COLUMBIA BASIN FISH & WILDLIFE COMPENSATION PROGRAM

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MOUNTAIN CARIBOU HABITAT USE, MOVEMENTS, AND FACTORS ASSOCIATED WITH GPS LOCATION BIAS IN THE ROBSON VALLEY, BRITISH COLUMBIA

PREPARED BY
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FOR
Columbia Basin Fish & Wildlife Compensation Program

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SUMMARY

We analyzed data collected from GPS collars deployed on 6 mountain caribou near the Robson Valley, British Columbia, during 1996 and 1997. Our objectives were to describe the dataset, describe seasonal habitat use and movement patterns, examine potential habitat bias associated with fix rate, and provide habitat conservation and research recommendations for the study area.

Three collars deployed in 1996 appeared to attempt hourly fixes, and four collars deployed in 1997 were programmed to attempt fixes every 6 hours. Slightly less than one-third of attempted fixes were successful, yielding 1384 locations. We screened the resulting data for locations associated with dead animals or dropped collars, and for outliers obvious when considering data in the context of sequential movements and maximum movement rates over time. Based on field studies relating GPS collar error to HDOP, the number of satellites, and differential correction success, we interpolated a probable error for each fix in the database. From this, we estimated that 92% of fixes were within ±501 m and 76% were within ±101 m.

We derived GIS-based forest overstory and terrain variables for an area encompassing all GPS data, and we summarized seasonal habitat use at stand- and landscape-levels. A significant proportion of daily locations fell within non-forested “alpine” during all seasons except early winter. There were only minor differences in use between stand and landscape levels for most variables, although some attributes did appear to be preferred at the stand-level. Across seasons, forested habitats used by caribou were mostly oldgrowth subalpine forests, and overall habitat use was consistent with that of a nearby population. Although elevation use was slightly higher during summer than during other seasons, elevation shifts that would normally be expected among seasons were only weakly apparent. This may have an ecological basis, or successful GPS fixes may have been biased to higher elevations.

We described caribou movements visually and also quantitatively by defining a probable movement area (PMA) associated with each movement vector. A spatial summation of PMAs, weighted according to the number of movements that could have occurred within a sampling

interval, depicted probable movement intensity. Maps of such highlight some areas that may be important for movement within each animal's home range. Similar to caribou use sites, areas identified as having high probable movement intensities were concentrated within old forest and the alpine, with very little use of young forests or recent cutblocks. There appeared to be extensive intra-herd connectivity within the Cariboo Mountains, but essentially no movement from there to other ecosections. The one caribou collared within the Northern Park Ranges showed very limited movement. No activity was recorded in the Quesnel Highland portion of the study area, and only at the periphery of the Upper Fraser Trench.

To quantify the influence of habitat attributes on the likelihood of a successful GPS collar fix, we compared attributes at successful fix locations to those of PMAs associated with at least one failed location fix. Generally, successful fixes were biased toward high elevations and alpine habitats and against low elevation valley bottoms associated with concave terrain curvature. We suggest that the negative correlations of fix success with deciduous species composition and southern aspects are spurious. A multivariate model derived from a subset of variables was statistically significant, suggesting that a linear combination of variables can predict the relative likelihood of a successful fix. We discuss non-habitat factors that may also influence fix success of GPS collars. Although it is an indirect approach, the method we describe for assessing habitat bias associated with a given dataset has some advantages over interpolating results from field studies.

We outline several technical issues that can be addressed to improve location fix success and the success of differential correction. We also recommend that conservative decision-rules be adopted when screening GPS data. For habitat selection analyses, some random error in the dataset is preferred over additional habitat bias that will result from excessive screening.

Habitat management decisions based on this dataset must acknowledge that use of low-elevation habitats may be underrepresented during early winter and other seasons. We provide recommendations for further research.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF MAPS

INTRODUCTION

In 1996 and 1997, 6 mountain caribou were fitted with GPS collars in the vicinity of the Robson Valley near McBride, British Columbia. These collars were intended to provide data on early winter habitat use and potential movement corridors important for caribou conservation. It was expected that GPS collars would fill information gaps that could not be adequately addressed by previous studies in the same area (Terry 1995) using conventional VHF radiocollars. However, GPS collars obtained successful fixes for only a small fraction of the 15,000 potential locations due to technical issues and the influence of topographic and habitat factors (Heard and Watts in press). We were contracted to address these issues, with an aim to improving the collection, processing, management, and analysis of GPS data, and to describe habitat use from the existing dataset. Our specific objectives were to:

1. describe the dataset, including dates each caribou was collared, collar setup options, total locations obtained, observation rate, and the date each collar ceased functioning;
2. describe seasonal habitat use at the stand and landscape scale, and, to the extent possible, comment on movements relative to topography and land cover;
3. examine the potential bias in observation rate caused by topography and/or vegetation; and
4. based on the above, where appropriate and supported by data, recommend: habitat conservation measures, changes to collar setup or other alternatives for examining early winter habitat use by Robson Valley caribou.

STUDY AREA

The study area was located northwest of McBride, British Columbia in the Columbia and Rocky Mountains and the intervening Rocky Mountain Trench (Figure 1). It included four ecosections (Demarchi 1996). The majority of the study area fell within the Cariboo Mountains ecosection, an area of rugged, ice-capped mountains with narrow valleys. The westernmost edge of the study area was within the Quesnel Highlands ecosection, which has more subdued terrain. The northeastern edge was located in the broad glacial plain adjacent to the Fraser River in the Upper Fraser Trench ecosection, and just into the Northern Park Ranges ecosection which has rugged, often ice-capped, mountains and moderately wide valleys.

Four biogeoclimatic zones occurred in the study area (Meidinger and Pojar 1991). Two zones occurred at the lowest elevations. Of these, landscapes with greater precipitation fell within the Interior Cedar Hemlock zone (ICH), in which western redcedar (*Thuja plicata*) and western hemlock (*Tsuga heterophylla*) are dominant climax tree species. Drier areas were in the Sub-Boreal Spruce (SBS) zone, having hybrid white spruce (*Picea engelmannii x glauca*) and subalpine fir as dominant climax species. Middle elevations occurred within the Engelmann

Spruce – Subalpine Fir (ESSF) zone. Climax species in the ESSF are Engelmann spruce (*P. engelmannii*) and subalpine fir. The Alpine Tundra (AT) zone is non-forested and occurs at the highest elevations within the Cariboo Mountains and Northern Park Ranges. Portions of it are glaciers or bedrock. Seral stands of lodgepole pine (*Pinus contorta*), trembling aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*) and Douglas-fir (*Pseudotsuga menziesii*) occur in forested zones, particularly in the SBS. Forest harvesting has occurred over large portions of the study area, particularly at lower elevations.

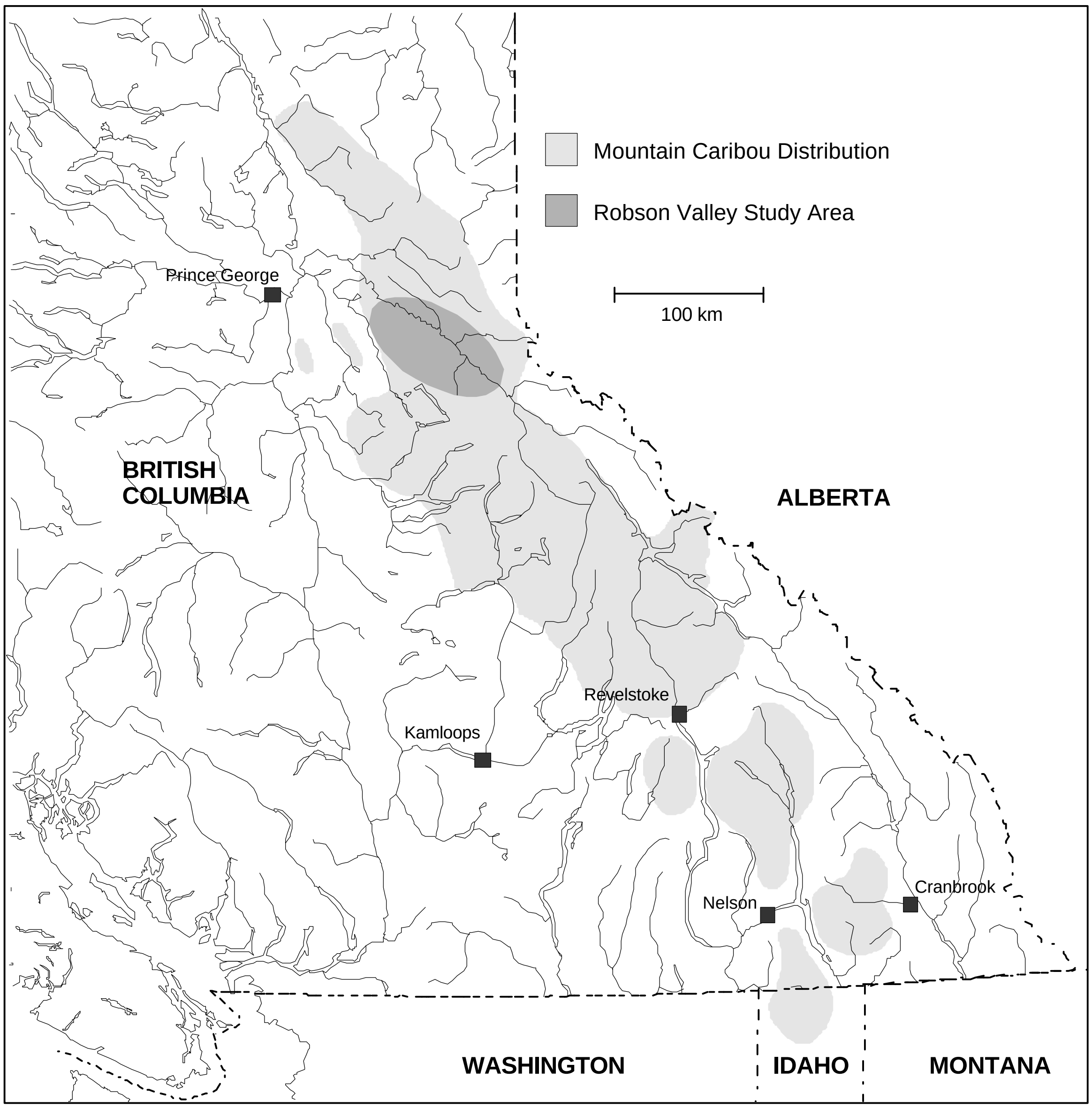

Figure 1. Current mountain caribou distribution and the Robson Valley study area.

METHODS

GPS Collar Data

We obtained the caribou GPS location data from D. Heard, MELP, Prince George. Six adult female caribou were fitted with *Lotek 1000* GPS collars (Lotek Engineering, Newmarket, Ontario) in 1996 and 1997. These collars were equipped with *Motorola PVT-6* 6-channel GPS receivers, motion sensors, temperature sensors, and nominal one-year battery packs. Three collars were deployed in March, 1996 but all failed prematurely in April or May of that year (Table 1). One of the same animals and 3 additional caribou were collared in January or April of 1997. The second deployment of collars provided data until between June and December, 1997. Collars were set to obtain fixes every six hours. However, those deployed in 1996 appeared to attempt fixes hourly, suggesting that they malfunctioned or were incorrectly programmed. Data were downloaded remotely from aircraft or upon recovery of collars using the vendor's *GPS Host* software, and were differentially corrected using the vendor's *N3WIN* software. Base station files were provided and processed by Terrapro GPS Survey Ltd, Prince George, BC. Files were 99% from the main Terrapro station within Prince George (53° 54' 36.1" N, 122° 47' 28.8" W), which used a Trimble *Pathfinder Pro XL 12* parallel channel receiver and *Pathfinder Community Base Station* software, version 2.03. About 1% of the files used for processing were from Terrapro's former "Forey" station, which was also in Prince George and used the same hardware and software.

We combined datasets from individual caribou into a common database and converted data fields into consistent formats. Locations were originally described as Geodetic (Lat/Long) microseconds, which we converted to UTM, zone 10, NAD83. For the one animal (Fran) known to have died prior to data downloading (D. Heard, BC Ministry of Environment, Lands and Parks, pers. comm.) we calculated apparent movements between sequential fixes to determine the date and time of death (i.e. when movements ceased). Using the same method, we determined that a second animal (BettyB) whose collar apparently lost its radio signal had either died or lost its collar prior to the last download. We deleted fixes obtained subsequent to cessation of movement for both animals. We also deleted fixes known to have been obtained prior to collar deployment. The files corrected with data from the Forey base station were all for animal BettyB. Because there was some temporal overlap with correction files from the main Terrapro station for Betty B, it was apparent that Forey-corrected data were offset to the north by exactly or very nearly 0.01° latitude, for unknown reasons. We therefore adjusted these locations accordingly. In total, slightly less than one-third of the attempted fixes were successful, yielding 1384 locations (Table 1; Appendix Map 1).

Collars recorded successful fixes as either 2D or 3D, depending on whether they were derived from signals of 3 or ≥ 4 satellites respectively, and provided a horizontal dilution of precision (HDOP) value for each. The database also indicated whether attempts to differentially correct each location were successful ("diff") or not ("fix"), and most successful locations were differentially corrected (Table 2). For this analysis, and for future data applications, we assigned a predicted mean error value to each fix in the database. The true error associated with any fix cannot be known, but the values assigned reflected the mean error for all fixes with a given HDOP. These were based on regression equations correlating HDOP to error for 2D "fix" and 3D "fix" data (Moen et al. 1996) and 2D "diff" data (Rempel et al. 1995), using *Lotek 1000* collars. True mean errors for 2D records in this study were almost certainly greater than those reported in the literature due to errors in assumed elevation that can be expected for 2D locations in the mountainous terrain of the study area (Moen et al. 1997), but should at least be scaled proportionately. For 3D "diff" data, the literature showed no significant relationship between HDOP and error (Rempel et al. 1995, Moen et al. 1997). However, HDOP was truncated at DOP < 6.0 for 3D locations in those studies, with mean predicted errors of <50 m in that range. In the absence of a regression equation, we adopted the following method of assigning mean error to 3D "diff" records:

1. We assigned a mean error of 50 m to any 3D "diff" record with HDOP <6.0
2. At cutpoints of 100, 200, 300, 400, 500, 1,000, 5,000 and 10,000 m error, we determined the quotient of corresponding HDOP values for 2D "diff" and 2D "fix" records, then multiplied this by the HDOP associated with each cutpoint for 3D "fix" records. The product was assumed to be the upper HDOP threshold for each error category.

