Quantifying forest stand and landscape attributes that influence mountain caribou habitat fragmentation

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SUMMARY

Mountain caribou telemetry studies have shown either high use or preference of old forests. However, the relatively coarse scale of VHF telemetry precluded the investigation of fine-scale factors that may influence the paths selected by mountain caribou for movement and foraging. In this study, we followed caribou paths in snow in areas where forest harvesting occurs to examine how caribou interact within a matrix of young, mid-seral, and old forests. Specifically, we asked: 1) How are caribou paths influenced by the matrix of old and young stands; 2) How do caribou make use of forest-cutblock edges?; 3) Do caribou select partial cuts of the type used in Englemann spruce-subalpine fir (ESSF) plateau forests? These questions were address by comparing used and available habitats at 2 spatial scales – buffers of 100 and 1000 m from the caribou path.

Relative to what was available, caribou selected areas closer to the forest-clearcut edge, regardless of whether the trail was in old forests or in clearcuts. Caribou were likely responding to windthrow and lichen litterfall, which is more common at edges. The attraction to edges was not apparent if there was residual structure in the cutblocks (i.e. partial cuts). Caribou avoided clearcuts, selected old forests at 1 scale, and tended to use partial cuts more than available at the larger scale, although this difference was not significant indicating an inconsistent level of use. Caribou strongly selected roads, likely for ease of movement. Although the magnitude of this effect was large in both ESSF and Interior Cedar-Hemlock (ICH) forests, the difference was only significant in ESSF forests.

Multivariate models included distance to edge variables, road density, amount of clearcut and old forests. Clearcuts were avoided, old forests selected, as were edges and higher road density. The abundance of partial cuts did not factor in any of the top multivariate models. Overall, partial cuts appeared to be an improvement over clearcut harvest systems because of the increased *Bryoria* growth documented in these stands. The preference of roads and edges needs to be interpreted in the context of larger-scale studies that show decreased chance of caribou persistence when these features are prominent on the landscape.

INTRODUCTION

Resource selection by animals occurs across a hierarchy of scales ranging from where the species occurs on a continent to sites they choose to rest and parts of organisms they eat (Johnson 1980, Wiens et al. 1986). Across these scales, a multitude of factors influence their selection patterns. Factors that influence resource selection by mountain caribou, a threatened ecotype of woodland caribou, have been quantified across a variety of spatial scales (Apps and McLellan 2006, Apps et al. 2001, Johnson et al. 2004, Kinley et al. 2003, Rominger and Oldemeyer, 1989, Serrouya et al. submitted, Servheen and Lyon 1989, Terry et al. 2000). A given factor may sometimes differ in magnitude across scales, such as the selection of rugged mountains at broad scales, contrasted with the selection of flat benches at the finest scales (Apps et al. 2001). However, across scales and studies, the importance of old forests remain constant; at broad scales, climatic factors that permit old forests to develop are important, at mid-scales the old forests themselves are important, and at finer scales, attributes found in old forests are important. The inverse of this conclusion, “what are the consequences of having young forests on the landscape?” has recently been recognized as perhaps a more important question.

It has been suggested that young forests are not only rarely used by mountain caribou, but they may even be harmful and two reasons for their harm have been proposed: 1) young forests (early seral stages) support higher densities of alternative prey and thus predators and these predators kill a significant number of caribou through a process called apparent competition (Holt 1977, 1984, Bergerud and Elliot 1986, Seip 1992, Wittmer et al. 2005a,b); and 2) caribou actively avoid traveling through young forests and thus they impede caribou movements by forcing them to circumvent young and mid-aged forests. In this report, we investigate factors that may influence caribou movements in landscapes with a history of forest harvesting. We mapped the actual paths caribou used in managed landscapes by trailing caribou in snow. Using this relatively accurate data on animal movements, we addressed the following questions: 1) How are caribou paths influenced by the matrix of old and young stands; 2) How do caribou make use of forest/cutblock edges?; 3) Do caribou select partial cut stands available in ESSF-plateau forests?

STUDY AREA

The study area is located in southeastern British Columbia within the Cariboo Mountains, Central Columbia Mountains and Shuswap Highlands Ecosections (Figure 1). The Caribou and Central Columbia Mountains have steep and rugged terrain between 610 m and >3000 m in elevation, while the Shuswap Highlands consists of steep valleys breaking to gently rolling plateaus above 1400 m. Overall, the study area receives greater than 2000 mm precipitation with most falling as snow (Meidinger and Pojar, 1991). The lower slopes (<1400 m) of the Cariboo and Columbia Mountains ecosections are in the "wet cool" and "very wet cool" Interior-Cedar-Hemlock (ICHwk and ICHvk, respectively) biogeoclimatic subzone (Meidinger and Pojar 1991), and are dominated by climax stands of western hemlock (*Tsuga heterophylla*) and western redcedar (*Thuja plicata*). Stands of Douglas-fir (*Pseudotsuga menziesii*), western white pine *(Pinus monticola*), and white birch (*Betula papyrifera*) are present on drier sites in the ICH, but less common in the ICHvk. Mid and upper slopes throughout the study area (1400–1900 m) are in the "very wet cold" Engelmann Spruce-Subalpine Fir subzone (ESSFvc) and the "wet cold" subzone (ESSFwc). These forests are usually dominated by Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) but mountain hemlock (*Tsuga mertensiana*) is common in some stands (Coupé et al. 1991). Above about 1900 m, subalpine fir grows in clumps forming mostly open subalpine parkland. Alpine, rock and glaciers are extensive features at higher elevations. Due to high snowfall and steep terrain, avalanche paths are common at all but the lowest elevations.

