subalpine fir for goat 9701 (*n* = 12) and either pure subalpine fir or subalpine fir/lodgepole pine stands for goat 9705 (*n* = 20). Goat 9701 was found in subalpine fir/spruce stands in all 4 cases where it was located in commercial forests. Lodgepole pine and subalpine fir dominated forest cover polygons where goat 9705 was located, with Douglas-fir and whitebark pine found in lower proportions (Table 8). Most (64.6%) commercial forest stands were mature in projected age class (81-140 years), while 11.4% were old aged stands (>140 years) and 24.1% were immature (21-80 years)(*n* = 79). All subalpine fir and Douglas-fir dominated stands were mature or old aged, and all lodgepole pine dominated stands were immature or mature in age.

Table 7. Distribution (%) of forest cover attributes in polygons containing GPS collar locations from mountain goats in the Robson Valley.

Goat no.	*n*	Alpine	Alpine forest	Commercial forest	Other[a]
9701	162	90.0	7.4	2.5	0
9705	917	89.3	2.2	8.2	0.3

[a] Other included non-productive brush and non-productive burn.

Table 8. Distribution (%) of the first and second leading commercial tree species (by gross volume) in forest cover polygons containing GPS locations from goat 9705, Robson Valley.

	n	Lodgepole pine	Subalpine fir	Douglas-fir	Spruce	Whitebark pine
Leading species	75	70.7	26.7	2.7	0	0
Second species	73	26.0	45.2	12.3	8.2	8.2

Comparison of GPS and VHF data

The GPS receiver provided vastly greater numbers of locations compared to the aerial relocations of the VHF transmissions. During the period when the GPS collars were functioning, 162 GPS fixes were obtained for goat 9701 compared with 4 aerial relocations. Similar figures for goat 9705 were 917 fixes and 7 relocations. Thus, comparisons of the results obtained using the 2 techniques were compromised by vast differences in sample sizes. Home range size comparisons were not possible due to the small number of aerial relocations, but it was obvious that the GPS collars demonstrated greater use of the habitat by the goats (Figs. 1, 2).

GPS fix accuracy and aerial telemetry accuracy was not field-tested. However, 11 aerial relocations occurred concurrent with functioning GPS collars (some relocations using VHF signals occurred after GPS functioning had ceased). The time difference between acquisition of GPS fix and relocation ranged from 8 minutes to 1.5 hours, thus varying degrees of movement between the 2 locations were expected. Five aerial relocations were taken <15 minutes of a GPS fix. Time and distance between GPS fix and relocation were, respectively: 8 minutes and 52 m (GPS fix first); 10 minutes and 92 m (relocation first); 10 minutes and 226 m (GPS fix first); 14 minutes and 90 m (relocation first); 14 minutes and 432 m (GPS fix first).

PDOP is apparently not related to accuracy, but 2 cases of suspicious movements by goats had high PDOP values. On 30 July sequential GPS fixes showed goat 9701 moved 512 m horizontally dropping 300 m elevation down a slope and across a valley in 2 hours, then return 511 m to almost the exact spot in 3.5 hours; the PDOP for the suspect movement was 8.1 (2D fix). On 10 September goat 9705 moved 1151 m in 1 hour to an area not frequented at any other time during the study, then returned 1198 m in the next hour to within 55 m of the original location; the PDOP for this outlier was 8.8 (2D fix). Both movements are within the travel ability of mountain goats, but both appear suspect. Less than 2.8% of GPS fixes had PDOP ≥8.0 ($n = 1079$), and most high PDOP values were associated with 2D fixes (77%, $n = 30$).

Mean elevation of locations as determined by GPS fixes and aerial relocations did not differ for each goat (t-test, $P > 0.64$), but aerial relocations captured only 62% of the range in elevation used for each goat as determined by the GPS fixes. Similarly, mean slope of locations did not differ for each goat by location method ($P > 0.17$), but aerial relocations captured only 49% (goat 9701) and 19% (goat 9705) of the range of slope use determined by GPS fixes.