From the assumed errors assigned to each fix, we estimated that 92% of fixes were within ±501 m and 76% were within ±101 m of their true location (Table 3). In comparison to these estimates, 95% of 63 2D and 3D "diff" locations on 2 dead caribou deviated from their mean coordinates by < 40 m, but an additional 3D and a 2D "fix" each deviated by 1.15 km. On stationary collars, 2D should be as accurate as 3D locations because the elevation assumed in calculating a collar's position for 2D locations is estimated using the mean value of previous 3D fixes.

We manually screened the data for extreme location error by examining apparent movements between sequential locations. Any sequential fix resulting in an apparent movement of > 5.0 km within a 24 hr period, followed by a return to < 1.0 km from the previous location was assumed to be erroneous and was excluded from analysis. The 5.0 km interval approximates the 95th percentile of net caribou movement per day (Figure 2)

Table 1. GPS location data distribution among caribou and seasons in the Robson Valley, British Columbia, 1996 – 1997. [a]

Animal	Data collection period	Fix Attempt Rate (hr)	Data Termination Reason	Early Winter[b]		Late Winter		Spring		Summer		Total	
				Fixes	SFR[c]	Fixes	SFR	Fixes	SFR	Fixes	SFR	Fixes	SFR
Anne	31 Mar – 02 May, 1996	1	battery failure	0	N.A.	68	18.3	70	17.7	0	N.A.	138	18.0
BettyA	29 Mar – 18 Apr, 1996	1	battery failure	0	N.A.	184	43.8	34	56.7	0	N.A.	218	45.4
Carol	31 Mar – 24 Apr, 1996	1	battery failure	0	N.A.	102	27.4	38	18.6	0	N.A.	140	24.3
BettyB[d]	24 Jan – 19 Nov, 1997	6	lost contact	8	10.8	210	64.4	61	33.2	71	11.6	350	29.3
Dianna	22 Apr – 30 Dec, 1997	6	battery failure	48	20.2	0	N.A.	42	26.6	219	35.7	321	31.8
Ethel	21 Apr – 24 Jun, 1997	6	battery failure	0	N.A.	0	N.A.	53	32.7	41	43.6	94	36.7
Fran	21 Apr – 04 Jul, 1997	6	death	0	N.A.	0	N.A.	65	40.1	70	52.2	135	45.6
Total				56	17.9	564	45.4	363	31.3	413	27.6	1384	35.7

[a] Does not include 64 fixes on 2 dead animals

[b] Season dates defined by Simpson et al. (1997): early winter ends 15 Jan; late winter ends 15 Apr.; spring ends 31 May; summer end 31 Oct.

[c] Successful fix rate (%) of minimum 2-D locations

[d] Same animal as BettyA, but re-collared.

Table 2. GPS location data fix success by fix type for caribou GPS collars in the Robson Valley British Columbia, 1996 – 1997. "Diff" = differentially-corrected GPS locations; "Fix" = non-corrected GPS locations.

Location type	Count	Proportion
Unsuccessful	2493	0.64
2D "Fix"	71	0.02
3D "Fix"	69	0.02
2D "Diff"	646	0.17
3D "Diff"	597	0.15
Total	3876	1.00

Table 3. Cumulative distribution of GPS locations by estimated spatial error and caribou in the Robson Valley, British Columbia, 1996 – 1997.

	Predicted Error (m)						
Animal	< 51	<101	< 201	< 301	< 501	< 1001	< 10001
Anne	15	107	118	124	125	127	138
BettyA	79	176	201	207	209	212	218
Carol	63	267	302	313	321	326	350
BettyB	33	106	121	123	127	130	140
Dianna	61	243	273	282	295	300	321
Ethel	19	58	66	70	74	76	81
Fran	26	99	119	124	128	128	135
Total	296	1056	1200	1243	1279	1299	1383

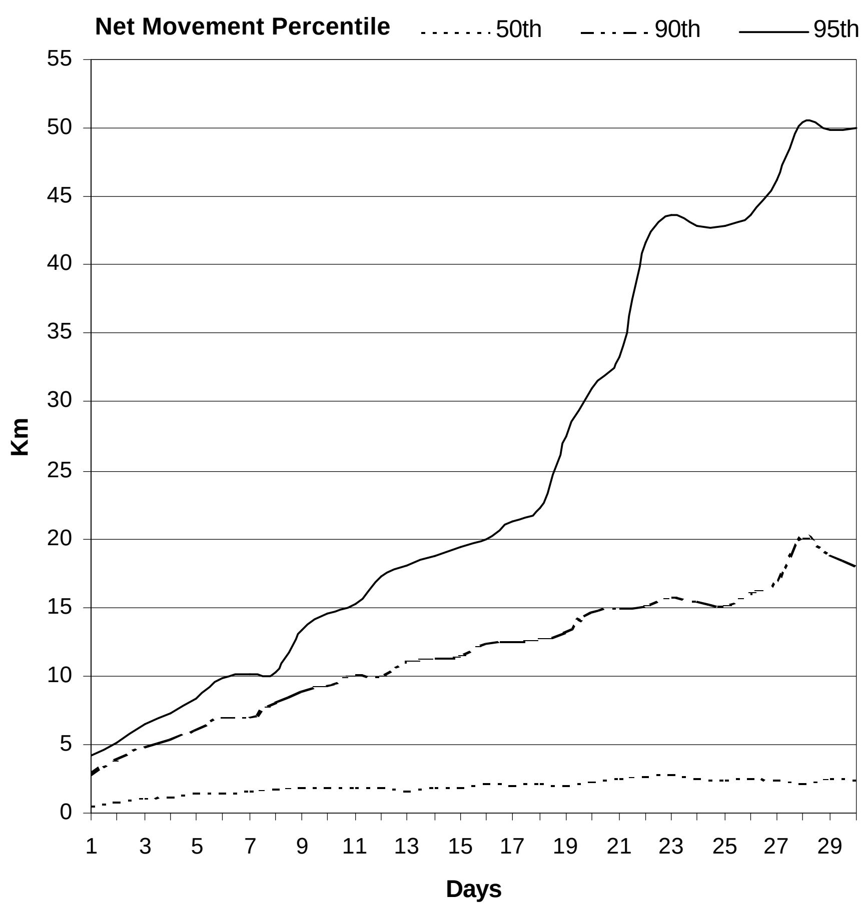

Figure 2. Net movements of 6 GPS-collared caribou over successive days in the Robson Valley, British Columbia, 1996 – 1997.

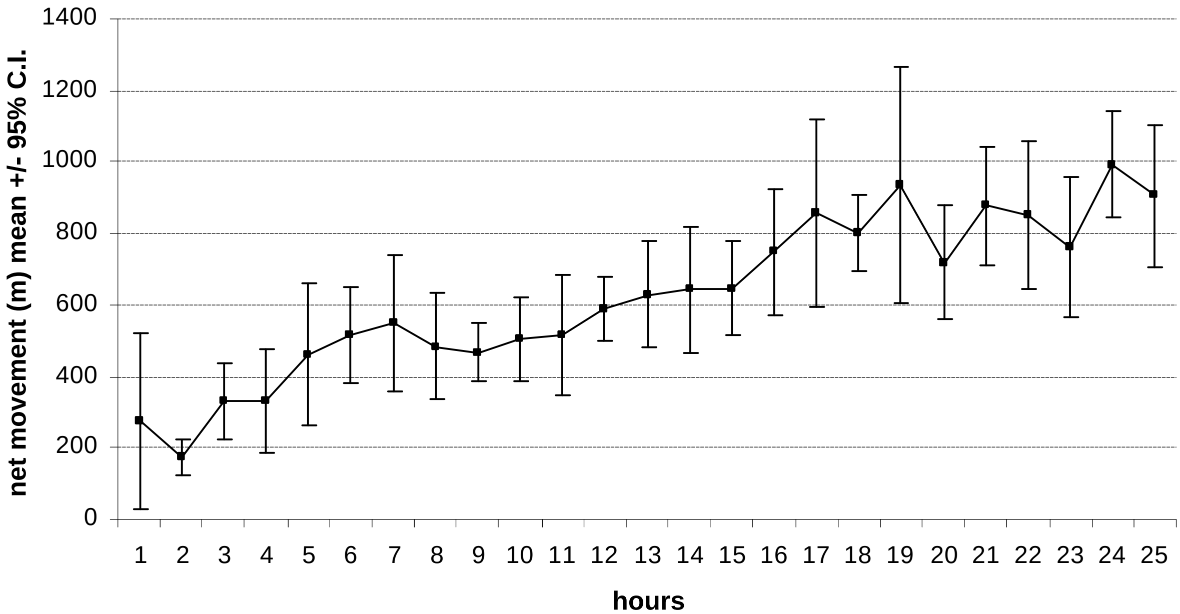

Figure 3. Net movements by caribou over hourly intervals (mean +/- 95% C.I.) as estimated from GPS location data in the Robson Valley, British Columbia, 1996 – 1997.

GIS Habitat Data

We assembled habitat data in a GIS for an approximately 9,000 km^2 rectangular area encompassing all GPS locations. Data were compiled from 1:20,000 digital forest inventory planning files (FIP; Resources Inventory Branch 1995) and Terrain Resource Information Management files (TRIM; Surveys and Resource Mapping Branch 1992) and were rasterized to 50 m resolution (cell size). From these data sources, we derived habitat variables associated with forest stand overstory and terrain attributes (Table 4). Several attributes thought to be important to mountain caribou may relate to stand age in a non-linear manner (Stevenson et al. 1994). We therefore derived 4 stand age classes reflecting gross structural differences expected among dominant tree species in the region, and which conform to the age class convention of the provincial forest inventory system. The CANOPY variable depicted the ocular cover of the stand overstory. The SITE variable reflected site productivity based on stand age and height as calculated by species-specific equations (Thrower et al. 1991). We considered overstory species composition for analysis because it may relate to seasonal forage availability and will indicate climatic variability. Individual or grouped species were included if their spatial composition was > 3% of the total analysis area. Non-forested ALPINE encompassed all habitat types above treeline, including rock and ice. Terrain variables included elevation (ELEV) and slope (SLOPE). Slope curvature (CURVA) reflected the maximum rate of change of a curve fit through each pixel.

Aspect was represented by two continuous (0→1) variables depicting north→south (SOUTH) and east→west (WEST) aspects. A terrain ruggedness index (TERRAIN), considered at the landscape-level only, was derived by adapting a technique (Beasom et al. 1983) for GIS using 150 m elevation contours, yielding a continuous (0→100) variable that is relative to the scale of contour data and pixel size. We defined a 100 m edge around all lakes as potential "seepage" sites (SEEPAGE), which we expected would influence stand structure and composition. All GIS applications employed the raster-based software *Idrisi 32* (Clark Labs 1999).

Habitat Use

After excluding outlying locations, we summarized habitat use from the pooled dataset. However, locations were weighted such that multiple locations obtained within a given day contributed an equivalent of one daily location. For each habitat variable, we determined mean use and variance within each of the following 4 caribou seasons defined by Simpson et al (1997): Early Winter ending 15 Jan., Late Winter ending 15 Apr., Spring ending 31 May, and Summer ending 31 Oct. We described habitat use at both a "stand" and "landscape" level, corresponding to a broad and fine spatial scale. Stand level habitat use reflected attribute values within pixels of 200 m resolution associated with each caribou location, assumed to encompass the majority (76%) of GPS location error. Landscape level habitat use reflected each attribute's aggregate value within a surrounding circular landscape of a 5.5 km radius. This distance is arbitrary but corresponds to the second broadest of 4 scales considered in other caribou habitat selection analyses (e.g. Apps et al. 2000). Because only 10% of net caribou movements exceeded 5.5 km over 18 days (Figure 2), this distance may also approximate the broadest landscape potentially "available" to Robson Valley caribou over at least 18 days.

Caribou Movements

We described caribou movements visually and quantitatively. For each animal, we overlaid movement vectors on a digital base map for the relevant portion of the study area. Movement vectors were color-coded with respect to time between sequential locations to indicate how realistic each straight-line movement is likely to be. We also identified a *probable movement area* (PMA) associated with each movement vector. This was defined by a circle with a perimeter running through each pair of sequential locations and a diameter equal to the distance between the two (Figure 4). For example, a 1 km movement in one 6 hr period (i.e. 2 successful, sequential fixes) would be associated with a PMA of 0.79 km^2. We assumed that the route the animal took between locations at least passed through the PMA, if it was not entirely encompassed within. We then weighted each PMA, regardless of its size, by the number of "movements" that could have occurred within the sampling interval. For example, the above-mentioned 0.79 km^2 PMA would be weighted the same as the 0.28 km^2 PMA associated with a

300 m movement in 6 hrs, but a PMA associated with a movement made over 12 hours (i.e. having an unsuccessful fix attempt between 2 successful fixes) would be weighted double. We assumed that fixes were attempted hourly for the 3 collars deployed in the first year (Table 1). We then overlaid and summed all PMAs to derive maps depicting probable movement *intensity* for each animal.

Table 4. Independent variables considered for analyses of caribou GPS collar data within the Robson Valley, British Columbia.