In the North Columbia Mountains ecosection caribou generally use ICH ecosystems (600-1300 m elevation) in early winter (November to early January) and ESSF ecosystems in late winter (January to mid April; Apps et al. 2001). While in low-elevation ICH forests during early winter, caribou make use of an array of forage, including lichen on standing trees, as litterfall or on windthrown trees as well as shrubs, and herbs on the ground in areas where snow has yet to accumulate substantially (Serrouya et al. submitted) In the Shuswap Highlands ecosection, caribou generally stay within ESSF forests on the high elevation plateaus (> 1300 m) throughout the early and late winter periods (November to mid April). In this area, caribou primarily forage on arboreal lichen on standing trees, on windthrown trees or litterfall.

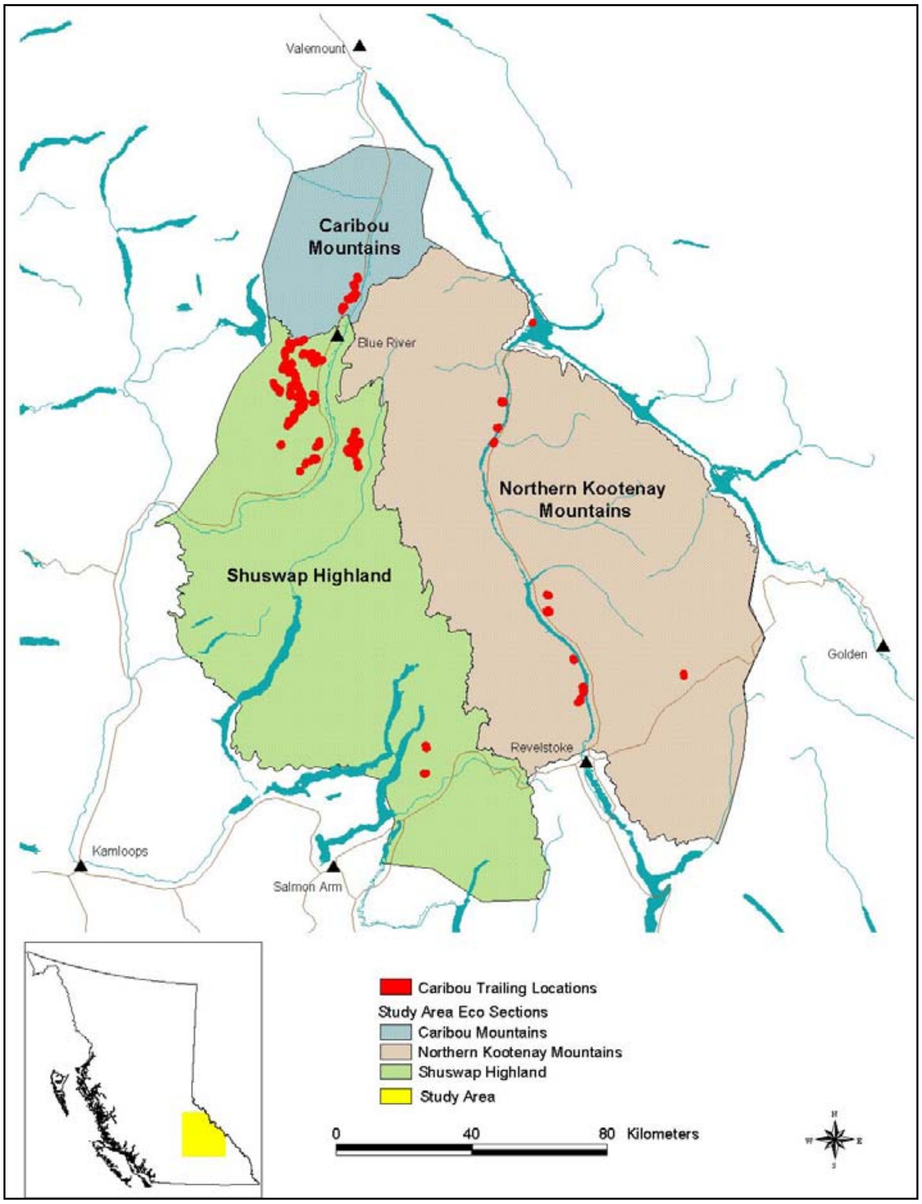

Figure 1. Caribou long-trailing study area.