Comparison of use of alpine and commercial forests as determined by GPS fixes and aerial relocations is difficult given the small sample sizes of aerial relocations. Only 1 relocation of goat 9701 was in a subalpine fir alpine forest, and no relocations were in commercial stands. The GPS collar placed goat 9701 in subalpine fir alpine forests 12 times (7% of fixes), and in subalpine fir commercial forests 4 times (2%). Goat 9705 was relocated in lodgepole pine dominated alpine forests once and was not found in commercial forests. The GPS collar placed goat 9705 in fir alpine forests on 20 occasions (2.2% of fixes) and in fir and pine commercial forests on 75 occasions (8.2%).

DISCUSSION

The GPS collars provided more detail on goat movements than possible through conventional telemetry. They appear to have provided a relatively systematic assessment of habitat use regardless of weather conditions with biases (primarily differences in observation rate based on habitat and terrain) that can be at least partially quantified (Rempel et al. 1995). Use of GPS collars would minimize aircraft disturbance, and possibly give a "truer" representation of animal behavior and movements compared to conventional telemetry using aircraft. The GPS collars would also tend to detect unique or rare movements more often, such as visits to licks.

Location data derived from GPS collars are not without their biases, including variable observation rates related to satellite signal interference by vegetation and terrain, and differing location accuracy depending upon 2D or 3D location mode and signal strength as measured by HDOP (Rempel et al. 1995, Moen et al. 1996). An assessment of location error was not possible with these data, nor was the ability to censor data by removing fixes with high HDOP to increase accuracy. The suspect locations with high PDOP values suggest that further examination of the relationship between PDOP and location accuracy is warranted.

GPS collar data suggested use of lower elevation sites during hours of darkness (goat 9705), and provided a more complete picture of the area and range of elevations used by each goat and the distance and timing of movements. The data presented here also suggest that aerial relocations have a significant effect on subsequent mountain goat movements, and that the effect may not be immediate. The GPS data suggested that although some longer distance movements occurred immediately after aerial relocation, on several occasions it was the following dawn or night that the longer movements occurred. Other researchers have noted the fright and hiding responses to aircraft (summarized in Côté 1996).

Costs of locations derived from GPS collars compared with conventional VHF collars and aerial relocation flights are difficult to compare. GPS collars cost roughly $4,000-$5,000 CDN, while VHF collars are approximately $400. Our relocation flights cost approximately $1,100-$1,300 to locate 6 to 16 goats. Using a hypothetical 6 GPS and 6 VHF collars, the costs for collars and flights for 20 aerial relocations would be approximately $24,400, while 6 GPS collars would cost $24,000 - $30,000. However, depending upon the frequency of GPS location attempts and the observation rate, the GPS collars could provide more than 6,000 locations (1,000 per collar) compared to 120 using aerial VHF telemetry. Costs will vary greatly depending upon aircraft type and ferry costs.

MANAGEMENT RECOMMENDATIONS

The primary objectives of this ongoing study are to examine seasonal variation in forest use and locate previously unknown mineral licks, preferably in areas where forestry development is slated but has not yet occurred. GPS collars appear to provide the best opportunity to locate mineral licks in undeveloped valleys where human access is difficult and aerial spotting is tough. GPS collars would also more readily detect lick use at night (Singer 1978). GPS collars deployed in late winter or spring would cover the critical spring/early summer period when lick use appears to be greatest (Hebert and Cowan 1971, Singer and Doherty 1985). Collar deployment should be prioritized for valleys where forestry development is slated and mineral lick information is lacking. Although both sexes should be sampled to examine differences in terrain, habitat and lick use between sexes, spring deployment of collars should target males to avoid disturbance to pregnant nannies or neonatal kids. Winter use of lower elevation forests can also be more efficiently addressed using GPS collars.