Variable	Description
AGE_1-2	Overstory stand age 1 – 40 yr (%)
AGE_3-5	Overstory stand age 41 – 101 yr (%)
AGE_6-7	Overstory stand age 101 – 140 yr (%)
AGE_8-9	Overstory stand age > 140 yr (%)
CANOPY	Overstory canopy closure (%)
SITE	Stand site index
B_SPP	Subalpine fir (*Abies lasiocarpa*) composition (%)
S_SPP	Spruce (*Picea* spp.) composition (%)
C_SPP	Western redcedar (*Thuja plicata*) composition (%)
H_SPP	Western hemlock (*Tsuga heterophylla*) composition (%)
P_SPP	Lodgepole (*Pinus contorta*) and white (*P. monticola*) pine composition (%)
FD_SPP	Douglas-fir (*Pseudotsuga menziesii*) composition (%)
DEC_SPP	Deciduous species composition (%)
ALPINE	Alpine tundra composition (%)
ELEV	Elevation (m)
SLOPE	Slope (%)
CURVA	Slope curvature (%)
SOUTH	North→south aspect (0→1)
WEST	East→west aspect (0→1)
TERRAIN	Terrain Ruggedness Index (0→100)
SEEPAGE	Potential seepage sites (%)

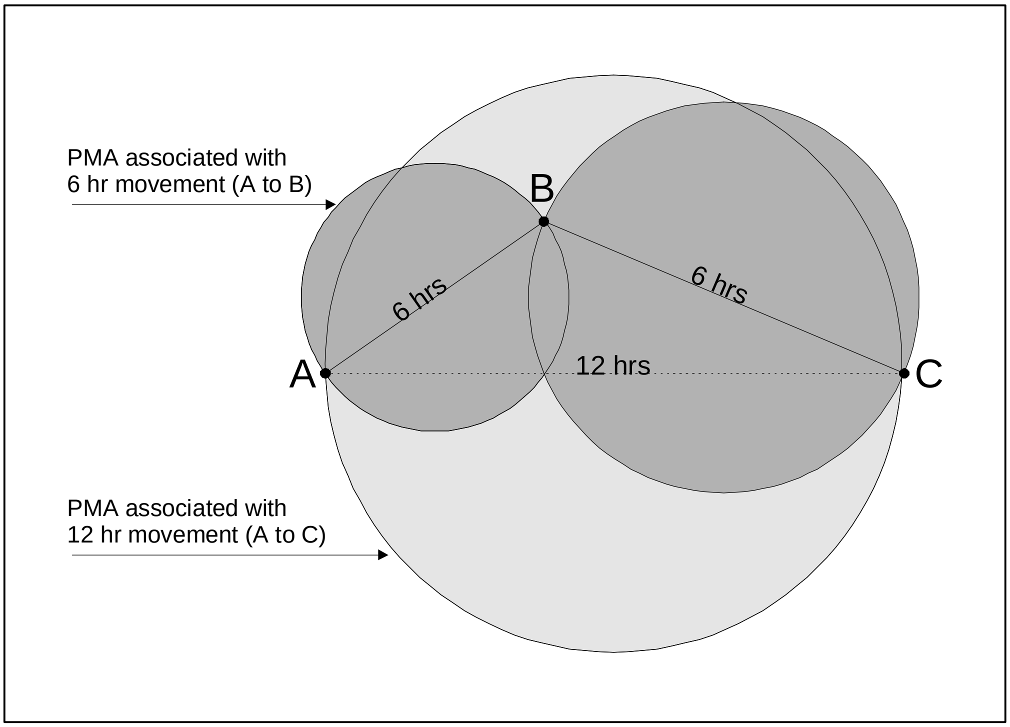

Figure 4. Schematic representation of probable movement areas (PMA) for describing movements of GPS-collared caribou, and for assessing habitat factors influencing GPS success rate. PMA A-B would have the same overall weighting as PMA B-C, so each pixel within the smaller A-B would have a greater weighting than each pixel in the larger B-C. If point B was not recorded (i.e. was an unsuccessful fix), then the PMA would be A-C and would be weighted double.

Factors Influencing Successful Fix Rate

We used PMAs to quantify the influence of topographic and forest overstory attributes on the likelihood that a GPS collar will obtain a successful fix. Habitat attributes were compared between successful fix locations and PMAs of movements associated with at least one failed location fix. The mean value of each attribute was extracted from 200 m pixels associated with successful locations and across unsuccessful fix PMAs. Each PMA was weighted according to the number of unsuccessful fixes with which it was associated, per ha (i.e. size of the PMA did not affect its weighting in the analysis). We compared differences between the two samples using univariate *t* tests for each variable. Pixels associated with non-forested “alpine” were assigned “missing values” for forest overstory attributes. For multivariate analysis, we assigned forest overstory “missing values” the median attribute value for respective variables.

We then employed multiple logistic regression (Hosmer and Lemeshow 1989) to identify a minimum linear combination of variables that best predict the likelihood of a successful fix. Caribou locations and PMAs respectively associated with successful and unsuccessful fixes represented the dichotomous dependent variable. We employed forward stepwise selection using the likelihood-ratio test (Ibid.) to derive a best-fit model. We used Pearson correlation coefficients to assess relationships among variables, and linear regression tolerance statistics to ensure that problematic multicollinearity (tolerance < 0.2) did not occur (Menard 1995). Among highly correlated variables, we excluded those of lesser univariate significance from model selection. We evaluated the improvement of the fitted model over the null model according to the reduction in (-2)loglikelihood ratios, and we evaluated the significance of variable coefficients using chi-square tests of Wald statistics (Hosmer and Lemeshow 1989.). We then applied the variable coefficients from our derived model to our spatial database using the MLR equation (Ibid.), producing a GIS-based model of successful GPS fix probability.

RESULTS AND DISCUSSION

Habitat Use

Daily location sample sizes for summarizing seasonal habitat use were 43, 123, 132, and 237 for early winter, late winter, spring, and summer, respectively. With the exception of early winter, a significant proportion of each sample fell within habitats defined by the FIP data as non-forested "alpine" (Figure 5). Figures 6 - 15 summarize year-round and seasonal habitat use, with results for forest overstory variables based only on data falling within forested habitats, and results for terrain variables based on the entire daily location sample.

On a cursory level, there were not large differences in habitat use between stand and landscape levels. This suggests that, for most variables, any habitat selection among study animals likely occurred at a broad, landscape level rather than at the stand level. This may be a function of habitat distribution and is consistent with the observation by Terry (1994) and Terry et al. (in press) that caribou in or adjacent to this study area preferred old-growth subalpine fir and Engelmann spruce stands during early winter, within which they were less selective. It contrasts with habitat selection results for some variables in the southern Purcell Mountains (Apps and Kinley 2000a), where caribou habitat may be subject to greater natural and human fragmentation. Still, there were some notable differences between stand- and landscape-level use, suggesting that certain attributes were preferred at the stand-level. Across seasons, caribou consistently used old-growth subalpine fir stands more than they occurred at the landscape level, but especially so during late winter (Figure 11). During summer, mean elevation use was slightly higher than during other seasons, and caribou more often used stands of lower site productivity, appeared to avoid stands associated with seepage, and appeared to prefer gentle slopes of northeast aspect.

Detailed comparisons of habitat associations between this study and others are not appropriate given (1) the small sample of animals, years and independent fixes, (2) the likelihood of habitat bias in GPS data, and (3) the fact that habitat use was not considered in the context of "availability". However, some general patterns are obvious from broad comparisons. Activity appeared to be heavily concentrated in old forests, as reported for the North Columbia Mountains (Simpson et al. 1987, Apps et al. 2000), North Thompson watershed (Apps and Kinley 1999) and southern Purcell Mountains (Apps and Kinley 2000a). The small elevation shift and associated low variability in forest overstory species used between seasons by Robson Valley caribou, in areas of relatively rugged terrain, contrasts with several other studies reporting small elevation shifts in areas with gentle terrain, or greater shifts in areas of rugged terrain (Simpson and Woods 1987; Seip 1990, 1992; Warren et al. 1996; Apps and Kinley 1999, 2000a, 2000b; Apps et al. 2000). This may have been due to the data for early winter being from only 2 caribou, which may not have been representative of the population. However, if the caribou were representative animals, the anomaly may be explained by the early-winter data having been collected during 1997, a year of relatively modest snow accumulation. Low snowfall would presumably lessen the need to move to low elevations during early winter. It may also reduce the elevation to which caribou ascend during late winter, as reported by Terry (1994). Alternatively, subdued shifts in elevation may be caused by caribou avoiding valley bottoms due to high predator densities or lack of forage (Terry et al. 1996). It is also probable that collars were biased against low elevation fixes due to topographic influences. This latter conclusion is supported by the low successful fix rate (17.9%) during early winter (Table 1), when low elevation use is expected relative to other seasons. We acknowledge that apparent use of other variables may have been biased by habitat and topographic influences on GPS fix success, potentially masking differences between stand and landscape use, as well as differences among seasons.

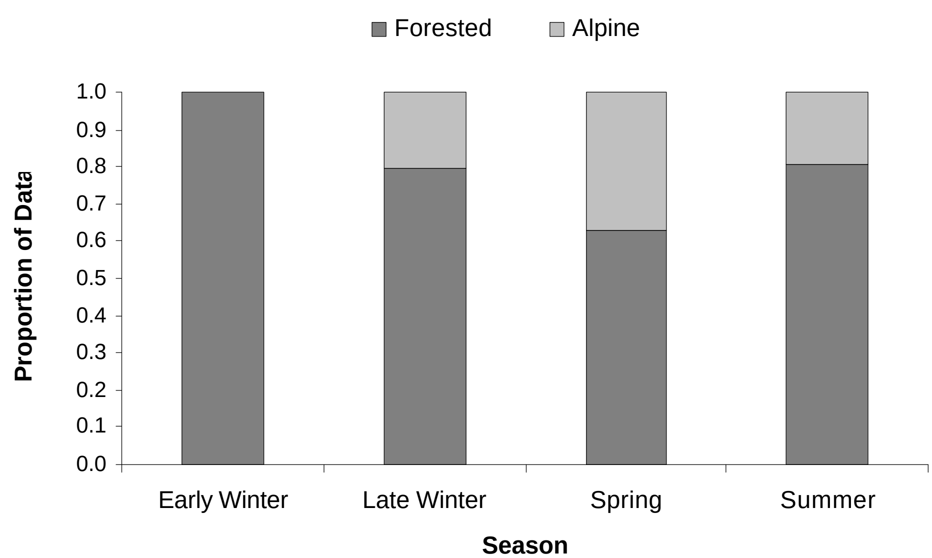

Figure 5. Proportional representation of caribou GPS collar fixes occurring within forested habitats and non-forested "alpine", in the Robson Valley, British Columbia, 1996 – 1997.

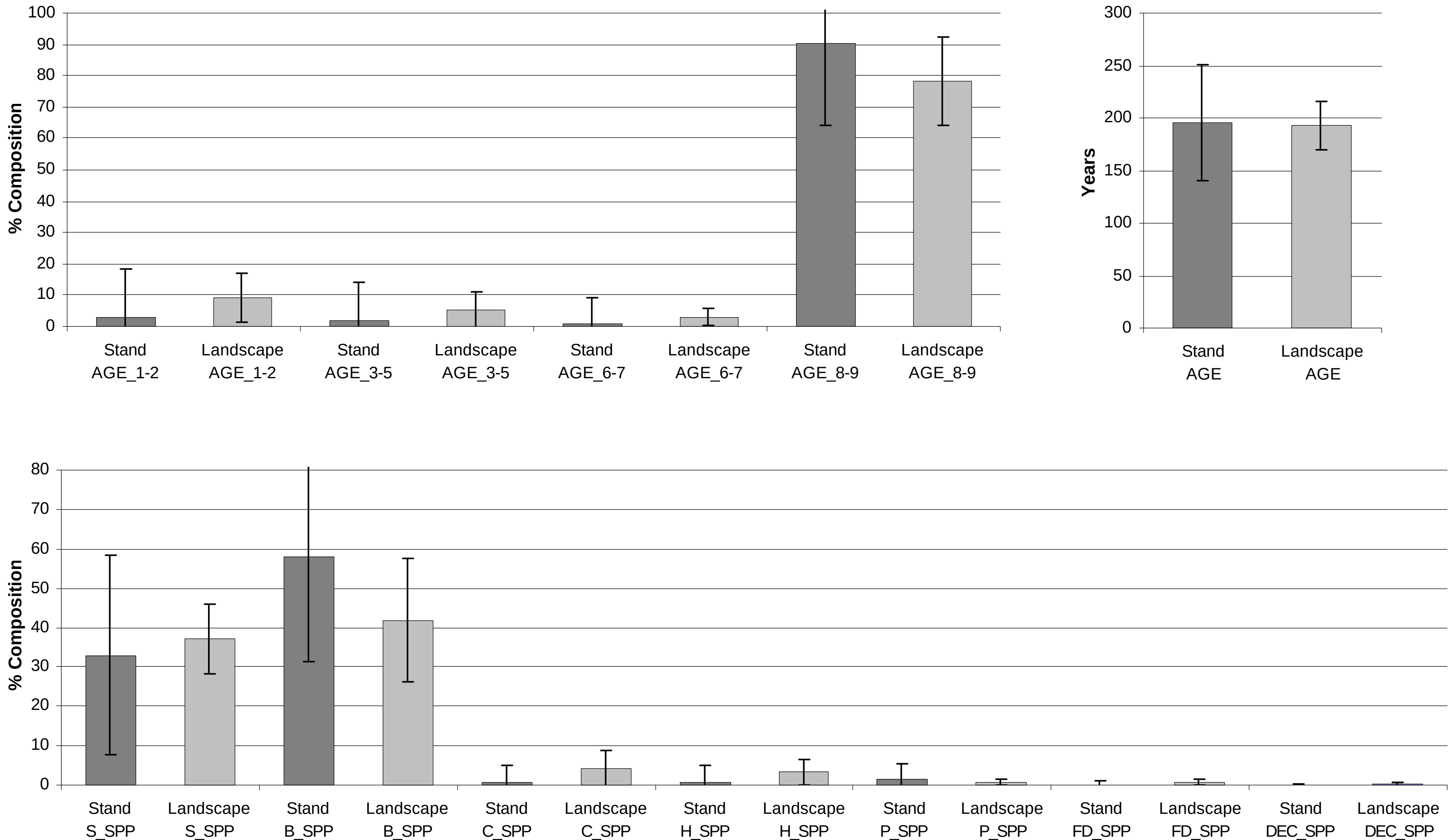

Figure 6. YEAR-ROUND caribou use (±1 SE) of overstory cover compostion variables at stand and landscape levels within the Robson Valley, British Columbia, 1996 – 1997. Results are based on non-alpine samples (*n* = 414).