METHODS

Field methods

The focus of the study was during the entire winter period (late October to early March) when caribou habitat overlap with timber harvesting is greatest. Because we were interested in caribou movements in landscapes with a history of forest harvesting, we limited our caribou trailing to areas where forest harvesting occurred in the past.

Caribou were captured using a net-gun fired from a helicopter during late winter in parkland habitat when > 85% of the population is readily observed and easily caught (Wittmer et al. 2005). During winter, radio-collared caribou were located and their locations recorded approximately once every 10−14 days from a Cessna 337 aircraft. We accessed sites primarily using snowmobiles, via forestry roads, using coordinates from the radio-collared animals to begin the trailing sessions. Once caribou tracks were located, we recorded the spatial position of the trail with a handheld GPS (Garmin GPS76 and GPS V; positional accuracy typically < 10 m). Tracking backwards along the caribou path was most common to ensure animals were not approached to avoid stressing animals or influencing their movements. If tracks were old, we sometimes tracked forward along the trail, ensuring we maintained a good distance from the animals and when fresh tracks were encountered we stopped trailing. We attempted to consistently follow the tracks of one animal or one groups of animals to avoid directional bias while recording movements, however many animals often used the same track and often individuals or groups repeatedly split off from and returned to the main trail. Thus, where many tracks circled and overlapped, we chose the trail that appeared to have the largest number of animals. If the trail split into smaller groups we systematically chose alternate trails, to avoid directional bias. Generally, caribou trails were followed as long as possible and ended when tracks were obliterated or daylight faded. We termed this type of trailing “long-trailing”, as opposed to fine-scale caribou foraging trailing reported elsewhere (Terry et al. 2000, Kinley et al. 2003, Serrouya et al. submitted). Occasionally, crews were able to begin following the same trail the next day and continue with the same trailing session. The end of the trailing session (i.e. the sample unit) was defined when it became impossible or impractical to continue trailing the same caribou path.

Along the caribou path, we recorded general habitat type classes including uncut old forest, clear cut, partial cut, road, and the location of changes in habitat types.

Although analyses were conducted using GIS basemaps (see below), field notes of habitat types provided continual ground truthing and were compared to GIS basemaps for each transect to ensure that the GIS maps were accurate. If the GIS maps did not reflect a certain feature like a recent cutblock, the GIS basemap was manually updated.

<u>Extraction of GIS data</u>

Caribou long-trailing use data was imported into ArcView 3.3 using DNR Garmin 5.1.1 software. Field crews spatially checked these trails with recent satellite imagery and orthophotos to confirm that the location of the trail was represented correctly.

The caribou-use trails were buffered at 10 m, 100 m, and 1000 m, to generate polygons for analysis. The 10-m distance was defined as the caribou use buffer and the 100-m and 1000-m distances were defined as the caribou habitat availability buffers (Figure 2).

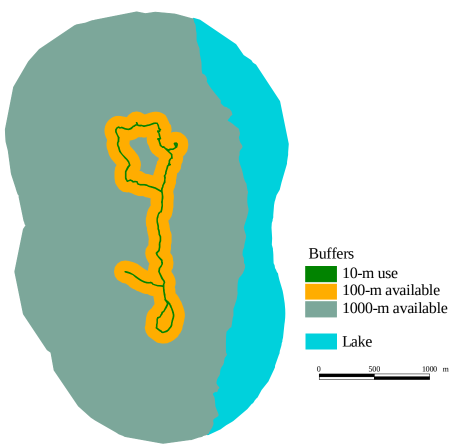

Figure 2. A hypothetical example of 3 polygon buffers generated for a caribou use trail. The lake, being non-caribou habitat, was excluded from analyses.