The GPS collars used in this study were set to obtain a location every hour because of field-test timing constraints, resulting in shorter overall length of coverage. Subsequent GPS collars should be set to obtain a location 3-4 times a day, or on a staggered 3 times in 25 or 26 hour schedule, to enable roughly equal sampling throughout the day and longer coverage period. Differentially correctable signals would increase the accuracy of the location data (Moen et al. 1997, Rempel and Rodgers 1997), that may aid in locating mineral licks. However, implementation of differential correction can involve increased costs in data handling, decreased battery-life expectancy, and fewer usable locations (Rempel and Rodgers 1997). Collection of HDOP by the GPS receiver would enable some censoring of position accuracy, at least in 2D fix mode (Rempel et al. 1995, Moen et al. 1996). Field tests of GPS collars in mountainous terrain have not been conducted, and may be useful to assess the influence of vegetation, terrain and collar type on location accuracy and location capture success (Moen et al. 1997). Preliminary results from this study suggest that GPS technology should prove of great benefit to studies not only on mountain goats but other mountain ungulates as well. These studies could include research into disturbance, examination of movement rates or nighttime habitat use, and documentation of rarely used habitats.

ACKNOWLEDGMENTS

Funding for this inventory was provided by Forest Renewal British Columbia, Resources Inventory Program, and was administered by BC Ministry of Environment, Lands and Parks (MELP), Prince George. Field and study assistance was provided by G. Watts, MELP, Prince George. The assistance of Dr. H. Schwantje, MELP, Victoria, during capture operations was greatly appreciated. Goat captures were skilfully performed by C. Wilson and his capture crews from Bighorn Helicopters, Cranbrook. B. Mcpherson and D. Brady, Yellowhead Helicopters, Valemount and McBride supplied additional helicopter support. D. Mair, Silvertip Aviation, Revelstoke, provided excellent and enthusiastic piloting for fixed-wing relocation flights. C. Kochanny and N. Christensen, ATS, Isanti, Minn., patiently answered endless questions regarding their GPS collars. V. Johnson, L. Macgregor and D. Pritchard, Timberland Consultants Ltd., conducted the GIS analyses and map production. G. Mowat, Timberland, provided constructive comments on the manuscript.

LITERATURE CITED

Côté, S. D. 1996. Mountain goat responses to helicopter disturbance. Wildlife Society Bulletin 24:681-685.

Festa-Bianchet, M. Urquhart, and K.G. Smith. 1994. Mountain goat recruitment: kid production and survival to breeding age. Canadian Journal of Zoology 72:22-27.

Haynes, L.A. 1992. Mountain goat habitat of Wyoming's Beartooth Plateau: implications for management. Biennial Symposium of the Northern Wild Sheep and Goat Council 8:325-339.

Hebert, D, and I.M. Cowan. 1971. Natural salt licks as a part of the ecology of the mountain goat. Canadian Journal of Zoology 49:605-610.

Heimer, W.E. 1994. Aerial survey and Dall sheep population size: comparative usefulness and internal population dynamics for management purposes. Biennial Symposium of the Northern Wild Sheep and Goat Council 9:43-50.

Hopkins, A., J.P. Fitzgerald, A. Chappell, and G. Byrne. 1992. Population dynamics and behavior of mountain goats using Elliot Ridge, Gore Range, Colorado. Biennial Symposium of the Northern Wild Sheep and Goat Council 8:340-356.

Kenward, R. 1987. Wildlife radio tagging: equipment, field techniques and data analysis. Academic Press, London, U.K. 222pp.

Mackinnon, A., J. Pojar, and R. Coupé, eds. 1992. Plants of northern British Columbia. Lone Pine Publishing, Vancouver, BC.

Mech, L.D. 1983. Handbook of animal radio-tracking. University of Minnesota Press, Minneapolis. 107pp.

Moen, R., J. Pastor, Y. Cohen, and C.C. Schwartz. 1996. Effects of moose movement and habitat use on GPS collar performance. Journal of Wildlife Management 60:659-668.

------, ------, AND ------. 1997. Accuracy of GPS telemetry collar locations with differential correction. Journal of Wildlife Management 61:530-539.

Poole, K.G. 1998. Low elevation forest use by mountain goats in the Robson Valley Forest District. Unpublished report submitted to BC Ministry of Environment, Lands and Parks, Prince George.

Rempel, R.S., A.R. Rodgers, and K.F. Abraham. 1995. Performance of a GPS animal location system under boreal forest canopy. Journal of Wildlife Management 59:543-551.