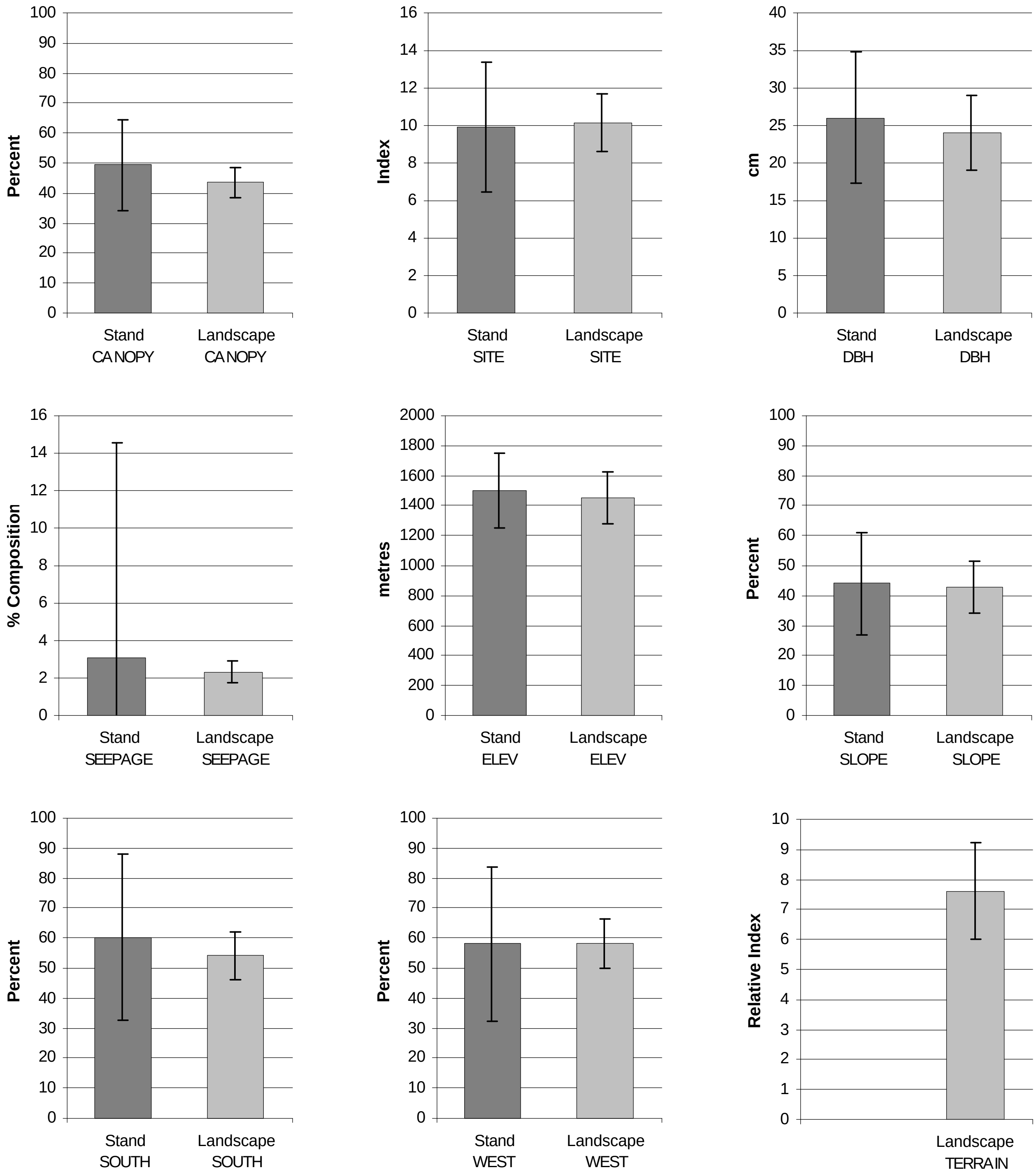

Figure 7. YEAR-ROUND caribou use (±1 SE) of overstory structure and terrain variables at stand and landscape levels within the Robson Valley, British Columbia, 1996 – 1997. Results for overstory variables are based on non-alpine samples (*n* = 414). Terrain ruggedness is a landscape variable only.

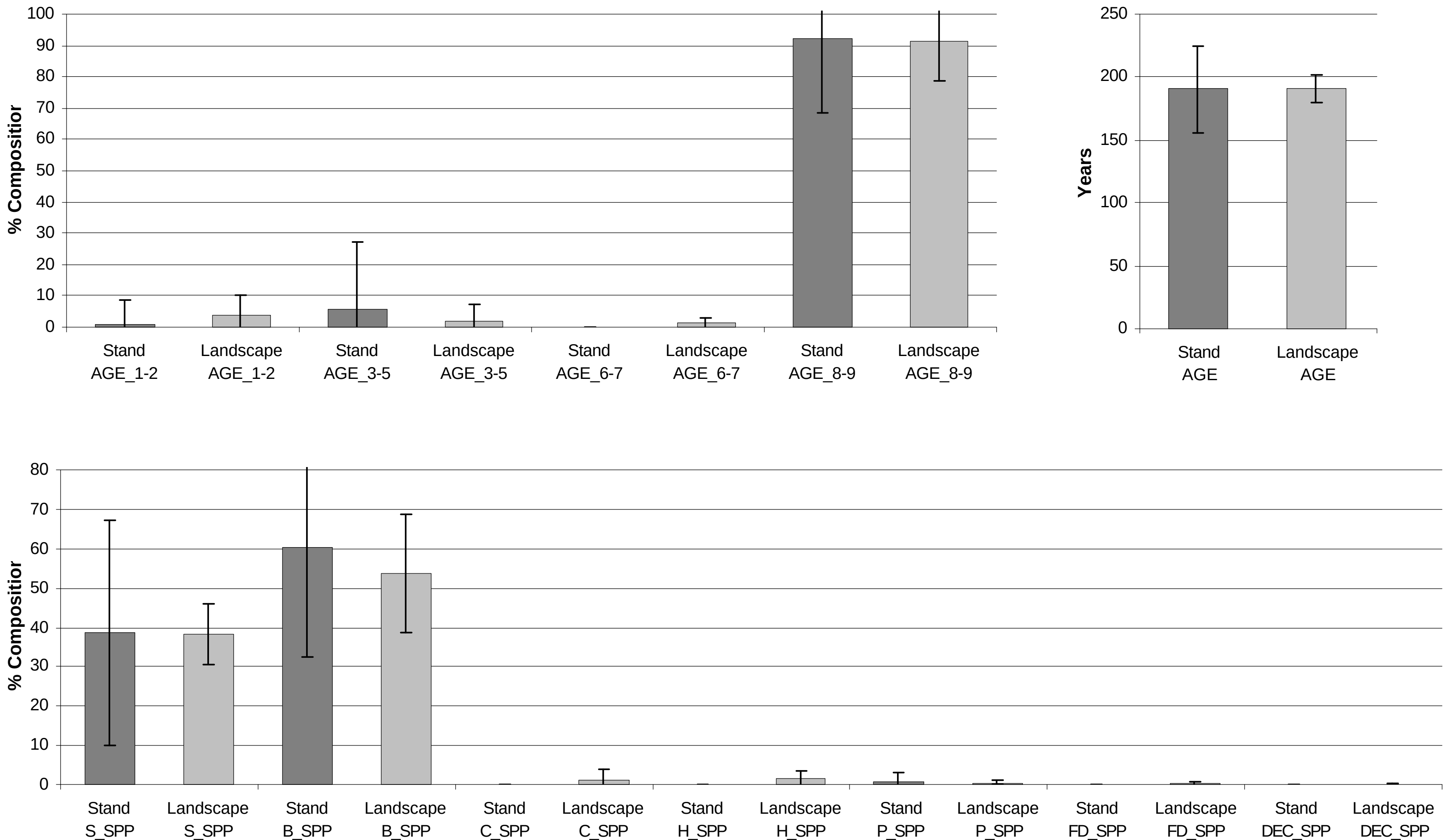

Figure 8. EARLY WINTER caribou use (±1 SE) of overstory cover compostion variables at stand and landscape levels within the Robson Valley, British Columbia, 1996 – 1997. Results are based on non-alpine samples (*n* = 42).

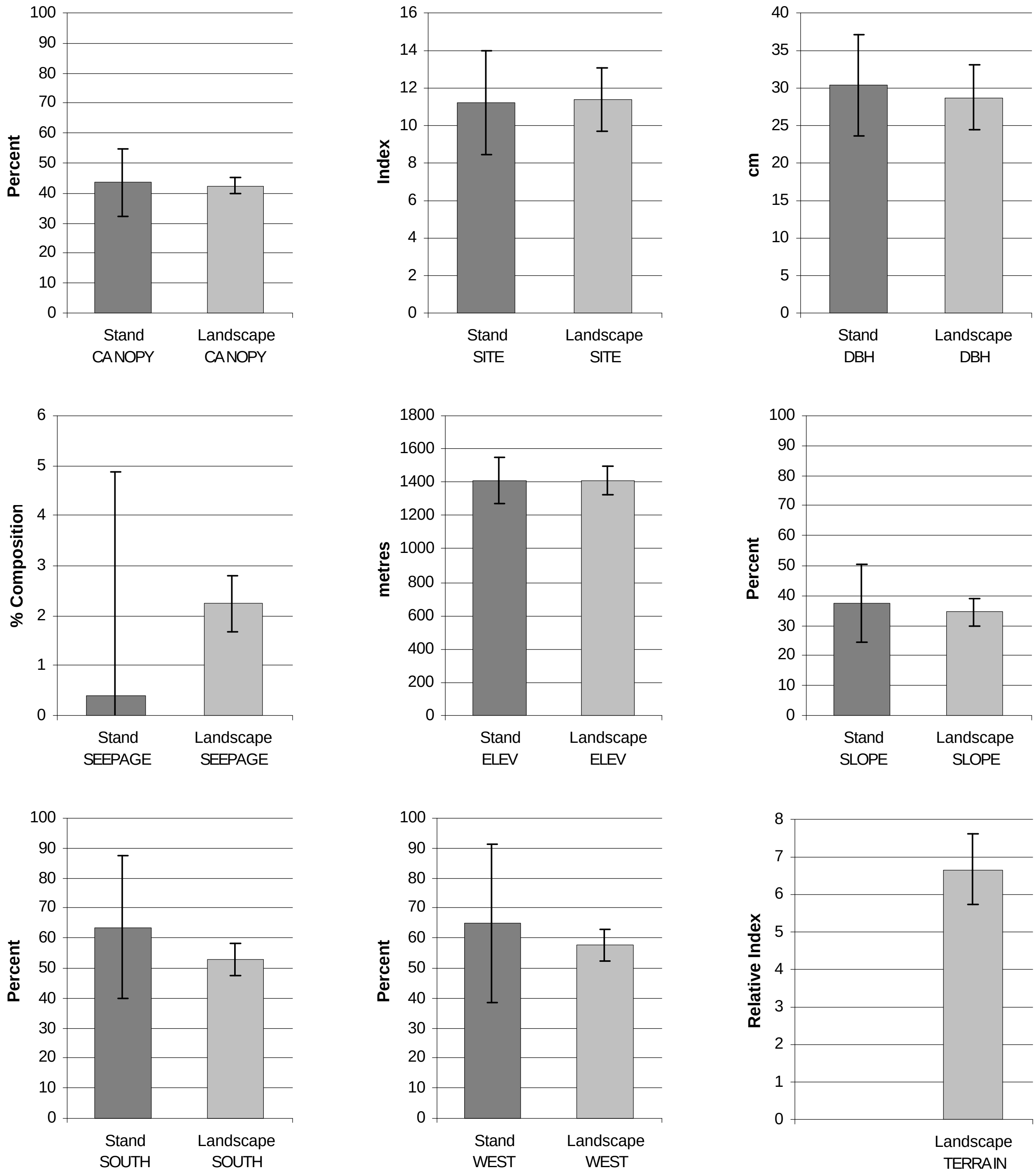

Figure 9. EARLY WINTER caribou use (±1 SE) of overstory structure and terrain variables at stand and landscape levels within the Robson Valley, British Columbia, 1996 – 1997. Results for overstory variables are based on non-alpine samples (*n* = 42). Terrain ruggedness is a landscape variable only.

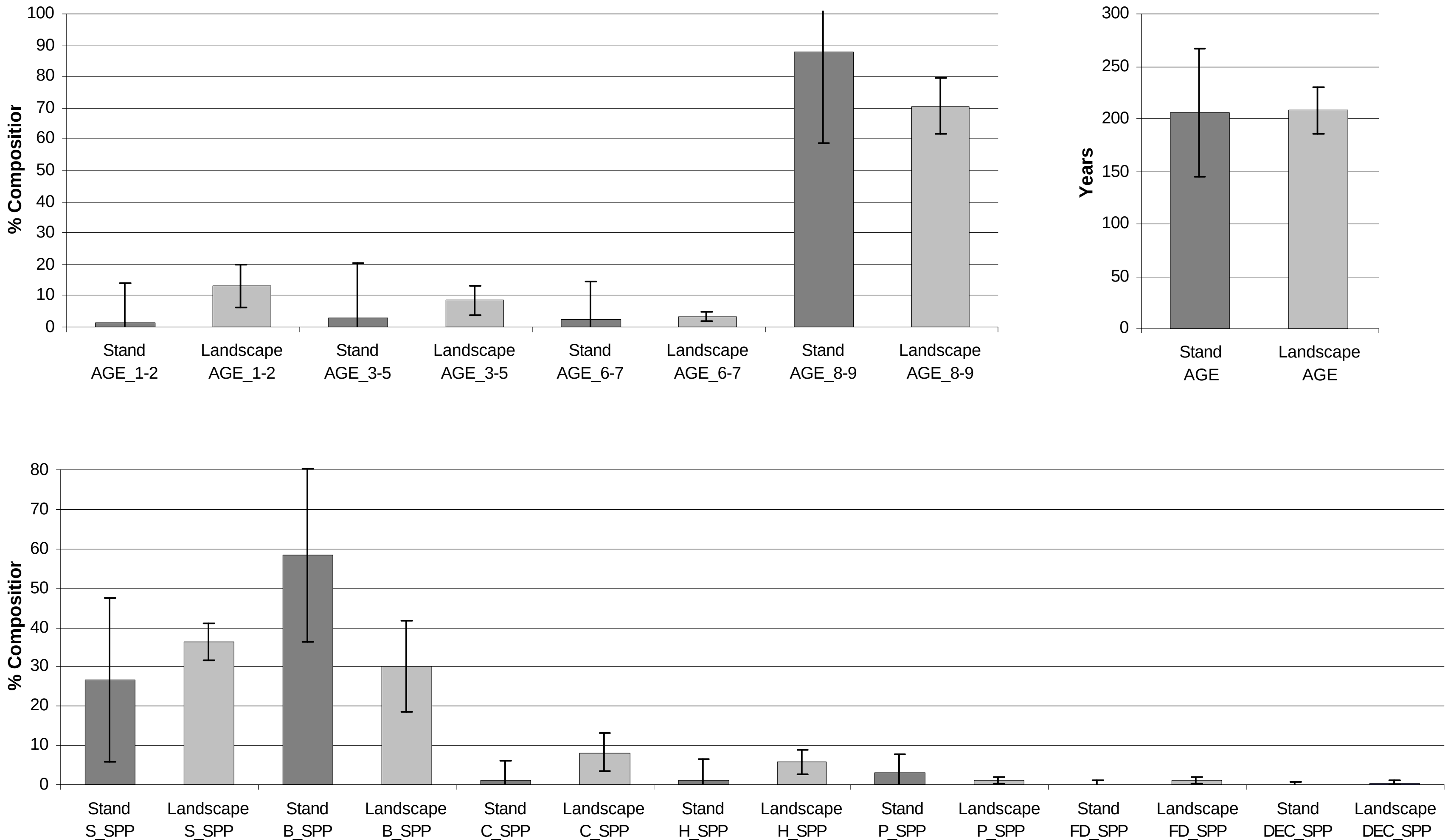

Figure 10. LATE WINTER caribou use (±1 SE) of overstory cover compostion variables at stand and landscape levels within the Robson Valley, British Columbia, 1996 – 1997. Results are based on non-alpine samples (*n* = 98).

