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HABITAT SELECTION BY BIGHORN EWES ON THREE WINTER RANGES IN THE EAST KOOTENAYS

PREPARED BY
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FOR
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Rocky Mountain Bighorn Sheep Habitat and Population Assessment
for the East Kootenay Trench

HABITAT SELECTION BY BIGHORN EWES ON THREE WINTER RANGES IN THE EAST KOOTENAYS

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EXECUTIVE SUMMARY

Bighorn sheep wintering at low elevations in the East Kootenay Trench are well below historic numbers. Reasons for these low numbers are not known, although speculation abounds regarding habitat degradation, predators, disease, and human harassment on winter ranges. Habitat management prescriptions have been suggested but specific plans cannot be formulated without a objective assessment based on current empirical data collected in the East Kootenay Trench. The East Kootenay Wildlife Association embarked on a 5 year project to examine the ability of the fall through spring bighorn ranges at Columbia Lake, Bull River, and Wigwam/Mount Broadwood to support bighorns.

Bighorn ewes were radiocollared and radio tracking has been conducted between 1997 and 2000 at the 3 fall through spring ranges. Radio tracking occurred primarily from the ground. Each study area was monitored intensively over 2 winters. The winter period was defined as from the beginning of December through until the end of April. During winters of intensive monitoring, all radiocollared ewes were located approximately 3 times per week. In statistical tests, we contrasted bighorn ewe radiolocations collected between December and April with available habitat. Sheep locations were buffered with a 100 m radius circle to take in account mapping error and the areas within the buffered points were sampled randomly. Available habitat was determined using a stratified random sample of the 100% minimum convex polygon (MCP) winter range of all radiocollared sheep at each study area. Variables used in the analysis were primarily topographical (e.g., elevation, aspect) or derived from 1:20,000 scale ecosystem mapping of the 3 ranges, that is, terrain ecosystem mapping (TEM). In addition, a greenness index derived from Landsat 5 TM satellite imagery was used to examine possible relationships between bighorn sheep distribution and this index of landscape productivity. Using TEM, univariate crosstabulations of use versus availability were conducted for site series and structural stages of the 2 primary vegetation communities within each ecosite. Discriminant function analysis (DFA) was used to conduct a multivariate analysis of bighorn sheep habitat use within the 3 study areas. Two DFA's were conducted for each study area, one including all variables and the second excluding variables from the TEM data. Binary models were developed to contrast land used by bighorn sheep with land that was not used within the 100% MCP cumulative winter range.

Thirty-two bighorn ewes were radio tracked at the 3 study areas and 2,092 radio locations were collected between December and April. Radiocollared bighorn ewes used habitat in a predictable fashion in all 3 study areas. Results from the different univariate and multivariate analyses of the radio telemetry data showed strong correlations between ewe distribution and several habitat types that provided life requisites: forage, security, and thermal cover. Over all 3 study areas, bluebunch wheatgrass site series were selected for, typically in the earlier seral stages such as grass/forb and shrub/herb. Selection for these within the second decile (the second most abundant site series within an ecosite) was sometimes directed toward older structural stages in which open stands of Douglas fir occurred with understories of bluebunch wheatgrass. In addition, the attraction to artificial opening was evident at 2 of the 3 study areas. Abandoned fields at Bull River and Wigwam/Mount Broadwood were strongly selected in the first decile. All site series strongly selected by bighorn ewes contained forage in the form of grasses, herbs, and/or shrubs. This emphasizes the generalist foraging strategy of bighorn sheep. They are capable of digesting a wide variety of plant species and many different forage species contribute to their diet. Site series in the second decile were an important part of bighorn ewe habitat selection. The DFA using all variables demonstrated this; site series in the second decile were contributors to the multivariate model in all 3 study areas. In some cases (e.g., Columbia Lake), a bluebunch wheatgrass site series from the second decile was ranked higher in importance to the model than the same site series in the first decile. These site series may be smaller inclusions of