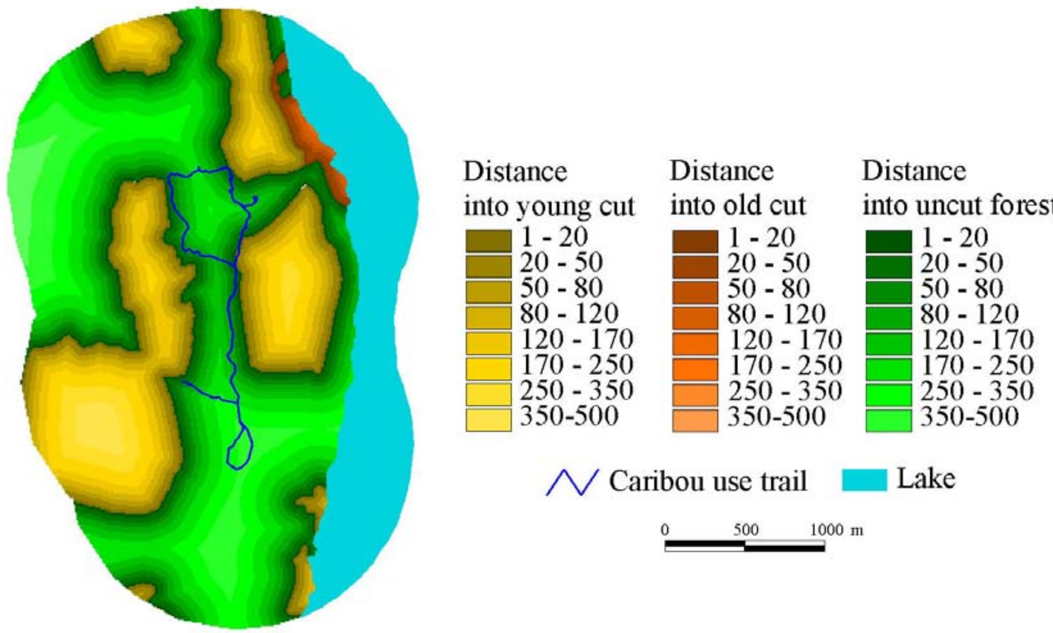

Figure 3. An example of the distances into 3 different habitat types for a 1000-m caribou availability buffer.

Ten meters was chosen for the use buffer to account for GPS error, while the 100 m and 1000-m distances were arbitrarily chosen to capture 2 scales of available habitat around each caribou trail. For each buffer, the average value for each variable was calculated based on GIS maps (Table 1, following page). Weighted averages of forest cover polygons were calculated based on the area they represented within each buffer.

Table 1. Variables extracted within each analysis buffer.

Variable	Description
PERC_CUT	Clear-cut logged (%)
PERC_PARTIAL	Partial-cut logged (%)
PERC_PARTIAL15	Low retention (15%) partial-cut logged (%)
PERC_PARTIAL70	High retention (70%) partial-cut logged (%)
PERC_FOREST	Primary forest (%)
YCUT_DIST	Distance into clearcuts <20 yrs (m)
OCUT_DIST	Distance into clearcuts 20−60 yrs (m)
PART_IN_DIST	Distance into partial cuts (m)
PART_70_DIST	Distance into high-retention partial cuts (m)
OLD_DIST	Distance into primary forests (m)
RDEN	Road density
AGE-MEAN	Projected forest cover age (yrs)
AGE2−5	Abundance of age class 2−5 forests (%)
CC	Forest cover crown closure (%)
DECID	Broadleaf tree (%)
SPRUCE	Any spruce (%)
CW	Western redcedar (%)
HEM	Any Hemlock (%)
FD	Douglas-fir (%)
SLOPE	Slope (%)

Tree species, stand age, canopy cover, and harvested blocks were extracted from digital forest cover data (Resources Inventory Branch 1995). The forest cover database was updated with new clear cut and partially cut polygon layers. Partial cuts were mostly balsam residual (~15% volume retention) stands harvested 10−30 yrs ago (often termed “Intermediate Utilization” stands), as well as some low removal (70% volume retention) dispersed single-tree selection stands. These partial cuts were digitized from ortho-corrected photos, labeled as partial cuts and incorporated into the GIS because their attributes (age and canopy structure) tend to be poorly represented in traditional digital forest cover databases. To further improve the forest cover database, manual identification of newly logged areas was done with 30-m resolution satellite imagery. Forest cover polygons with a non-forest descriptor for large lake, alpine, ice and rock were removed and assigned a null value to represent non-caribou habitat (Fig. 2). Topographic features for the study area were derived from a 20-m resolution digital elevation model (DEM). Percent slope were calculated from the DEM and extracted for each polygon buffer (Table 1).

To analyze distance-to-edge metrics for different habitat types, forest cover polygons were combined to define four habitat types: Young cutting units, old cutting units, primary forest, partial cut forests, and high-retention partial cut forest (Table 1). Projected age class, satellite images, and the partially cut polygon layer were used to identify these habitat types. Each habitat type was rasterized to a 10-m resolution. The shortest distance to each habitat-type edge was calculated and exported as a new 10-m distance raster (Fig. 3). Zero values were assigned a null value so distance means would only be calculated on the portion of the distance raster contained within the polygon buffers for the given habitat type.

Statistical analyses

Using each long-trailing session as the independent sample unit, we obtained means and SEs for each habitat attribute for each buffer level. We conducted paired t-tests between use and both levels of availability buffers, by matching the use buffer with its respective availability buffer. We also performed multivariate analyses on first order variables, by again taking advantage of the matched design to use conditional logistic regression by comparing use buffers to 100 and 1000-m availability buffers. Highly correlated ($r > 0.7$) variables were eliminated from the analysis, and the variable we retained was thought to have greater relevance to caribou ecology and management. All analyses were stratified by Biogeoclimatic Ecosystem Classification (BEC) zone.

RESULTS

During the winters of 2004, 2005, and 2006, we conducted 33 different trailing sessions in ESSF forests and 12 sessions in ICH forests. Trailing sessions averaged 4.6 (SE=0.6; range 0.9−19.2) km long in ESSF forests and 2.7 (SE=0.5; range 0.4−5.4) in ICH forests. Because of lower sample size in ICH forests, fewer comparisons were statistically significant, which made it difficult to achieve the same level of confidence in the results relative to the sampling in ESSF forests.