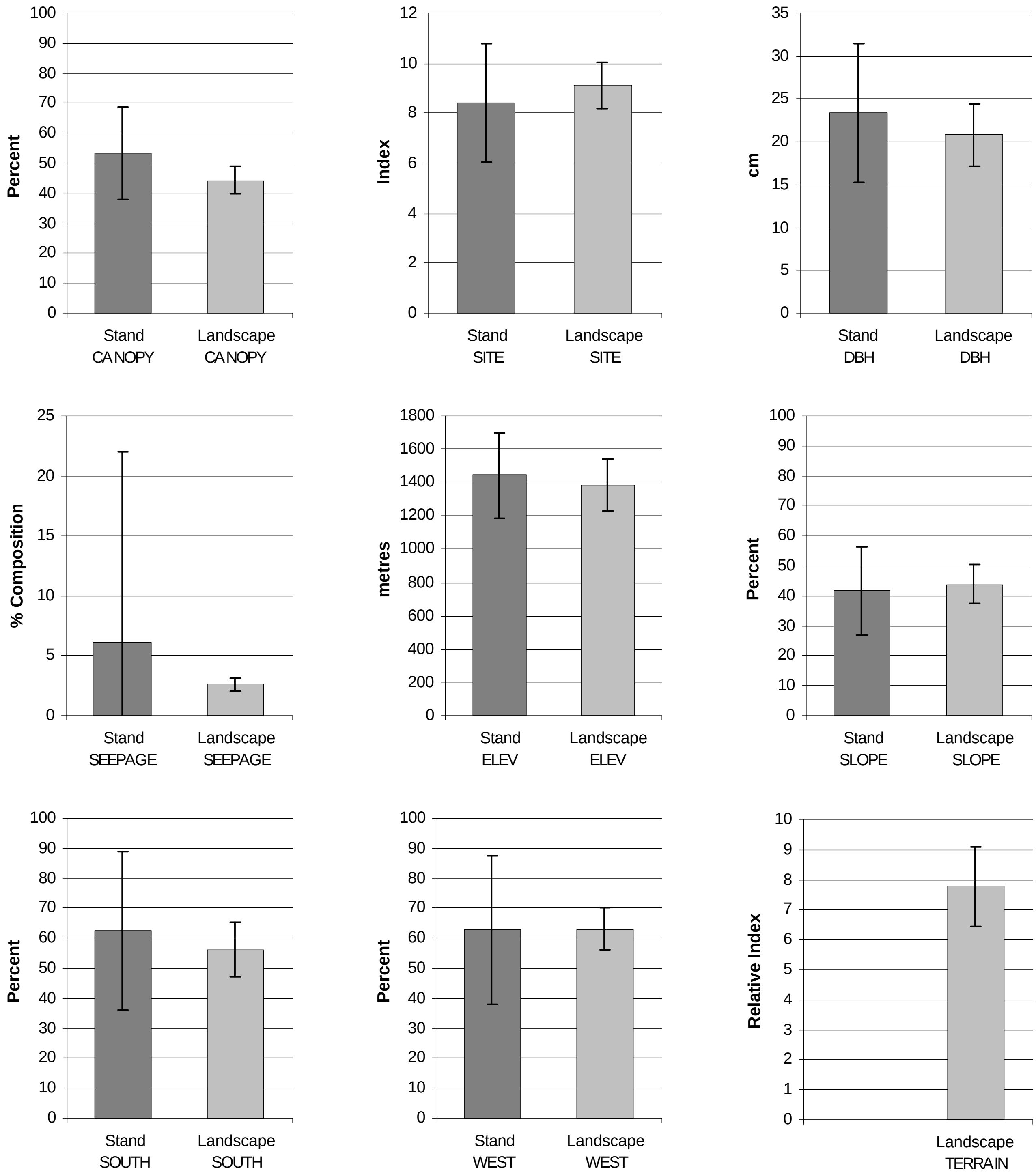

Figure 11. LATE WINTER caribou use (±1 SE) of overstory structure and terrain variables at stand and landscape levels within the Robson Valley, British Columbia, 1996 – 1997. Results for overstory variables are based on non-alpine samples (*n* = 98). Terrain ruggedness is a landscape variable only.

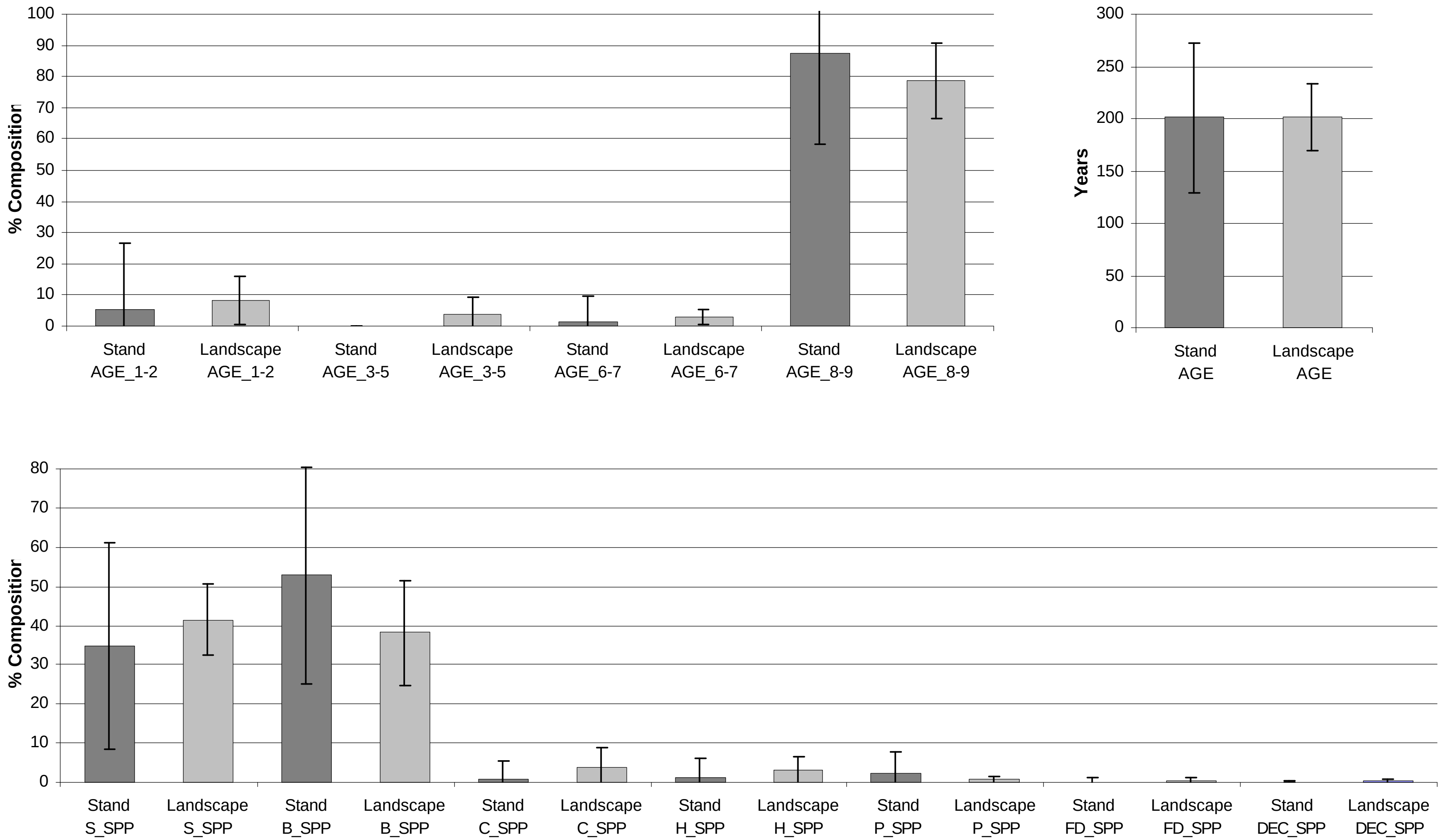

Figure 12. SPRING caribou use (±1 SE) of overstory cover compostion variables at stand and landscape levels within the Robson Valley, British Columbia, 1996 – 1997. Results are based on non-alpine samples (*n* = 83).

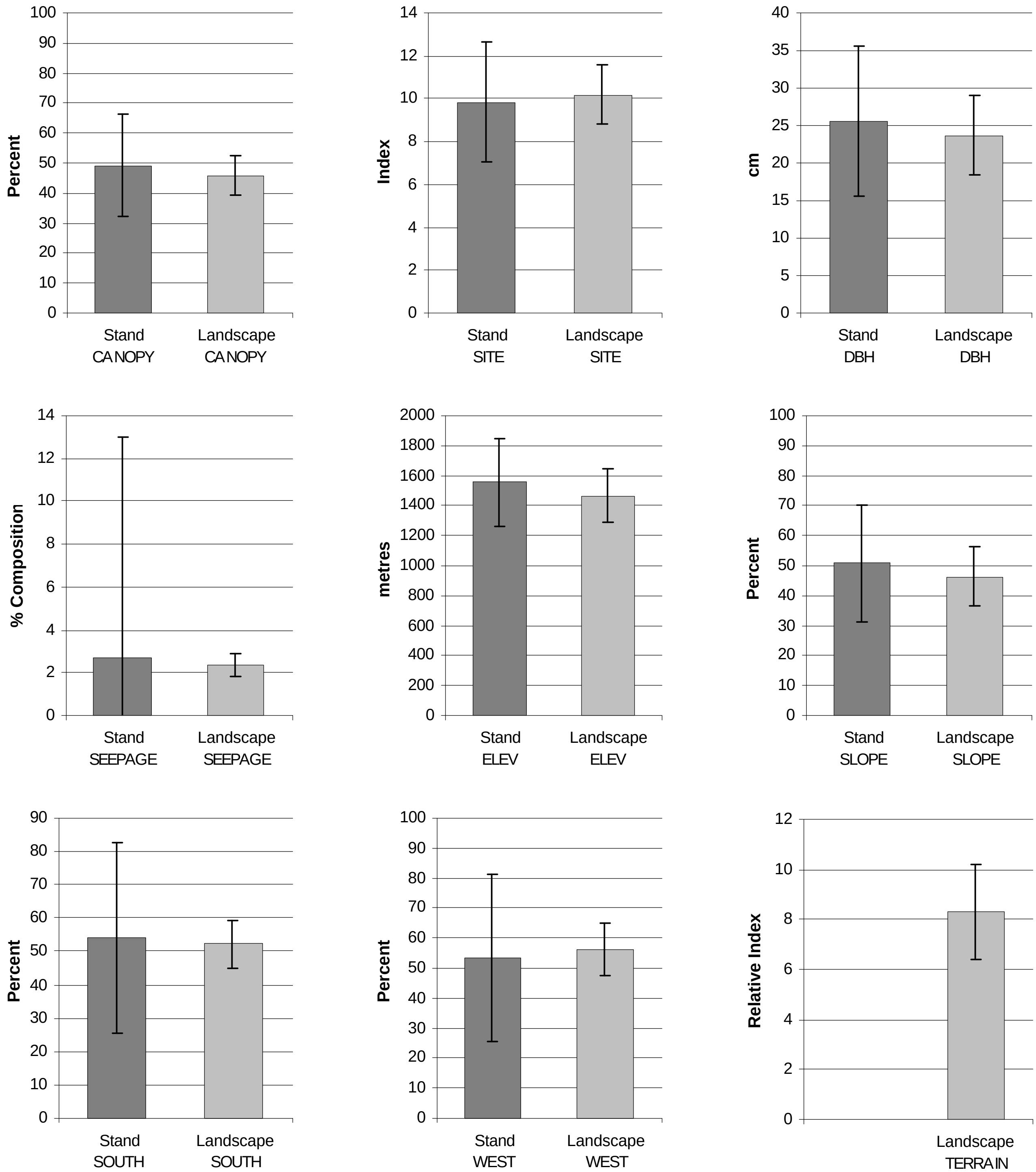

Figure 13. SPRING caribou use (±1 SE) of overstory structure and terrain variables at stand and landscape levels within the Robson Valley, British Columbia, 1996 – 1997. Results for overstory variables are based on non-alpine samples (*n* = 83). Terrain ruggedness is a landscape variable only.