preferred habitat in a matrix of less suitable habitat. Crosstabulations of use versus availability showed the importance of escape terrain in the second decile at Bull River and Columbia Lake. Rock outcrops were strongly selected at Columbia Lake while at Bull River, talus was strongly selected in the second decile. A greenness band derived from Landsat 5 TM satellite images appear to be well-correlated with ewe winter range use in the East Kootenay Trench. Radiocollared bighorn ewes strongly selected lower greenness values than would be expected by chance. Topographical variables demonstrated the importance of terrain attributes to bighorn ewe habitat selection. Elevation, and bighorns' selection for lower elevations within their winter ranges, was ranked high in all models. Lower elevations within the winter ranges likely have less snow accumulation through the winter than higher elevations making for easier foraging by bighorns. Steep terrain, distance to steep terrain, and terrain ruggedness all provide some measure of ewe habitat selection for security. These attributes appear to correlate well with escape terrain. In most DFA's, at least one of these variables was a significant contributor to the model. Increased terrain ruggedness, increased slope, and decreased distance to steep terrain characterized ewe habitat selection. Aspect, another topographical variable, was another frequent contributor to the DFA's. In particular, southerly aspects tended to be strongly selected. Southerly aspects have greater exposure to solar radiation in the winter and as such accumulate less snow. In the same manner as lower elevations, southerly aspects are preferred feeding sites since bighorns have to dig less to gain access to forage.

This analysis emphasizes some of the strengths and weaknesses of using TEM as a tool to examine bighorn sheep habitat relationships. The TEM variables showed strong correlations with bighorn sheep habitat use. By identifying site series and structural stages that are strongly selected as well as those strongly avoided by bighorn ewes, habitat manipulations can be specifically targeted to increase the ability of the winter range to support sheep. In particular, ecosites with preferred site series (e.g., a bluebunch wheatgrass type) but occurring in structural stages that are avoided by bighorns can be targeted for habitat enhancement. These sites could be manipulated to bring them back to an earlier seral stage (i.e., a lower structural stage), one that is preferred by sheep. These management prescriptions can be very specific so that only those ecosites that are occurring in proximity to ecosites that are heavily used by bighorns are manipulated. This should increase the likelihood that habitat enhancement sites will be discovered quickly by bighorns on the winter range. A weakness of the TEM data is its limited areal extent. Even though sheep populations at the 3 study areas are currently low relative to historic numbers, the 100% MCP winter range in each study area extended beyond the boundaries of the TEM area. Data regarding habitat selection of ewes outside the TEM boundaries couldn't be used. Similarly, the results of the habitat selection analysis can only be applied to areas with TEM data in place. Bighorn winter ranges without TEM data cannot benefit from the analysis.

The topographical and satellite image based variables do not suffer from this problem. They are available across the landscape and relationships developed in the 3 study areas can be applied throughout low elevation sheep range on the east side of the Trench. In addition, although the DFA's which excluded the TEM variables were weaker than DFA's which used all available variables, they were not significantly weaker. Because the DFA's which did not incorporate the TEM variables used fewer variables that are more widely available and yet did not have significantly lower classification success, they are the preferred model from an regional perspective.

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1.0 INTRODUCTION

Bighorn sheep populations in the East Kootenay Trench have undergone cyclic epizootic die-offs followed by slow recovery, with a general trend toward lower numbers. Bighorn sheep wintering at low elevations at East Columbia Lake, Bull River, and Wigwam Flats are well below historic numbers. Reasons for these low numbers are not known, although speculation abounds regarding habitat degradation, predators, disease, and human harassment on winter ranges. Habitat management prescriptions have been suggested but specific plans cannot be formulated without a objective assessment based on current empirical data collected in the East Kootenay Trench. The East Kootenay Wildlife Association embarked on a 5 year project to examine the ability of the fall through spring bighorn ranges at Columbia Lake, Bull River, and Wigwam/Mount Broadwood to support bighorns. Bighorn ewes were radiocollared and radio tracking has been conducted between 1997 and 2000 at the 3 winter ranges. This report is a preliminary statistical assessment of habitat selection by radiocollared ewes on these winter ranges.

2.0 STUDY AREAS

Bighorn ewes have been radio tracked at 3 low-elevation winter ranges, Columbia Lake, Bull River, and Wigwam Flats, on the east side of the Kootenay Trench (Fig. 1).

3.0 METHODS

3.1 Radio Tracking

Radio tracking occurred primarily from the ground. Each study area was monitored intensively over 2 winters. The winter period was defined as from the beginning of December through until the end of April. During winters of intensive monitoring, all radiocollared ewes were located approximately 3 times per week. Locations of radiocollared sheep were initially determined by triangulation. When the general area of a collared sheep was determined, then a visual location was determined whenever possible. Once a sighting was made, the general habitat type was recorded, as well as the presence of conspecifics.