------, AND ------. 1997. Effects of differential correction on accuracy of a GPS animal location system. Journal of Wildlife Management 61:525-530.

SAS Institute Inc. 1988. SAS user's guide: statistics. Version 6.03. SAS Institute Inc., Cary, N.C. 1028pp.

Singer, F.J. 1978. Behavior of mountain goats in relation to U.S. Highway 2, Glacier National Park, Montana. Journal of Wildlife Management 42:591-597.

------, and J.L. Doherty. 1985. Movements and habitat use in an unhunted population of mountain goats, *Oreamnos americanus*. Canadian Field-Naturalist 99:205-217.

Smith, C.A. 1994. Evaluation of a multivariate model of mountain goat winter habitat selection. Biennial Symposium of the Northern Wild Sheep and Goat Council 9:159-165.

Stevens, V., and D.B. Houston. 1989. Reliability of age determination of mountain goats. Wildlife Society Bulletin 17:72-74.

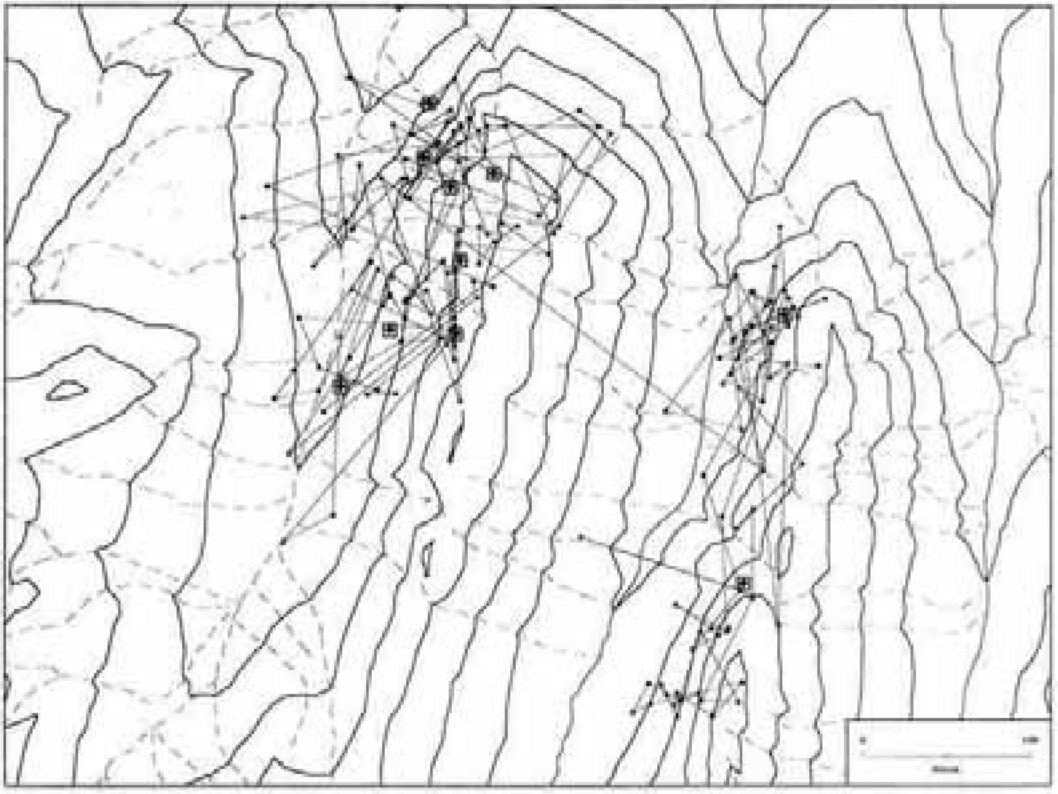

Fig. 1. **GPS fixes (circles) and VHF relocations (diamonds within a box) for goat 9701, Robson Valley. GPS fixes cover 26 July – 18 August 1997, VHF relocations cover 31 July – 7 October 1997.**

