MULTISCALE HABITAT MODELING FOR WOODLAND CARIBOU IN THE ITCHA, ILGACHUZ AND RAINBOW MOUNTAINS OF WEST-CENTRAL BRITISH COLUMBIA

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For

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SUMMARY

The total range of “northern” caribou has declined in British Columbia during this century. There is concern for the long-term conservation of herds associated with the Itcha, Ilgachuz, and Rainbow mountains of west-central British Columbia due to a lack of protection for a large portion of their winter range and the threatened status assigned this portion of northern caribou range. To ensure that caribou requirements are considered in integrated resource management areas, a long-term monitoring program was initiated in 1995 to feed into the development of a conservation plan. From these data, we analyzed patterns of caribou habitat selection specific to herd, season, and wintering strategy. Our intent was to improve understanding of caribou-habitat associations in this area and to develop spatially-explicit decision-support tools for application at strategic planning levels.

We considered caribou habitat selection for 30 variables derived from 1:20,000 digital forest overstory and terrain data, 1:250,000 Baseline Thematic Mapping data, and Landsat 7 Thematic Mapper data. Caribou associations with each variable were analyzed at 3 spatial scales using a previously described design. Habitat selection was significant among most variables and seasons, especially at broader spatial scales. During summer, both the Itcha-Ilgachuz and Rainbow herds were associated with high elevation, dry, alpine landscapes of little vegetation productivity or overstory cover, although the former did prefer old subalpine fir at the broadest scale. Preferred landscapes were also associated with higher elevations, more rugged terrain and more northeasterly aspects than random expectation. During winter, alpine-dwelling animals from both herds were associated with high elevation, dry landscapes with little forest cover and low productivity, while low elevation, wet landscapes with open or closed forest cover were avoided. Winter habitat selection by forest-dwelling caribou was for broad landscapes of closed-canopy lodgepole pine overstory and higher site productivity at lower elevations. Itcha-Ilgachuz animals exhibited associations that were strongly positive for old forests and strongly negative for young forests. Although broad landscapes preferred by Rainbow animals had higher proportions of forests < 20 years of age, this was not reflected at the finest scale. Broad landscapes with open, wet habitats were avoided by Itcha-Ilgachuz caribou, while those with open, dry habitats were avoided by Rainbow caribou. Sites of highest vegetation productivity were avoided by both herds across scales. Although relatively dry, alpine landscapes were avoided at the broadest scale, wet sites were avoided at finer scales. Landscapes preferred by both herds were associated with gentle terrain conditions, and northeasterly aspects.

We derived multivariate habitat models specific to herd, season and wintering strategy. Models represent the minimum subset of variables whose linear combination best predicts caribou habitat use. Applied within a GIS, models represent decision-support tools for application in strategic planning. We provide recommendations based on habitat selection results and model

output as applied to the study area. These include: (1) maintain forested winter habitat values north, east and south of the Itcha Mountains and in the upper Dean River valley from about Kappan Lake northward to roughly the boundary between the very dry and moist subzones of the SBPS zone; (2) if a special management target is available, consider maintenance of winter range in the Caribou Flats area, for use by a potentially restored Charlotte Alplands herd and to allow for range shifts among the Itcha-Ilgachuz and Rainbow herds; (3) ensure that retained habitats are aggregated in large patches rather than being dispersed, which will require careful planning in key areas that are already highly fragmented, such as the east boundary of Tweedsmuir Park, the Chilcotin-Dean divide, and the northern headwaters of the Chilcotin River; (4) conduct further research into the patterns of terrestrial lichen development and arboreal lichen use relative to stand types, given that results are consistent with some non-traditional interpretations relative to those factors; and (5) in the future, determine whether bull habitat selection is consistent with predicted cow habitat values.

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INTRODUCTION

Woodland caribou (*Rangifer tarandus caribou*) in the north and west portions of British Columbia are considered to be of the “northern” ecotype (Heard and Vagt 1998). Caribou of this ecotype occur in mountainous areas receiving relatively low snowfall. They typically winter either in mature to old low-elevation forests or on windswept alpine slopes, and their winter diet consists primarily of terrestrial lichen. Herds at the southern limit of this ecotype’s distribution, along with the “mountain” ecotype immediately to the southeast, are listed as threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2000). The total range of northern caribou in BC has declined during this century (Spalding 2000) and some subpopulations have been reduced in number.

Caribou herds associated with the Itcha and Ilgachuz mountains, and the nearby Rainbow Mountains of west-central British Columbia consist of approximately 2000 and 125 animals respectively (Young and Freeman 2001). As these two herds share a common winter range, they are considered to be part of the same population (Hatler 1987). Although overall population numbers are considered to be stable, their long-term conservation is of concern due to a large portion of their winter range occurring outside of protected areas and being subject to forestry development (Young and Shaw 1998). The development of a conservation plan for this population is required by the Cariboo-Chilcotin Land Use Plan (CCLUP) to facilitate integrated resource management outside of protected areas (BC Government 1996). This necessitates prescriptive guidelines for application at strategic and operational planning levels. The conservation efficacy of such measures depends on our understanding of caribou habitat associations and requirements at multiple spatial scales. These are expected to differ among subpopulations, reflecting variations in physiography, climate, vegetation, behavior and human impacts.

In response to requirements of the CCLUP, the Wildlife Branch of BC Environment and Lands initiated a long-term caribou research and inventory program within and adjacent to the Itcha, Ilgachuz and Rainbow mountains in 1995. That program provides updated and expanded data to supplement information collected during a similar project undertaken from 1984 to 1988 (see Cichowski 1993). In this report, we summarize the caribou VHF-telemetry and GPS monitoring data collected to date from both program periods, and we analyze habitat associations in order to provide decision-support tools for caribou habitat conservation. Specifically, we (1) analyze season- and behavior-specific habitat selection relative to defined variables derived from digital data sources at 3 spatial scales, and (2) derive predictive habitat models reflecting a minimum subset of variables that best explain caribou habitat selection across spatial scales. Our increased understanding of caribou-habitat associations and resulting spatially explicit models will allow probable caribou requirements to be considered in forest and land management at strategic planning levels.

STUDY AREA

The analysis area (Figures 1, 2 and 3) falls largely within the Western Chilcotin Upland, Nazko Upland, Nechako Upland and Chilcotin Plateau ecosections of the Fraser Plateau Ecoregion, but also includes parts of the Western Chilcotin Ranges, Kitimat Ranges, and Northern Pacific Ranges ecosections of the Chilcotin Ranges, Coastal Gap, and Pacific Ranges ecoregions respectively (Demarchi 1996). The Rainbow, Ilgachuz and Itcha mountain ranges are volcanic features rising above the surrounding plateau. The Rainbow Mountains are the westernmost of these ranges and are the broadest and highest, with peaks to over 2,450 m. The Rainbows are separated from the Ilgachuz Mountains by the Dean River, with a valley bottom elevation of about 1,100 m. This is the lowest portion of the study area. The Ilgachuz Mountains reach nearly 2,400 m and are separated from the Itcha mountains by a saddle at about 1,600 m. The Itchas are the lowest and least extensive of the three ranges, with maximum elevations of 2,350 m. Collared caribou ranged within an area of over 10,000 km^2 in this region.

The biogeoclimatic subzones within the study area are among the least productive in the region for tree growth. Winters are cold and summers are cool with frequent growing-season frost, largely due to the study area’s position in the strong rainshadow of the Coast Mountains and its moderately high elevations. The low precipitation, dry air and clear skies in the rainshadow result in significant nighttime radiation cooling and low overnight temperatures (Steen and Coupé 1997). With descending elevation, forests generally become shorter lived and more prone to disturbance.

The four biogeoclimatic zones (Meidinger and Pojar 1991) dominating the study area are, in descending elevational order, the Alpine Tundra (AT), Engelmann Spruce – Subalpine Fir (ESSF), Montane Spruce (MS), and Sub-Boreal Pine – Spruce (SBPS). The AT covers extensive areas at the uppermost elevations of all three ranges and is devoid of forest. Its predominant cover is terrestrial lichen, grass and dwarf shrubs (Cichowski 1993). Below the AT, the ESSF (predominantly the ESSFxv or very dry, very cold subzone) occurs in a narrow band between roughly 1650 and 1825 m. Within the ESSFxv, mature forests are dominated by lodgepole pine (*Pinus contorta*) with some areas of Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*) or whitebark pine (*Pinus albicaulis*), with *Bryoria* as the major hair lichen (Coupé et al. 1991, Young and Shaw 1998). The undergrowth vegetation is dominated by grouseberry (*Vaccinium scoparium*), crowberry (*Empetrum nigrum*), mountain sagewort (*Artemisia arctica*) and by abundant ground lichens (primarily *Cladonia* spp.; Steen and Coupé 1997). The very dry, very cold subzone of the MS (MSxv) occurs below the ESSF as a narrow band at the eastern edge of the Rainbows and western edge of the Ilgachuz Range, and over broad areas north, east and south of the Itcha-Ilgachuz complex at elevations of about 1,200 to 1,650 m. Mature forests within the MSxv are predominately even-aged, even-sized lodgepole pine, with scattered hybrid white spruce (*Picea glauca* x *englemannii*). Vegetation succession in this climate is very slow with pine stands more than 200 years old often having few spruce or subalpine fir trees in the canopy. The undergrowth vegetation is dominated by crowberry, grouseberry, mosses and lichens. The SBPS occurs below the MS, and largely consists of the moist, cold (SBPSmc) subzone in the northern half of the study area and the very dry, cold (SBPSxc) subzone in the south, with the dry, cold subzone (SBPSdc) in the extreme northeast. Open stands of even-aged lodgepole pine are dominant, with hybrid white spruce occurring mainly in wet areas and in mixed stands with lodgepole pine. The undergrowth vegetation is dominated primarily by kinnikinnick (*Arctostaphylos uva-ursi*), pinegrass (*Calamagrostis rubescens*), mosses, and abundant terrestrial lichens (*Cladina* spp., *Cladonia* spp., *Stereocaulon* spp., *Peltigera* spp.). Where cold air ponds on dry sites, meadows of fescue (mainly Altai fescue: *Festuca altaica*) and terrestrial lichen occur. Shrub-carrs of scrub birch (*Betula glandulosa*) and willow (*Salix* spp.) and sedge fens occur on sites having water tables near the surface (Clement 1987).

The Rainbows are located within Tweedsmuir Provincial Park, while the Ilgachuz and Itcha mountains are mainly within Itcha-Ilgachuz Provincial Park. These protected areas are predominantly AT and ESSF, with lesser amounts of MS. The SBPS occurs almost entirely outside of the parks. In general, forest harvesting has been concentrated at lower elevations and in the southern and eastern portions of the analysis area. There has been little or no forestry or road development in the parks, in the area north from the Rainbow, Ilgachuz and Itcha mountains to the Blackwater River, and directly between the Rainbow and Ilgachuz mountains.

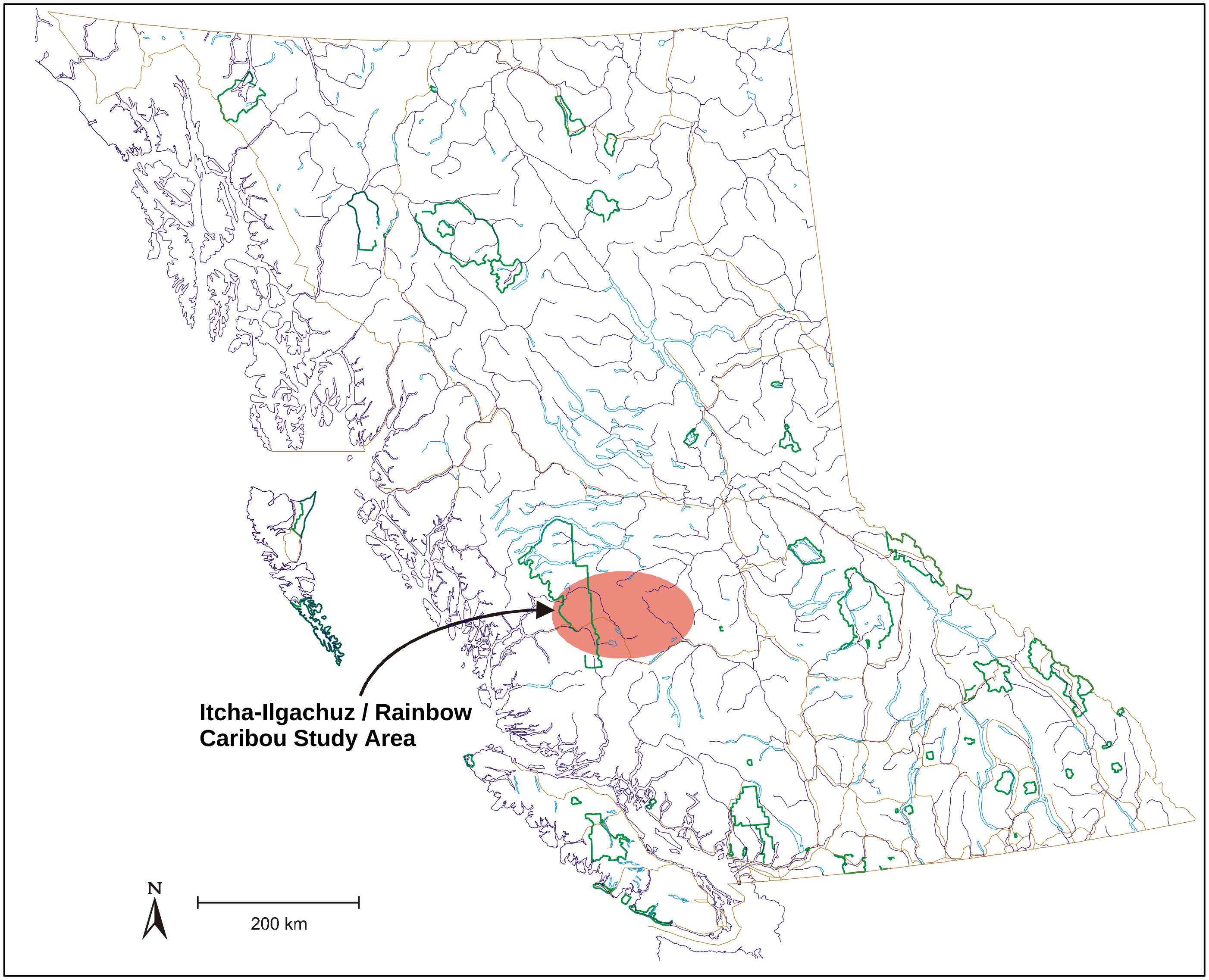

Figure 1. The study area, associated with the Itcha, Ilgachuz, and Rainbow mountains of west-central British Columbia. Protected area boundaries (green) are not current.

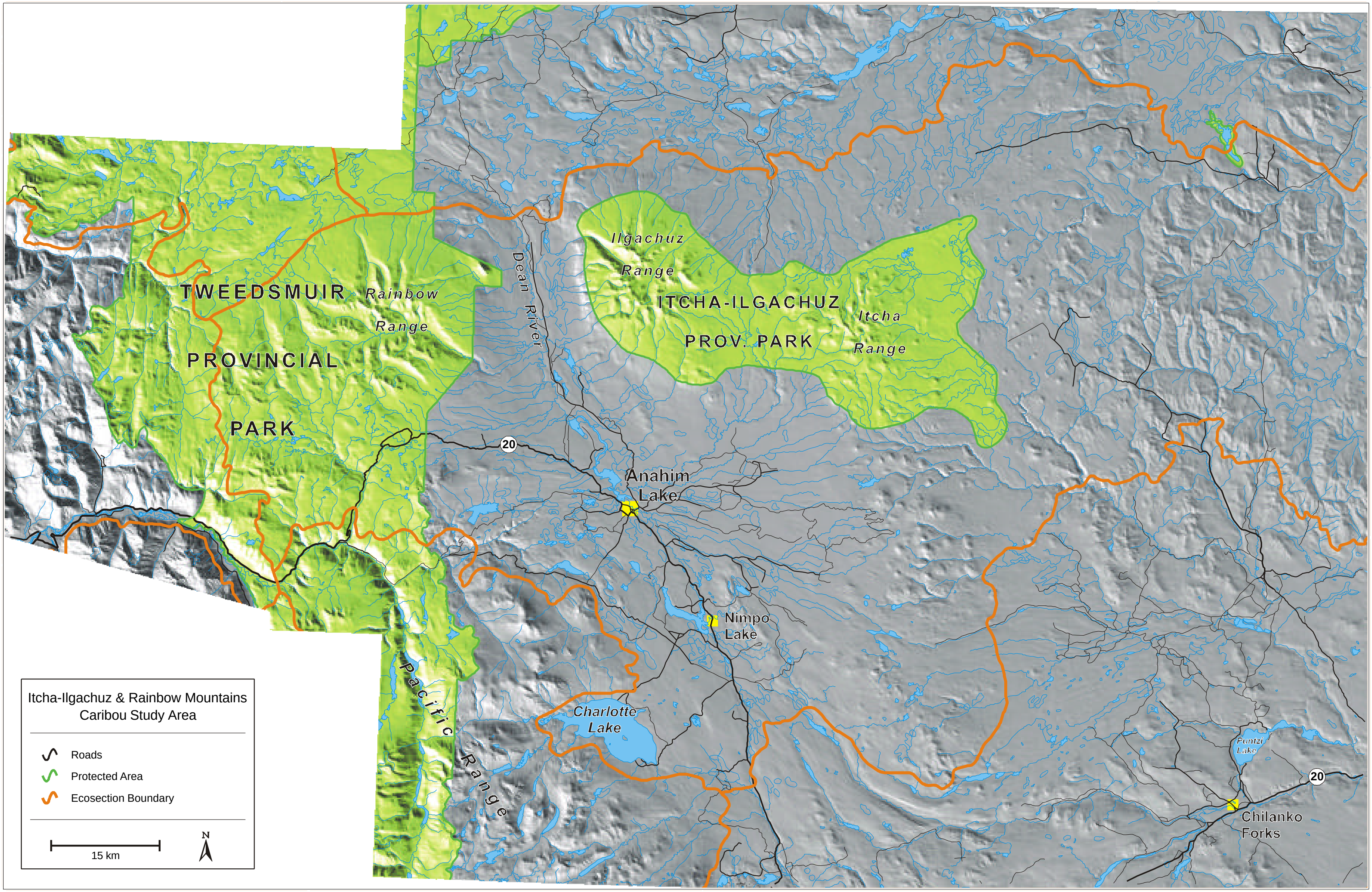

Figure 2. Itcha-Ilgachuz and Rainbow mountains caribou study area in west-central British Columbia.

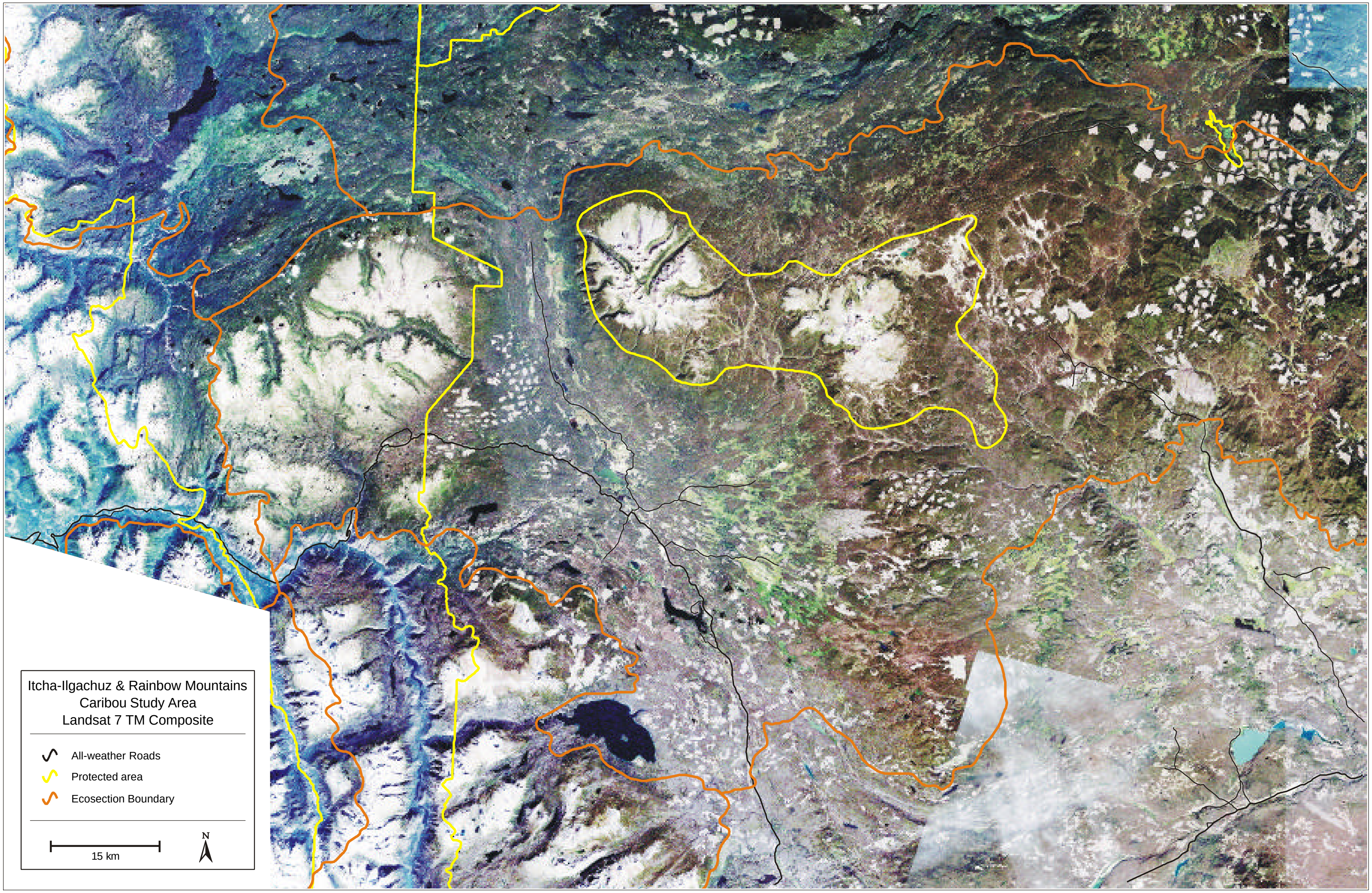

Figure 3. Composite Landsat 7 TM image of Itcha-Ilgachuz and Rainbow mountains caribou study area, west-central British Columbia. The image is a mosaic of scenes taken during August and September, 1999.

SUMMARY OF EXISTING INFORMATION

Female caribou within the study area calve and remain for the summer in either the Rainbow Mountains or the Ilgachuz and Itcha Mountains, mainly within the ESSF and AT. On the basis of calving locations, animals are defined as belonging to either the Rainbow (hereafter RB) or Itcha-Ilgachuz (hereafter I-I) herds, although some individuals occasionally shift locations. Wintering sites differ between herds, individuals and years, but animals generally express one of two distinct wintering behaviors: “alpine-dwelling” or “forest-dwelling”. Although in some years, members of the RB herd winter in the ESSF and AT zones of the Rainbow or Ilgachuz mountains, most winter in the SBPS and MS of the Dean River valley near Anahim Lake. The same pattern occurs among I-I caribou; in some years a portion of the herd remains in the AT and ESSF of the Itcha and Ilgachuz ranges, while the majority typically winter north, east and south of there in the MS and SBPS (Young and Shaw 1998). Thus, forest-dwelling caribou typically occur at the highest elevations during the summer, at gradually decreasing elevation from fall through late winter, and again at increasing elevation during spring. Among RB caribou, the drop in elevation during fall has been found to occur later, and the minimum winter elevations found to be lower, than among I-I caribou. In contrast, alpine-dwelling caribou remain at higher elevations during the winter and spring, but mean elevations decrease slightly in portions of early winter and spring. Among animals of both behavior patterns, there is a marked, but temporary, decline in elevation at the end of summer (Young and Shaw 1998). Based on movement and habitat use patterns, 7 seasons were proposed by Cichowski (1993) and adopted by Young and Shaw (1998; Table 1).

When wintering at low elevations, caribou typically occur within dry pine forests and, until prohibited by excessive snow accumulation, fescue-lichen meadows. In these locations, they crater primarily for terrestrial lichens. Arboreal lichen is also occasionally used, typically in forested wetlands and other sites with a spruce component (Cichowski 1993). Relatively little is known of foraging strategies for winter alpine-dwelling caribou.

Table 1. Seasons and seasonal cutpoints used by Cichowski (1993) and Young and Shaw (1998) for caribou habitat in west-central British Columbia.

Season	Dates
Spring (SP)	1 May – 31 May
Summer (SU)	1 June – 31 August
Early Fall (EF)	1 September – 31 October
Late Fall (LF)	1 November – 30 November
Early Winter (EW)	1 December – 15 January
Mid Winter (MW)	16 January – 15 March
Late Winter (LW)	16 March – 30 April

METHODS

Collar Deployment

Adult female caribou were captured for radiocollaring and subsequently monitored in two periods: 1984-1988 and 1995-2000. This included VHF collars deployed within both the I-I and RB herds during the 1980's and the 1990's, and GPS collars deployed in the I-I herd from 1998 to 2000.

From October through May of 1984-1987, caribou were captured either by net-gunning from a helicopter or using a helicopter to herd them into nets. Caribou were fitted with VHF radiocollars (Telonics Inc., Mesa, Arizona), some of which had mortality sensors, and each was eartagged. The monthly sample varied from 5 to 15 (21 total) among the I-I herd, and 4 to 7 (7 total) among the RB herd, depending on mortalities, movements between herds, collar failures, and recollaring efforts (Appendix A). For both herds combined, the sample varied from 9 to 21 (27 total) during the 1980's.

During 1995, 1996 and 1998, caribou were captured in October, November, December and February using net guns fired from helicopters. Caribou were fitted with either VHF radiocollars having mortality sensors (I-I and RB herds) or remotely-downloadable *Lotek 1000* GPS radiocollars (Lotek Engineering, Newmarket, Ontario) equipped with temperature and motion recorders (I-I only). The monthly VHF sample comprised 5 to 6 (8 total) among the RB herd, and 14 to 23 (29 total) among the I-I herd, for a combined sample of 14 to 29 (40 total). The I-I GPS collar sample varied between 3 and 6 (6 total) between December, 1998 and August, 2000 (Appendix B). Three caribou collared with VHF units within the range of one herd subsequently moved to the other.

Caribou Location Data

During the 1980's, fixed-wing flights to record collared caribou locations were conducted approximately weekly from December through March, and every 2 to 3 weeks from April through November. Locations were plotted on 1:100,000 topographic maps, then converted to UTM coordinates on a 0.5 km grid (Cichowski 1993). In the 1990's, caribou were aerially located 2 to 4 times monthly. Throughout the monitoring, animal locations were obtained with an aircraft-mounted GPS unit and approximately 80% of locations were associated with direct observations of study animals. During flights, relevant information was recorded including a description of the habitat the animal was observed within. Following each flight, GPS-recorded data were transferred to 1:50,000 maps and visually assessed to ensure they were consistent with both the general location and habitat attributes recorded during the flight. If they were, the GPS-recorded data were accepted, but if not, minor adjustments to the UTM coordinates were made such that coordinates fell within the habitat the animal was observed within (Young and Shaw 1998). Data collected until 19 June, 2000 are included in this analysis.

Combining the 2 sample periods and 2 herds resulted in 5,423 VHF records (Table 2). This included seasonal samples of 340 to 1316 radiolocations, with each individual contributing 6 to 175 locations for all seasons combined (Appendix C).

Table 2. VHF collar radiolocations from female caribou in the Itcha, Ilgachuz, and Rainbow mountains, west-central British Columbia, 1984 – 1988 and 1995 – 2000.