The greatest difference in magnitude between used and available features was road density, which was much higher in used vs. available areas in both BEC zones, although it was only significant in ESSF forests (Table 2). When caribou paths were located in young and old cutblocks, they tended to be significantly closer to the edge of old forests, suggesting that the middle of the cutblocks were avoided (Table 2, Fig. 4). In the ESSF, caribou ventured an average of 59.1 m into young cutblocks whereas the average availability of young cutblocks was 90.2 m from the closest edge at the 1000-m scale. In ICH forests, caribou ventured less far into young blocks (47.9 m) than into young blocks in the ESSF, even though the average available distance was greater at 114.5 m in the ICH (Table 2, Fig. 4). At the smaller scale, the avoidance of distances into clearcuts was again significant for both BEC zones.

Caribou trails were located an average of 91.5 m into the old forests from a cutting unit edge in the ESSF and 101.3 m into old forests in the ICH. Although this distance was 1.7−3.4 times as far as what they walked into any type of harvested forest (Table 2) the average distance available into the forest from a cutting unit edge was 143.5 and 130.6 m in the ESSF and ICH respectively (at the 1000-m scale) and thus the caribou remained significantly closer to the edge than expected (Table 2, Fig. 4).

For partial cuts, which only existed in ESSF forests, the selection of edges did not hold. Caribou ventured 73.2 m into partial cuts, which was similar to what was available (76.6 m at the 100-m scale and 86.3 m at the 1000-m scale). When the analysis is restricted to partial cuts that contain high residual volume (70%), caribou paths were located disproportionately further into the cuts than what was available, but this difference was not significant.

In this study, partial cuts comprised 11.5% of the use buffers, which was similar to available at the smaller scale, but occupied only 7.5% of the larger scale availability buffers, indicating positive selection for partial cuts when the larger landscape was considered. This pattern held for both low retention (15%) and high-retention (70%)

partial cuts (Table 2). However, none of these comparisons were statistically significant meaning that although the difference was relatively large, it was inconsistent among different caribou trails and this variability lead to not knowing if the results were due to chance or caribou were actually selecting partial cuts. In contrast, caribou avoided traditional clearcuts at both scales, but this difference was significant only in ESSF forests. In ICH forests, caribou selected uncut, older forests with more canopy cover at the larger scale (Table 2). Depending upon BEC zone and scale, caribou used mid-seral forests (age class 2−5 forests) 19.5−56 % less than what was available, but these differences were only significant in ESSF forests.

<u>Multivariate analyses</u>

In ESSF forests at the fine scale (use to 100-m buffer comparison), road density, distance-into-young and old cutblocks, and the percent clearcut were the strongest variables influencing the location of the caribou paths (Table 2). Caribou paths were positively associated with road density, but all other variables negatively affected the probability of finding a caribou path. At the broader scale (1000-m comparison), road density was no longer in the top models, but distance-into young and old cuts, and the percent harvested were still key variables (Table 5) negatively associated with caribou paths. Additionally, distance-into old forest was present in the top models, with a negative parameter estimate.

There was a greater degree of model selection uncertainty in ICH forests at the fine scale, evidenced by the presence of 6 models in the top model set (Table 6). The “distance into young cutblocks” variable was present in all 6 models, suggesting strong predictive ability, and was negatively associated with caribou presence meaning that caribou avoided the center of cutblocks. Other variables that caribou paths were positively associated with included percent uncut forest and road density. Percent cutblock and distance into old forests were also present in the top model set, and both were negatively associated with caribou paths (Table 6). At the larger scale, only 1 model containing 1 variable was in the top set; distance into young cut was negatively associated caribou trails (Table 7).

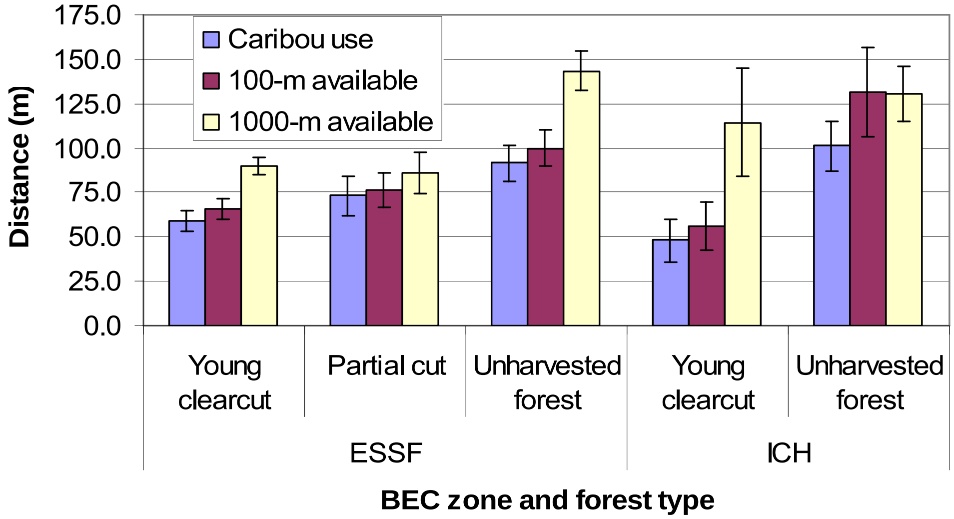

Figure 4. Distance into habitat features of caribou paths relative to 2 scales of available areas. Error bars are 1 SE.