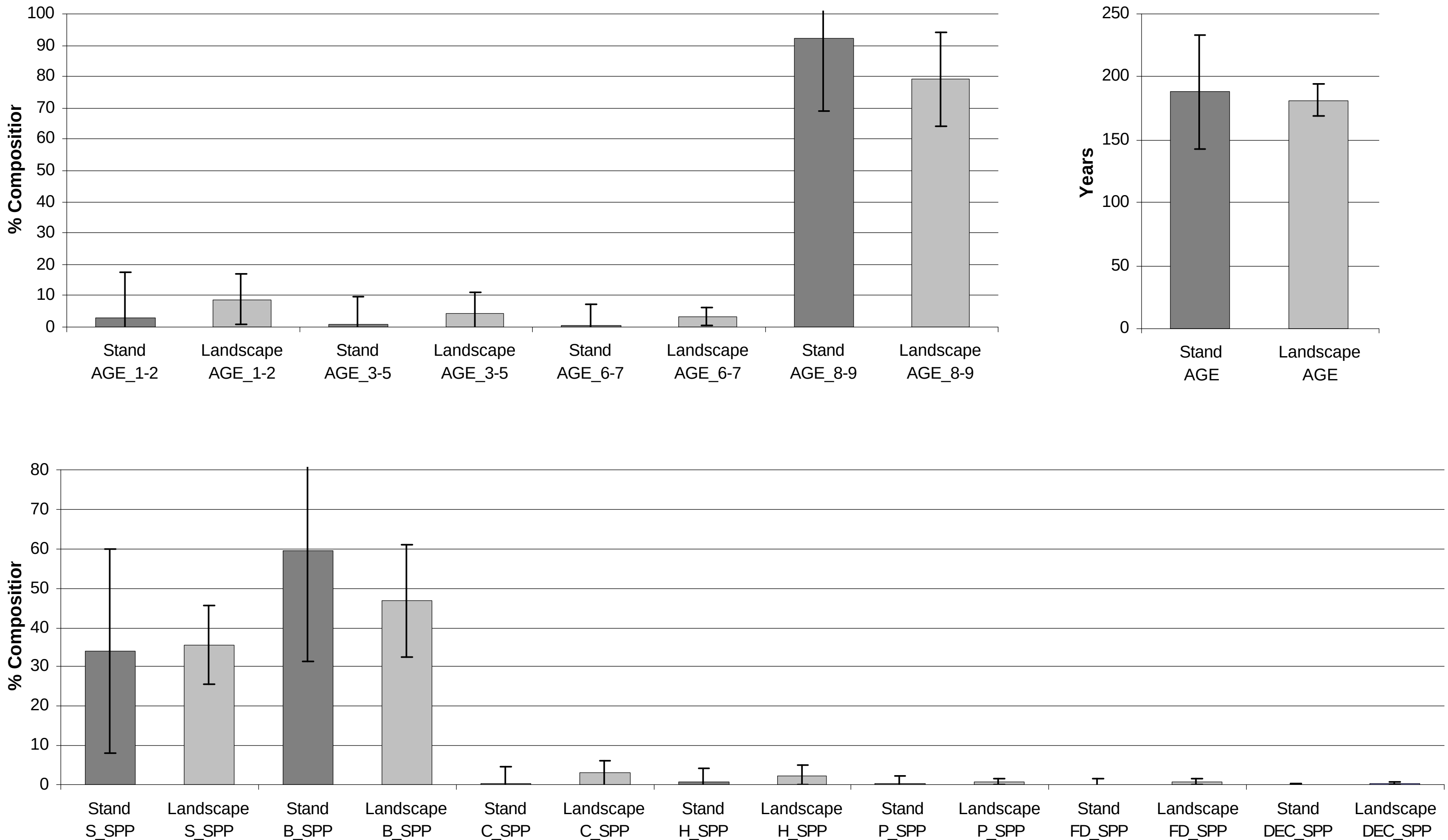

Figure 14. SUMMER caribou use (±1 SE) of overstory cover compostion variables at stand and landscape levels within the Robson Valley, British Columbia, 1996 – 1997. Results are based on non-alpine samples (*n* = 191).

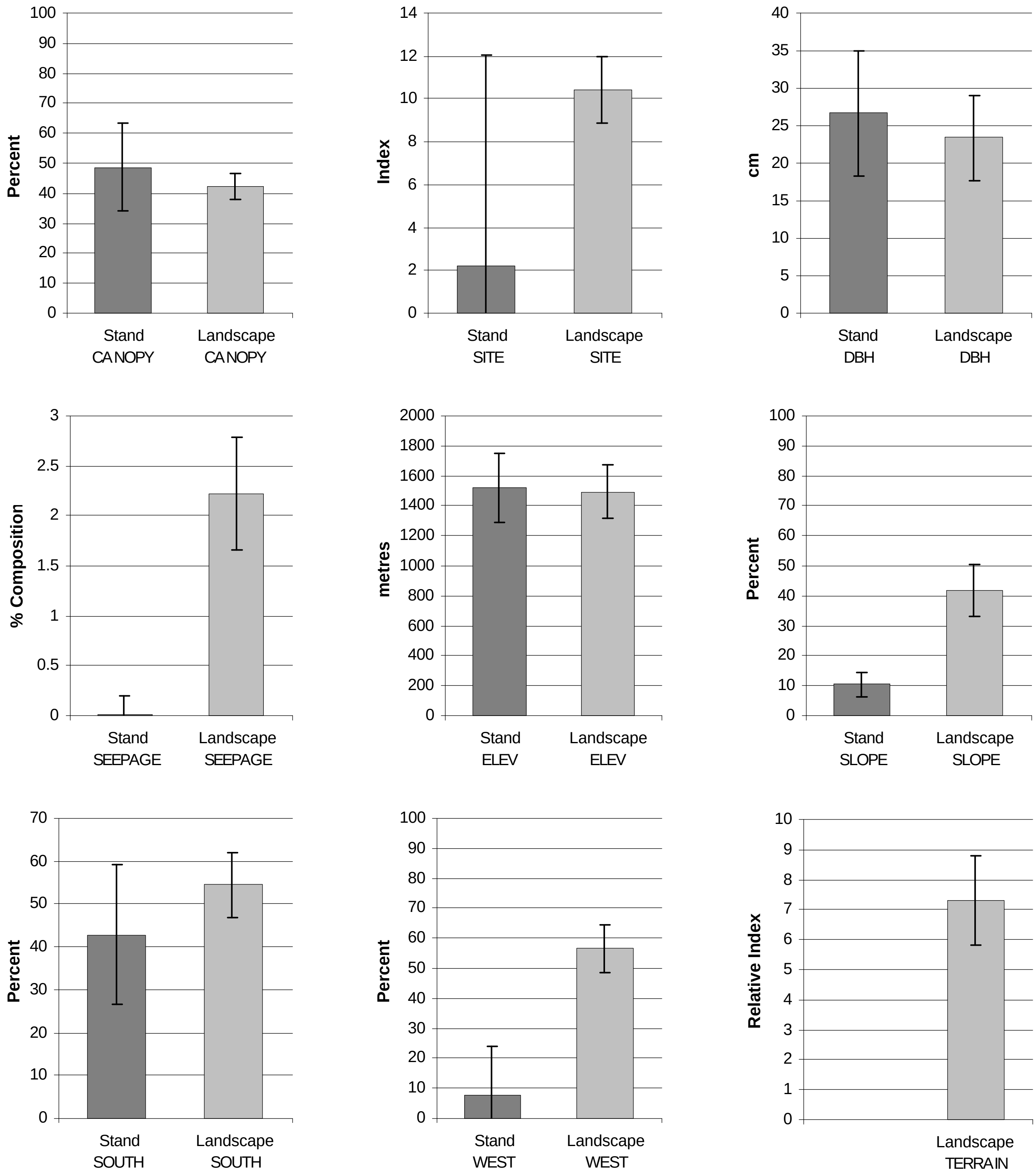

Figure 15. SUMMER caribou use (±1 SE) of overstory structure and terrain variables at stand and landscape levels within the Robson Valley, British Columbia, 1996 – 1997. Results for overstory variables are based on non-alpine samples (*n* = 191). Terrain ruggedness is a landscape variable only.

Caribou Movements and Connectivity

Caribou movements (Appendix Maps 2 and 3) coded according to the time between sequential locations are illustrated for each study animal in Appendix Maps 4 - 7. A quantification of probable movement intensity for each animal (Appendix Maps 8 - 11) accounted for the uncertainty associated with movement vectors of increasing time interval. Although the dataset was somewhat limited for assessing habitual movement routes, these maps highlight some areas that may be important for caribou movement within each animal's home range. The probable movement intensity maps reflect our level of confidence that caribou actually moved within or through specific areas. Many of the obvious nodes are likely associated with sedentary foraging behaviour, rather than "movement routes" *per se*. If this analysis is done in the future with a more extensive a dataset, habitual movement routes will also become more apparent on these maps, even though animals may have spent little time there. In such cases, nodes of intensive foraging will also be apparent, but the scale of movement intensity can be adjusted to ensure that habitual movement routes are highlighted.

In the northwest (Appendix Maps 4 and 8), the movement vectors are all from Dianna's data from July through December, 1997. Movement intensity was concentrated from just south of Sugarbowl Mountain along the height-of-land between the Bowron and Fraser rivers, southward through the headwaters of Grizzly Bear Creek on the Bowron side, and eastward through the headwaters of Slim Creek on the Fraser side of the divide, to Tumuch Lake. Southeastward from Tumuch Lake (Appendix Maps 5 and 9), movement vectors from this animal shift back to near the height-of-land then descend slightly into the headwaters of upper Haggen Creek (Bowron side) then move to a node of concentrated activity in the eastern headwaters of Dome Creek (Fraser side). Activity in Dome Creek occurred from April through June, 1997, while the movement through Haggen to Tumuch Lake occurred between 21 June and 02 July, 1997. Anne's movements overlapped those of Dianne in a portion of upper Haggen, but Anne moved through lower tributaries of Haggen in the first two weeks of April, 1996 to the Pinkerton Mountain area before her battery failed. Movements of Carol, Ethel and Fran are recorded on the southeast mapsheet (Appendix Maps 6 and 10). All were on the Fraser River side of the height-of-land. Carol's records were restricted to April, 1996, and occurred almost exclusively in one tributary of the Goat River. Ethel's movements began in late April, 1997, between the upper Goat River and its tributary North Star Creek, went northward across the upper Goat about May 1 and eastward across the Goat and Milk Rivers to the western edge of West Twin Creek about the 4^{th} week of May. Fran's movements originated in the area between the headwaters of the Goat and Milk rivers, then crossed eastward to the east side of the Milk and west side of West Twin Creek on 02 May, 1997. She apparently made one foray across the West Twin to a point directly above the Fraser valley between 19 May and 01 June, 1997 (another 13 day data gap). Overall, the movement intensity mapping for the southeast map sheet shows a high probability of movements through the upper (but not extreme headwaters) of the Goat, Milk and West Twin drainages. Betty was the only caribou occurring in the Northern Park Ranges ecosection. She had moved about 9 km west between the time her first collar was removed and her second was deployed, but showed movements restricted to less than 5 km^2 for both the 1-month initial collar deployment and the 10-month second deployment (Appendix Map 7). As a result, her movement intensity mapping (Appendix Map 11) shows 2 nodes of intensive activity, one on the east side of lower Fleet Creek, and one on the east side of the middle reaches of East Twin Creek.

Movements were almost exclusively through areas of old forest, alpine tundra and, to a limited extent, avalanche paths (Appendix Map 3), so it did not appear that habitats attributes for movements differed appreciably from those from the general landscape around fix points. However, there were a few exceptions. The movement by Dianna through the major divide bisecting the Cariboo Mountains (in which Slim and Pinkerton creeks lie) would have necessitated crossing 2 – 5 km of recent cutblocks and young forest in most places. However, the use of the Tumuch Lake area, likely including Tumuch Lake itself, would have minimized this and potentially provided a very narrow corridor with no cutblocks. That route took the caribou temporarily away from the height-of-land, possibly for this reason. Anne's movements in the lower tributaries of Haggen were mainly peripheral to the many cutblocks there, but she may have made a few movements across them. Betty was mainly in old forest, but had a minority of movements in young forest and several movements through avalanche paths. In sum, it appears that the expected preference for old forest and avoidance of cutblocks and young forest when foraging was not appreciably relaxed when traveling.

Within the limitations of the small sample size, and subject to the possible avoidance of extensively logged areas described above, it appears that there is a relatively high degree of movement and potential intra-herd mixing in the Cariboo Mountains portion of the study area. In that ecosection, maximum straight-line distances of 5, 19, 23, 24 and 60 km were recorded over periods of <1 month to 10 months. One caribou crossed the broad divide (Slim and Pinkerton creek valleys) that separates the northernmost part of the Cariboo Mountains from the rest of that ecosection, and 2 had movements crossing the Fraser/Bowron height-of-land. This preliminary information suggests that genetic mixing and colonization are possible within the northwestern part of the study area. More data are required to assess the frequency of such movements, and to quantify possible links from there to the upper Goat River area and to the large protected area to the south (Bowron Lakes, Cariboo Mountains and Wells Gray parks). The greatest movement per animal occurred from early April through late June, but data were extremely limited for other times of the year. None of the caribou occurred within the Quesnel Highlands ecosection, and no records of movement between ecosections was recorded, except for 1 foray from the Cariboo Mountains to the Upper Fraser Trench, and concentrated activity by Betty on the boundary of the Trench and the Northern Park Ranges. This is perhaps not surprising based on the very limited sample, but more extensive research to determine whether and to what degree inter-ecosection movements occur would have implications for long term genetic viability and resilience to stochastic or human-induced events.

Factors Influencing Successful Fix Rate

Some differences were apparent in comparing attributes of PMAs associated with unsuccessful fix attempts to those of successful fix locations (Table 5). Notably, fix success was positively correlated with ALPINE and ELEV and negatively correlated with CURVA, SOUTH and SPP_DEC. Although other studies of GPS collar bias have found relationships with forest structure and composition (Moen et al. 1996, Moen et al. 1997, Rempel and Rodgers 1997, Dussault et al. 1999), they were not conducted in highly mountainous study areas. Near the Robson Valley, the influence of the overstory stand attributes may be overridden by terrain factors. Where topography is complex, a broader horizon and therefore greater satellite availability can be expected at higher elevations, even though slopes are typically steeper. This may explain why fixes appear to have been more successful at high elevations and in alpine habitats, and less successful in areas of higher curvature index, which would be expected in valley bottoms where terrain is typically concave. These results contrast with those of Dussault et al. (1999), who found 100% success for the 126 total fix attempts on 3 sites with no overstory vegetation, but 0, 15 and 30° of the horizon obscured by topography. That study used the same model of collar used for this analysis. However, it may be that sites at lower elevations in the Robson Valley study area typically had >30° of the horizon obscured, either by terrain alone or in combination with large trees. Because deciduous species composition is higher in valley bottom habitats, the association we found with this variable may be spurious. The negative association with southern aspects may be an artifact of seasonal habitat use differences. The use of south aspects was greatest during early winter, when fix success rate was lowest, while northern aspects were recorded for >50% of daily locations only during summer, when fix success rate was greatest.