Period	Itcha-Ilgachuz	Rainbow	Total
1980's	1067	397	1464
1990's	3061	898	3959
Total	4128	1295	5423

GPS collar schedules varied during the study. Collars were set to attempt 8 fixes per day (56 fixes per week) at 3-hour intervals, beginning at 01:00 on Wednesdays and Saturdays and 02:00 on other days. This programmed schedule applied from their deployment in December, 1998 through April 30, 1999, then from November 5, 1999 until their removal in August, 2000. From May 1 to November 5, 1999, collars were set to attempt 7 fixes per week (nominally 1 fix per day) on a varying schedule. Fixes were attempted at 04:00 on Sundays, 08:00 on Mondays, 12:00 on Tuesdays, 16:00 on Wednesdays; 20:00 on Thursdays, and 00:00 and 01:00 on Saturdays. No fixes were attempted on Fridays. At each attempt, the collars collected ephemeris files from each satellite with which they communicated, indicating the identity of the satellites and the time required for signals to reach the GPS collar. Files were downloaded from the collars remotely via modem from aircraft, using the manufacturer's *GPS Host* software. The ephemeris files were then differentially corrected with the vendor's *N3Win* software, with Williams Lake base station data, obtained about 200 km east/southeast of the collar deployment area. Locational data were converted to the Universal Transverse Mercator (UTM) North American Datum 1983 (NAD83) format. The database output from the differential correction process provided additional information, including horizontal dilution of precision (HDOP)[1], convergence[2], external temperature, and an index of movement over the previous 4 minutes. Based on the number of satellites from which the collar had collected ephemeris files, each successful attempt was recorded as 2D (3 satellites) or 3D (4 or more satellites). Locations were not recorded when 2 or fewer satellites were available. Default settings in the collar hardware converted any 3D locations with HDOP = 10 to 2D locations by deleting files from one of the satellites. Data were further classified as "diff" (successfully differentially corrected) or "fix" (not successfully corrected)[3]. Thus, each successful fix was recorded as "2Dfix", "2Ddiff", "3Dfix", or "3Ddiff".

GPS Data Screening

GPS collar location data were screened to eliminate points that were likely to be highly erroneous. Three methods were employed to do so.

1. *HDOP Screen*. Regression equations have been developed that correlate HDOP to mean accuracy for 2Dfix and 3Dfix data (Moen et al. 1996) and 2Ddiff data (Rempel et al. 1995). We used these equations to determine HDOP cut points at which expected (mean) error would match that recorded when VHF collar relocation tests were conducted in the study area (157 m; Young and Shaw 1998; Table 3). For 3Ddiff data, errors have been found to be < 50 m, with no correlation between accuracy and HDOP (Rempel et al. 1995, Moen et al. 1997). However, the collars used in those studies recorded 3D fixes only for points with HDOP < 6.0 (locations with greater DOP were calculated as 2D). The collars for the current study truncated 3D data points at < 10.0, so no regression equation is available for HDOP values between 6.0 and 9.9 for 3Ddiff locations. Therefore, we (a) assumed errors of < 50 m for 3Ddiff points with HDOP < 6.0, and (b) for 3Ddiff location data with HDOP values of 6.0 - 9.9, we assumed that the quotient of the 2Ddiff and 2Dfix error, multiplied by the 3Dfix error associated with that HDOP would approximate the expected error for a 3Ddiff point (Table 3).

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[1] HDOP is a unitless measure of satellite geometry. The value decreases as satellites used to estimate a position become more widely spaced, generally resulting in a location of higher accuracy.

[2] Convergence is another measure of satellite geometry.

[3] Unsuccessful differential correction is generally due to a mismatch between satellites used to derive collar fixes and those associated with base station files. This is more likely to occur with greater distances between collars and the base station.

2. *Return Movement Screen*. We employed a screen used by Apps and Kinley (2000a) for mountain caribou, in which we determined whether the second in every series of 3 successive GPS points was > 5,000 m from the first point and the third was < 1,000 m from the first. Where this extreme "out-and-back" apparent movement occurred, the second of the 3 successive points was assumed to be erroneous and deleted.
3. *Visual Screen*. Finally, all GPS locations were mapped, and any single points that were obviously outside of the main cluster of data points were deleted. The distribution was such that these visually-screened points were a minimum of about 30 km from the main cluster.

Of the 13,430 GPS points, 576 (4.3%) were screened and removed from the data set (Table 4). Almost all of these were identified via HDOP only (563) or HDOP plus one or more other screens (6). The Return Movement screen alone identified only 3 additional points, 2 more were identified by both the Return Movement and Visual screens, and 2 by the Visual screen alone.

Among the 17,836 attempted GPS locations, 75% (13,430) were successful locations, with the success rate varying among individuals from 52 to 91% (Appendix D). After screening, the sample represented 72% of attempted locations. Of these, 0.5% were 2Dfix, 46.8% 2Ddiff, 0.5% 3Dfix and 52.2% 3Ddiff.

Table 3. HDOP values corresponding to expected errors of 157 m. All GPS locations with greater HDOP values were removed from the database prior to further analysis.

Data Type	HDOP Corresponding to Expected (Mean) Error of 157 m
2D "fix"	8.0
2D "diff"	9.9
3D "fix"	11.1[a]
3D "diff"	14.3 [a]

[a] Hypothetical values only, as GPS collars converted locations from 3D to 2D if HDOP > 9.9. Therefore, all 3D locations would have an expected error or less than 157 m.

Table 4. Number of 13,430 GPS collar locations removed from database after screening by various methods. In cases where multiple methods are indicated, each method individually identified that number of suspect points.

Screening Methods	Points Eliminated
HDOP only	563
HDOP + return movement	2
HDOP + visual	3
HDOP + return movement + visual	1
Return movement only	3
Return + visual	2
Visual only	2
TOTAL all methods	576
TOTAL that included HDOP screen	569
TOTAL that included return movement screen	8
TOTAL that included visual screen	8

Data Subsampling

Considering the typical movement patterns of woodland caribou, we expected that the high temporal sampling frequency of GPS collars would provide data that were autocorrelated at the scales at which we intended to analyze habitat selection. Moreover, differences in sampling frequencies between VHF and GPS data would grossly bias results to a small number of GPS-collared caribou relative to the overall animal sample. To help determine the broadest scale appropriate for analysis and the rate at which GPS data should be subsampled, we conducted 2 analyses of caribou movement rates using both GPS and VHF data. First, we used the GPS dataset to determine caribou movement rates in 3-hour increments, up to 48 hours (Figure 4). Then we randomly subsampled the GPS dataset to ≤1 location per day, thinning locations from 12833 to 3085 (Table 5). We combined these data with the VHF dataset to determine net movement rates over successive days (Figure 5). We estimated that subsampling GPS data on a 4-day interval, resulting in 701 locations (Table 5), would allow GPS collared caribou to contribute to the analysis in approximately the same proportion as their representation in the overall animal sample[4]. We used this 4-day interval and corresponding movement rates to determine the broadest scale appropriate for habitat selection analysis (see Scale-Dependent Analysis Design). Although a greater proportion of GPS data can be considered independent at finer spatial scales,

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[4] VHF animal sample = 62; locations/animal: $\bar{x}$ = 88 ±53, 1SD. GPS animal sample = 6; locations/animal at 4-day sampling interval: $\bar{x}$ = 117 ±42, 1SD.

we did not include more than the 701 GPS locations subsampled at a 4-day interval in analysis of any scale to ensure that results were not biased to individual caribou.

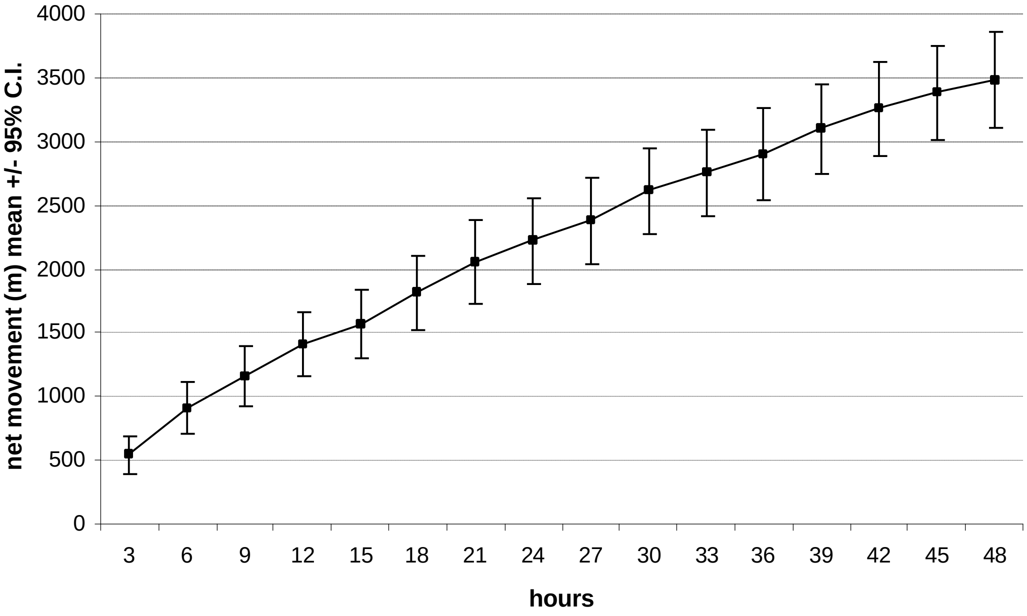

Figure 4. Net movements by caribou over 3-hour intervals (mean +/- 95% C.I.) as estimated from GPS location data in the Itcha and Ilgachuz Mountains, west-central British Columbia, 1998 – 2000.

Table 5. Sample size of VHF and GPS data after subsampling to ensure independence at successively larger sampling intervals.

Data Type	Original Sample[a]	Minimum Sampling Interval (days) 1	2	3	4	5	6	7	8	9	10
VHF	5423	5423	5413	5411	5401	5274	5022	4419	3801	3185	2754
GPS	12833	3085	1235	893	701	569	477	421	368	329	296

[a] after screening of GPS data

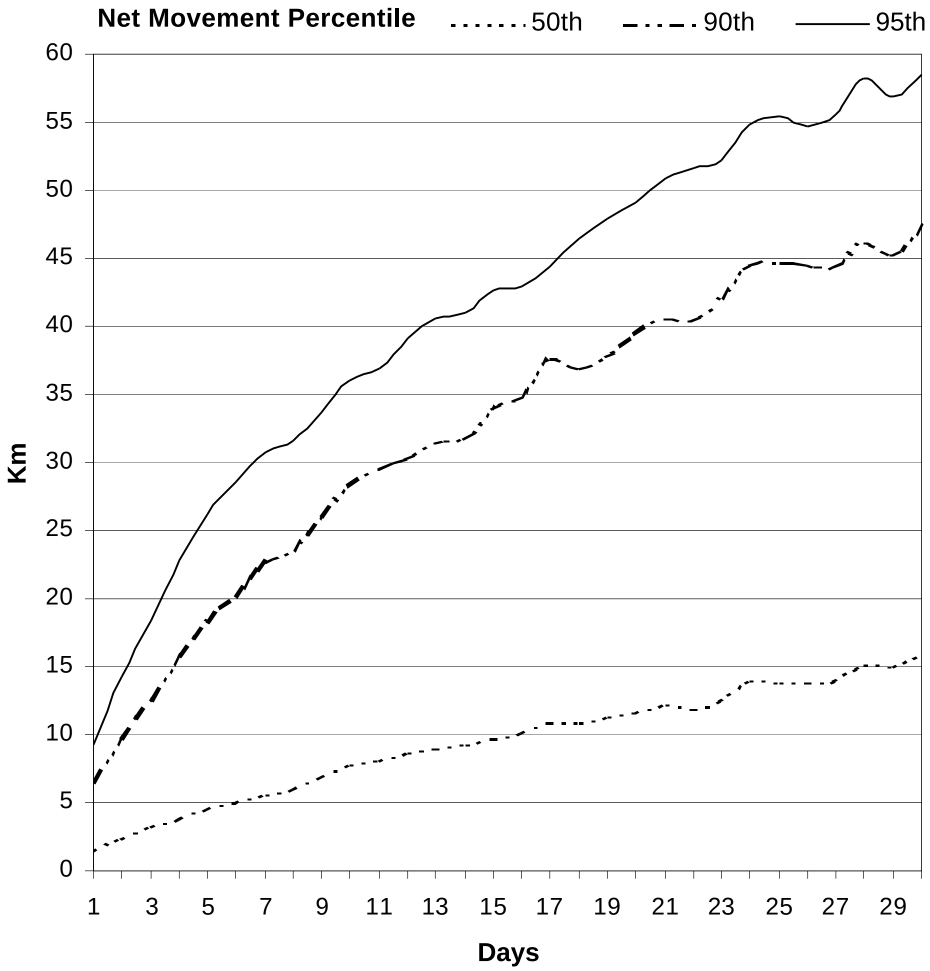

Figure 5. Net movements of GPS- and VHF-collared caribou over successive days in the Itcha, Ilgachuz, and Rainbow mountains of west-central British Columbia, 1984 – 1988 and 1995 – 2000.

GIS Habitat Data

We assembled habitat data in a GIS for an analysis area of approximately 20,000 km^2, encompassing all caribou location data. All data were rasterized to 100 m resolution (cell size), roughly equivalent to the minimum mapping unit. Habitat variables (Table 6) were derived from several digital data sources. All GIS applications employed the raster-based software *Idrisi 32* (Clark Labs 1999).

Topographic variables were derived from 1:20,000 Terrain Resource Information Management files (TRIM; Surveys and Resource Mapping Branch 1992). Terrain variables included elevation (ELEV) and slope (SLOPE). Terrain curvature (CURVA) reflected the maximum rate of change of a curve fit through each pixel in the context of its neighbors, and was derived using the profile curvature algorithm (Pellegrini 1995). For example, slope change will be

Table 6. Independent variables considered for analyses of caribou habitat selection within the, Itcha, Ilgachuz, and Rainbow mountains of west-central British Columbia, 1984 - 1988 and 1995 - 2000. All variables are ratio-scale, and represent either the mean or proportional composition within a surrounding landscape.

Variable	Description
AGE_0-1	Overstory stands “not sufficiently restocked” to 20 yrs (%)
AGE_2-4	Overstory stand age 21 to 80 yrs (%)
AGE_5-7	Overstory stand age 81 – 140 yrs (%)
AGE_8-9	Overstory stand age > 140 yrs (%)
CANOPY	Overstory canopy closure (%)
HEIGHT	Stand height (m)
SITE	Stand site index
DBH	Mean diameter at breast height (cm)
B_SPP	Subalpine fir (*Abies lasiocarpa*) composition (%)
S_SPP	Spruce (*Picea* spp.) composition (%)
P_SPP	Lodgepole (*Pinus contorta*) composition (%)
DEC_SPP	Deciduous species composition (%)
OPEN_WET	Wet openings: “swamp”, “clearing”, “hayfield”, “meadow” and “non-productive brush” (%)
OPEN_DRY	Dry openings: “open range” (%)
ALPINE	Alpine tundra composition (%)
BTM_ALP	Baseline thematic mapping “alpine” composition (%)
BTM_FO	Baseline thematic mapping “old forest” composition (%)
BTM_FY	Baseline thematic mapping “young forest” composition (%)
BTM_WET	Baseline thematic mapping “wetland” composition (%)
BTM_RANG	Baseline thematic mapping “rangeland” composition (%)
NDVI	Landsat Normalized Difference Vegetation Index
GVI	Landsat Green Vegetation Index
WVI	Landsat Wet Vegetation Index
BVI	Landsat Bright Vegetation Index
ELEV	Elevation (m)
SLOPE	Slope (%)
CURVA	Terrain curvature index
SOUTH	North→south aspect (0→100)
WEST	East→west aspect (0→100)
TERRAIN	Terrain Ruggedness Index (0→100)

greater near peaks, ridges, saddles or gullies. Aspect was represented by 2 continuous (0→100) variables depicting north→south (SOUTH) and east→west (WEST) aspects (Apps et al. 2001). For example, direct south aspects reflected values of 100 for south and 50 for WEST, direct east aspects reflected 50 for SOUTH and 0 for WEST, and direct northwest aspects reflected 25 for SOUTH and 75 for WEST. A terrain ruggedness variable (RUGGED) 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 pixel size and landscape radius. For example, an index of 100 would represent a landscape with at least one contour passing through each pixel, while an index of 0 would represent a landscape with no contours passing through any pixels.

We derived forest overstory variables from 1:20,000 digital forest inventory planning files (FIP; Resources Inventory Branch 1995). Forest inventory data for Tweedsmuir Provincial Park were derived from an earlier system of polygon mapping and classification and are assumed to be of lower quality than those available for other lands within the study area. Several attributes thought to be important to the northern ecotype of caribou may relate to stand age in a non-linear manner. We therefore derived 4 stand age classes (AGE_0-1, AGE_2-4, AGE_5-7, AGE_8-9) 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. Canopy closure (CANOPY) depicted the ocular cover of the stand overstory. Site index (SITE) reflected site productivity based on stand age and height as calculated by species-specific equations (Thrower et al. 1991). Mean diameter at breast height (DBH) was that of the leading overstory layer. 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 tundra (ALPINE) encompassed all habitats above treeline other than rock and ice. Non-forested habitats interspersed within forests may be ecologically significant to northern caribou, and are either lowland seepage areas or upland dry lichen meadows. We defined swamps, clearings, hayfields, meadows (typically sedge fens), and non-productive brush (shrub-carr and tall shrub-fen wetlands) as non-forested wet areas (OPEN_WET). We defined open range (fescue/lichen meadows associated with frost hollows) from the forest inventory as non-forested dry areas (OPEN_DRY).

We derived several variables from 1:250,000 Baseline Thematic Mapping (BTM) of present land cover, which in turn was derived from Landsat Thematic Mapper (TM) data (Surveys and Resource Mapping Branch 1995). Although land cover classes were similar to variables derived from forest cover data, they were defined differently and may improve the explanatory power of habitat models. We considered these data to be appropriate for this analysis because the minimum mapping unit was 15 ha, smaller than the 95% error associated with our caribou location data. We extracted alpine (BTM_ALP), areas virtually devoid of trees at high elevations.

We also extracted the two forest classes, old forest (BTM_OF) and young forest (BTM_FY), stands > 6 m in height and older and younger than 140 years, respectively. Wetlands (BTM_WET) included swamps, marshes, bogs, or fens. Rangelands (BTM_RANG) were defined as unimproved pasture or grasslands with cover of drought-tolerant grasses, sedges and shrubs up to 6 m in height and < 35% forest cover.

We obtained Landsat 7 TM data from Geographic Data BC for the analysis area. The assembled Landsat coverage was a mosaic of scenes from August and September, 1999. For each of the 7 spectral bands, we adjusted reflectance values to maximize their relative consistency across the analysis area. We minimized the effects of atmospheric haze by applying radiometric correction techniques, and we adjusted reflectance values for topographic influence using band-ratioing (Eastman 1999). From the final reflectance values for the spectral bands, we derived the Normalized Difference Vegetation Index (NDVI; Rouse et al. 1974). Using the Tasseled Cap Transformation (Crist and Cicone 1984), we also derived an index of vegetation greenness (GVI), wetness (WVI), and brightness (BVI).

Scale-Dependent Analysis Design

Our analysis design conformed to Thomas and Taylor’s (1990) study design 2, with inferences relevant at the population level. We considered the study animals a representative sample of the population, and we pooled location data among caribou, as is appropriate where few locations are obtained from many animals (Manly et al. 1993).

We employed a scale-dependent analysis design following methods previously described by Apps et al. (2001). Spatial scale in ecology is characterized by the geographic extent of analysis and the spatial resolution of data. We analyzed caribou-habitat associations at 3 spatial scales, corresponding to successively smaller landscapes of used and available habitat. At each analysis level, we adjusted the resolution of habitat variables by aggregating data (Bian 1997) using a GIS moving window routine. Pixels thus reflected each variable’s mean value or proportional composition within a surrounding circular landscape. Landscape composition was sampled at each caribou location and at a paired location of fixed distance but random azimuth from each caribou location (Figure 6). At level 1, the broadest scale of analysis, caribou and paired random locations were separated by 22.7 km (Figure 7). We assumed that habitats within this distance were potentially available to caribou within a 4-day sampling interval because ≥5% of associated caribou movements exceeded this distance. By applying a 0.25 multiplier to this distance, we defined the radius (5.7 km) of circular landscapes within which we measured habitat composition at caribou and random locations. At levels 2 and 3, random locations were generated at distances equivalent to the landscape radius at the previous level, and habitat composition was again measured within a radius of 0.25 of this distance. Although this multiplier was arbitrary, it ensured that the radius used to scale habitat composition at level 3, the finest

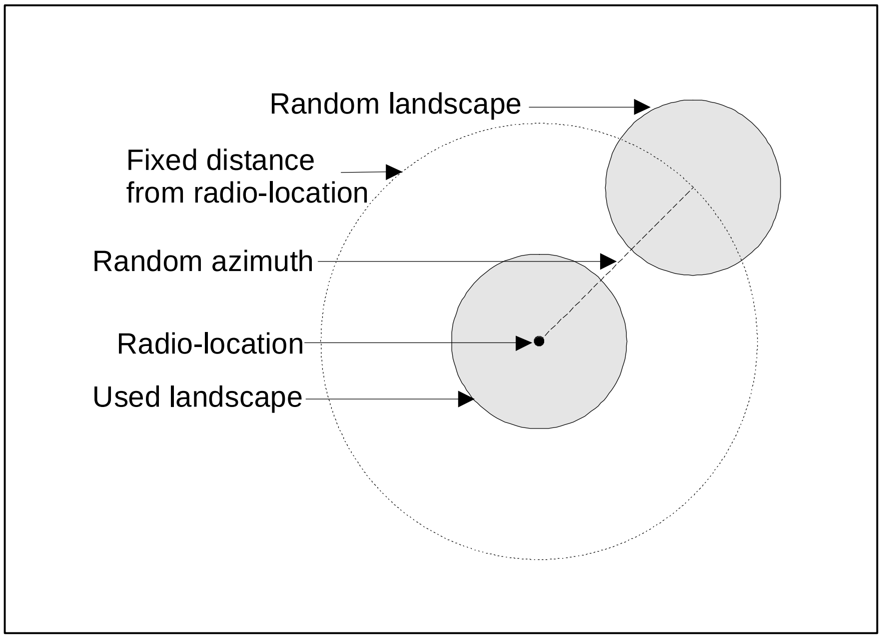

Figure 6. Scale-dependent design for analyzing caribou habitat selection in west-central British Columbia.

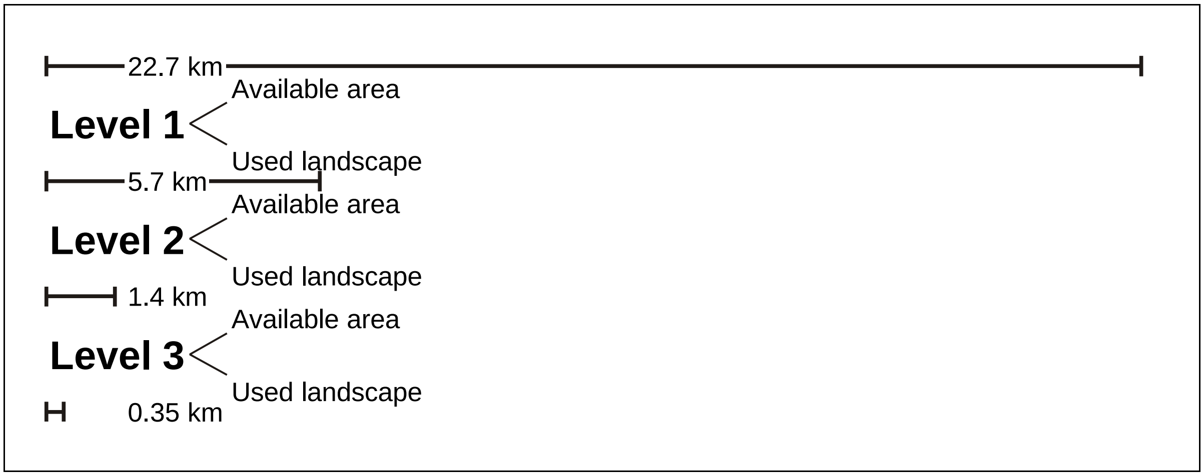

Figure 7. Hierarchical scales considered in analyzing caribou habitat selection in west-central British Columbia. Scales were defined by radii of available areas and landscape composition. The radius of "available area" was the distance from caribou radiolocations at which landscapes were randomly sampled. The "landscape" radius was that within which habitat composition was defined.

scale of analysis, approximated our estimated 95% location error (350 m)[5] within the pooled dataset. Although the true location of some data may fall outside this error zone, we chose to accept the lower statistical power to detect habitat selection, relative to sample size, that will result from a random misassignment of habitat attributes for these data. Moreover, habitat selection may still be detected from data falling outside the expected error zone given that random locations occurred at a markedly greater fixed distance of 1.4 km. The proportion of used landscape to available area was equal at all levels, and used landscapes did not overlap with paired random landscapes. Lands for which any of the habitat data sources were not available, and water bodies defined within FIP data, were not considered part of the landscape when aggregating data using the moving window routine.

At each analysis level, we extracted attributes associated with caribou and random landscapes to a database. However, the VHF data collected during the 1980s (Cichowski 1993) are approximately 12 years older than the current forest inventory date. Therefore, prior to extracting attributes for these locations, we modified overstory variables to better reflect stand conditions at the time those data were collected. We back-projected stand age by 12 years and, where disturbances occurred within 12 years of the forest inventory date, we interpolated overstory attributes from immediately adjacent, undisturbed stands. As described previously (see Data Subsampling), GPS data were subsampled at 4-day intervals for analysis at all levels.

Habitat Bias of GPS Location Data

The fix success rate of GPS locations may relate to habitat conditions, potentially biasing the results of habitat selection analyses using these data. For example, in areas of subdued terrain, forest structure and composition have been found to bias fix success rate (Moen et al. 1996, Moen et al. 1997, Rempel and Rodgers 1997, Dussault et al. 1999). Also, in an area of highly mountainous terrain, successful GPS fixes were biased toward high-elevation alpine habitats and against low-elevation valley bottoms associated with concave terrain curvature (Apps and Kinley 2000b).

We tested for influence of forest structure and/or terrain conditions on successful fix rate of GPS locations by comparing habitat use between GPS and VHF datasets. To control for differences that may be attributed to landscape condition, we used only VHF data for the I-I herd. Because all of the GPS data were from forest-dwelling animals, we considered only data from forest-dwelling VHF animals. To control for differences that may be attributed to variation in conditions among years, we restricted the analysis to only that time period when GPS locations were obtained (Appendix B): December, 1998 to June, 2000. Within this period, we recognized that data were not likely to be distributed equally between the 2 groups by month. Therefore, to

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[5] Recall that VHF data from the 1980s were recorded using a 0.5 km grid. This introduces a maximum reference error of 353 m, which we assume included at least 95% of observation error.

minimize the influence of conditions varying through time, we calculated a weighting factor to ensure that, within each month, data within each group contributed equally to the analysis. For each variable, we compared mean habitat use between the GPS and VHF samples using Mann-Whitney *U* tests ($\alpha = 0.05 / 30$ variables $= 0.0017$). Because we would expect GPS location bias to be most apparent at the fine scale, variables were only considered at level 3.