Table 2. Comparison of habitat variables around caribou use paths relative to 100 and 1000-m available-habitat buffers in ESSF and ICH forests. Values in bold indicate significant differences at α=0.05.

	ESSF								ICH							
Habitat variable[1]	10-m use	SE	100-m available	SE	1000-m available	SE	PD[2] 10 m to 100 m	PD 10 m to 1000 m	10-m use	SE	100-m available	SE	1000-m available	SE	PD 10 m to 100 m	PD 10 m to 1000 m
PERC_CUT	22.1	3.2	26.0	3.2	30.2	2.6	**-14.8**	**-26.7**	24.6	9.5	28.2	8.0	34.4	4.7	-12.9	-28.4
PERC_PARTIAL	11.5	3.7	11.0	3.3	7.1	1.6	5.0	63.1								
PERC_PARTIAL15[3]	5.7	2.6	5.4	2.2	3.6	1.2	5.5	57.0								
PERC_PARTIAL70[3]	5.6	2.7	5.3	2.5	3.2	1.2	5.5	74.0								
PERC_FOREST	66.3	3.8	63.0	3.1	62.0	1.7	**5.3**	7.0	75.4	9.5	69.6	7.6	52.1	6.4	8.3	**44.7**
YCUT_DIST	59.1	6.1	65.7	5.4	90.2	4.9	**-10.0**	**-34.5**	47.9	12.2	55.8	13.6	114.5	30.2	**-14.1**	**-58.1**
OCUT_DIST	41.0	6.5	48.9	4.6	82.4	6.4	**-16.1**	**-50.3**	36.0	16.5	37.5	9.3	69.2	9.1	-3.9	**-47.9**
PART_IN_DIST	73.2	11.3	76.6	9.7	86.3	11.5	-4.5	-15.2								
PART_70_DIST[4]	77.9	13.0	72.1	9.3	65.2	2.5	8.0	19.5								
OLD_DIST	91.5	10.2	100.0	10.3	143.5	11.3	**-8.5**	**-36.3**	101.3	14.2	131.3	25.1	130.6	15.2	-22.9	-22.5
RDEN[5]	15.7	5.0	5.9	1.1	1.8	0.3	**167.9**	**771.5**	70.5	36.2	11.6	4.1	1.9	0.4	506.5	3665.8
AGE-MEAN	151.4	10.6	147.0	8.5	143.6	6.0	3.0	5.5	195.1	25.7	184.8	21.0	147.7	14.2	5.6	**32.1**
AGE2-5	6.3	1.5	7.8	1.5	13.2	2.0	**-19.7**	**-52.4**	3.8	1.8	6.3	2.9	8.6	3.1	-40.2	-56.0
CC	28.0	2.0	27.2	1.6	28.0	1.1	2.9	-0.1	45.1	6.6	43.2	5.7	35.4	3.9	4.4	**27.3**
DECID	0.0	0.0	0.0	0.0	0.0	0.0	-100.0	-100.0	0.1	0.1	0.3	0.2	0.9	0.4	-58.2	-84.4
SPRUCE	47.1	2.7	48.7	2.4	48.4	1.5	**-3.2**	-2.7	13.5	4.3	15.3	4.2	21.4	3.4	-11.5	**-36.8**
CW	0.2	0.2	0.4	0.2	1.7	0.6	-29.6	**-85.4**	28.3	5.3	27.8	4.3	23.7	2.7	1.8	19.4
HEM	0.5	0.5	0.5	0.5	1.5	0.8	4.2	**-64.1**	36.8	8.0	36.7	7.3	28.7	4.5	0.5	28.6
FD	0.3	0.3	0.3	0.3	0.6	0.3	-6.7	-54.1	3.2	2.0	3.6	1.8	5.4	1.4	-10.4	-41.1
SLOPE	18.3	1.3	18.6	1.3	20.9	1.4	-1.5	**-12.3**	40.7	3.9	39.6	3.0	33.3	3.8	2.8	22.4

[1]See table 1 for variable descriptions
[2]PD=percent difference ([use-available]/available x 100)
[3]These variables are subsets of the PERC_PARTIAL variable
[4]This variable is a subset of the PART_IN_DIST variable
[5] m/m^2 x 10^{-4}

Table 3. Top conditional logistic regression model set used to predict caribou paths in ESSF forests relative to habitat available using 100-m buffer. Null model shown for contrast. Direction of parameter estimates given in brackets[1].

Model structure	AICc	k	-2lnl	ΔAIC_c	$AIC_c\omega$
RDEN(+) OLD_DIST(-) YCUT_DIST(-)	27.3	3	20.4	0.0	0.31
RDEN(+) OLD_DIST(-) YCUT_DIST(-) OCUT_DIST(-)	28.4	4	19.0	1.2	0.17
RDEN(+) PERC_CUT(-) YCUT_DIST(-)	28.9	3	22.1	1.6	0.14
NULL	45.7	0	45.7	18.5	0.00

Table 4. Top conditional logistic regression model set used to predict caribou paths in ESSF forests relative to habitat available using 1000-m buffer. Null model shown for contrast. Direction of parameter estimates given in brackets.