3.2 Analysis

In statistical tests, we contrasted bighorn ewe radiolocations collected between December and April with available habitat. Sheep locations were buffered with a 100 m radius circle to take in account mapping error and the areas within the buffered points were sampled randomly. Available habitat was determined using a stratified random sample of the 100% minimum convex polygon (MCP) winter range of all radiocollared sheep at each study area. Variables used in the analysis are listed in Table 1 and were primarily topographical (e.g., elevation, aspect) or derived from 1:20,000 scale ecosystem mapping of the 3 winter ranges, that is, terrain ecosystem mapping (TEM). In addition, a greenness index derived from Landsat 5 TM satellite imagery was used to examine possible relationships between bighorn sheep distribution and this index of landscape productivity.

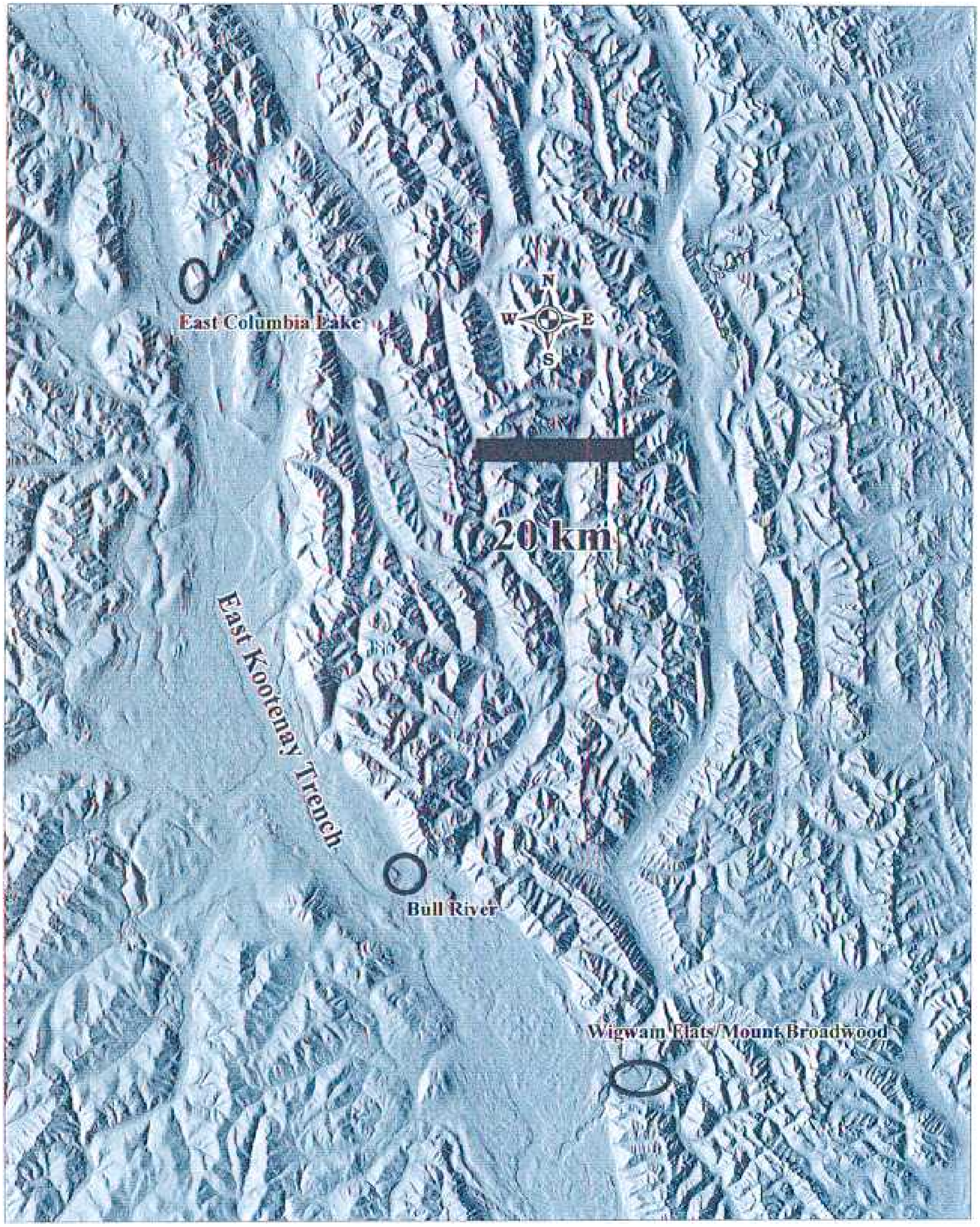

Figure 1. Locations of 3 low elevation sheep ranges, Columbia Lake, Bull River, and Wigwam/Mount Broadwood in the East Kootenay Trench.