Data Stratification and Statistical Analyses

As described earlier, 7 caribou seasons (3 winter, 4 non-winter) have been previously applied within the study area, corresponding to different foraging and/or habitat use strategies as observed by researchers (Cichowski 1993, Young and Shaw 1998). Study animals belong to 2 herds, using different parts of the study area, and within each herd, animals exhibit 2 disparate wintering strategies corresponding to the use of primarily alpine or forest habitats. This resulted in 20 potential analysis strata, the logical groupings of which we evaluated using cluster analysis. Prior to cluster analysis, we applied principal components analysis (PCA) on standardized values of our 90 variables (30 original variables x 3 spatial scales) to reduce them to a smaller number of factors that explained most of the variation among variables. For interpretation, we applied the latent root criterion (McGarigal et al. 2000), retaining only those principal components with eigenvalues > 1.0. To improve component interpretation, we applied a varimax rotation of the principal component axes (Ibid.). For each caribou and random location, principal component scores calculated using regression were saved as new variables. For each principal component, we then determined a mean score for each of the 20 strata. For this, we used only VHF locations because wintering strategy was known for these data. We then ran hierarchical agglomerative clustering to assess between-group linkage using the squared Euclidean distance similarity measure (McGarigal et al. 2000). We considered coefficients of similarity at each clustering stage in conjunction with sample sizes to define logical groupings for habitat selection analyses and model development.

We analyzed caribou habitat selection for each original variable, at each spatial scale, using univariate techniques. For each analysis stratum, we used *t* tests to compare mean composition of landscapes at caribou locations to that of paired random locations. Due to the number of variables and levels considered, all univariate tests were appropriately conservative ($\alpha = 0.0005$).

We developed multivariate habitat selection models for each stratum. Variables were entered into multiple logistic regression (MLR) to derive probabilistic resource selection functions (Manly et al. 1993) across all 3 spatial scales. Landscapes used by caribou and random landscapes represented the dichotomous dependent variable. However, the design differed from the scale-dependent univariate analyses in that paired random locations occurred at distances ranging from 1.4 – 22.7 km, spanning the 3 spatial scales. We employed forward stepwise selection using the likelihood-ratio test (Ibid.) to derive the most parsimonious variable combinations that best discriminated caribou used landscapes from random landscapes. We evaluated the improvement of fitted models over null models according to the reduction in (-2)loglikelihood ratios, and we evaluated the significance of variable coefficients using chi-square tests of Wald statistics (Ibid.). Variables included in best-fit models were examined for multicollinearity using linear regression tolerance statistics (Menard 1995). Where problematic collinearity occurred (tolerance < 0.2; Ibid.), we inspected correlation coefficients to identify offending variables. Of highly correlated pairs, variables that were less significant in univariate analyses were excluded from the next iteration of model selection. We continued this iterative process until tolerance values associated with best-fit models were ≥ 0.2. We further evaluated goodness of fit and predictive power of each model by calculating the Nagelkerke R^2, Hosmer-Lemeshow statistic, and *c* statistic (Norusis 1999). All analyses employed the software SPSS 10.0 (SPSS Inc. 1999).

Using resource selection function equation 8 of Manley et al. (1993), we applied each MLR habitat model to the study area using algebraic raster overlays. We reclassed the resulting habitat probability surfaces into 3 habitat probability classes that we expected would be most useful for decision-support. Where > 1 model could logically be depicted on the same map, such as for 2 models of the same season but different herds, we defined respective application areas using key physiographic features or by allocating the study area to the appropriate model according to the comparative density of corresponding location datasets.

RESULTS

After accounting for possible variation in conditions among years and over months within the time period of comparison, significant differences between GPS and VHF datasets were apparent for 1 of 30 variables, while marginal differences were noted for 6 other variables (Table 7). GPS data were associated with a greater proportion of the oldest stand age class (AGE-89). GPS data were also associated with marginally greater proportions of taller (HEIGHT) and larger (DBH) trees, and greater mean NDVI and GVI values, whereas they were associated with marginally smaller proportions of immature forests (AGE-24 and BTM FY). Slightly lower collar performance within immature stands was consistent with test results undertaken prior to deployment, but such stands also had greater canopy closure than open sites and mature stands that were sampled (J. A. Young, unpublished data). Because these results suggest that any difference that can logically be attributed to a habitat influence on GPS successful fix rate would be marginal at best (see Discussion), we did not modify habitat selection analyses to account for GPS location bias.

Based on results of hierarchical clustering (Figure 8) in conjunction with sample size considerations and knowledge of seasonal movements of animals within each herd, we

Table 7. Test results of differences between VHF and GPS location samples near the Itcha and Ilgachuz Mountains, west-central British Columbia.

Variable	Direction [a]	P [b]	Significance [c]
AGE-01	-	0.278	
AGE-24	-	0.001	* *
AGE-57	-	0.041	*
AGE-89	+	< 0.001	* * *
CANOPY	+	0.865	
HEIGHT	+	0.001	* *
DBH	+	0.001	* *
SITE	+	0.405	
SPP_P	-	0.351	
SPP_S	+	0.294	
SPP_B	-	0.052	*
SPP_DEC	-	0.027	*
ALPINE	+	0.966	
OPEN_DRY	+	0.402	
OPEN_WET	+	0.682	
BTM_ALP	+	0.776	
BTM_FO	+	0.018	*
BTM_FY	-	0.007	* *
BTM_WET	+	0.150	
BTM_RANG	-	0.068	*
NDVI	+	0.001	* *
GVI	+	0.004	* *
WVI	+	0.550	
BVI	-	0.443	
ELEV	+	0.327	
SLOPE	-	0.948	
SOUTH	-	0.023	*
WEST	-	0.150	
TERRAIN	+	0.234	
CURVA	-	0.618	

[a] Indicates whether higher values were associated with GPS (+) or VHF (-) datasets.

[b] Mann-Whitney U test.

[c] $P < 0.1$ (*); $P < 0.01$ (* *); $P < 0.001$ (* * *).

determined that the original 20 strata could be pooled into five main groups. The cluster analysis suggested that, within the I-I herd, summer and early fall could be treated as one stratum, and forest-dwelling animals during early, mid, and late winter could be treated as one stratum. Within the RB herd, forest dwelling animals during early, mid, and late winter could also be treated as one stratum. Among animals that employ an alpine wintering strategy, some RB animals were known to winter in the Ilgachuz Mountains during some years, and winter sample sizes of I-I alpine-dwelling animals were low. Therefore, we pooled alpine-dwelling animals between both herds and among the 3 winter seasons as one stratum. During summer and early fall, habitat use by RB animals was less similar than that of I-I animals, but we pooled these data to increase sample size and remain consistent with the I-I strata. Cluster analysis results were consistent with the transitional nature of the late-fall and spring seasons. Therefore, within these seasons, we allocated data either to the summer/fall season or to the winter season using cut-dates corresponding to the greatest elevation shift observed within each herd during each year. Average cut-dates differed slightly between herds and wintering behaviours (Table 8). Data assigned to the winter season were further allocated to alpine- or forest-dwelling strategies. For each VHF-collared caribou, the entire radiolocation dataset for each winter had previously been assigned to either the alpine-dwelling or forest-dwelling stratum based on a subjective assessment of where the majority of locations fell. We then defined the winter-dwelling strategy of GPS-collared caribou by plotting the winter data for each animal against the elevational distribution of known alpine- and forest-dwelling VHF-collared animals and assigning each GPS-collared animal to a corresponding strategy.

Habitat selection by caribou was significant among most variables and seasons, especially at broader spatial scales (Table 9). With few exceptions, habitat selection did not vary dramatically across scales. Similar to habitat selection patterns within the two broad seasons, habitat use within the original 7 seasons defined by Cichowski (1993) was typically consistent across scales (Appendix E).

During winter, alpine dwelling animals in both herds were associated with landscapes devoid of forest cover and of low productivity, although a positive relationship with old-growth subalpine fir was apparent at the broadest scale. Open, dry alpine habitats were preferred, while moister, open and closed habitats at lower elevations were avoided. Habitats classified by BTM data as rangeland were highly preferred at the finest scale. Results for Landsat indices suggested that caribou were associated with dry habitats of little forest cover, and low vegetation productivity. A positive association with landscapes of steeper slopes and rugged terrain was apparent at only the broad scale. A strong association with northerly aspects was also apparent at broader scales. Strong associations with terrain curvature occurred at both the broadest and finest scales.

During summer, I-I and RB animals were both associated with little to no overstory cover and low productivity, but I-I animals did prefer broad landscapes with higher composition of old-growth subalpine fir than random. Associations with alpine habitats were strongly positive for both herds. Broad landscapes of open, wet habitats were avoided, but marginal selection for these habitats by I-I caribou was noted at the finest scale. At the broadest scale, BTM-defined rangeland habitats were avoided by I-I animals but were preferred by RB animals. Both herds were negatively associated with Landsat indices reflecting vegetation moisture and productivity. At broader scales, both herds preferred higher elevations, rugged terrain, and steeper slopes. At the broadest scale, RB caribou preferred northeast aspects and I-I caribou preferred east aspects. Both herds were associated with greater terrain curvature at broad scales.

During winter, habitat selection by forest-dwelling animals differed somewhat between herds. Both herds preferred broad landscapes of closed-canopy lodgepole pine overstory cover and high site productivity. However, I-I caribou were strongly associated with old age classes and negatively associated with young age classes, while RB caribou were associated with broad landscapes of age class 1 or less. Landscapes of open, wet habitats were avoided by I-I caribou, while open, dry habitats were avoided by RB caribou at the broadest scale. BTM defined rangeland was avoided by I-I caribou at broader scales. Highly productive vegetation types (defined by GVI and WVI) were avoided across scales, especially by I-I caribou. Although associations with the wet vegetation index were positive at the broadest scales, they were negative at finer scales. Patterns were opposite for the bright vegetation index. At the broadest scale, the association with elevation was positive for I-I caribou but negative for RB caribou. Associations with slope were negative across scales for I-I caribou, but only at the broadest scale for RB caribou. Landscapes of northeast aspect were preferred by both herds at the broadest scale. Both herds were also negatively associated with terrain curvature at the broadest scale.

The best-fit MLR models for each of the 5 analysis strata were significant ($\chi^2 > 154.6$, df $\geq$ 10, $P < 0.001$). For each stratum, models predict the probability (p) that any given site represents the broad- and fine-scale landscape conditions that characterize caribou habitat. The derived models achieved a classification success of used and random locations (cutpoint $p = 0.5$) ranging from 59.9% to 73.5% and explained approximately 9 to 38% of the variation within each dataset, while other tests indicated that the models fit the data well and carried significant predictive power (Table 10). For each model, the predictive subset of variables represented all 3 scales (Table 11). Model performance across cutpoint probability values suggested that optimal discrimination occurred at approximately $p = 0.5$ for each stratum (Figure 9). Within the GIS, the application of each model to its representative area is portrayed in Appendix F.

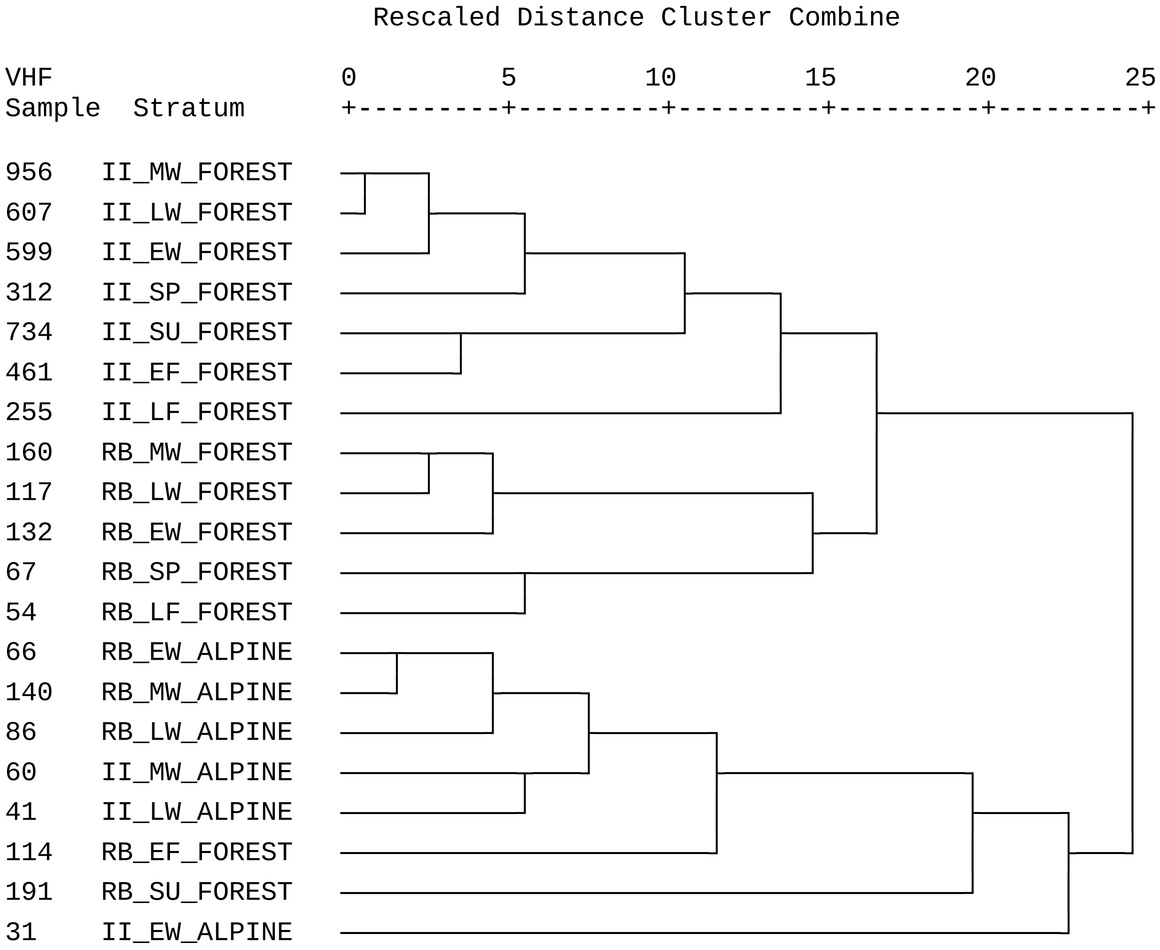


Figure 8. Hierarchical cluster analysis dendrogram illustrating relationships of caribou habitat use among defined strata in west-central British Columbia. Strata are defined by: the Itcha-Illchaguz (I-I) or Rainbow (RB) herds; early winter (EW), mid winter (MW), late winter (LW), spring (SP), summer (SU), early fall (EF) and late fall (LF); and "forest" or "alpine" dwelling.

Table 8. Defined strata and corresponding sample sizes for caribou habitat selection analyses and model development in the Itcha-Ilgachuz and Rainbow mountains, west-central British Columbia, 1984 – 1988 and 1995 – 2000.

Stratum	Average Seasonal Dates Among Years	Sample
Itcha-Ilgachuz / Summer-Fall	7 May – 5 November	1742
Itcha-Ilgachuz / Winter / Forest Dwelling	6 November – 6 May	2867
Rainbow / Summer-Fall	8 May – 22 November	408
Rainbow / Winter / Forest Dwelling	23 November – 7 May	427
Itcha-Ilgachuz & Rainbow / Winter / Alpine Dwelling	15 November – 7 May	453

Table 9. Univariate analysis results of scale-dependent caribou habitat selection by season in the Itcha-Ilgachuz and Rainbow mountains of west-central British Columbia, 1984 – 1988 and 1995 – 2000. Results are based on univariate t tests.[a] Variables are defined in Table 6.

	II / RB / WI / ALP [b]			II / SU			II / WI / FOR			RB / SU			RB / WI / FOR		
Variable	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
AGE-01	- - -	o	o	- - -	+	o	- - -	- -	o	- - -	o	o	+++	+++	o
AGE-24	- - -	- - -	-	- - -	- - -	-	- - -	- - -	- - -	- - -	- - -	o	o	- - -	-
AGE-57	- - -	- - -	o	- - -	- - -	-	-	+	o	- - -	- -	o	o	o	o
AGE-89	+++	- - -	-	+++	- - -	- -	+++	+++	+	-	- - -	- - -	+	o	o
CANOPY	- - -	- - -	-	- - -	- - -	- - -	+++	++	o	- - -	- - -	- -	+++	o	o
HEIGHT	- - -	- - -	-	- - -	- - -	- - -	+++	+++	o	- - -	- - -	- -	+++	o	o
DBH	- - -	- - -	o	- - -	- - -	- - -	+++	+++	o	- - -	- - -	o	+++	o	o
SITE	- - -	- - -	-	- - -	- - -	- - -	++	++	o	- - -	- - -	-	+++	o	o
SPP_P	- - -	- - -	o	- - -	- - -	- -	+++	+++	o	- - -	- - -	o	+++	o	o
SPP_S	o	- - -	-	- - -	- - -	- - -	- - -	- - -	- -	- - -	- - -	- - -	o	- -	o
SPP_B	+++	- - -	-	+++	+++	- -	- - -	-	o	+++	- - -	- - -	- - -	-	o

Table 9. Continued.

	II / RB / WI / ALP [b]			II / SU			II / WI / FOR			RB / SU			RB / WI / FOR		
Variable	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
SPP_DEC	- - -	o	o	- - -	- - -	o	- - -	- - -	o	- - -	o	o	-	-	o
ALPINE	+++	+++	++	+++	+++	+++	- - -	- -	o	+++	+++	+++	- - -	++	o
OPEN_DRY	+++	-	o	++	o	o	-	O	+	o	o	o	- - -	- -	-
OPEN_WET	- - -	- - -	o	- - -	- - -	+	- - -	- - -	o	- - -	- -	o	o	o	o
BTM_ALP	+++	+++	++	+++	+++	+++	- - -	-	o	+++	+++	+++	- - -	+++	o
BTM_FO	+	- - -	- - -	+++	- - -	- -	+++	+++	o	- - -	- - -	- - -	o	o	o
BTM_FY	- - -	- - -	o	- - -	- - -	- -	- - -	O	-	- - -	- - -	o	+++	- -	o
BTM_WET	- - -	- - -	o	- - -	- - -	++	- - -	O	+	- - -	- -	o	++	-	o
BTM_RANG	-	-	+++	- - -	o	o	- -	- - -	o	+++	o	-	- -	o	o
NDVI	- - -	- - -	-	- - -	- - -	o	- - -	- - -	- - -	- - -	- - -	-	++	- - -	o
GVI	- - -	- -	-	- - -	- - -	o	- - -	- - -	- - -	- - -	- - -	-	o	- - -	- -
WVI	- - -	- - -	- - -	- - -	- - -	- - -	+++	O	- - -	- - -	- - -	- - -	++	- - -	-
BVI	+++	+++	+++	+++	+++	+++	- - -	- - -	+	+++	+++	+++	- - -	++	o
ELEV	+++	+++	+	+++	+++	+++	+++	O	o	+++	+++	+	- - -	o	o
SLOPE	+++	o	o	+++	+++	o	- - -	- - -	- - -	+++	o	-	- - -	o	o
SOUTH	- - -	- - -	+	o	o	o	- -	O	+	- - -	o	o	- - -	- - -	o
WEST	+	+	+	- - -	o	o	- - -	O	o	- - -	o	o	- - -	o	o
TERRAIN	+++	o	o	+++	+++	o	- - -	-	o	+++	o	o	- - -	-	o
CURVA	+++	o	+++	+++	+++	o	- - -	- -	o	+++	+	o	- - -	o	o

[a] Preference/avoidance (t-tests) is indicated by +++/- - - (P < 0.0005), ++/- - (P < 0.005), +/- (P < 0.05), or “o” ($P \geq$ 0.05).

[b] Analysis strata defined by Itcha-Ilgachuz (I-I) or Rainbow (RB) herds, winter (WI) or Summer (SU) seasons (see Table 7), and alpine (ALP) or forest (FOR) winter-dwelling strategies.

[c] Analysis level: broad (1) to fine (3) spatial scales.

Table 10. Significance and of fit of predictive multivariate caribou habitat models for each stratum.

Stratum	c^2 P [a]	CS [b]	R^2 [c]	H-L P [d]	c Stat [e]
II-RB_WI_ALP	< 0.001	73.5	0.38	0.79	0.81
II_SU	< 0.001	63.5	0.19	0.29	0.70
II_WI_FOR	< 0.001	59.9	0.09	0.29	0.64
RB_SU	< 0.001	72.9	0.34	0.56	0.79
RB_WI_FOR	< 0.001	67.2	0.22	0.25	0.72

[a] Model chi-square statistic, testing the null hypothesis that coefficients for all model terms are 0.

[b] Model classification success at cutpoint probability $p = 0.5$.

[c] Nagelkerke R^2: the approximate variation in the dataset explained by the model.

[d] P value from the Hosmer and Lemeshow statistic, testing the null hypothesis that the model adequately fits the data (i.e., $P < 0.05$ indicates a poor fit).

[e] The proportion of pairs of caribou and random locations for which the model results in a higher habitat probability for the caribou location. A value of 0.5 would indicate a model that is no better than a random guess.

Table 11. Variables and parameters associated with best-fit multiple logistic regression models of seasonal caribou habitat selection in the Itcha-Ilgachuz and Rainbow mountains, west-central British Columbia.

Stratum	Variable	Level [a]	β [b]	SE	P [d]	Exp(B) [e]
II/RB-WI-ALP	ELEV	3	0.003	0.001	<0.0001	1.003
	WEST	3	0.015	0.004	<0.0001	1.015
	SOUTH	1	-0.061	0.010	<0.0001	0.941
	ALPINE	2	0.058	0.013	<0.0001	1.060
	SPP_B	2	0.079	0.020	<0.0001	1.082
	DBH	2	0.586	0.101	<0.0001	1.797
	HEIGHT	2	-0.510	0.117	<0.0001	0.600
	SLOPE	3	-0.033	0.009	0.0005	0.968
	WVI	3	-0.027	0.010	0.0045	0.973
	SOUTH	3	0.013	0.005	0.0104	1.014
	BTM_FO	3	-0.007	0.003	0.0256	0.993
	SITE	1	0.220	0.104	0.0336	1.246
	Constant	0	-9.154	1.911	<0.0001	0.000

Table 11. Continued.

Stratum	Variable	Level [a]	β [b]	SE	*P* [d]	Exp(B) [e]
II-SU	AGE_0-1	1	0.033	0.014	0.0189	1.034
	CANOPY	1	0.040	0.006	<0.0001	1.041
	TERRAIN	1	0.084	0.023	0.0002	1.088
	SPP_DEC	1	-1.091	0.328	0.0009	0.336
	ELEV	2	0.004	0.001	<0.0001	1.004
	AGE_2-4	3	-0.012	0.003	<0.0001	0.988
	GVI	3	0.019	0.005	0.0001	1.020
	OPEN_WE	3	0.007	0.003	0.0265	1.007
	SLOPE	3	-0.010	0.005	0.0576	0.990
	WVI	3	-0.025	0.004	<0.0001	0.976
	AGE_5-7	1	-0.006	0.003	0.0415	0.994
	Constant	0	-7.421	0.897	<0.0001	0.001
II-WI-FOR	AGE_2-4	3	-0.006	0.001	<0.0001	0.994
	SPP_P	3	0.011	0.002	<0.0001	1.011
	GVI	3	-0.042	0.007	<0.0001	0.959
	BTM_WET	1	-0.058	0.008	<0.0001	0.944
	SLOPE	3	-0.049	0.008	<0.0001	0.952
	SITE	3	-0.079	0.017	<0.0001	0.924
	CANOPY	3	-0.010	0.003	0.0001	0.990
	DBH	2	0.041	0.012	0.0005	1.041
	SPP_DEC	1	-0.114	0.033	0.0006	0.892
	BTM_RANG	2	-0.028	0.009	0.0022	0.972
	SOUTH	1	-0.008	0.003	0.0042	0.992
	OPEN_DRY	2	0.014	0.005	0.0059	1.014
	CURVA	1	1.684	0.621	0.0066	5.387
	Constant	0	-0.571	0.287	0.0465	0.565

Table 11. Continued.

Stratum	Variable	Level [a]	β [b]	SE	*P* [d]	Exp(B) [e]
RB-SU	BVI	3	0.018	0.003	<0.0001	1.018
	WVI	3	-0.024	0.005	<0.0001	0.977
	SLOPE	3	-0.029	0.007	<0.0001	0.971
	SPP_B	1	-0.034	0.009	<0.0001	0.966
	AGE_5-7	1	-0.035	0.010	0.0007	0.966
	WEST	1	-0.024	0.007	0.0008	0.976
	BTM_WET	1	-0.127	0.039	0.0009	0.880
	BTM_FY	2	0.017	0.005	0.0011	1.017
	SPP_S	2	-0.030	0.010	0.0019	0.970
	BTM_RANG	3	-0.027	0.010	0.0087	0.974
	BTM_RANG	1	0.116	0.046	0.0128	1.123
	CURVA	1	1.021	0.517	0.0482	2.776
	AGE_2-4	3	-0.088	0.048	0.0646	0.915
	Constant	0	0.101	0.652	0.8765	1.107
RB-WI-FOR	BTM_ALP	3	0.028	0.005	<0.0001	1.029
	AGE_5-7	1	-0.046	0.008	<0.0001	0.955
	SPP_B	1	-0.109	0.026	<0.0001	0.897
	SITE	1	0.217	0.069	0.0017	1.242
	AGE_2-4	3	-0.019	0.006	0.0021	0.981
	SLOPE	3	-0.048	0.018	0.0067	0.953
	SPP_P	3	0.008	0.003	0.0106	1.008
	TERRAIN	2	-0.085	0.040	0.0334	0.919
	OPEN_DRY	2	-0.278	0.149	0.0626	0.758
	Constant	0	-0.204	0.624	0.7440	0.816

[a] Indicates spatial scale of variable, from broadest (1) to finest (3).

[b] Variable coefficient.

[c] Significance of Wald chi-square statistic.