Based on variables with univariate significance of at least $P < 0.25$, the best-fit multiple logistic regression model was significant ($\chi^2 = 249.2$, 7 df, $P < 0.0001$), with an overall classification success of 63.2% (cutpoint $P = 0.5$). Model parameters (Table 6) indicate a minimum linear combination of variables that explain the maximum variation in the data, and which can predict the likelihood of a successful fix on a GPS-collared caribou within this study area. These results suggest that terrain variables CURVA, SOUTH, ELEV, and SLOPE explain much of the difference between PMAs associated with successful versus unsuccessful fix attempts. The positive contribution of SITE is marginally significant and is also consistent with lower elevations. The variables AGE_3-5, SPP_DEC, and ALPINE that were significant in univariate tests were not included in the best-fit model. We expect that this is because they are

Table 5. Results of univariate comparisons of attributes associated with successful GPS fix locations and PMAs associated with unsuccessful GPS fixes of collared caribou in the Robson Valley, British Columbia, 1996 – 1997.

Variable	mean diff.[a]	SE	*t*	*P*	relationship[b]
AGE	2.524	1.947	1.30	0.195	o
AGE_1-2	-0.310	0.617	-0.50	0.615	o
AGE_3-5	-1.762	0.583	-3.03	0.002	- -
AGE_6-7	0.286	0.353	0.81	0.418	o
AGE_8-9	-0.054	1.006	-0.05	0.957	o
DBH	-0.484	0.319	-1.52	0.129	o
HEIGHT	-0.025	0.264	-0.10	0.923	o
CANOPY	1.174	0.547	2.15	0.032	+
SITE	-0.251	0.111	-2.26	0.024	-
SEEPAGE	-0.293	0.305	-0.96	0.337	o
SPP_S	-0.877	0.887	-0.99	0.323	o
SPP_B	-0.923	0.939	-0.98	0.326	o
SPP_C	0.105	0.134	0.79	0.432	o
SPP_H	-0.113	0.141	-0.80	0.421	o
SPP_P	0.112	0.116	0.97	0.333	o
SPP_FD	-0.037	0.044	-0.86	0.392	o
SPP_DEC	-0.205	0.049	-4.18	0.000	- - -
ALPINE	11.626	1.055	11.02	0.000	+ + +
ELEV	81.386	6.780	12.00	0.000	+ + +
SLOPE	1.156	0.473	2.44	0.015	+
CURVA	-0.00147	0.00013	-11.32	0.000	- - -
SOUTH	-4.814	0.754	-6.39	0.000	- - -
WEST	0.617	0.732	0.84	0.399	o

[a] mean attribute value of successful fix locations minus that of unsuccessful fix PMAs.

[b] Positive associations with fix success: "+" ($P < 0.1$), "+ +" ($P < 0.01$), "+ + +" ($P < 0.001$); Negative associations with fix success: "-" ($P < 0.1$), "- -" ($P < 0.01$), "- - -" ($P < 0.001$);

Table 6. Variables and parameters associated with best-fit multiple logistic regression models of the relative likelihood of GPS collar fix success in the Robson Valley, British Columbia, 1996 – 1997.

Variable	*B*	S.E.	*P*	*R*
CURVA	-72.149	8.802	< 0.0001	-0.120
SOUTH	-0.009	0.002	< 0.0001	-0.076
ELEV	0.001	0.000	< 0.0001	0.076
SLOPE	0.008	0.002	0.0004	0.045
SITE	0.025	0.013	0.0491	0.020
Constant	-1.187	0.322	0.0002	

somewhat correlated with other terrain variables that may relate more directly to collar fix success. Application of this model to the GIS database spatially depicts the probability of a successful GPS collar fix, but we suggest that it is applicable only within physiographic and forest conditions characteristic of areas from which data were sampled, as defined by ecosections (Appendix Map 12). This spatially-explicit model represents a testable hypothesis, and it can be used in sampling design for a more rigorous field-based assessment of GPS collar bias.

Non-habitat factors may also influence fix success of GPS collars. Although satellite configuration may vary throughout the day, there was little apparent difference in fix rate among 6-hour daily time intervals (Figure 16). We also detected little variation in DOP values across the range of ambient temperatures associated with successful fixes (Figure 17). It is more likely that fix success rates related to the specifications of the collars themselves.

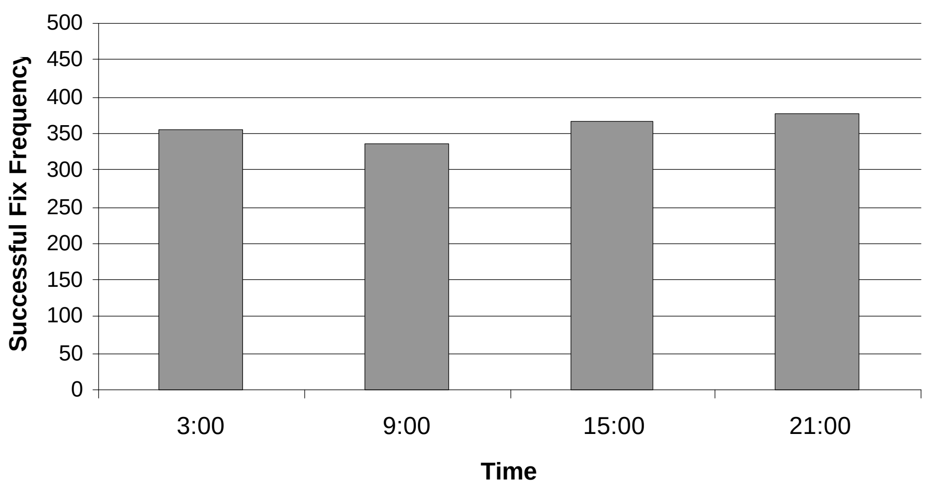

Figure 16. Frequency of successful caribou GPS collar fixes at 6 hour time intervals in the Robson Valley, British Columbia, 1996 – 1997.

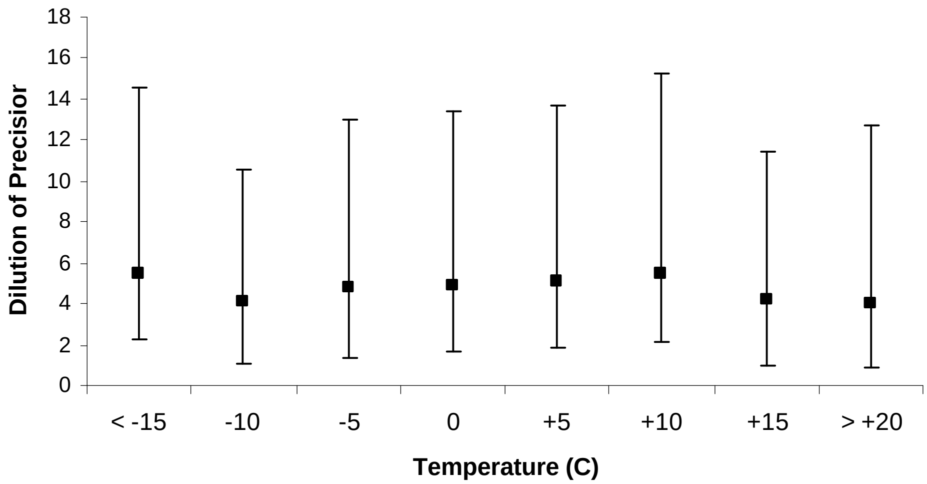

Figure 17. Median and 50% spread of dilution of precision (DOP) values for GPS collar fixes at 5 degree Celsius temperature intervals in the Robson Valley, British Columbia, 1996 – 1997.

RECOMMENDATIONS

GPS Collars, Database Management, and Assessment of Habitat Bias

GPS Collar Capabilities.—Recent GPS collars produced by Lotek and other companies have more channels to receive satellite signals (typically 8 or 12 rather than 6) and appear to have greater sensitivity than those used in this study. For example, GPS collars of the same version used in this study were deployed on caribou in the southern Purcell Mountains and provided an identical success rate. However, more recent 8-channel collars produced by Advanced Telemetry systems and also deployed in the southern Purcells had greater than double the success rate (T. Kinley, Sylvan Consulting Ltd., unpublished data). This was likely due to in part to greater sensitivity and in part to the collar being programmed to make up to 3 sequential fix attempts per period. Using newer technology and customizing collar programming should improve the ability of collars to successfully record fixes, leading to larger sample sizes and less bias relative to habitat conditions.

Similar results, along with increased mean accuracy, might also be achieved if a greater proportion of fixes were differentially correctable (10% of fixes could not be corrected in this study). Failure to correct data is generally due to a mismatch of satellites recorded by base stations and by collars. Assuming a base station has a clear view of the sky, is reasonably close to the collar deployment site and is functioning properly, it should normally receive signals from all of the satellites from which the collar receives signals and therefore allow differential correction of the collar fixes. For trials using stationary *Lotek 1000* collars in a variety of habitats and on free-ranging moose, correction failure generally occurred on ≤3% (maximum 7%) of the fixes (Moen et al. 1997). In contrast, for caribou near Germansen Landing (north of Prince George) fitted with the same collars, non-correctable fixes could be reduced to 3% of the database only after developing a program to optimize the selection of files from 2 base stations. In that study, databases corrected only with files from the main Terrapro base station in Prince George had a much higher non-correctable rate (C. Johnson, University of Northern British Columbia, pers. comm.). Thus, the 10% non-correction rate recorded for the Robson Valley is considerably higher than the rate recorded in the literature but about on par with what was found from another local study. Since both the Robson Valley and Germansen Landing studies used the same base station, this initially suggests that files from the base station may have been missing or corrupt. However, that station is in an open area, is within 150 km of the collar deployment area, and used software and hardware that meets BC government standards. Another possibility is that some pseudorange data was lost from the collars, or that the *Lotek* GPS post-processing software periodically failed to recognize or process data. While this apparently did not occur or not to the same degree in the study reported by Moen et al. (1997), experience with *Lotek 1000* collars has uncovered a host of errors and malfunctions, many of which are sporadic (Johnson et al. in prep.; T. Kinley, Sylvan Consulting Ltd., pers. comm.). Operator error alone is not likely the problem, as the Germansen Landing and Robson Valley data were processed by different people. Regardless of the causes, we recommend that differential correction of GPS collar data be considered an iterative process, with the post-correction database examined for segments having fewer corrections and portions re-processed with new base station files if necessary. A related issue that should be addressed is the apparent consistent difference between resulting locations after processing by the Forey base station versus the main Terrapro station, as outlined in Methods: GPS Collar Data.

Scheduling GPS Location Fix Attempts.—The ideal schedule by which GPS collars should be programmed to attempt location fixes needs to balance the spatio-temporal scale of habitat use and movement data required with the collar's data storage capacity and battery life. If habitat selection at the level of the animal's home range or study area is the objective, and data must be sampled over several seasons or years, then a less intensive schedule can be used. In this case, we suggest that collars be programmed to attempt daily fixes. This will easily facilitate random subsampling to weekly locations, which is the minimum that we expect will be necessary to provide an independent sample of habitat use for comparing to availability within a typical home range. A daily fix schedule should allow a *Lotek 1000* collar with a "one-year" battery pack and of the same specifications used in this study to operate for several years, with annual downloads.

We expect that most investigators will require sampling that maximizes data for finer-scale analyses of both habitat selection and movements. The maximum sampling frequency necessary depends on (1) the scale of habitat data for analysis, (2) the expected maximum (95^{th} percentile) error of GPS fixes, and (3) the maximum (95^{th} percentile) expected movements within a given time interval. Under the assumption that analyses will be against 1:20,000 polygon (e.g. FIP) data with a minimum mappable unit of approximately 4 ha, it is not necessary to discern movements within approximately 100 m, and the maximum sampling frequency will be determined by expected GPS error. Apparent movements over 1 hour intervals may be largely overwhelmed by location error, but meaningful data appropriate for analysis against 1:20,000 habitat mapping may be provided at ≥ 2 hour sampling intervals (Figure 3). At this rate, a Lotek 1000 collar with a "1 year" battery pack should operate for ~6 months.

Data Screening.-- We suggest that data not be deleted unless it is highly probable that a location is associated with excessive spatial error. For example, as we have done, these can be identified by comparing sequential movements to the 95^{th} movement percentile of the same time interval. We suggest this as the primary screening method even for locations for which DOP values indicate extreme error is likely. Excessive data screening relative to DOP value is almost certain to introduce bias in favor of locations that have broad horizons and minimal canopy. Erroneous data that may be included by adopting conservative screening rules merely introduces additional random error, reducing statistical power for detecting habitat selection. Moreover, data of progressively greater error can be used for analyzing space use and habitat selection at broader scales. Data that are accurate but apparently highly autocorrelated in time will always be independent for habitat analyses at some scale, however fine. Increasing GPS board sensitivity and increasing numbers of satellites should result in greater proportions of successful fixes, 3-D fixes, and differentially corrected fixes in the future, resulting in less bias and error.

Assessment of Habitat Bias.-- The definition and use of PMAs that we describe is an indirect way of assessing habitat bias associated with GPS collar fix rate. A controlled, stratified sampling design using stationary collars and measuring attributes in the field may test habitat bias more accurately and precisely. However, one advantage of the method we describe is that it can provide insight on habitat bias associated directly with a given dataset. This is useful because habitat conditions within which the actual data were collected may differ from those considered in field studies of collar bias. Also, the results of field testing will be specific to the make and model of collar, the differential correction software used, and the location of the base station relative to the study area. In comparison, determining differences between fix sites and PMAs is independent of collar specifications and can be done for any study.

Habitat Management

Stands and Landscapes.--The overall habitat use patterns that we report are consistent with other research conducted for mountain caribou in that they show an association with old-growth subalpine forests. Results are also consistent with patterns reported by Terry et al. (1996) for nearby caribou. Hence general stand-management recommendations for mountain caribou (e.g. Stevenson et al. 1994) should provide appropriate interim guidance for this population. However, while the early winter habitat use that we describe is based on extremely limited data, our results coupled with the actual successful fix rate suggest that use of low elevation habitats may be underrepresented during this and other seasons. Even if such stands are used infrequently, they may still be critical at specific times of the year and under certain weather conditions. Until research based on longer term and less biased sampling is completed, we recommend that, within broad landscapes of potential caribou habitat, old-growth stands be maintained at low elevations and with maximum aggregation and connectivity. Landscape planning should also consider the dispersion of cutblocks, which may initially increase the vulnerability of caribou to predation (Kinley and Apps in press) and which may represent barriers to movement by caribou, especially when they become densely-stocked, mid-age stands. Within the few areas intensively used by GPS collared caribou, maps of movement intensity may assist landscape planning for habitat connectivity, but the value of such maps for decision-support is entirely dependent on the sample size of underlying movement vectors on which they are based.