3.2.1 Univariate Analysis of Terrain Ecosystem Mapping Variables

Using TEM, univariate crosstabulations of use versus availability were conducted for site series and structural stages of the 2 primary vegetation communities within each ecosite to determine if radiocollared ewes were using the winter range within their 100% MCP winter ranges in a random manner. The sign and value of adjusted residuals were used to determine the strength of selection or avoidance. Absolute values of adjusted residuals of greater than or equal to 3 standard deviations indicated significant selection or avoidance at the 99% level.

3.2.2 Discriminate Function Analysis

Discriminant function analysis (DFA) was used to conduct a multivariate analysis of bighorn sheep habitat use within the 3 study areas. Two DFA's were conducted for each study area, one including all variables and the second excluding variables from the TEM data. We used the Mahalanobis distances criterion in the stepwise method for variables' entry and removal. Binary models were developed to contrast land used by bighorn sheep with land that was not used within the 100% MCP cumulative winter range. We judged the relative contribution of the variables by analyzing the order in which the variables were entered/removed, combined with the analysis of the structure matrix and the magnitude of the Standardized Canonical Coefficients. If DFA is to be used as a predictive tool, then the Standardized Canonical Coefficients should be given a greater weight. However, if there are several variables with Standardized Canonical Coefficients of significant size, then interpretation is more complex and the value of the Standardized Canonical Coefficients for individual variables may be misleading. A better understanding of the individual variables can be attained by examining the absolute value of the Structure Matrix Coefficients; higher values indicate greater importance to the model. We estimated the overall power of the models by scrutinizing the Eigenvalues, Wilk's Lambdas, Canonical Correlation Coefficients, and the percentage of correctly classified cases.

Table 1. Variables used in the analysis of bighorn sheep distribution in the Columbia Lake, Bull River, and Wigwam/Mount Broadwood study areas.

Variable	Source
Site Series – first decile	1:20,000 scale Terrain Ecosystem Mapping (TEM)
Structural Stage – first decile	
Site Series – second decile	
Structural Stage – second decile	
Elevation	Digital Elevation Model (DEM)
Terrain ruggedness	
Slope (degrees)	
Aspects, 8 cardinal directions and flat	
Greenness	Landsat 5 satellite imagery, Bull River and Columbia Lake only

3.2.3 General Linear Modeling (GLM)

General linear modeling (GLM) was used to examine the similarities and differences in availability and use of habitat within the 3 study areas. Estimated marginal means of topographical variables were contrasted between Columbia Lake, Bull River, and Wigwam/Mount Broadwood to test whether habitat availability and use were significantly different between the 3 winter ranges. TEM variables could not be used in this analysis because classification of site series and structural stages was not consistent across the 3 study areas.

3.0 RESULTS

3.1 Radio telemetry

3.1.1 Columbia Lake

Ten ewes were radiocollared in late January, 1997. These ewes were radio tracked on average 3 times per week until they left their winter range to lamb in early summer 1997. When they returned to the winter range in fall 1997, intensive radio tracking resumed. An additional ewe was radiocollared to replace a ewe that had died. Radio locations were again collected on average 3 times per week for all ewes until they left their winter range in early summer 1998. Opportunistic monitoring, at an intensity of once per week or less was continued between December and April in 1998-99 and in 1999-2000. Six hundred thirty-two radiolocations were collected from ewes using the Columbia Lake winter range between 1997 and 2000. Most radiolocations, 73%, were collected during the first 2 winters (Table 2). Use of the Columbia Lake winter range was concentrated at the south end of the lake immediately north of Canal Flats (Fig. 2). However, the cumulative 100% MCP for all radiocollared ewes included the entire east side of Columbia Lake between Canal Flats and Fairmont.