[d] Odds ratio: change in odds of habitat use with a one-unit increase in the value of the variable

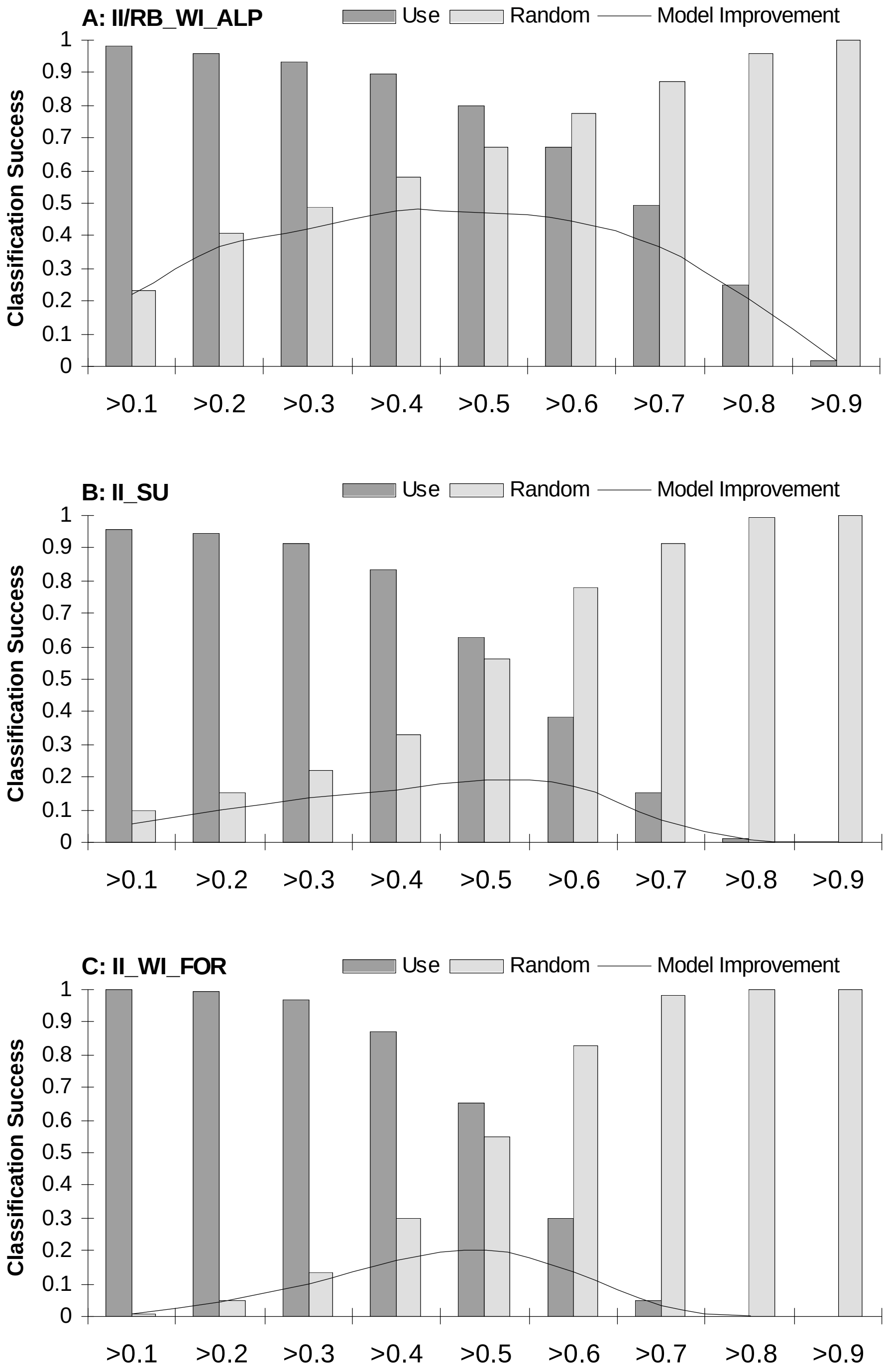
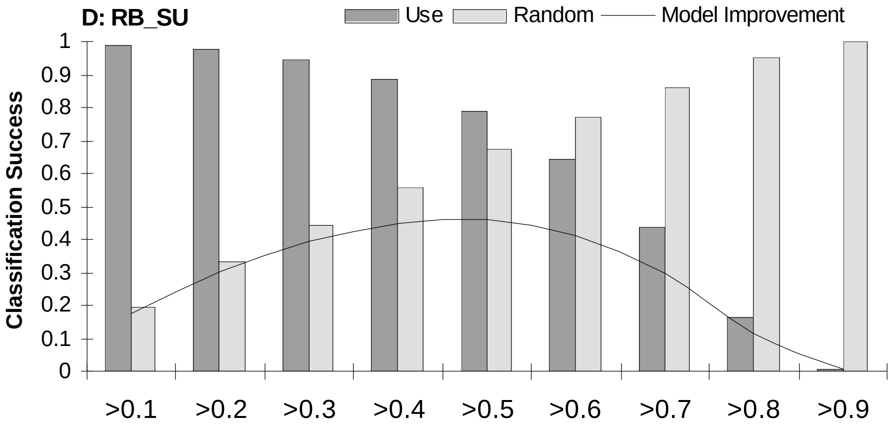


Figure 9. Predictive efficiency of season- and herd-specific caribou habitat models across cutpoint probability levels in the Itcha-Ilgachuz and Rainbow mountains, west-central British Columbia. Model improvement (correctly classified caribou minus incorrectly classified random) indicates the optimal classification cutpoint in discriminating caribou from random locations.



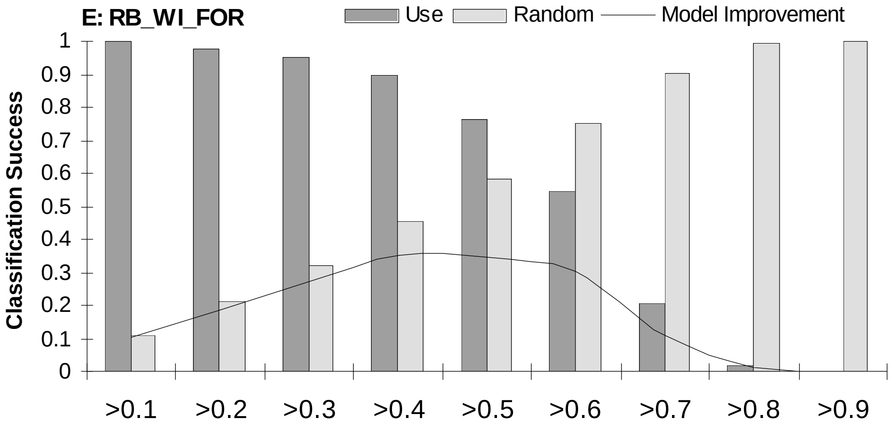


Figure 9. Continued.

DISCUSSION

Habitat Bias of GPS Location Data

Although we did find some minor differences in habitat attributes associated with GPS and VHF datasets, it is not clear whether any of these can logically be attributed to a habitat influence on GPS fix rate. In fact, some results are contrary to what would be expected based on previous studies. A greater proportion of GPS locations were associated with old stands with larger DBH values and taller trees, attributes shown by other studies to either have no effect on or decrease fix success (Rempel et al. 1995, Moen et al. 1996, Dussault et al. 1999). Moreover, in Canada, most of the GPS satellites occur in the southern sky; therefore, the slightly greater (but not significant) proportion of GPS locations occurring on northerly aspects also cannot be attributed to location bias. We speculate that the majority of significant differences we did find are real and not due to collar bias. Given the small sample of GPS collars (5 at most times), relatively subtle but consistent differences in habitat use among those animals relative to the VHF sample could easily have resulted in the observed pattern. Moreover, the spatial distribution of capture effort for GPS-collared animals within the Itcha-Ilgachuz section of the study area was not the same as that of VHF-collared animals and may have influenced observed differences in habitat use.

The fact that we did not detect an obvious bias associated with GPS fix rate is not unexpected. Given that GPS-collared caribou in this study occurred within landscapes of subdued topography, terrain conditions should not have been a factor, as they were in the Columbia and Rocky mountains (Apps and Kinley 2000b). Biases associated with forest structure and composition that other studies have measured are partially related to the level of moisture in the canopy, interfering with signal strength. Given that the predominantly pine forests in which GPS-collared caribou occurred are considered to be some of the driest forests in Canada, one would expect GPS collars to perform with minimal bias here relative to most other areas. In addition, the open spacing and light canopies typical of most stands used by caribou would have provided minimal woody material to reduce signal strength.

Habitat Selection

We found clear differences in habitat selection strategies between animals following the two wintering behaviors described by Cichowski (1993). Winter “alpine-dwelling” caribou avoided almost all variables associated with forested land, and selected areas with attributes typical of the AT. Thus, they preferred open, dry locations with low productivity at high elevations, but not necessarily the most rugged areas available. The exception to the general pattern we observed was broad-scale association with old subalpine fir stands typical of the ESSF. However, fir was avoided at finer scales, consistent with a preference for habitats slightly above treeline. In contrast, the negative association with pine and spruce by alpine-wintering caribou may have been due to their considerable availability in the landscape rather than true avoidance. Actual use of pine at the finest scale was 10 to >50% among the I-I herd and 3 to 18% among the RB herd, while spruce use was 5 to 17% and 2 to 8% respectively, with particularly high values for both species in early and mid winter. While subalpine fir is generally considered the most important lichen-supporting species for the arboreal lichen-dependent mountain caribou ecotype, pine trees at higher elevations in this study area do support notably high volumes of *Bryoria* lichen (H. Armleder, Ministry of Forests, Williams Lake, British Columbia, personal communication). Thus, habitat selection was consistent with caribou primarily cratering for terrestrial lichen on ridges and other exposed, wind-swept sites, with some use of both terrestrial and arboreal lichens near but below treeline, particularly in early winter. Predominant use of terrestrial lichens has been reported for alpine-dwelling animals of the Wolverine herd (Johnson 2000). This has also been suggested for our analysis area (Young and Shaw 1998), and is supported by very limited local winter fecal pellet sampling showing somewhat more terrestrial than arboreal lichens in pellets from the alpine (Cichowski 1998, p. 48). However, it has not been verified with extensive local sampling at high elevations. Occasional to predominant use of arboreal lichens by animals wintering at high elevations within other herds of the northern ecotype has been reported (Thomas et al. 1996, Wood 1996, Johnson et al. 2000, Poole et al. 2000).

The initially high but decreasing use of forested sites through the winter by alpine-dwelling caribou noted above, particularly for the Itcha-Ilgachuz herd, was matched by increasing use of other variables associated with the alpine-wintering strategy. This pattern probably reflected the lower snowfall and greater canopy interception at intermediate relative to high elevations. Low snow accumulation during early winter may have facilitated terrestrial lichen foraging. This may not have been possible later in the winter, when snow depths even at mid-elevation sites would be expected to force caribou to forage on wind-swept ridges. Contrary to the pattern among the mountain ecotype of caribou (Stevenson et al. 2001), there was no indication of any increase in arboreal lichen feeding in forested areas as snow deepened and consolidated, providing easier access to higher portions of trees, because no tree species either were preferred or received increasing use from early to late winter. Thus, habitats preferred by winter “alpine-dwelling” animals appears to include both sides of the ESSF/AT transition, with suitable foraging sites differing considerably depending on snow conditions.

In contrast to habitat selection by animals wintering at high elevations, winter “forest-dwelling” caribou of each herd preferred lower elevation landscapes primarily associated with pine forests. The preference for pine was not evident at the finest scale, but this was apparently just a reflection of relative availability because the use of pine forests was consistent across scales during the winter. The distribution of subalpine fir was very limited at lower elevations, and deciduous stands would not be expected to provide terrestrial lichen. There was almost no use of either species, and both were avoided at broader scales. Although they received somewhat greater use, spruce stands were also avoided. Among non-alpine caribou, Cichowski (1993) reported more arboreal lichen (*Bryoria*) foraging sites on moist ground having a spruce component than on drier, pine-dominated stands, with caribou in certain habitat types foraging almost entirely on arboreal lichen. She also reported increasing *Bryoria* foraging later in the winter, when snow depths were greater. Based on this, it would be expected that spruce and older age classes (which support more available *Bryoria*) would be used increasingly through the winter. However, we found that, at the finest scale, use of spruce increased only marginally in the I-I herd and decreased in the RB herd through the winter, and the use of the oldest age classes peaked in mid winter rather than late winter. From a limited sample, Cichowski (1993; p. 48) showed that terrestrial lichen was only slightly more abundant than arboreal lichen in fecal pellets collected from November through April at low elevations (37 versus 32% of contents), and arboreal lichen presence was as great or greater in November and December than later in the winter. Even accounting for potential differences in the digestibility of arboreal versus terrestrial lichens, which might overemphasize the use of arboreal lichen, the lack of increase in arboreal lichens in pellets over the winter suggests that either the relative numbers of arboreal versus terrestrial lichen feeding sites did not correlate with the amount of arboreal lichen consumed (i.e., caribou ate more at each arboreal lichen site than at each terrestrial lichen site), or the small pellet sample was not representative of the population. These data and our results are consistent with arboreal lichen feeding (1) being important throughout the winter, not just the latter part of it, and (2) occurring to a relatively high degree in pine, not just spruce stands, with the lichen availability therefore being limited mainly to the relatively meager amounts available on branches and boles of standing pine trees or the sporadically abundant amount on windthrown branches or trees.

Among forest-dwelling animals during winter, there was one notable difference between herds. At broader scales, RB animals did not exhibit the strong preference for old forests and avoidance of youngest forests that I-I animals did. In fact, RB animals apparently preferred youngest forests (recent cutblocks) at broad scales. However, this difference may have little ecological significance. The actual use of age class 8 and 9 forests was similar between herds and was roughly equal to the use of all other age classes combined, indicating differences in relative availability between herds. The slightly greater amounts of age class 0 and 1 forests within landscapes used by RB animals was most likely due to extensive logging that has occurred in their traditional winter range in the upper Dean Valley, such that cutblocks occurred in the immediate proximity of winter foraging areas. Little terrestrial lichen (Miège et al. 2001) and essentially no arboreal lichen would be expected in recent cutblocks.

Furthermore, Smith et al. (2000) found that caribou avoided portions of their winter range fragmented by recent cutblocks. Alternatively, cutblocks may be favored by RB animals because they provide long sight lines to detect predators, prior to significant tree regeneration, or because of grasses planted on roadsides.

Young and Shaw (1998) noted that the winter-alpine strategy appeared to be used less in years with greater snow accumulation. In contrast, for the Wolverine herd, all collared caribou used the alpine in a winter with record snowfall (Wood 1996), no clear relationship between wintering strategy and snow depth among years was found (Terry and Wood 1999), and caribou sometimes shifted from forests early in the winter to alpine later in the winter (C. J. Johnson, University of Northern British Columbia, Prince George, British Columbia, personal communication). Thus, we do not expect a linear relationship between snow accumulation and proportion of animals using each wintering strategy within the Itcha-Ilgachuz and Rainbow mountains. No snow or very shallow snow should make feeding on the abundant terrestrial lichen the most efficient strategy across the full range of elevations. Increasing snow depth or snow conditions that make cratering difficult may, up to a point, force more caribou to shift their terrestrial foraging to lower-elevation forests. Increasing snow depth may also result in increasing use of arboreal lichens in stands where their growth is abundant and where snowpacks will lift caribou high enough to provide access to them, or where there is adequate blowdown to provide arboreal lichen on the snow surface. A landscape of unconsolidated snow in high-elevation forests, combined with wind scouring on exposed ridges, likely makes arboreal lichen use at upper elevations inefficient by late winter in most years, while very deep, crusted snow may preclude cratering at low elevations during extreme years, forcing the use of windswept ridges at the highest elevations. Finally, caribou use of alpine ridges during winter may be an anti-predator strategy functioning to distance them from wolves that primarily hunt moose wintering at lower elevations. Regardless of the underlying causes of the “alpine” and “forest” wintering strategies, both are commonly used by animals of the RB and I-I herds, and both terrestrial and arboreal lichens are consumed by caribou exhibiting each strategy.

Summer habitat selection for non-forested sites at higher elevations was very similar between herds, and also similar to selection within the winter-alpine strategy. However, RB animals showed somewhat greater use than I-I animals of the alpine and attributes associated with it. Thus, preference for older subalpine fir forests was evident among I-I animals, but forests of all ages were avoided by RB animals.

Our results for Landsat vegetation indices must be interpreted with caution, as we suspect that caribou associations with these variables were non-linear and highly scale-dependent, particularly among forest-dwelling animals during winter. For example, based on Cichowski’s (1993) report, we expected that forest-dwelling caribou would avoid lowland brushy wet meadows and prefer dry, upland lichen-fescue meadows. However, at the broad scale, both herds were positively associated with the wet vegetation index. These results likely relate to avoidance of alpine habitats associated with much lower values for the WVI. At finer scales, wetness was in fact strongly avoided by both herds.

Multivariate Modeling

Because it can be difficult to discern ecologically meaningful relationships from multivariate models (Rextad et al. 1988), we do not attempt ecological interpretation of variables and parameters associated with best-fit MLR models. However, multivariate results do suggest that a linear combination of variables we considered can efficiently discriminate caribou use from random locations across scales and therefore are useful predictors of caribou habitat quality within the study area. During each season, the scales at which the best predictive variable subsets were represented indicate that models explained both broad- and fine- scale variation in the data. Applied within a GIS (resource selection probability equation 8.5: Manly et al. 1993), models developed by season, herd, and wintering strategy represent decision-support tools useful for strategic forestry planning and spatially explicit timber and habitat supply analyses (Appendix F).

MANAGEMENT IMPLICATIONS

Because ongoing land use decisions pursuant to the Cariboo-Chilcotin Land Use Plan are intended to be based, to a large extent, on maintaining caribou habitat values, one application of the habitat models we describe is in identifying areas where occupied or potential habitat falls outside of protected areas. Habitat probability maps (Appendix F) indicate that the proportion of habitat lying outside of parks varies dramatically between seasons and wintering strategy. The great majority of occupied RB summer habitat and winter-alpine habitat for both herds is within Tweedsmuir or Itcha-Ilgachuz parks, but at least one-third of the occupied I-I summer habitat is outside of Itcha-Ilgachuz Provincial Park, and virtually all the winter-forest habitat for both herds, whether used by collared animals or not, is outside of protected areas. With the exception of Itcha-Ilgachuz Park, very little I-I summer habitat occurs outside of locations shown to also provide winter-forest habitat, thus the latter model provides a sound basis for designating protection or special management for caribou.

Based on level of use and habitat potential, key locations for consideration in special management or habitat retention are:

1. In a large “question mark” shape from the area immediately north of the saddle between the Itcha and Ilgachuz mountains, northeastward to the headwaters of the Coglistiko and Baezaeko rivers, then south-southwestward through the northeastern headwaters of the

Chilcotin River and headwaters of Palmer Creek and its tributaries as far south as the Chilanko River. This includes much of the area along the height-of-land between the Dean and Chilcotin rivers, with a greater concentration of both habitat potential and habitat use on the eastern (leeward) side of the divide. Patches of habitat with significant levels of use also extend eastward from the Dean-Chilcotin divide to Chilcotin and Puntzi lakes, and westward from the divide toward Nimpo and Long lakes. This area is used almost exclusively by animals of the Itcha-Ilgachuz herd and is predominantly in the MSxv subzone.

2. In the upper Dean and Hotnarko drainages. The northwest boundary of this block runs from near the south end of the large wetland west of the Ilgachuz Mountains, southwestward to where the Tusulko Rivers exits Tweedsmuir Park. This approximates the boundary between a very dry suzone of the SBPS to the south and a moist SBPS subzone the north. Its southwest boundary then runs southeastward to near Kappan Lake, skirting around Hotnarko Lake. The east boundary extends into the valley as far as Anahim Lake, except to remain west of the Pelican Creek drainage south of Anahim Lake, and west of the Dean River between Anahim Lake and the Poison Lakes. The northern portion of this block is used by Rainbow animals for movement between the Rainbow and Ilgachuz Mountains.

The portion of the Dean valley that lies immediately northwest of the Rainbow Mountains, and the Netchako Plateau north of that, appear to form a large patch with high value for winter forest-dwelling caribou and lie adjacent to areas heavily used by caribou. The fact that this habitat was not used by collared animals may relate to its location within the Sub-boreal Spruce biogeoclimatic zone (moist, cool subzone). The higher precipitation in this zone relative the very dry subzones of the MS and SBPS would likely inhibit winter ground foraging due to deeper snow and greater competition between terrestrial lichen and vascular plants or mosses. In addition, the extremely large burn that lies partly in and north of this patch may result in high concentrations of moose and wolves, leading to either current avoidance or past losses of family groups that used that area.

Despite the large patches of potentially suitable habitat near Caribou Flats (McClinchy Creek valley), minimal use has been recorded there except for limited activity by I-I animals near Long Lake, about 10 km to the northeast. Presumably the area's local name was based on historic use by caribou, as would be expected given the large concentration of predicted suitable habitat. The historic loss of caribou from the adjacent Charlotte Alplands may explain the lack of activity in Caribou Flats, as it would have provided some of the nearest habitat for Charlotte animals exhibiting the forest-dwelling wintering strategy. This area is likely to be used more in the future if current efforts to re-establish a population center in the Charlotte Alplands are successful, or even by members of the RB or I-I herds as winter range use shifts over time. This consideration should play a role in the deployment of habitat retention or special management "budgets".

It is not clear at what point levels of development exceed the threshold at which habitat effectiveness can be maintained, due to increased predation, loss of foraging habitat, increased energetic cost of movement between patches, or barriers to movement as cutblocks succeed into plantations. At the strategic planning level, to the extent possible, habitat should be retained in large patches rather than dendritic or “checkerboard” patterns. Several areas within tracts of high-use and high-suitability habitat have already experienced significant reductions and fragmentation of forested habitat due to timber harvesting and burns, and may be at or approaching a threshold. These include the area immediately east of Tweedsmuir Park between roughly the Tusulko and Beef Trail rivers, south of Bald Face Mountain in the upper Chilcotin drainage, and along the Dean-Chilcotin divide between Punkutlaenkut and Palmer creeks. Given the high use within and travel through these areas and the level of habitat alteration that has already occurred there, retention of stands and appropriate attributes within remaining habitat patches should be of particularly high priority if the greater landscape is to be managed for caribou over the medium to long term.

We suggest that future research consider (1) continued investigation into the types of stands and stand treatments that are likely to maintain abundant terrestrial and arboreal lichen over the long term, and (2) the need for more detailed information on the level and locations of use of arboreal lichens relative to stand type within low-elevation landscapes. The available information suggests that arboreal lichen is an important part of caribou diet throughout the winter, and given the very low use of spruce relative to pine, there is a good chance that it is obtained from pine stands to a much greater degree than previously reported. If so, this could have significant implications for management. If caribou are obtaining significant amounts of *Bryoria* from pine stands, then targets for age and stand architecture might be different than if pine stands were important only due to terrestrial lichen loads. In relation to terrestrial lichen, the ability of very old pine stands to support *Cladina* in abundance may be due to periodic low-intensity ground fires or other disturbances that create or maintain an open structure and stop the spread of kinnikinnick. Continued caribou foraging then disperses lichen and further enhances *Cladina* colony development. In the absence of stand-maintenance fire, or when stand replacement fires occur, *Cladina* development may be severely restricted through unrestricted growth of kinnickinnick or the development of very dense pine stands respectively (Goward 2000). Such a pattern is consistent with the observed high use of and preference for stands greater than 140 years of age, and the absence of *Cladina* and *Cladonia* from young forests (Brulisauer et al. 1996).

One potential limitation of our results and models is that they are based entirely on female caribou. Bulls are considered less critical for management, given that they do not support calves and their relative abundance has far less impact on future population maintenance. However, prime, older bulls that lose physical condition during the rut, and which also carry traditional knowledge and potentially the most adaptive genetic material, may require especially good habitat for recovery immediately after rutting and prior to mid winter. If this habitat differs significantly or occurs in distinct locations from cow habitat, management based on cow models may not be adequate to optimize future population maintenance. Therefore, future research should include monitoring of bull habitat use to ensure that it is consistent with that of cows, and habitat retention or management patterns should be modified if it is not.

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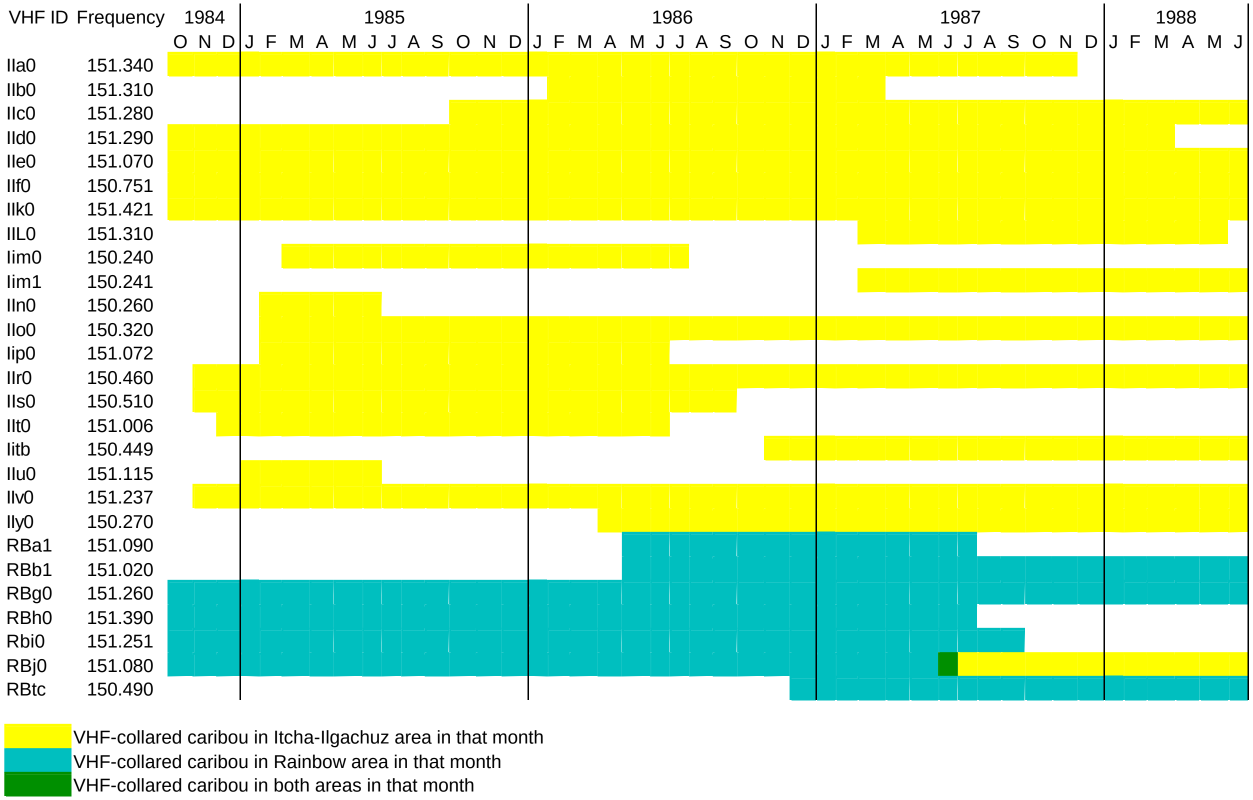
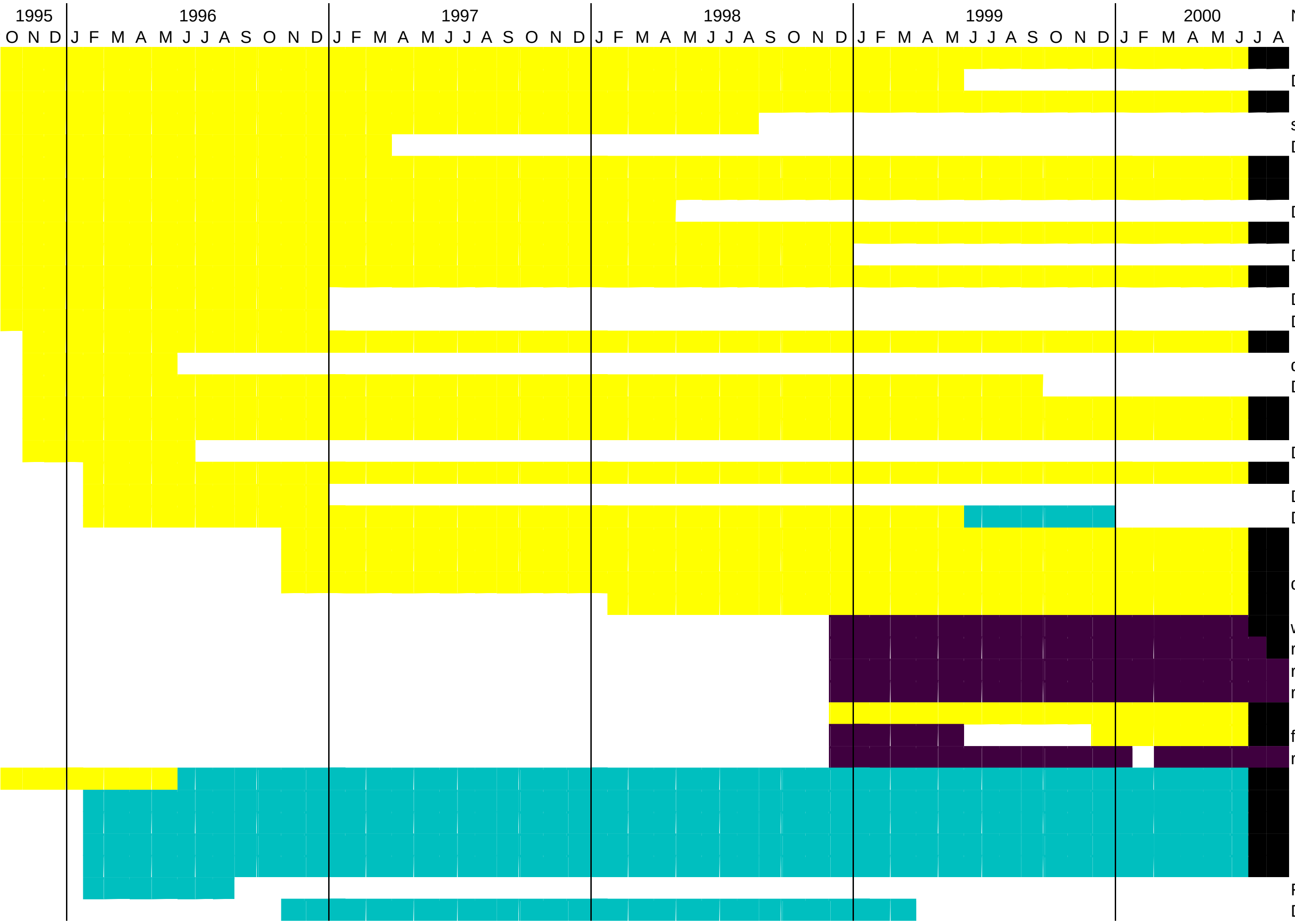
Appendix A. Radiocollar deployment schedule among female caribou in the Itcha-Ilgachuz (I-I) and Rainbow (RB) mountains herds, west-central British Columbia, 1984 – 1988.