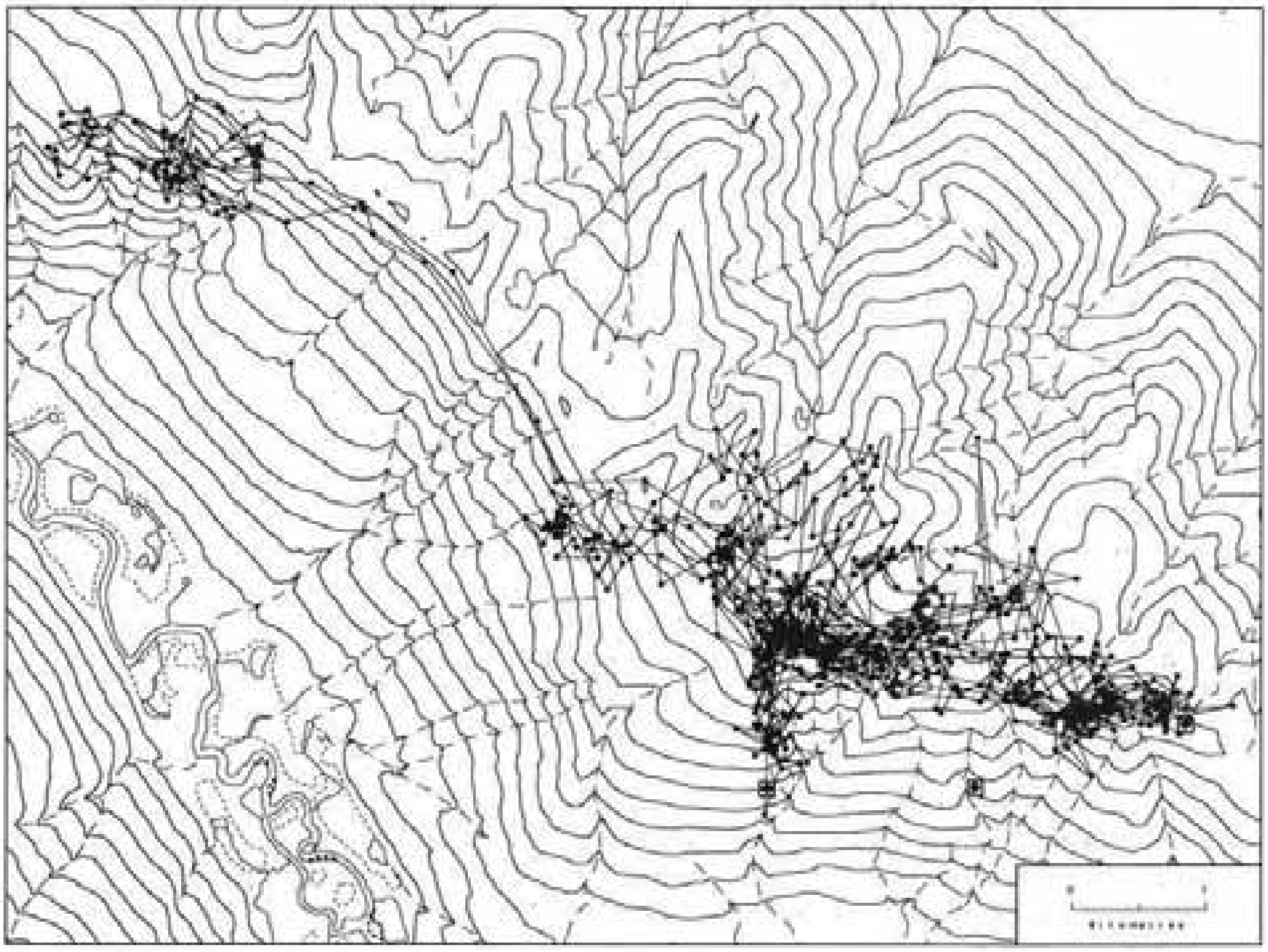

Fig. 2. GPS fixes (circles) and VHF relocations (diamonds within a box) for goat 9705, Robson Valley. GPS fixes cover 26 July – 12 September 1997, VHF relocations cover 31 July – 10 November 1997.