Connectivity.—Although the dataset was limited for assessing habitual movement, the results of the PMA analyses and movement plots illustrate the importance of cross-valley connectivity. Low elevations may be infrequently used through much of the year, but intact habitat connections may be critical for movements that minimize energetic costs, stress, and mortality risk.

Given the sample size and distribution of animals and movements, these data, and the maps in this report, must not be solely relied upon in managing for connectivity within the study area. The PMA approach to assessing habitual movements and connectivity directly from the data will be of greater value as the sample size of both animals and movements increase and become more representative of the local population. With an extensive dataset, we expect that habitual movements will be difficult to discern by plotting movement vectors alone. For such datasets, we recommend that PMA analyses be conducted to assess probable movement intensity.

Further Research

Mountain caribou habitat associations have and continue to be extensively studied throughout British Columbia. However, habitat selection patterns may vary due to differences in forest overstory composition distribution, physiography, climate, predators, and foraging strategies. Hence, habitat models are best derived from a local dataset of a maximum sample of animals and years, approximating the population distribution. The existing dataset assessed in this report is not adequate for confident habitat modeling due to a low animal sample of limited distribution and an independent location sample that is highly limited for analyzing landscape-level habitat selection. However, the technology of GPS collars and software has improved considerably since 1996, and habitat biases are expected to be much less. Despite potential habitat bias, GPS collars have advantages over VHF due to the potential for cost-effective, intensive data collection. Further, they provide data useful for analyzing fine-scale habitat selection and movement routes, highly relevant to management, but which have not been addressed through field research. We suggest that GPS collars continue to be deployed on caribou with representative distribution in the Robson Valley environs, and that, if necessary, collars be periodically moved to different animals to maximize the animal sample and geographic representation. Subsequent to this, we recommend that scale-dependent habitat selection analyses and modeling (*sensu* Apps et al. 2000) be conducted specific to this study area, and the habitual movement routes be re-assessed using the PMA approach described herein. A field-based study of habitat bias using stationary collars of the same make and version, moved within areas being used by study animals according to a stratified sampling design, would best address habitat bias and provide benchmarks for calibrating habitat selection results. The probable habitat bias results described in this report may provide a testable hypothesis and help to stratify field sampling. Alternatively, an additional location sample obtained through a regular schedule of aircraft locations from VHF or GPS collars could be used to correct GPS results for habitat bias.

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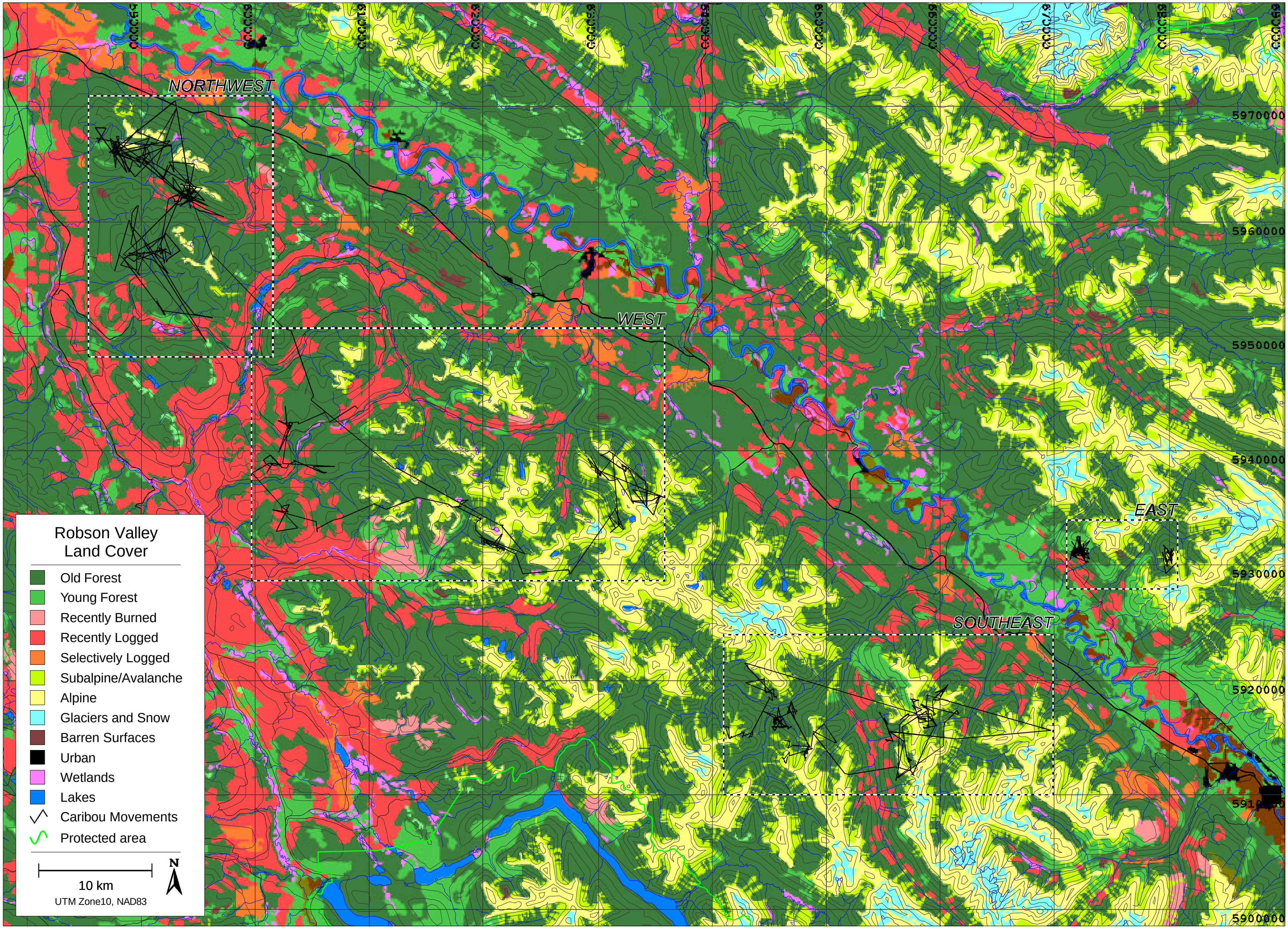
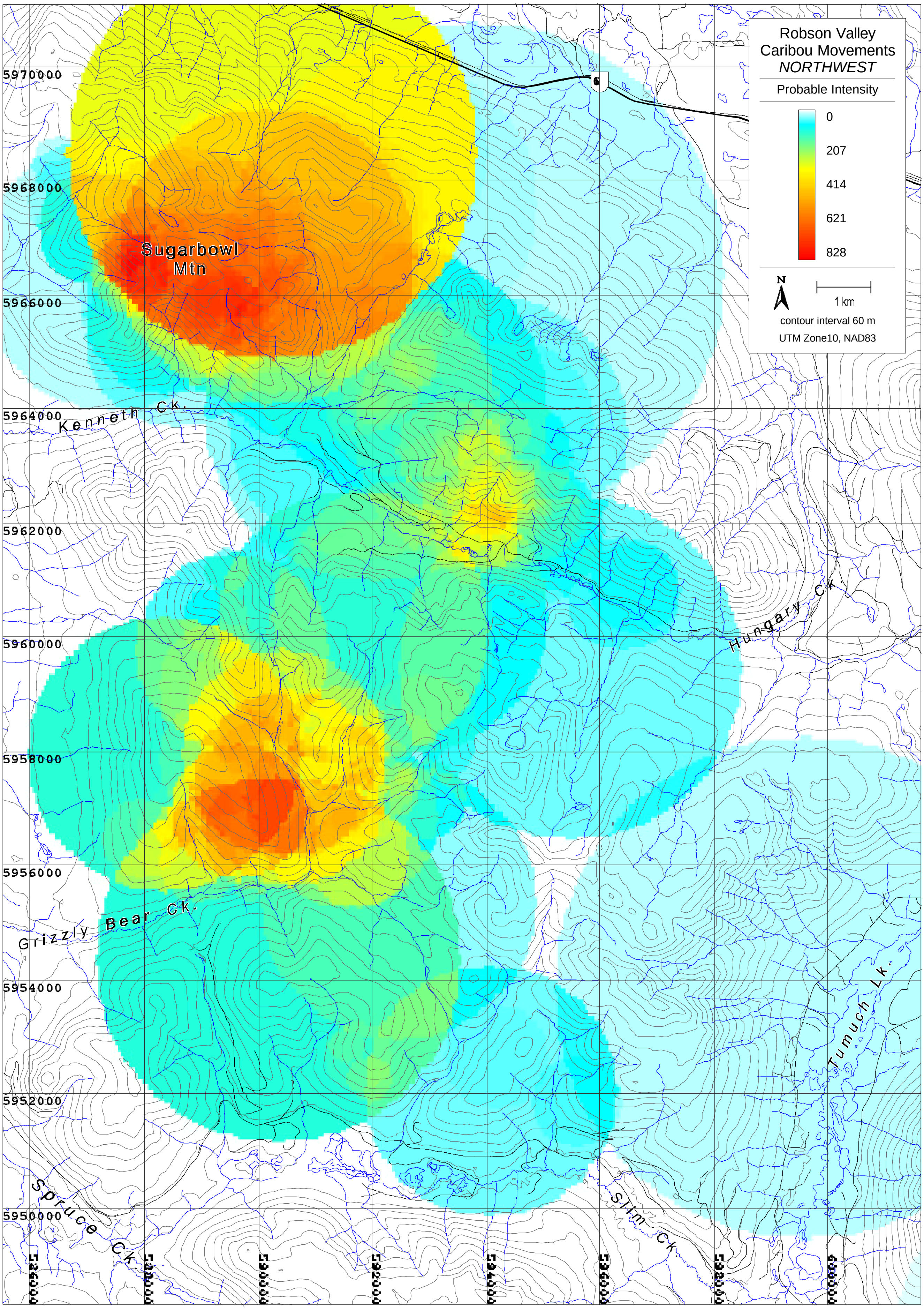
Appendix 1. Maps

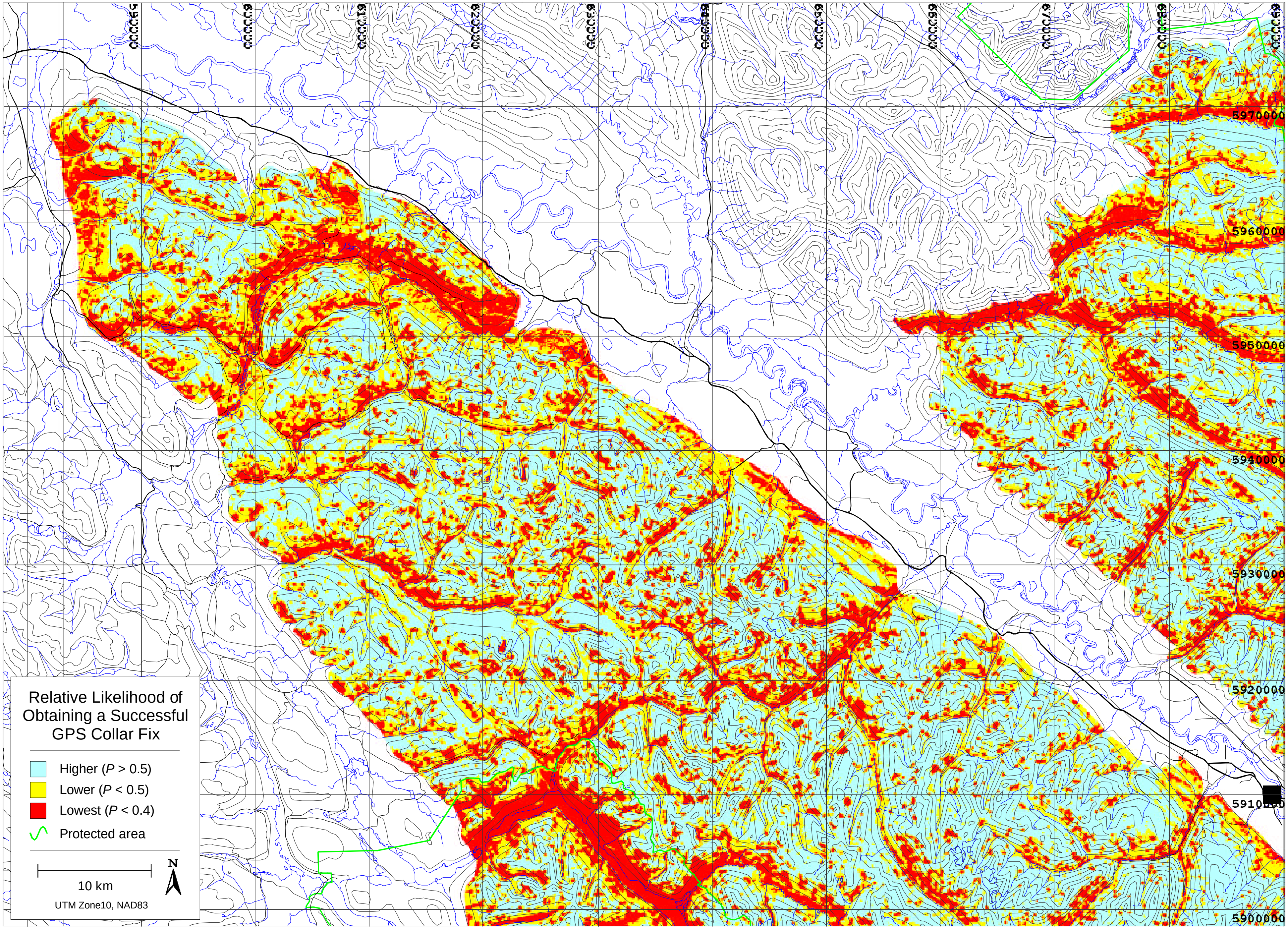
Due to the large byte size of the maps, only maps 3, 8 and 12 have been included in this PDF version of the report. The other maps are available by contacting CBFWCP via phone or email.



Map 3. Land cover classes (Baseline Thematic Mapping) and movement vectors of GPS collared mountain caribou near the Robson Valley, British Columbia, 1996 - 1997. Windows provide an index to larger scale maps of caribou movements.



Map 8. Probable movement intensity interpolated from NORTHWEST GPS location data.



Map 12. Predicted relative likelihood of obtaining a successful fix from caribou GPS collars deployed during 1996 - 1997 near the Robson Valley, British Columbia. Model is applied only to ecosections within which most data were collected.