VHF ID	Frequency
IIa0	151.340
IIb0	151.310
IIc0	151.280
IId0	151.290
IIe0	151.070
IIf0	150.751
IIk0	151.421
IIL0	151.310
Iim0	150.240
Iim1	150.241
IIn0	150.260
IIo0	150.320
Iip0	151.072
IIr0	150.460
IIs0	150.510
IIt0	151.006
Iitb	150.449
IIu0	151.115
IIv0	151.237
IIy0	150.270
RBa1	151.090
RBb1	151.020
RBg0	151.260
RBh0	151.390
Rbi0	151.251
RBj0	151.080
RBtc	150.490

🟨 VHF-collared caribou in Itcha-Ilgachuz area in that month
🟦 VHF-collared caribou in Rainbow area in that month
🟩 VHF-collared caribou in both areas in that month

Appendix B. Radiocollar deployment schedule among female caribou in the Itcha-Ilgachuz (I-I) and Rainbow (RB) mountains herds, west-central British Columbia, 1995 –



VHF ID	GPS ID	Frequency	Notes
II01		150.754	
II02		150.662	Died
II03		150.807	
II04		150.691	shot Sep/88
II05		150.671	Died
II06		150.826	
II07		150.816	
II08		150.767	Died
II10		150.612	
II11		150.650	Died
II12		150.561	
II13		150.630	Died
II15		150.450	Died
II17		150.463	
II18		150.432	died ~May/96; last location Jun/96
II20		150.621	Died
II21		150.549	
II22		150.571	
II23		150.511	Died
II25		150.641	
II26		150.421	Died
II32		150.590	Died
II35		150.531	
II36		150.470	
II37		150.119	died Sep/00
II38		150.321	
II40	6	151.050	weak signal Jun/00; assumed failed Jul/0
II41	5	150.040	replaced with VHF 150.671 Aug/00
II42	4	150.030	replaced with VHF 150.681 Aug/00
II43	2	150.010	replaced with VHF 150.659 Aug/00
II44		150.181	
II46	3	150.020	failed May/99, repl by VHF 150.731 Nov/9
II47	1	150.000	replaced with VHF 150.581 Aug/00
RB09		150.701	
RB27		150.522	
RB28		150.602	
RB29		150.500	
RB30		150.441	
RB31		150.682	Failed
RB33		150.581	Died

🟨 VHF-collared caribou in Itcha-Ilgachuz area in that month
🟦 VHF-collared caribou in Rainbow area in that month
🟪 GPS-collared caribou in Itcha-Ilgachuz area in that month
⬛ collars present but data not available or not included in analysis

Appendix C. VHF collar radiolocations by season and individual for female caribou in the Itcha-Ilgachuz and Rainbow mountains herds, west-central British Columbia, 1984 – 1988 and 1995 – 2000.

Animal	Period	Season							
		SP	SU	EF	LF	EW	MW	LW	Total
Iia0	1980’s	5	11	10	5	9	17	8	65
Iib0	1980’s	2	5	3	2	5	12	3	32
Iic0	1980’s	5	11	7	3	11	25	9	71
Iid0	1980’s	6	12	9	4	12	26	11	80
Iie0	1980’s	7	13	10	5	13	26	12	86
Iif0	1980’s	7	14	10	6	13	26	12	88
Iik0	1980’s	7	13	9	7	13	26	12	87
IIL0	1980’s	3	5	3	2	4	9	7	33
Iim0	1980’s	4	5	3	1	2	7	5	27
Iim1	1980’s	3	6	3	2	4	9	7	34
Iin0	1980’s	2	1	0	0	0	1	2	6
Iio0	1980’s	5	13	7	5	11	26	11	78
Iip0	1980’s	3	4	2	2	1	7	4	23
Iir0	1980’s	6	14	9	5	13	23	11	81
Iis0	1980’s	4	7	4	2	3	6	4	30
Iit0	1980’s	3	4	2	0	3	7	5	24
Iitb	1980’s	3	7	2	3	9	18	7	49
Iiu0	1980’s	2	1	0	0	1	1	2	7
Iiv0	1980’s	6	12	7	6	12	25	9	77
Iiy0	1980’s	5	11	6	3	10	18	8	61
RBa1	1980’s	4	9	3	1	5	7	4	33
RBb1	1980’s	4	8	6	3	10	17	7	55
RBg0	1980’s	7	13	8	6	12	25	11	82
RBh0	1980’s	6	9	6	3	10	16	9	59
Rbi0	1980’s	6	11	8	3	10	16	9	63
RBj0*	1980’s	1/5	6/7	3/6	2/4	4/10	9/17	3/9	28/58
RBtc	1980’s	3	6	3	2	9	17	7	47
Il01	1990’s	12	31	21	12	25	37	27	165
Il02	1990’s	9	21	13	8	20	28	19	118
Il03	1990’s	13	35	23	11	27	36	27	172
Il04	1990’s	8	21	11	7	14	23	15	99
Il05	1990’s	2	6	6	3	7	15	7	46
Il06	1990’s	14	33	21	11	25	36	26	166
Il07	1990’s	12	31	22	11	26	36	24	162
Il08	1990’s	5	14	11	6	15	23	16	90
Il10	1990’s	13	31	20	9	26	36	24	159
Il11	1990’s	6	22	16	9	16	22	15	106
Il12	1990’s	13	32	21	11	25	35	25	162
Il13	1990’s	2	6	6	3	4	8	6	35
Il15	1990’s	2	6	6	3	7	8	6	38
Il17	1990’s	14	30	15	10	24	35	27	155
Il18	1990’s	1	1	0	1	3	8	5	19
Il20	1990’s	8	31	17	8	20	29	19	132
Il21	1990’s	13	29	20	10	26	35	26	159
Il22	1990’s	14	33	21	9	25	35	26	163
Il23	1990’s	2	2	0	1	2	8	6	21
Il25	1990’s	14	33	21	8	22	34	27	159
Il26	1990’s	2	6	5	2	2	5	6	28
Il32*	1990’s	10/0	22/8	15/6	8/2	16/2	26/0	22/0	119/18
Il35	1990’s	12	28	15	10	24	31	20	140
Il36	1990’s	12	25	9	8	23	28	19	124
Il37	1990’s	10	27	15	10	21	29	20	132
Il38	1990’s	7	19	11	5	12	16	15	85
Il44	1990’s	6	11	6	2	9	14	11	59
Il46	1990’s	3	2	0	1	6	8	4	24
RB09*	1990’s	9/13	0/30	1/20	2/9	5/23	8/28	6/21	31/144
RB27	1990’s	13	34	19	9	23	33	27	158
RB28	1990’s	13	33	20	9	22	33	27	157
RB29	1990’s	13	34	20	9	23	33	27	159
RB30	1990’s	13	32	20	9	22	33	27	156
RB31	1990’s	2	5	0	0	0	5	6	18
RB33	1990’s	9	14	9	7	17	20	12	88
TOTAL		**448**	**1016**	**631**	**340**	**828**	**1316**	**851**	**5423**

* animals occurred in both herds; sample sizes for Itcha-Ilgachuz listed first, then Rainbow

Appendix D. Fix success rate and nominal sample size of GPS radiolocations by season, fix status and animal for female caribou in the Itcha-Ilgachuz Mountains, west-central British Columbia, 1998 – 2000.

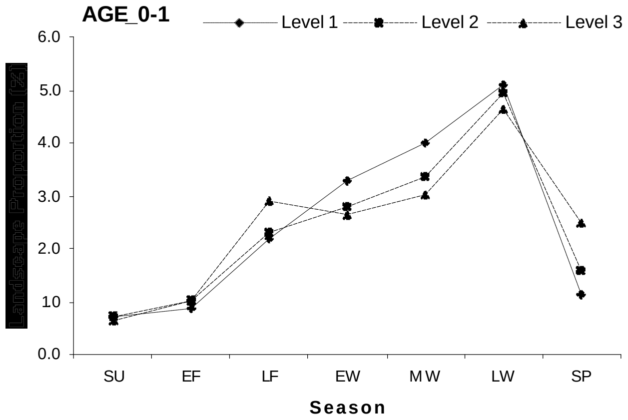
Animal	Attempted GPS Locations (n)								Success Rate (%)								Composition of Locations (%)			
	SP	SU	EF	LF	EW	MW	LW	Tot	SP	SU	EF	LF	EW	MW	LW	Tot	2Dfix	2Ddiff	3Dfix	3Ddiff
II40	279	216	61	212	604	952	736	2958	26	27	69	66	72	69	60	62	0.8	53.0	0.5	45.7
II40*									25	26	66	62	69	64	57	59	0.7	50.8	0.5	48.0
II41	279	704	61	212	620	952	736	3557	13	9.4	56	84	85	70	47	52	0.6	54.8	0.6	44.0
II41*									13	8.8	54	82	83	68	44	50	0.5	53.4	0.7	45.4
II42	279	704	61	212	620	952	736	3557	92	89	98	92	90	89	96	91	0.5	44.5	0.4	54.5
II42*									85	83	95	90	89	87	92	88	0.4	42.8	0.4	56.4
II43	279	704	61	212	620	952	736	3518	88	89	90	68	79	72	93	83	0.4	45.2	0.4	53.9
II43*									83	85	87	65	74	68	88	79	0.4	42.3	0.4	57.0
II46	8	0	0	0	252	472	368	1098	88				91	93	89	91	0.5	58.6	0.4	40.5
II46*									88				89	90	86	89	0.5	57.5	0.4	41.6
II47	279	704	61	212	592	588	736	3148	87	92	90	81	77	62	84	81	0.5	48.1	0.5	50.9
II47*									81	89	87	78	73	58	79	77	0.4	45.4	0.5	53.7
Total	1403	3032	305	1060	3308	4868	4048	17836	61	67	80	78	81	75	77	75	0.6	49.0	0.5	50.0
Total*									58	64	77	76	79	72	73	72	0.5	46.8	0.5	52.2

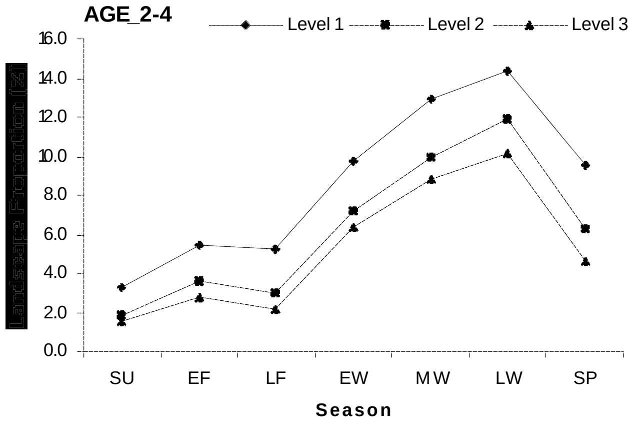
* after screening

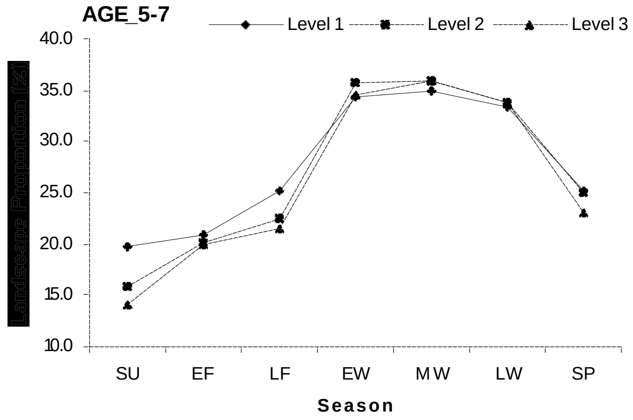
Appendix E

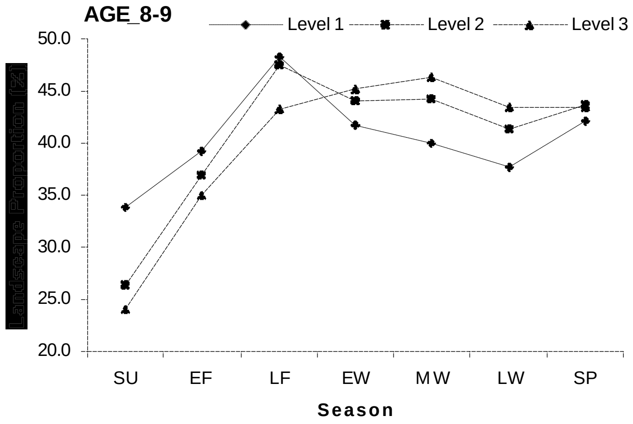
Caribou use of each habitat variable from broad (level 1) to fine (level 3) spatial scales across seasons as originally defined. Results are presented separately for the Itcha-Ilgachuz and Rainbow herds and for animals exhibiting "alpine" and "forest" winter-dwelling strategies. Comparisons among variables or strata should be made with caution, as the Y-axis scale varies.

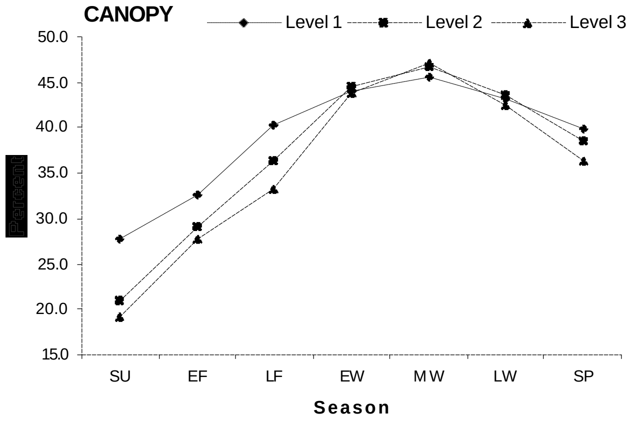
ITCHA-ILGACHUZ HERD

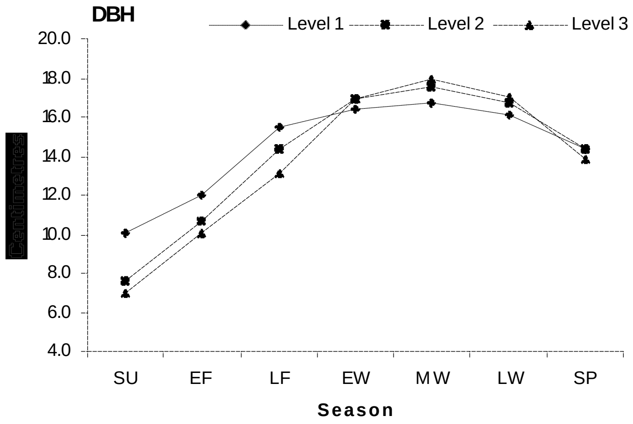


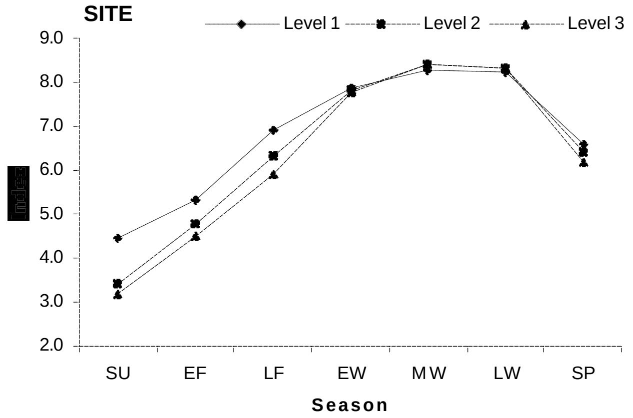


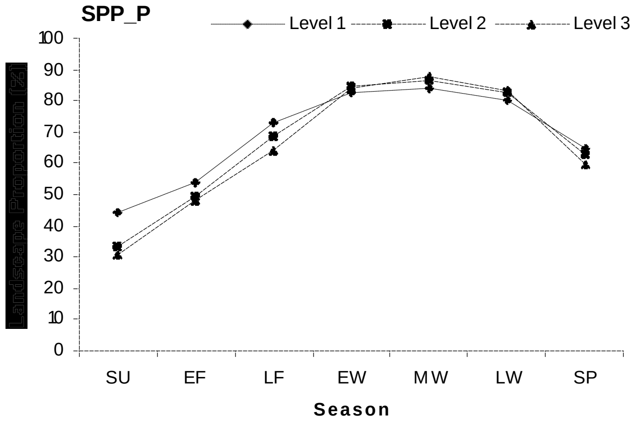












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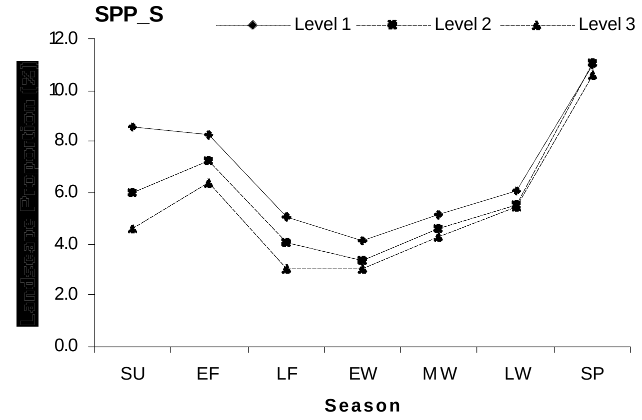

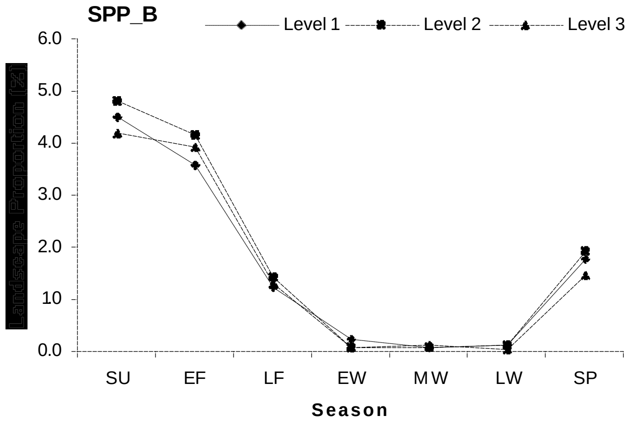

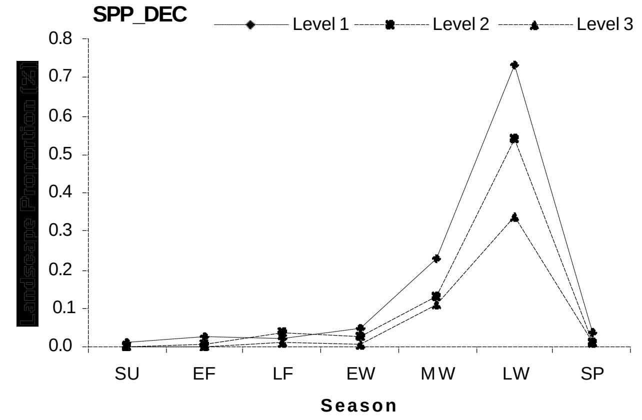

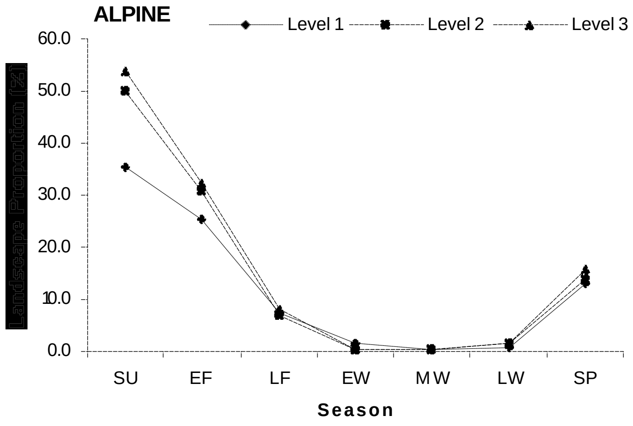

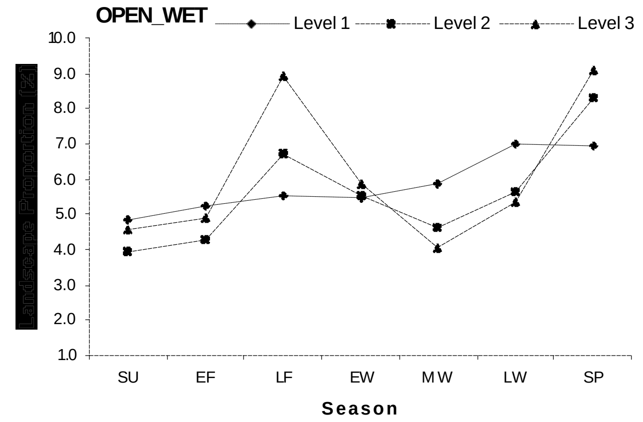

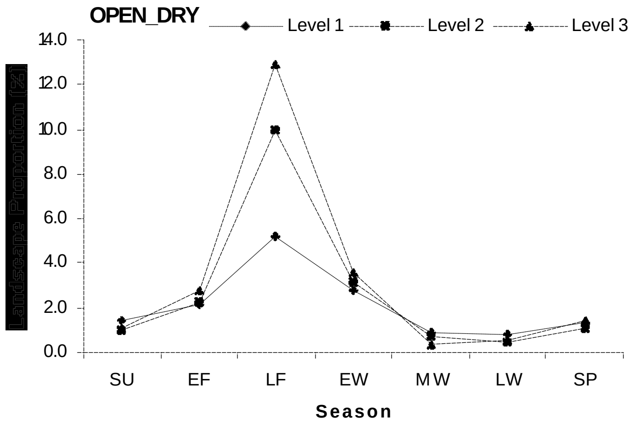

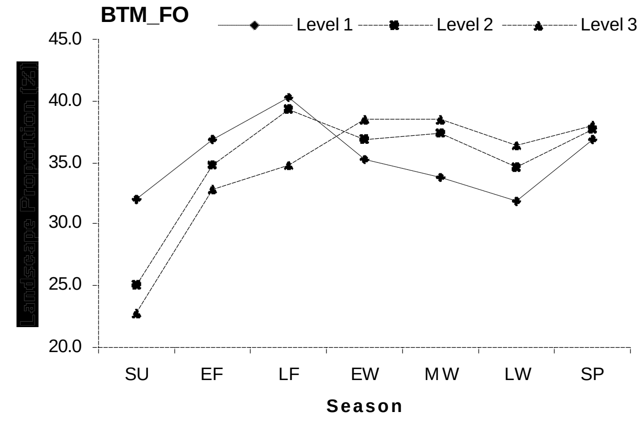

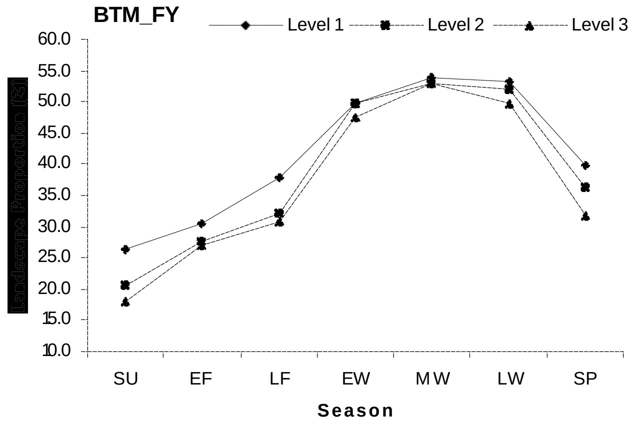

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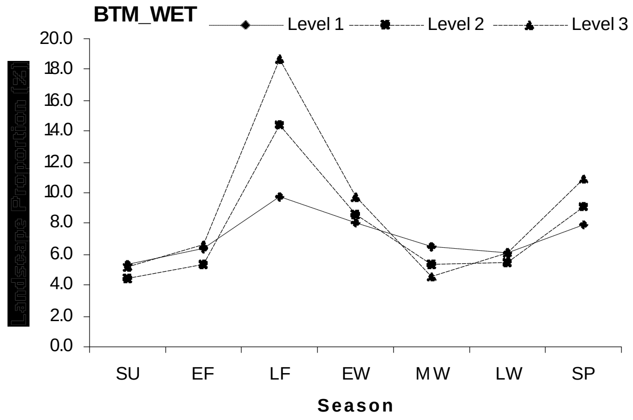