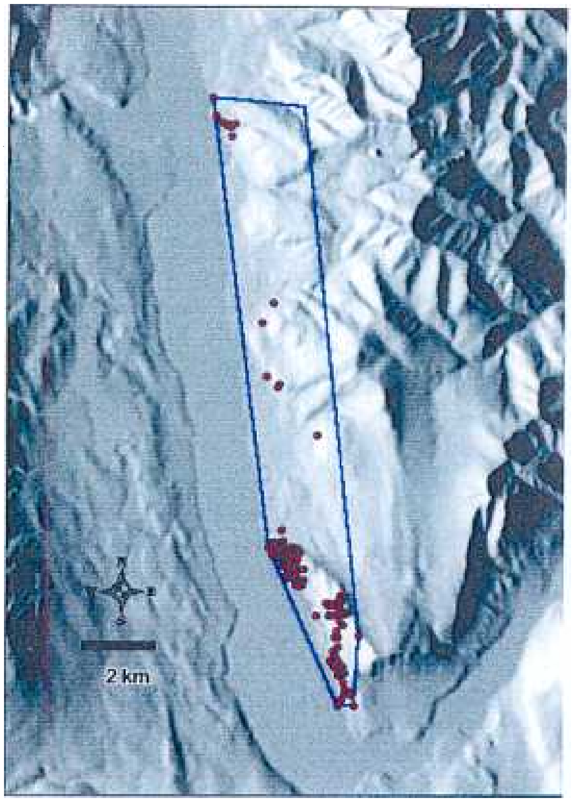

Figure 2. Radio locations and 100% MCP of radiocollared ewes on the Columbia Lake winter range.

3.1.2 Bull River

Ten ewes were radiocollared in February, 1997. As was the case with the Columbia Lake ewes, these ewes were radio tracked on average 3 times per week until they left their winter range to lamb in early summer 1997. An additional 2 ewes were radiocollared to replace ewes that had died. When ewes returned to the winter range in fall 1997, intensive radio tracking resumed. Radio locations were collected on average 3 times per week for all ewes until they again left their winter range in early summer 1998. Opportunistic monitoring, at an intensity of once per week or less was continued between December and April in 1998-99 and in 1999-2000. Seven hundred twenty-two radiolocations were collected from ewes using the Bull River winter range between 1997 and 2000. Most radiolocations, 70.6 %, were collected during the first 2 winters (Table 2). The majority of locations were along the north side of the Bull River although there were also centres of activity in the Norbury Hills and on the Hawke Ranch to the west (Fig. 3).

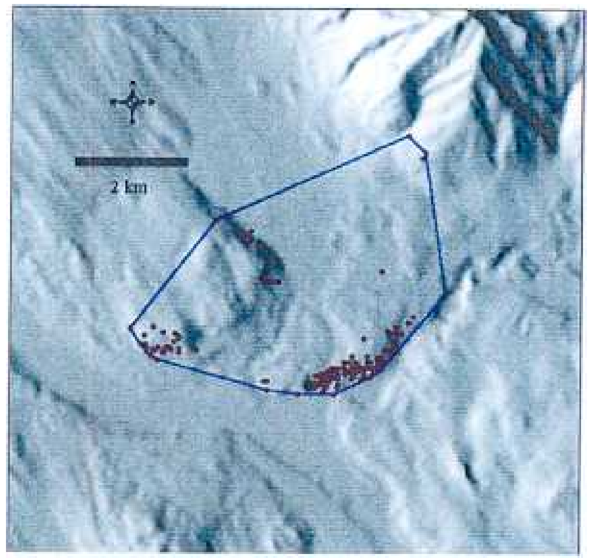

Figure 3. Radio locations and 100% MCP of radiocollared ewes on the Bull River winter range.

Table 2. Radiolocations collected each December – April period on each winter range.

Study Area	**Year**			
	1997	**1997-1998**	**1998-1999**	**1999-2000**
Columbia Lake	224	238	38	132
Bull River	170	340	45	167
Wigwam/Mount Broadwood			274	464

3.1.3 Wigwam Flats

Nine ewes were radiocollared in late January, 1999. These ewes were radiotracked on average 3 time per week until they left their winter range to lamb in early summer 1999. When they returned to the winter range in fall 1999, intensive radio tracking resumed. Radio locations were collected for all ewes until they again left their winter range in early summer 2000. Seven hundred thirty-eight radiolocations were collected from ewes using the Wigwam Flats winter range between 1999 and 2000 (Table 2). Most radio locations were in proximity to confluence of the Elk and Wigwam Rivers (Fig. 4).