Model structure	AICc	k	-2lnl	ΔAIC_c	$AIC_c\omega$
OLD_DIST(-) YCUT_DIST(-)	14.2	2	9.8	0.0	0.43
PERC_CUT(-) YCUT_DIST(-) OCUT_DIST(-)	15.9	3	9.0	1.7	0.19
NULL	45.7	0	45.7	31.6	0.00

Table 5. Top conditional logistic regression model set used to predict caribou paths in ICH forests relative to habitat available using 100-m buffer. Null model shown for contrast. Direction of parameter estimates given in brackets.

Model structure	AIC_c	k	-2lnl	ΔAIC_c	$AIC_c\omega$
YCUT_DIST(-)	12.2	1	9.8	0.0	0.18
YCUT_DIST(-) PERC_FOREST(+)	12.8	2	7.5	0.6	0.13
OLD_DIST(-) YCUT_DIST(-)	13.3	2	7.9	1.1	0.10
RDEN(+) YCUT_DIST(-)	14.0	2	8.6	1.8	0.07
PERC_CUT(-) YCUT_DIST(-)	14.0	2	8.7	1.9	0.07
RDEN(+) YCUT_DIST(-) PERC_FOREST(+)	14.2	3	5.2	2.0	0.07
NULL	16.6	0	16.6	4.4	0.02

Table 6. Top conditional logistic regression model set used to predict caribou paths in ICH forests relative to habitat available using 1000-m buffer. Null model shown for contrast. Direction of parameter estimates given in brackets.

Model structure	AICc	k	-2lnl	ΔAIC_c	$AIC_c\omega$
YCUT_DIST(-)	3.8	1	1.4	0.0	0.73
NULL	16.6	0	16.6	12.8	0.00

[1] For tables 3-6, AICc means Akaike Information Criteria corrected for small sample size, k is the number of parameters in the model, -2lnl is the -2 log likelihood, ΔAIC_c is the change in AIC value, and $AIC_c\omega$ is the AIC weight for each model.

DISCUSSION

The 2 scales of analysis, although arbitrary, enabled us to determine factors that influenced movement paths selected by caribou relative to what was available within their immediate surroundings (100-m from their path), and through a broader landscape (1000-m form their path). We were also able to compare factors that appeared to influence paths caribou selected across these 2 scales because the same variables and groups of models were evaluated at each scale.

The consistent selection of forest-clearcut edges across scales and BEC zones suggests that there are important habitat elements for caribou at forest edges. Finer-scale foraging studies indicate that caribou feed heavily on lichen litterfall and windthrown trees (Serrouya et al. submitted), and windthrow is more common near forest edges (Huggard et al. 1999). The attraction to edges was not apparent in partial cuts however, as evidenced by the lack of avoidance of areas deep into partial cuts. Thus, the residual structure inside partial cuts likely lessened the contrast that occurs at forest-clearcut edges and thus did not provide the same level of attraction for caribou compared to the more abrupt boundary of a forest-clearcut edge.

It has been postulated that retaining a proportion of trees and snags in cutblocks maintains some habitat attributes sought by caribou because of increased arboreal lichen growth resulting from improved light and moisture regimes (Lewis 2004, Lewis et al. 2005). In some cases, the Intermediate Utilization (IU; balsam residual partial cuts) harvesting that occurred historically in the Shuswap Highlands provided old trees with a climatic environment that favours *Bryoria* spp. establishment and growth. Much of this lichen was abundant in the lower canopy of residual trees, which is within reach of caribou and is similar to lichen biomass found in natural ESSF parkland forest (Lewis et al. 2005). It is clear that the residual structure left in blocks provides a benefit when compared to traditional clearcuts. However, it was less apparent whether low-retention or high-retention partial cuts were more beneficial to caribou, because neither were more strongly preferred, relative to what was available. More sampling will be needed to clarify this comparison. On the other hand, clearcuts were avoided at all scales in ESSF forests, indicating that this is the less preferred harvest system for caribou, relative to partial cuts. However, the inconsistent use of partial cuts at the larger scale, and the lack of selection at the small scale, suggests that these blocks are not as valuable to caribou as uncut forests. Indeed more than two-thirds of the caribou path lengths were located in uncut forests, which was significantly more than available for 1 scale in both

ICH and ESSF forests. As well, the abundance of partial cuts did not factor in any of the multivariate models, but undisturbed forests had predictive importance in the ICH fine-scale models. Finally, selection for old forests has also been demonstrated at scales that are larger than the ones considered in our study, so the opportunity for selection at these finer scales were constrained and thus difficult to detect.