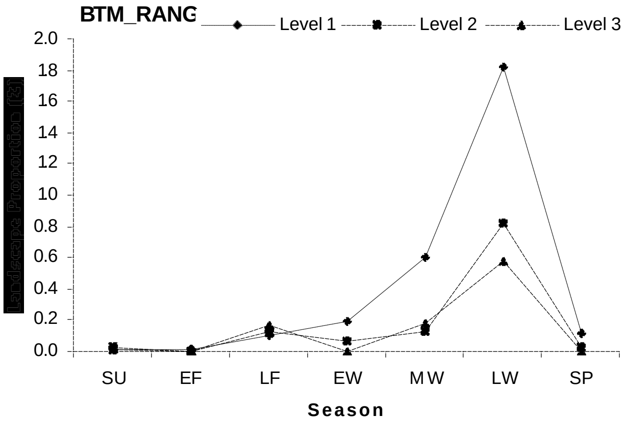

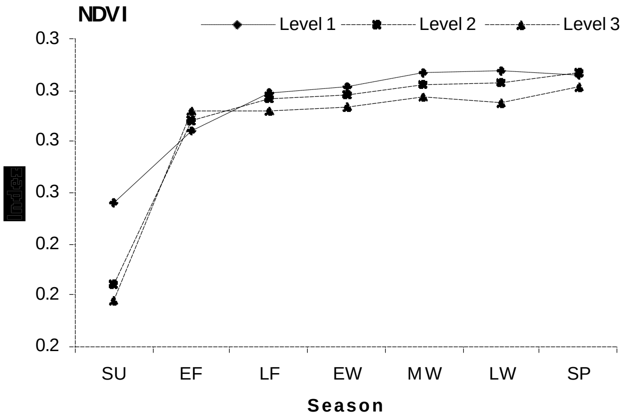

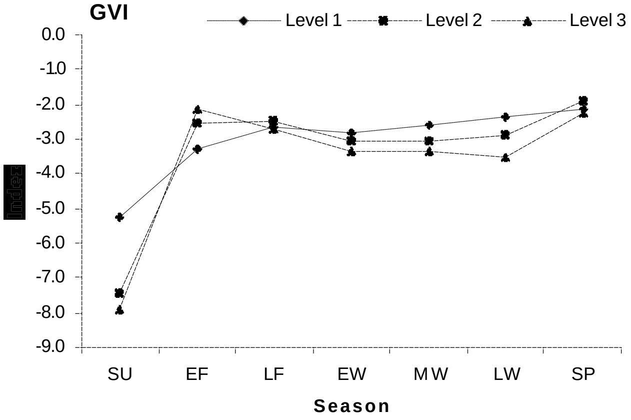

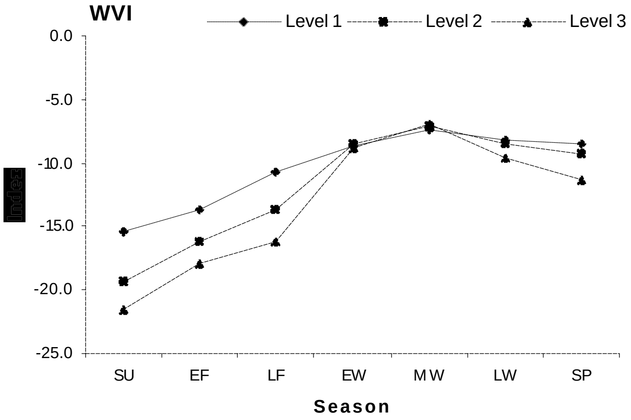

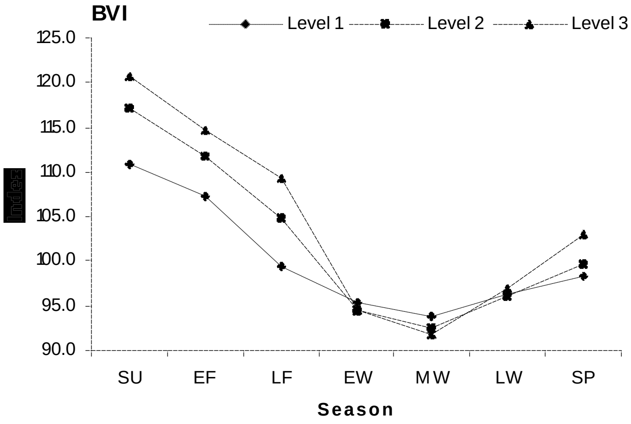

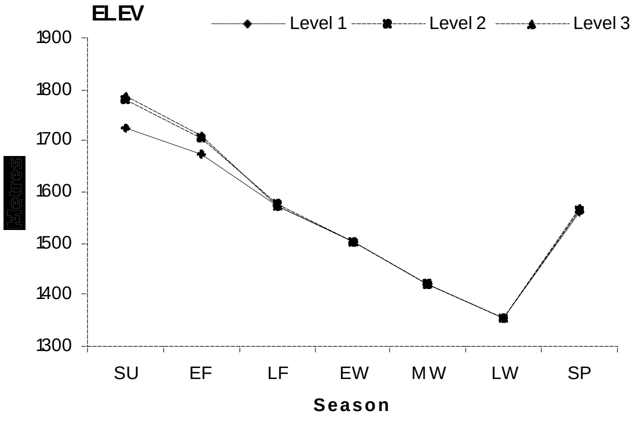

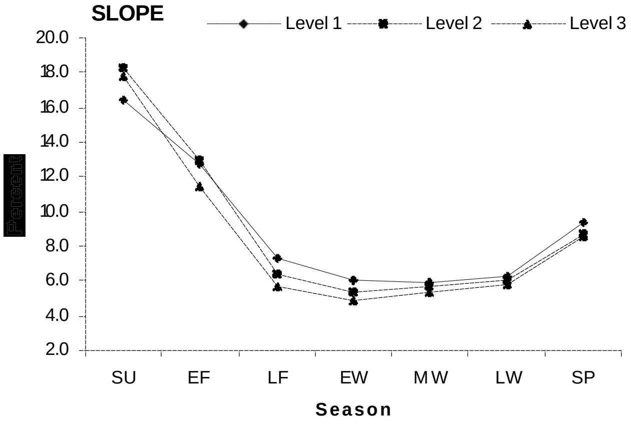

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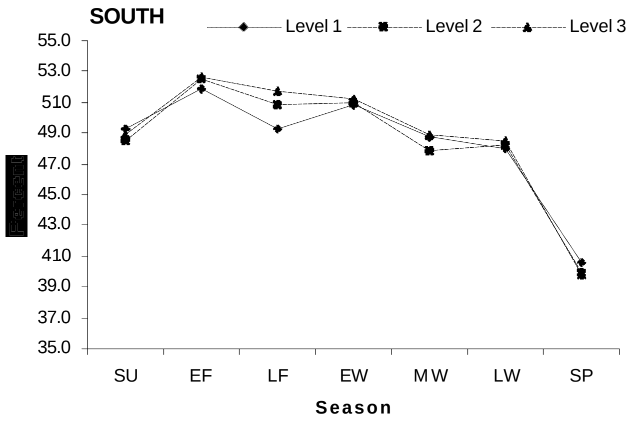
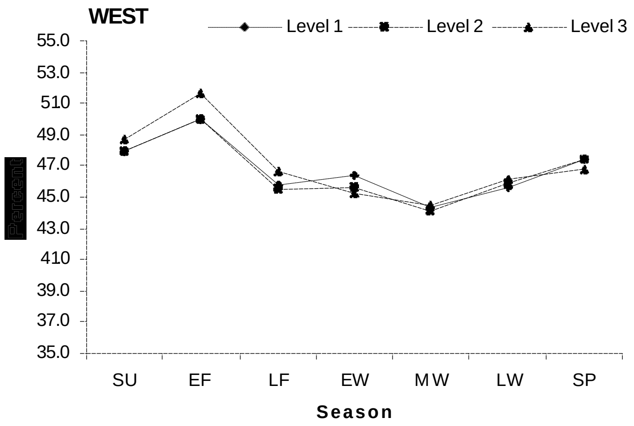
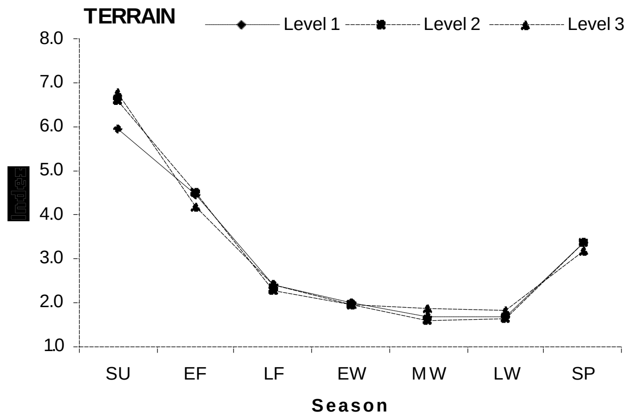
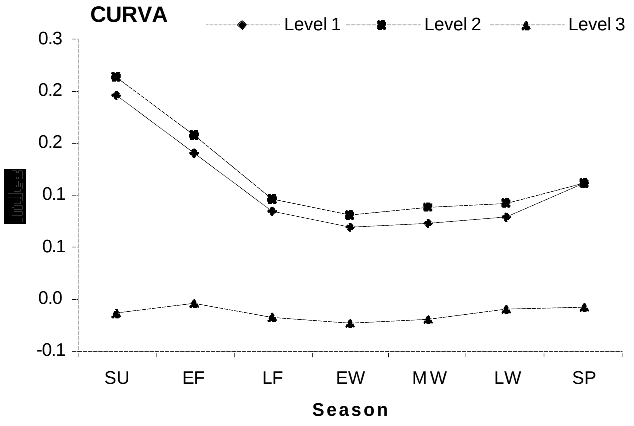
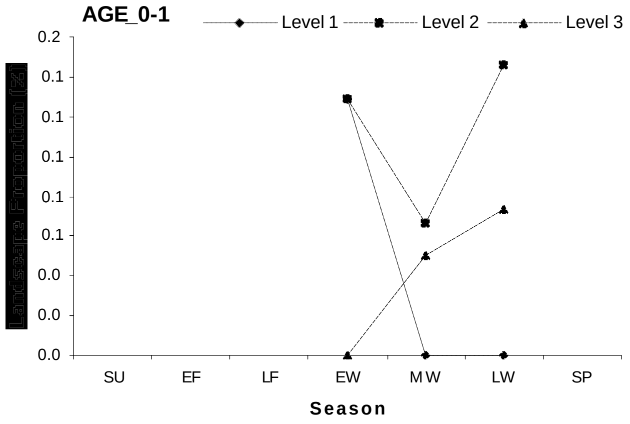


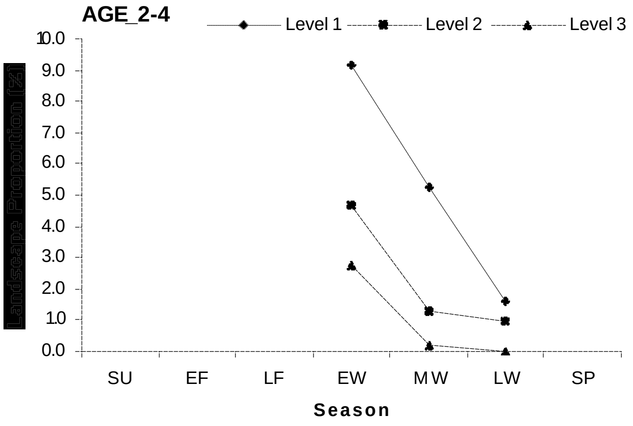


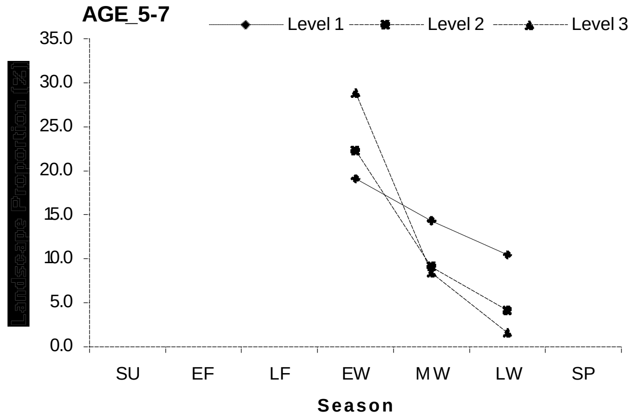


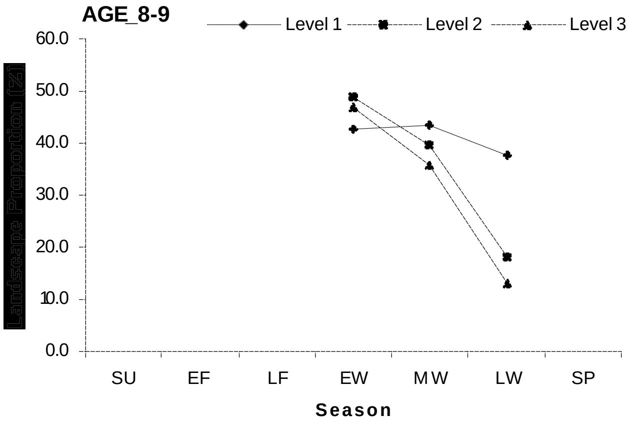


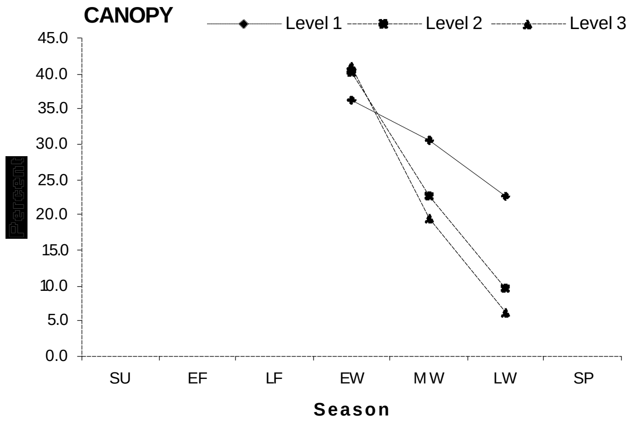
ITCHA-ILGACHUZ / WINTER / ALPINE-DWELLING

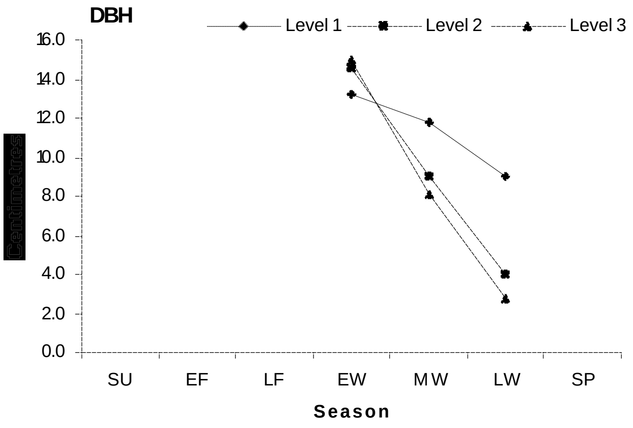


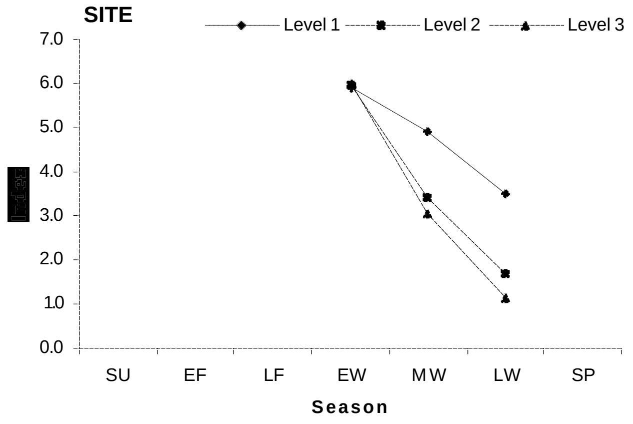


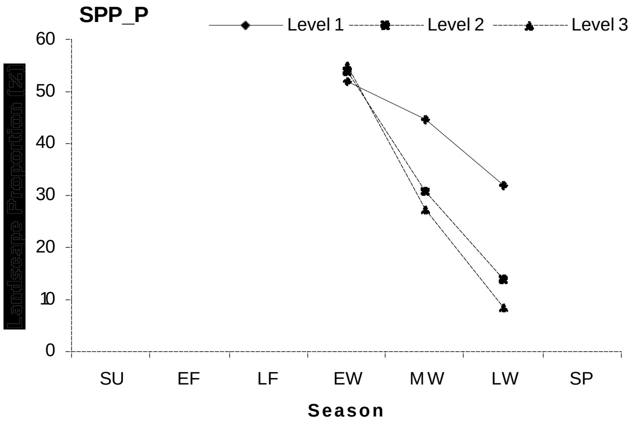




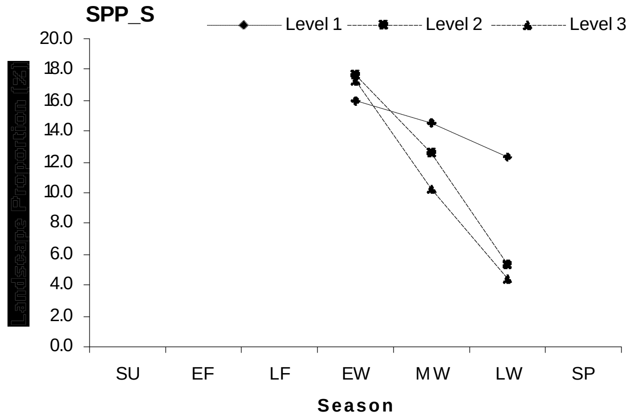


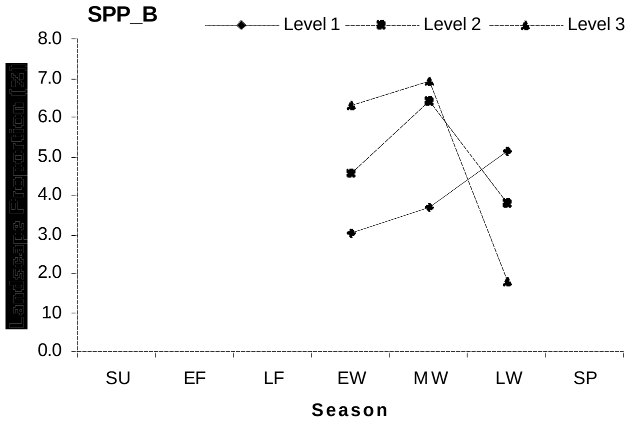


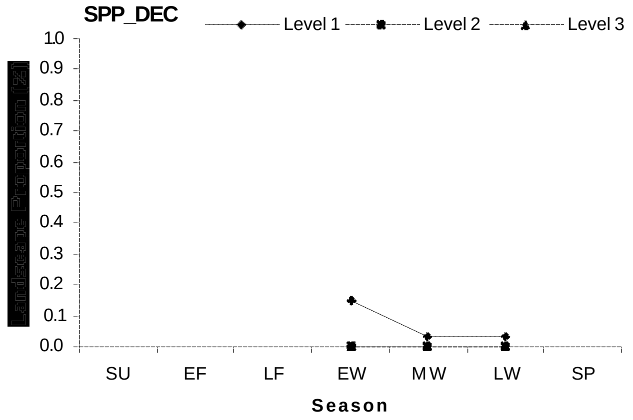


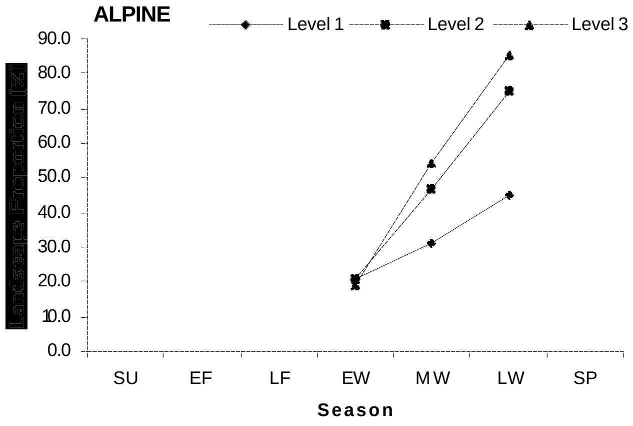


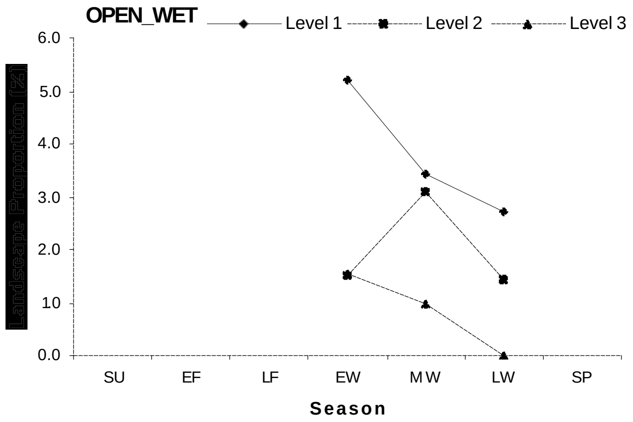
ITCHA-ILGACHUZ / WINTER / ALPINE-DWELLING

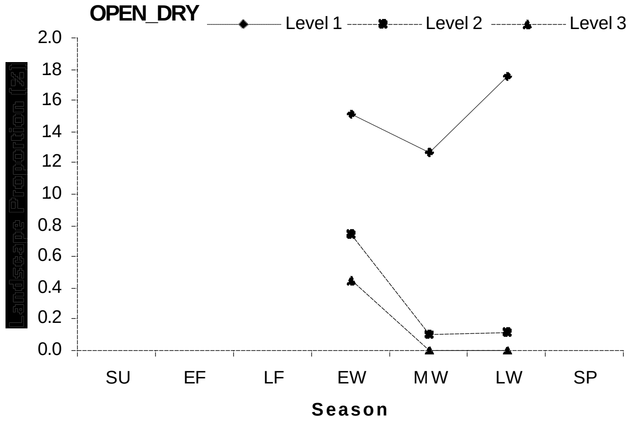


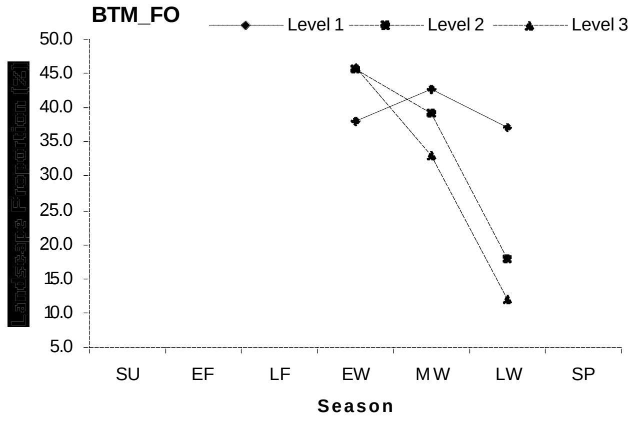


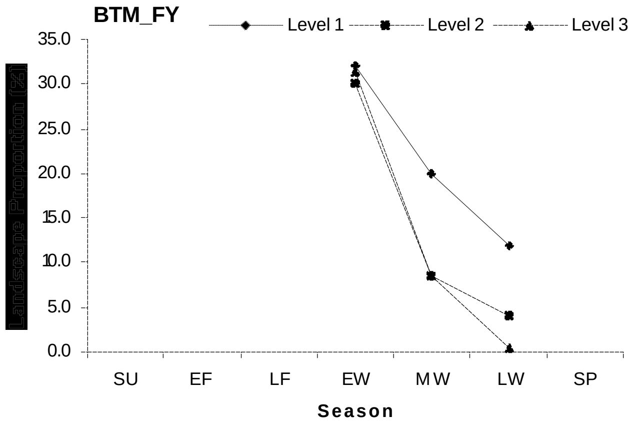




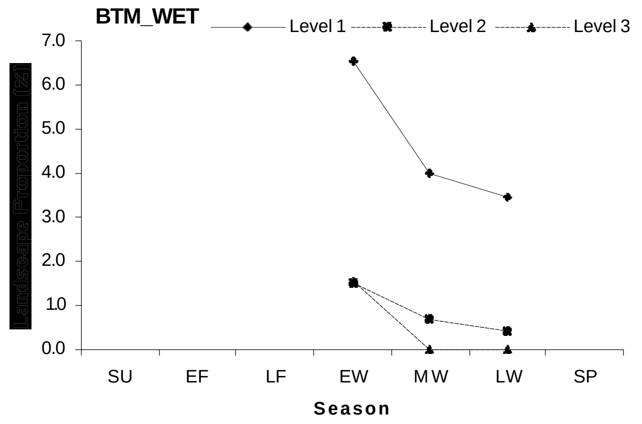


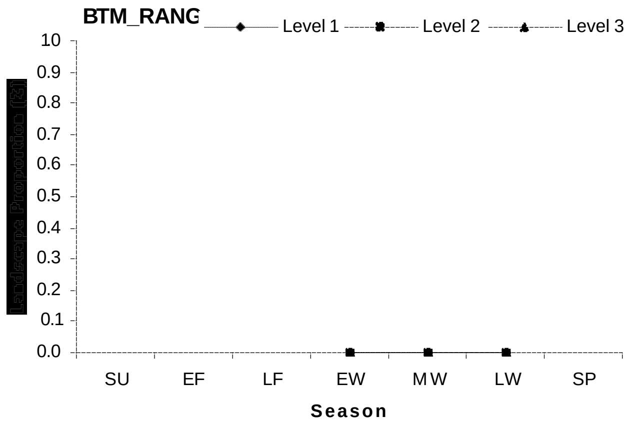


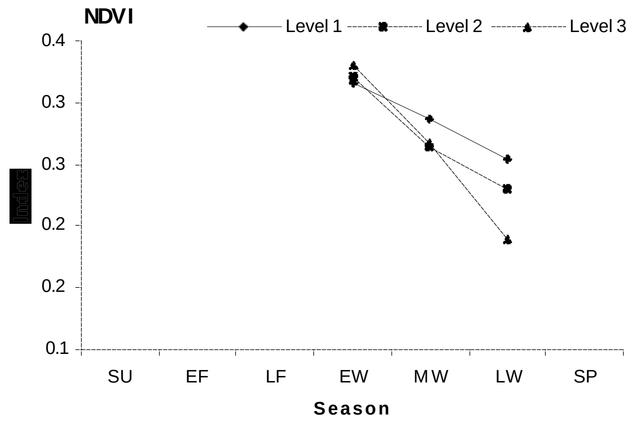


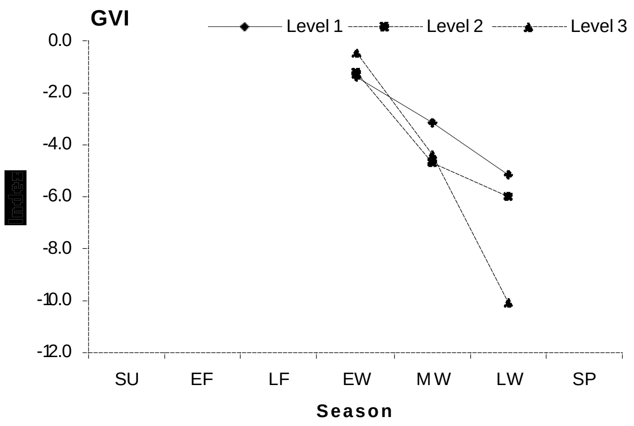


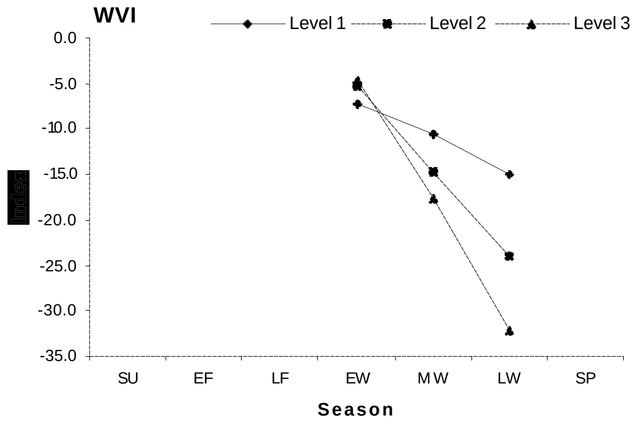
ITCHA-ILGACHUZ / WINTER / ALPINE-DWELLING

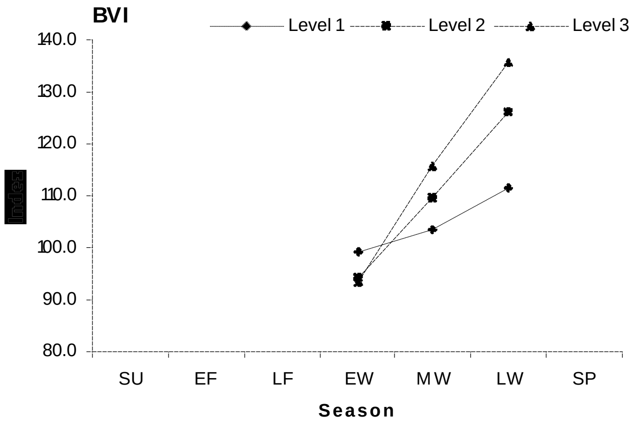


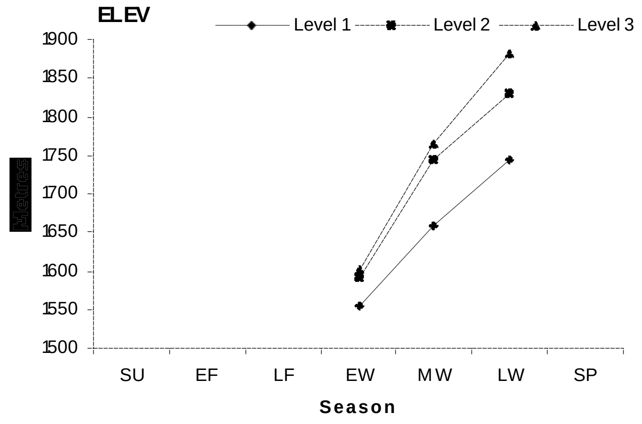


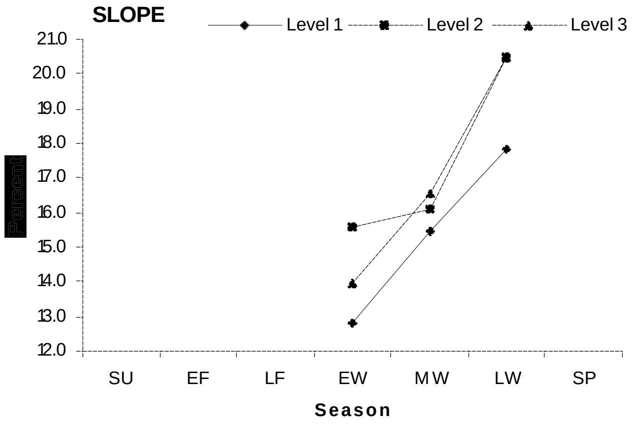




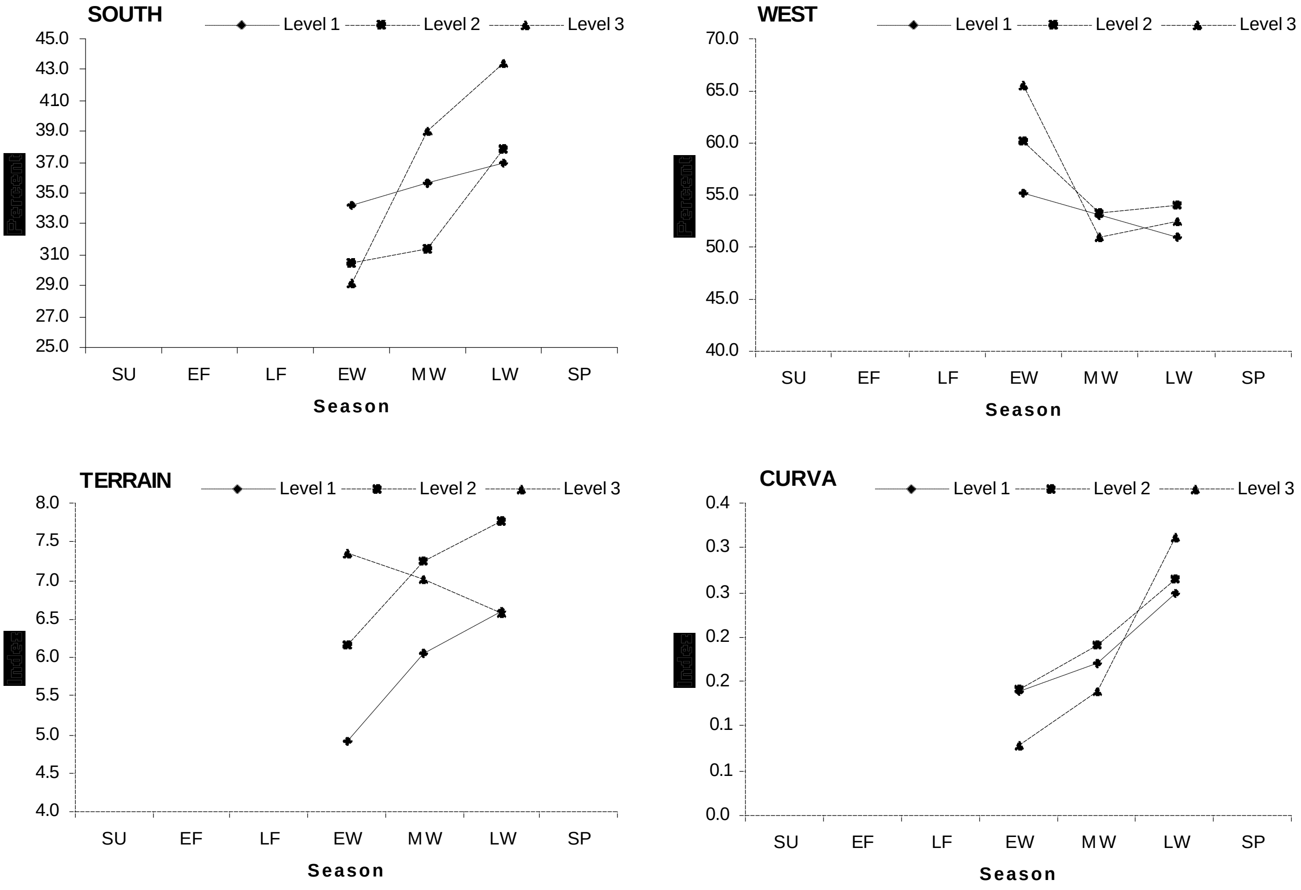








ITCHA-ILGACHUZ / WINTER / ALPINE-DWELLING



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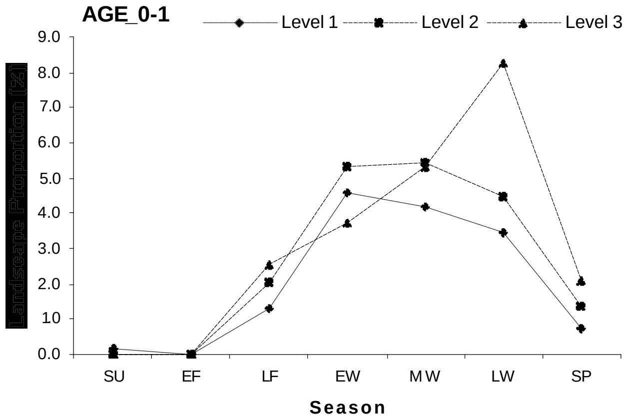

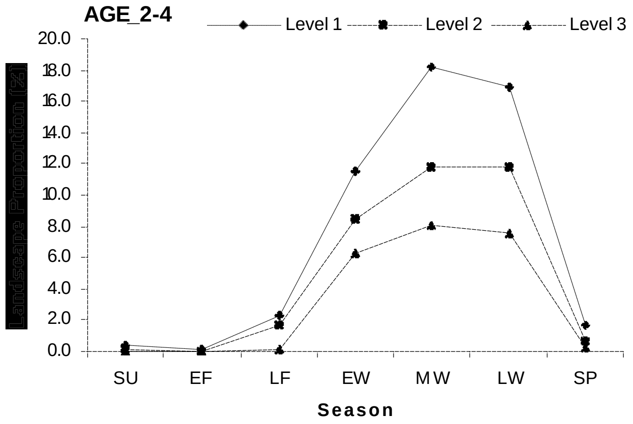

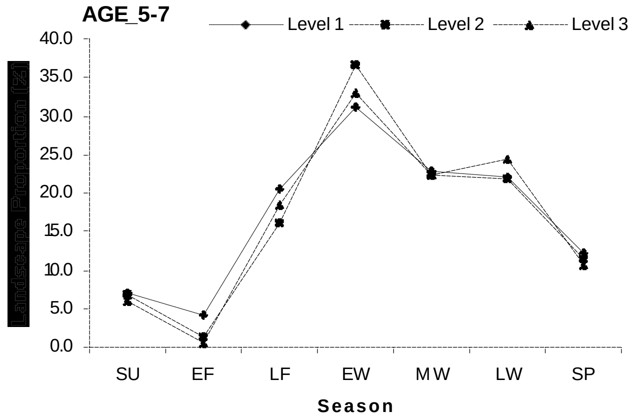

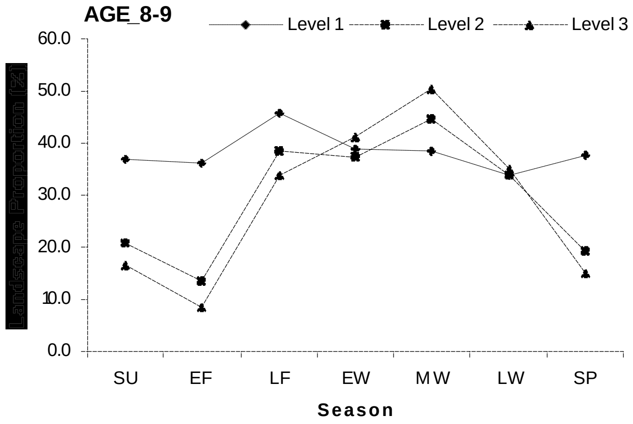

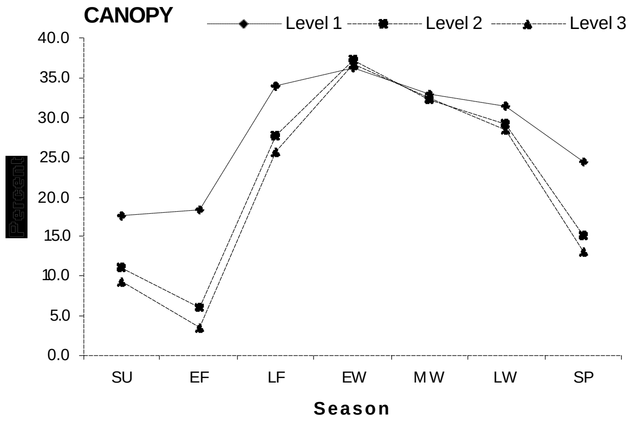

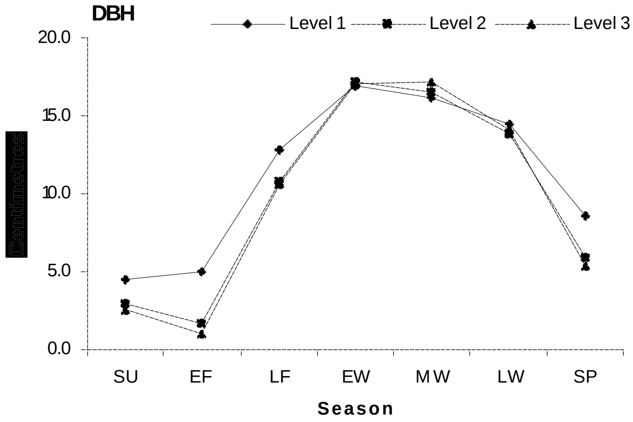

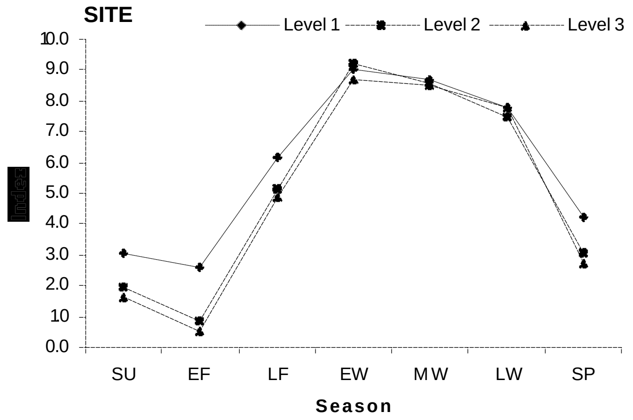

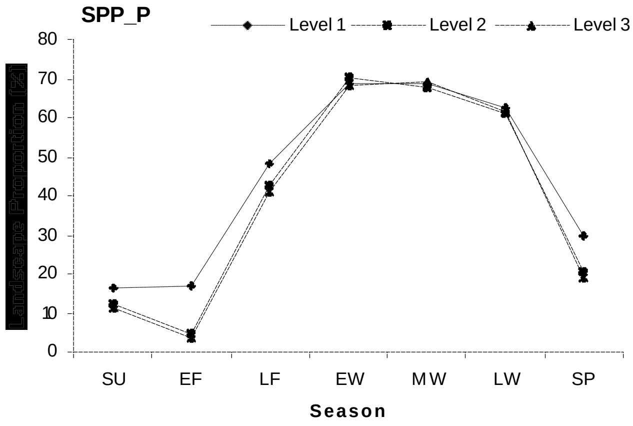

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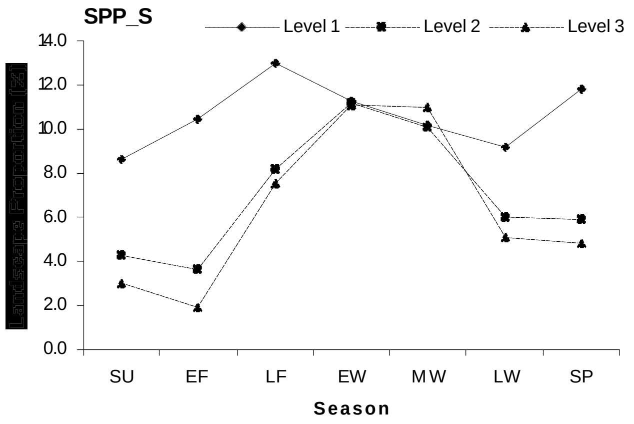

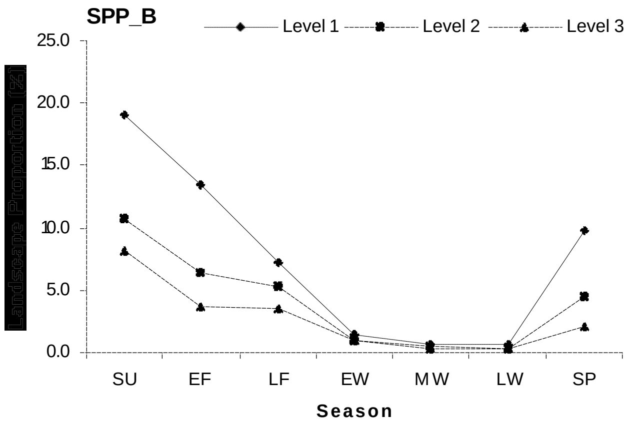

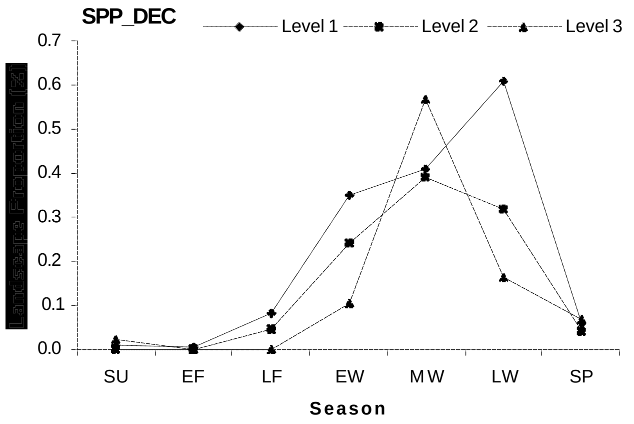

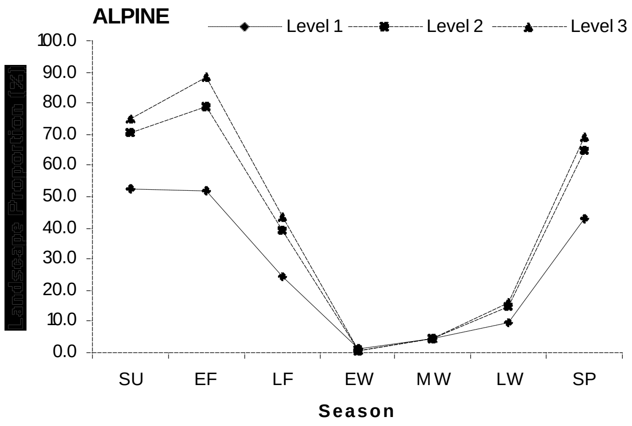

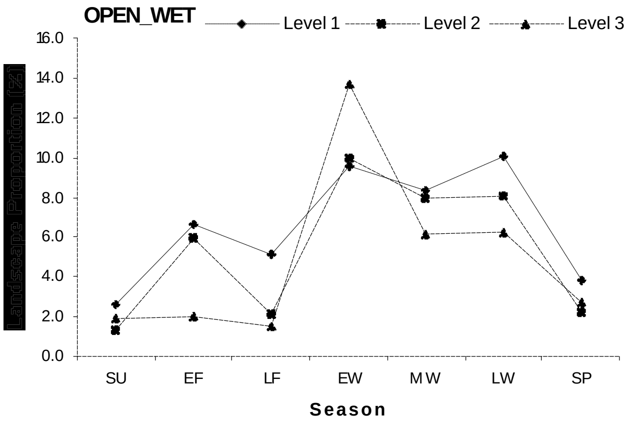

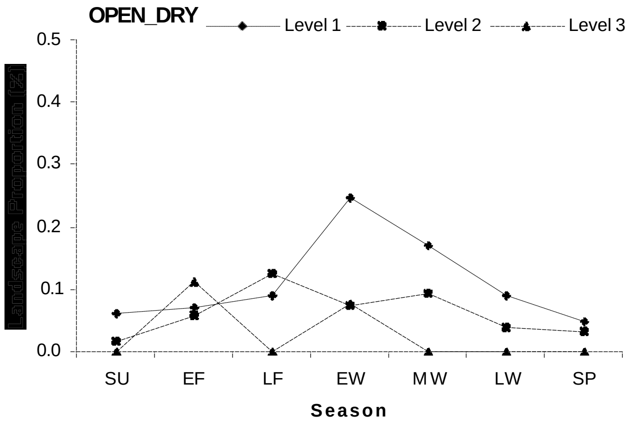

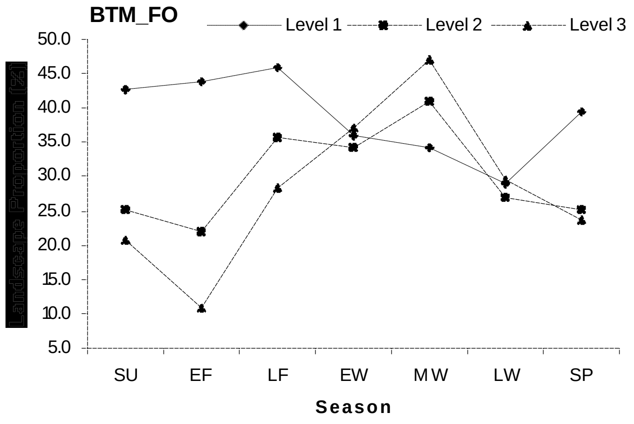

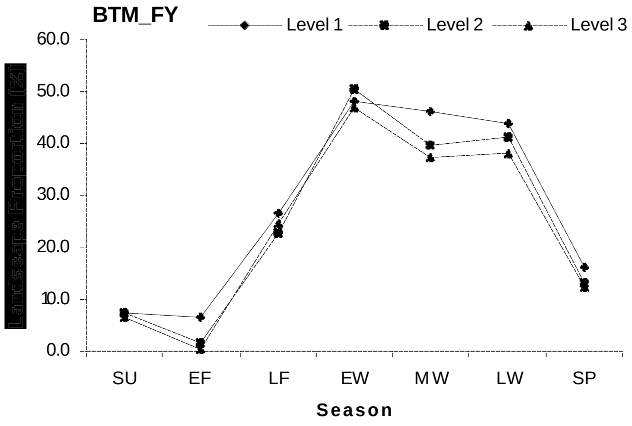

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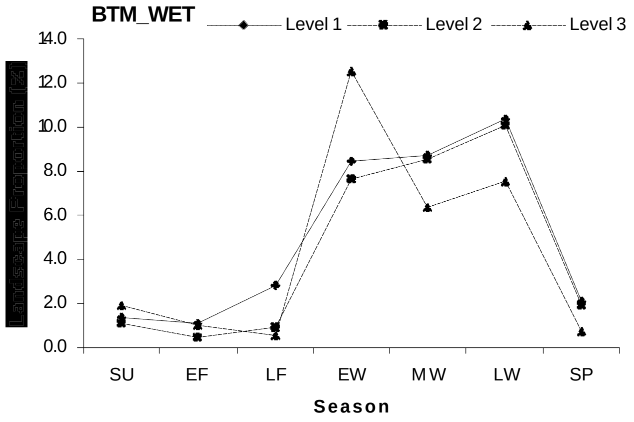

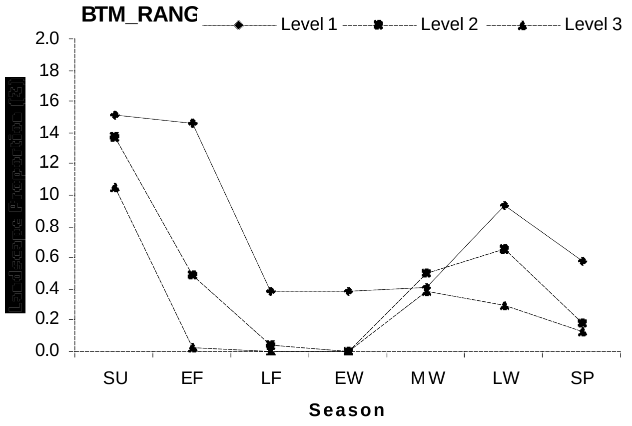

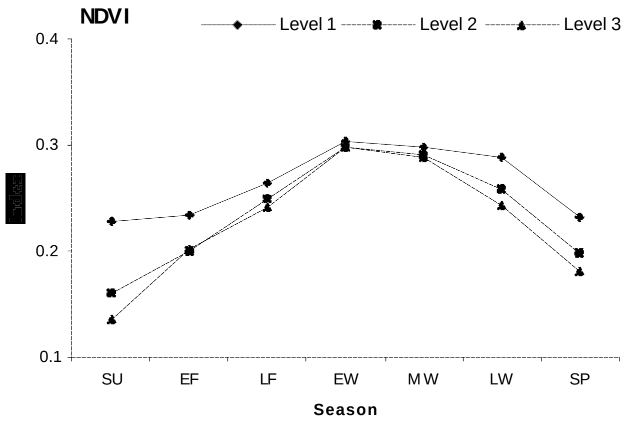

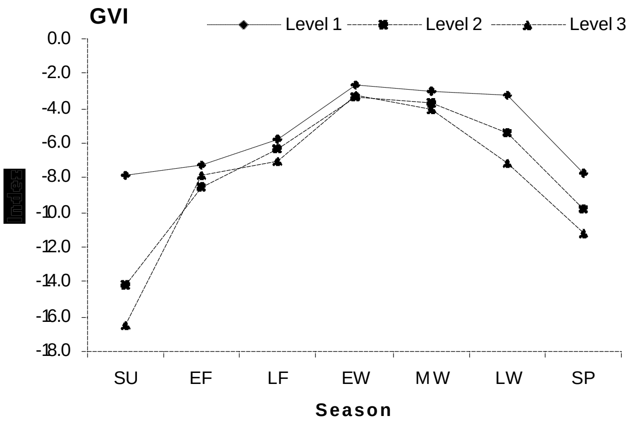

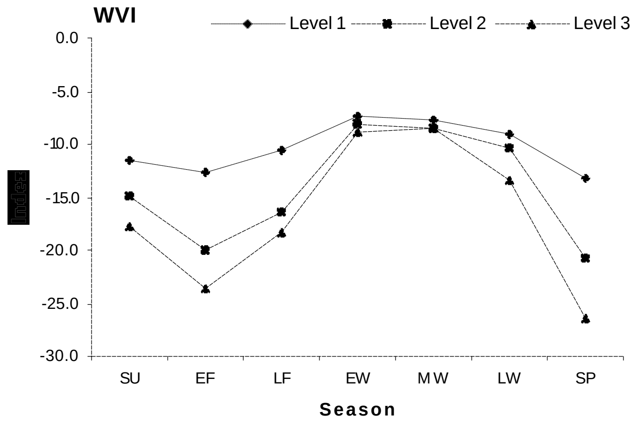

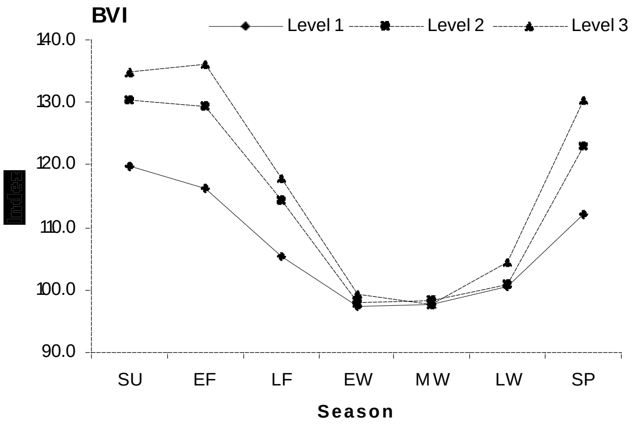

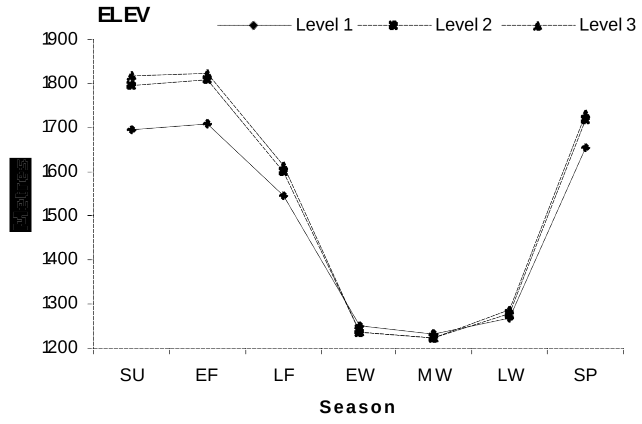

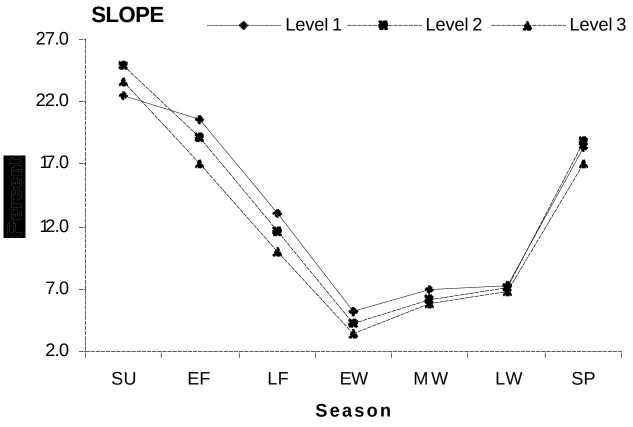

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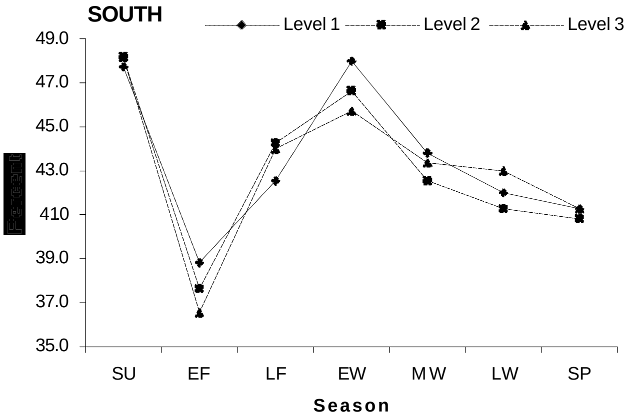
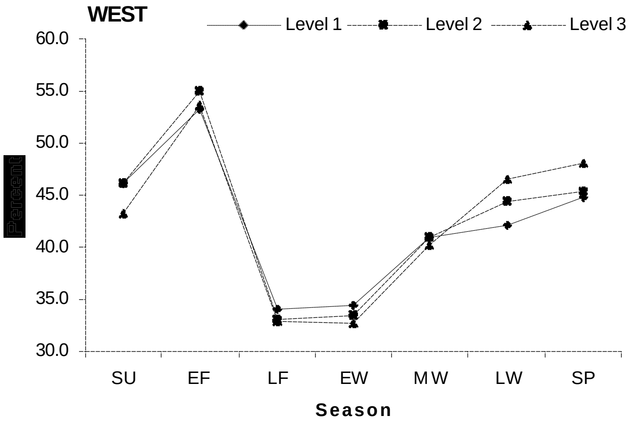
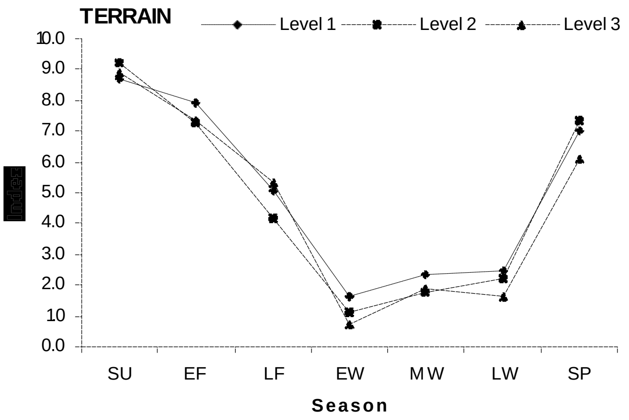
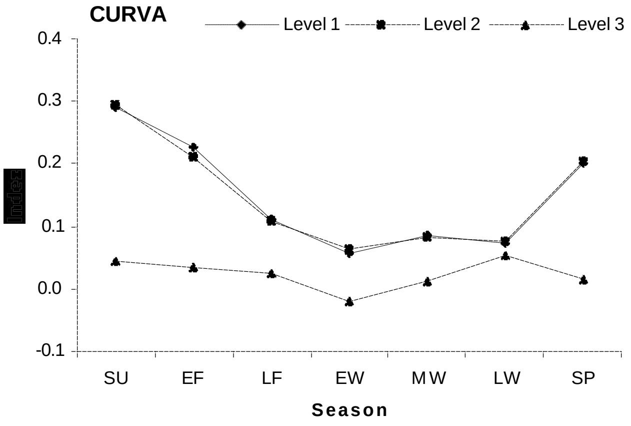
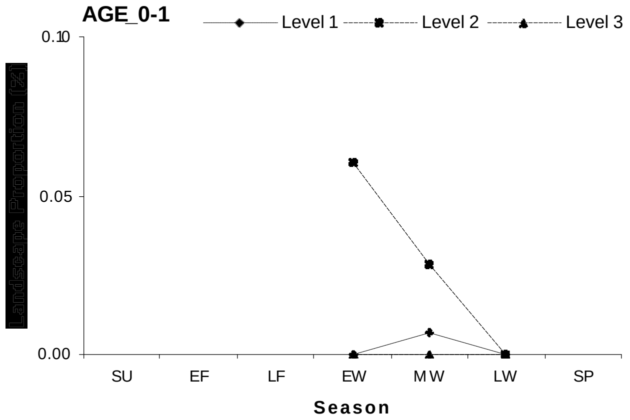