The strong selection of roads at the fine scale reflects our observations in the field that caribou often use roads for movement. Although the magnitude of used vs. available roads was large in ICH forest, it was not significant indicating inconsistent use of roads by caribou in lower-elevation forests. Additionally, it is possible that the selection of roads by caribou may be a function of access bias by researchers attempting to get to trailing areas via snowmobile, however, we attempted to minimize this bias by beginning our trailing session near the latest aerial telemetry location. That roads were selected even at the finer scale, where the opportunity for selection was more constrained, indicates that the observed selection was likely meaningful. However, when the influence of roads are considered across much larger scales such as the entire distribution of mountain caribou, road densities are negatively associated with the persistence of mountain caribou (Apps and McLellan 2006). Thus, selection of roads for movement or partial cuts and edges for foraging may be an indication of caribou opportunistically deriving benefits at smaller scales, but the management strategies that produce these conditions may have negative consequences to populations at larger scales.

The phenomenon of animals attracted to certain habitats because of a short-term benefit (i.e. a foraging or easy movement opportunity) but resulting in increased mortality risk (i.e. “mortality sink” habitats) is an important ecological problem that is the subject of intensive theoretical research and debate (Van Horne 1983, Remes 2003). What appears less equivocal for mountain caribou is that contiguous old forests have been shown to provide consistent foraging opportunities at small scales (Terry et al. 2000, Kinley et al. 2003, Serrouya et al. submitted), and greater chance of persistence at large scales (Wittmer 2004, Wittmer et al. in prep, Apps and McLellan 2006).

Clearly this study was focused only on areas where forest harvesting occurs and we did not compare caribou use to available in landscapes without any forest harvesting. Comparing disturbed to undisturbed areas has already been done using aerial telemetry with results indicating heavy use or selection of old forests (Apps et al. 2001, Terry et al.

2000, Johnson et al. 2004). As such, the inference from our study applies only to areas where forest harvesting has occurred.

Future work

After completing this initial analysis, several opportunities to improve this study became apparent. First, it may be useful to differentiate 2 types of track patterns while trailing caribou: movement tracks vs. foraging-related tracks. This differentiation would help clarify what caribou were doing in the different habitat types. It is possible that some habitat types were used disproportionately for moving relative to foraging, and this would affect the interpretation of the results. Based on field notes we will be able to reconstruct this information, and any subsequent trailing will specifically differentiate between movement and foraging tracks.

The second improvement would be to base available areas on more biological criteria. For example, using radio telemetry Apps and McLellan (2006) reported that caribou movement distances asymptote after about 8 days. A similar, although finer-scale rationale to determine buffer-size cutpoints could be developed and applied to our analysis.

Another improvement may be to stratify the analysis of roads as to whether they were packed or unpacked by snowmobiles. This stratification may only be possible on the use trails, as available areas were extracted using GIS, therefore it would be difficult to obtain this information for the entire availability buffers.

Management implications

Caribou displayed selection for portions of the landscape with more old forest, less clearcut area, and generally avoided crossing deep into clearcuts. In addition, given that more than 2/3 of the length of caribou trails occurred in undisturbed forests within highly managed landscapes, this study supports the patterns observed at larger scales regarding the association of old forests with mountain caribou.

A key piece of new information gained from this study is that even partial cuts with low retention (< 50%) were selected more than clearcuts because these stands appeared to provide increased foraging opportunity to mountain caribou relative to clearcuts (Lewis et al. 2006). While low-retention partial cuts provide very little short-term habitat value due to loss of trees and associated lichens, the residual structure allows for the rapid colonization and accumulation of *Bryoria* spp (Lewis 2004). Therefore, it is possible that this low level of retention will accelerate the suitability of these stands in a shorter time period (within 20-30 years) relative to clearcut harvest systems (Lewis 2004, Lewis et al. 2005).

The avoidance of mid-seral stands (age class 2–5) has implications for landscape permeability and resource selection, given that these age classes will become more abundant as harvest rotations progress. Because these age classes were avoided by caribou, it is possible that landscape-level permeability will be negatively affected with increasing abundance of these age classes.

Both the use of edges and partial-cut stands by caribou for foraging is evidence of caribou utilizing conditions that favor the availability of abundant lichen forage either in standing trees, on windthrow or as litterfall. Thus, the use of edges and partial cuts support many of the partial-cut silviculture systems recommendations made by Stevenson et al. (2001). In addition, because caribou avoided areas “deep” into traditional clearcuts, the implication is that large openings provide little habitat value and may be considered barriers to movement. Maintaining small openings will allow a greater proportion of harvested stands to be used by caribou, and in ICH forests these small openings will likely reduce shrub growth that benefits other ungulates and associated predators. However, low-removal silviculture systems will create edges and increase the need for extensive short-term road networks to access timber, and these factors have been shown to negatively affect persistence of caribou populations (Wittmer 2004, Wittmer et al. in prep, Apps and McLellan 2006). More work is needed to develop management strategies that strike a balance between providing small scale stand-level attributes that are beneficial to caribou (i.e. maintain forage and movement opportunities) without creating large-scale patterns on the landscape (i.e. roads and early seral habitat) that negatively impact populations.

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