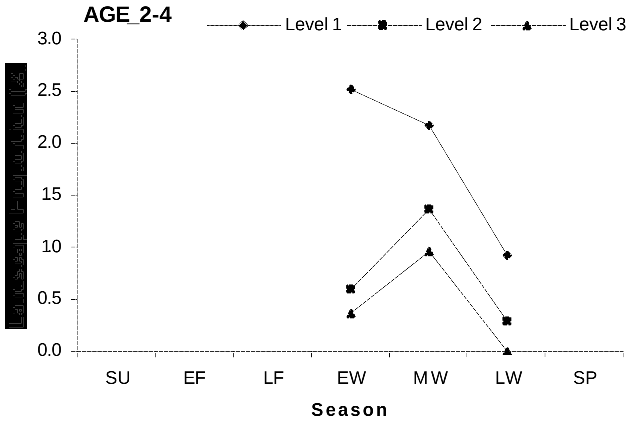


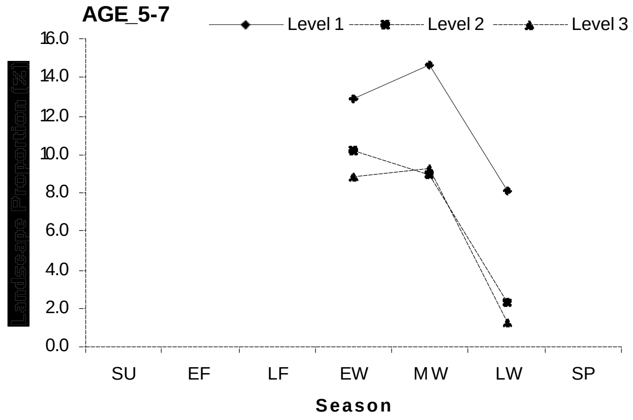


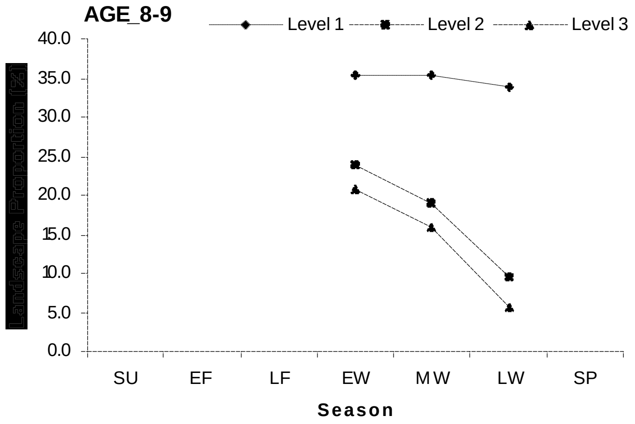


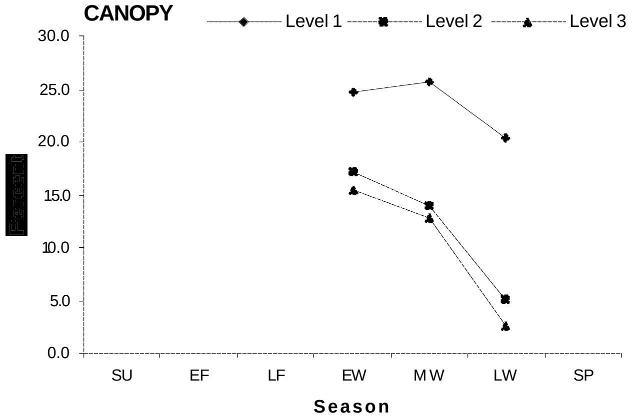
RAINBOW / WINTER / ALPINE-DWELLING

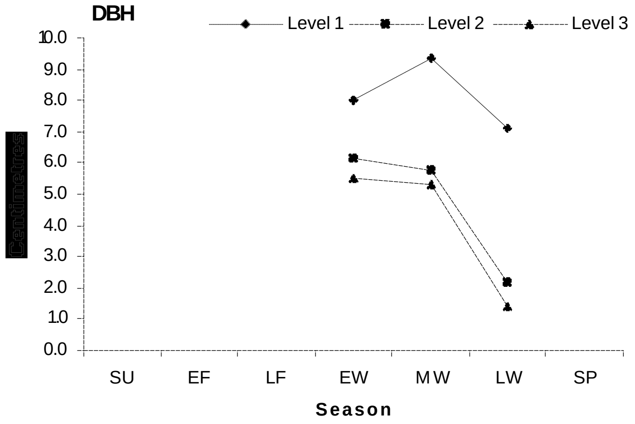


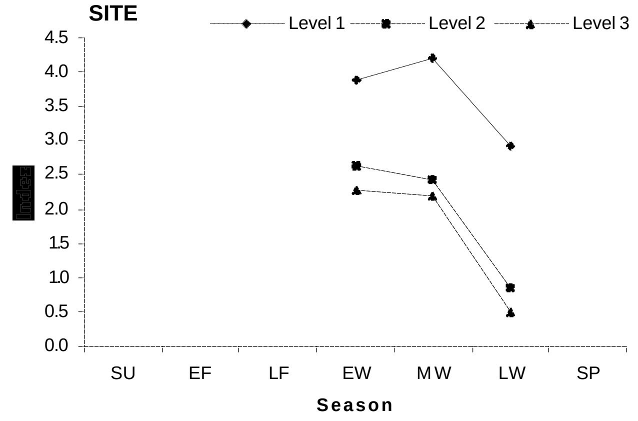


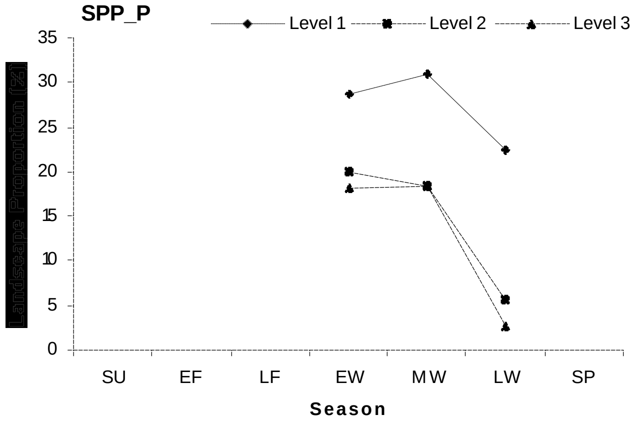












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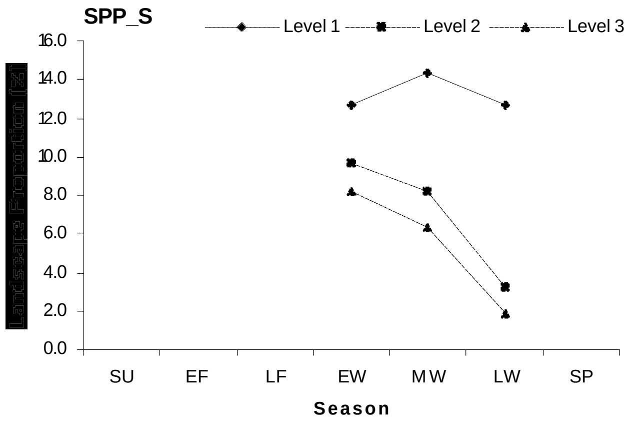

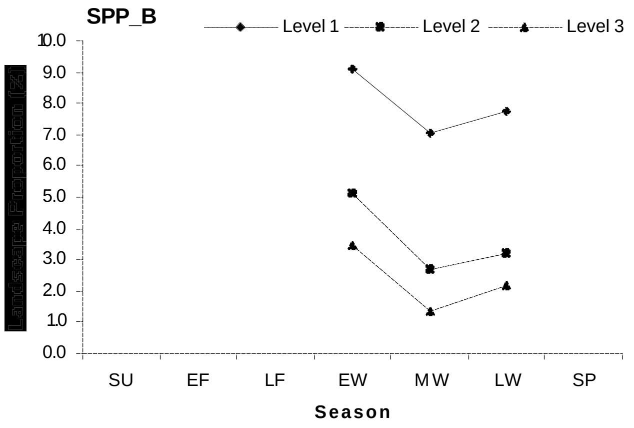

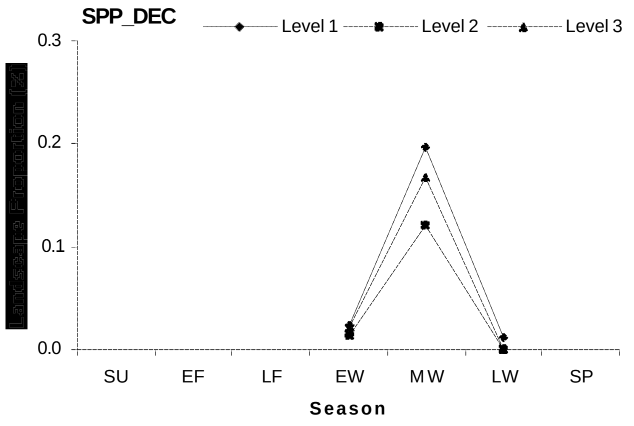

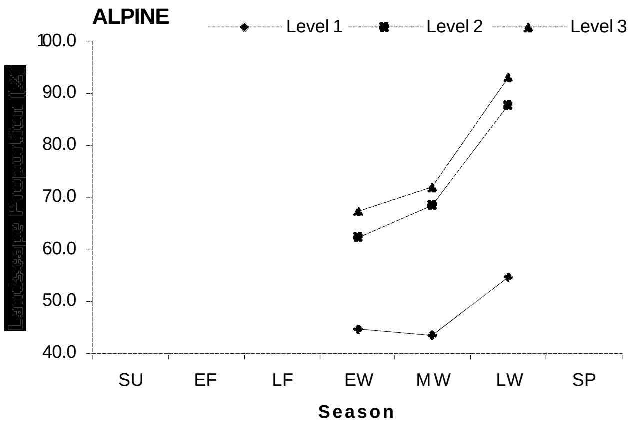

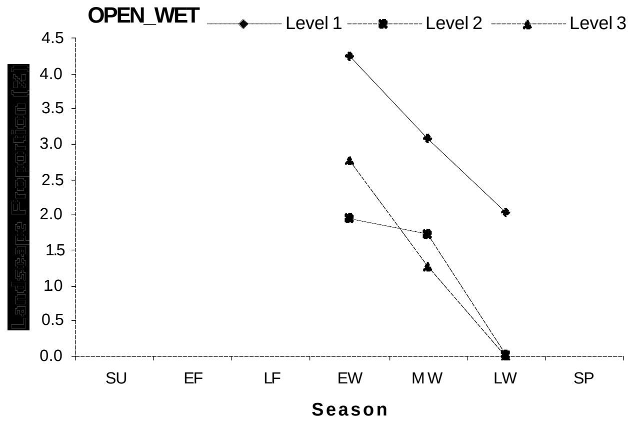

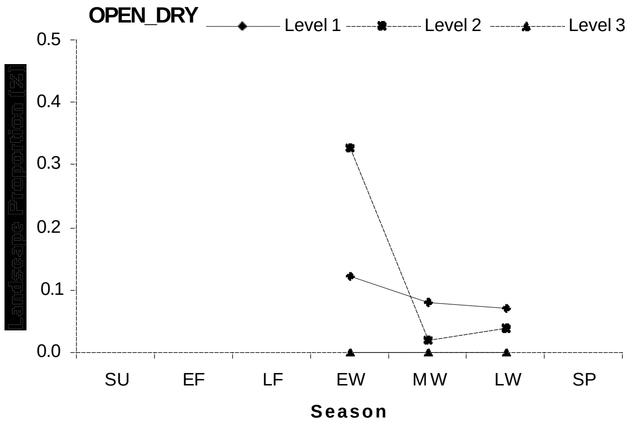

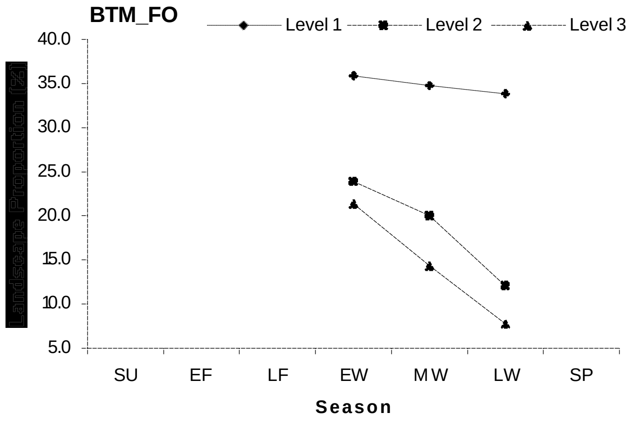

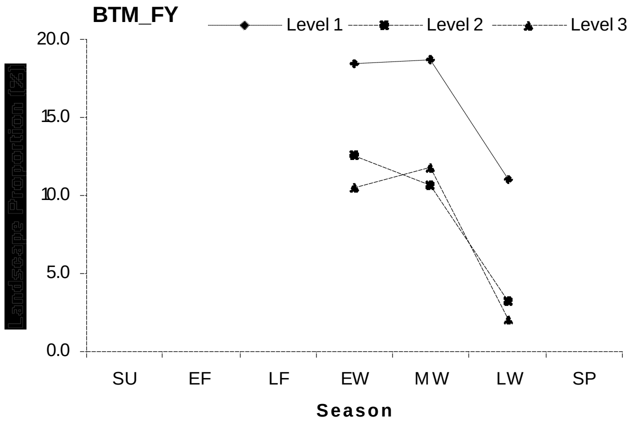

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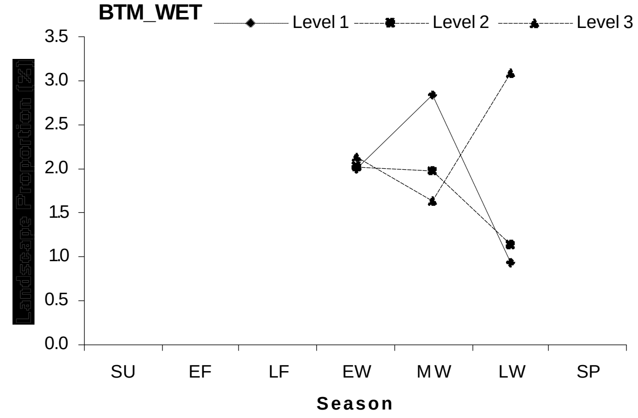
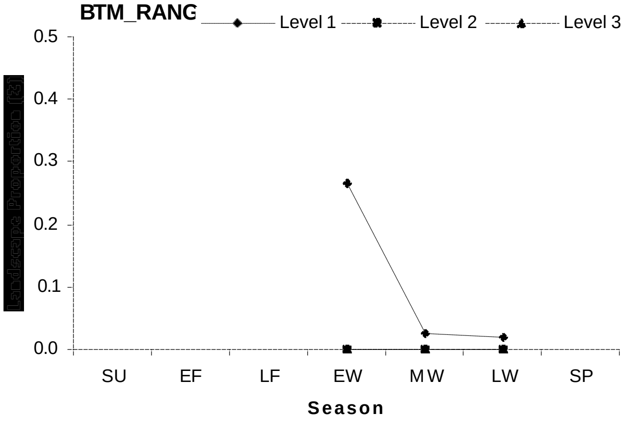
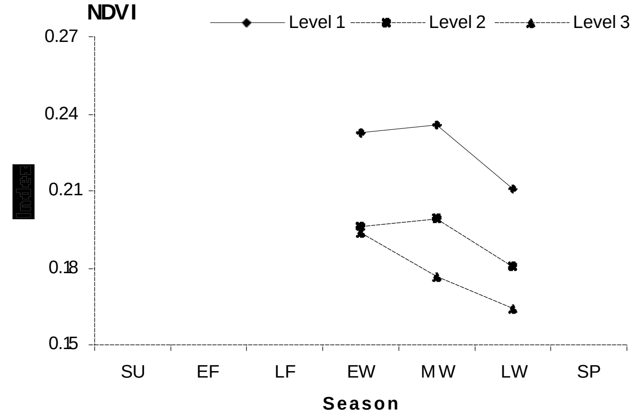
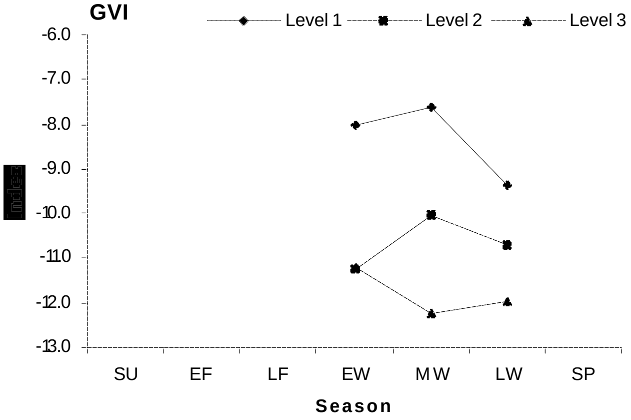
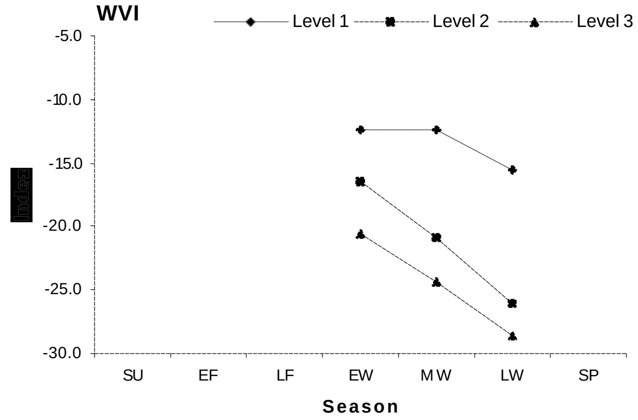
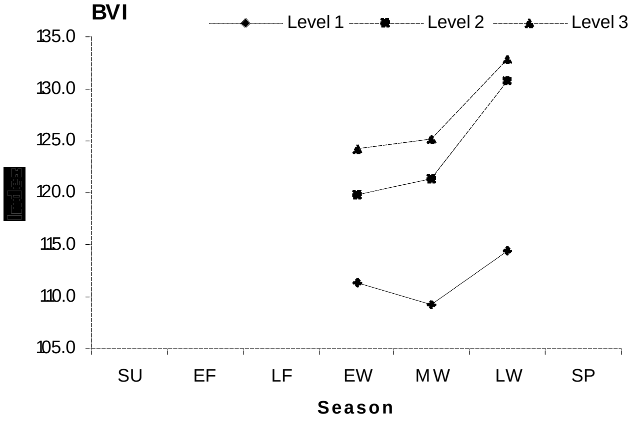


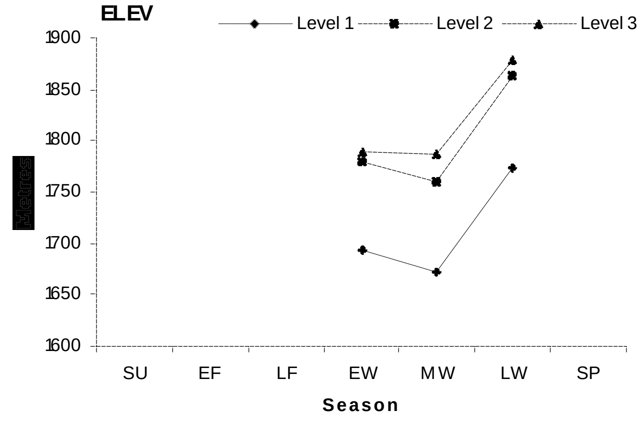


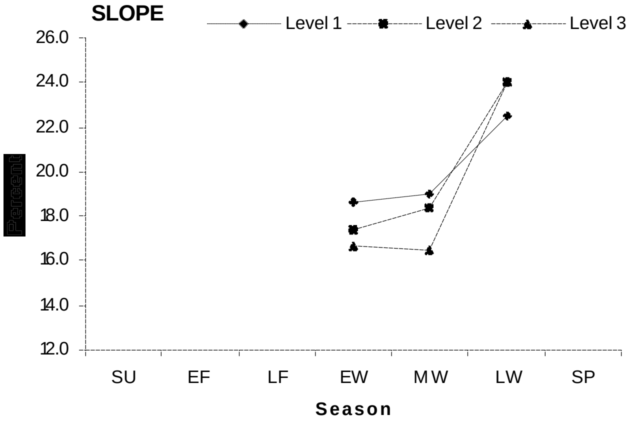




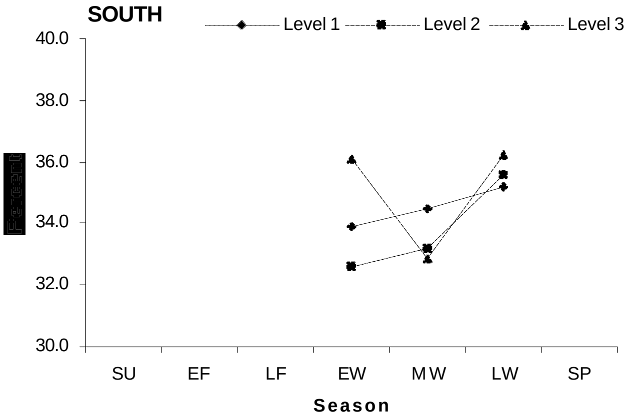


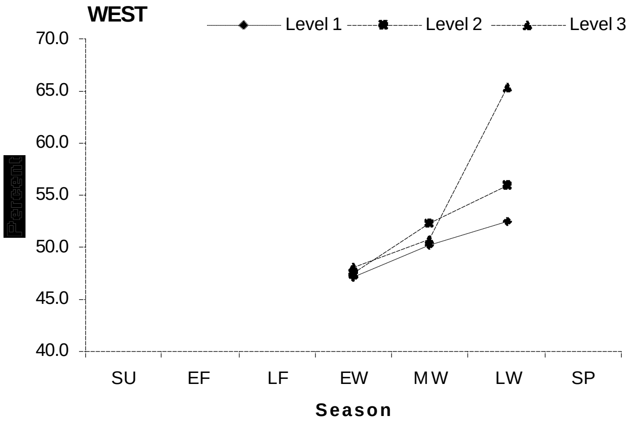


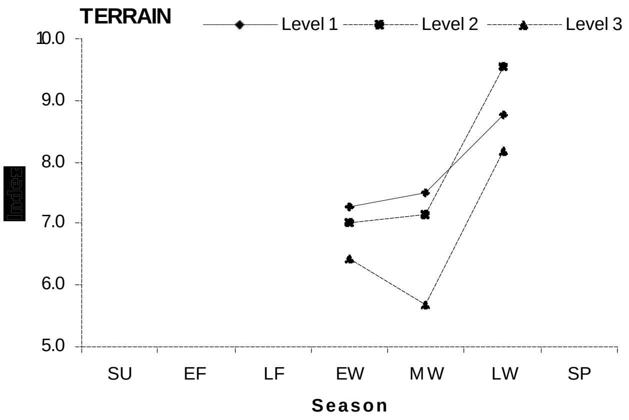


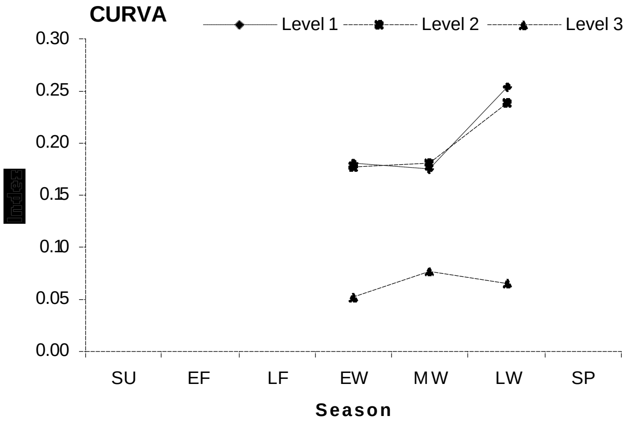


RAINBOW / WINTER / ALPINE-DWELLING









Appendix F

Maps of predicted caribou habitat in the Itcha-Ilgachuz and Rainbow mountains study area, west-central British Columbia. Maps for “winter forest-dwelling” and “summer” are based on models developed separately for the Itcha-Ilgachuz and Rainbow herds, with the model application zone defined by a white line. The first 3 maps depict models merged with a hill-shaded terrain image. The second 3 maps depict models as merged with Landsat 7 TM panchromatic data.