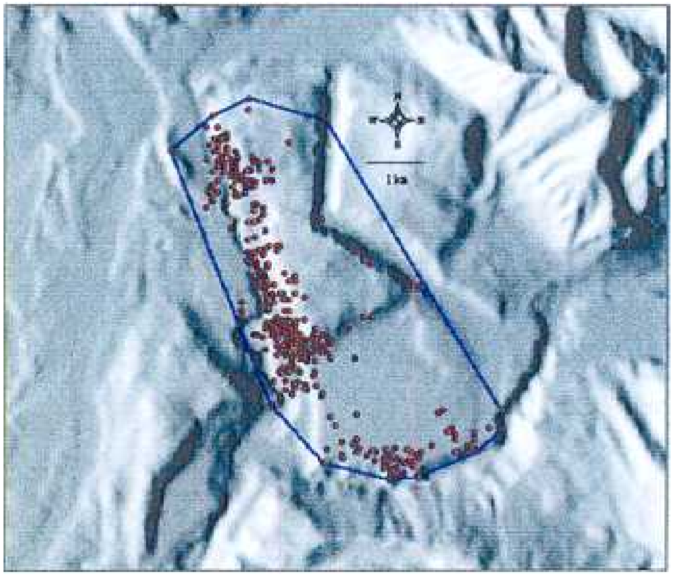

Figure 4. Radio locations and 100% MCP of radiocollared ewes on the Wigwam Flats winter range.

3.2 Habitat Selection Analysis

Radiocollared bighorn ewes at all 3 study areas appear to be using habitat within their 100% MCP winter ranges in a non-random fashion based on a visual examination of the distribution of radio locations within each winter range. Habitat selection analysis was conducted 2 ways. First, TEM variables for each winter range were used to examine sheep use relative to availability in a univariate manner. Second, DFA was employed using topographic, satellite, and TEM data to examine multivariate habitat selection.

3.2.1 Terrain Ecosytem Mapping (TEM)

Individual ecosites within the TEM database were composed of up to 3 vegetation communities (i.e., site series) and the areal extent of each site series within an ecosite was estimated to the nearest 10%. The first decile represented the most common site series, followed by the second decile, and the third. Each site series was described by dominant plant species (>20% cover) and associates (5-20% cover). In addition, each decile was assigned a structural stage, the current successional or seral stage of the site series at the time of mapping. Structural stage scales varied between the 3 study areas (Table 3). Analysis was restricted to the first 2 deciles. Complete TEM descriptions of each study area are available elsewhere and will not be duplicated in this report (JMJ Holdings 1994, 1996, 1997).

Columbia Lake

Four site series were strongly selected by radiocollared bighorn ewes within the first decile. Pasture sage – bluebunch wheatgrass (SW) was most strongly selected, followed by antelope brush – bluebunch wheatgrass (AW), exposed soil (ES), and Rocky Mountain juniper – bluebunch wheatgrass ecosite types (DJ) (Fig. 5). The most strongly-selected structural stages in the first decile were grass/forb, herb/shrub, and non-vegetated/sparsely vegetated (Fig. 6).

Table 3. Structural stage scales used for the 3 terrain ecosystem mapping study areas.

Structural stage	Columbia Lake	Bull River	Wigwam/ Mount Broadwood
non-vegetated/sparsely vegetated	1	1	
grass/forb	2	2	
shrub/herb	3	3	1
low shrub	3a	3a	
tall shrub	3b	3b	
pole sapling	4	4	2
young forest	5	5	3
mature forest	6	6	4
old forest	7	7	5

Site series and structural stages strongly avoided by bighorn ewes were, in increasing order, red-osier dogwood (CD), sarsaparilla (SS), pine grass-step moss (DP), spruce-pine grass (SP), oregon grape-pine grass (LP), snowberry-balsamroot (DS), juniper-pine grass (LT), pine grass-twinflower (DT), and soopolallie-grouseberry (SG) (Fig. 5), and the 4 forest types, pole sapling, and young, mature, and old forest (Fig. 6).

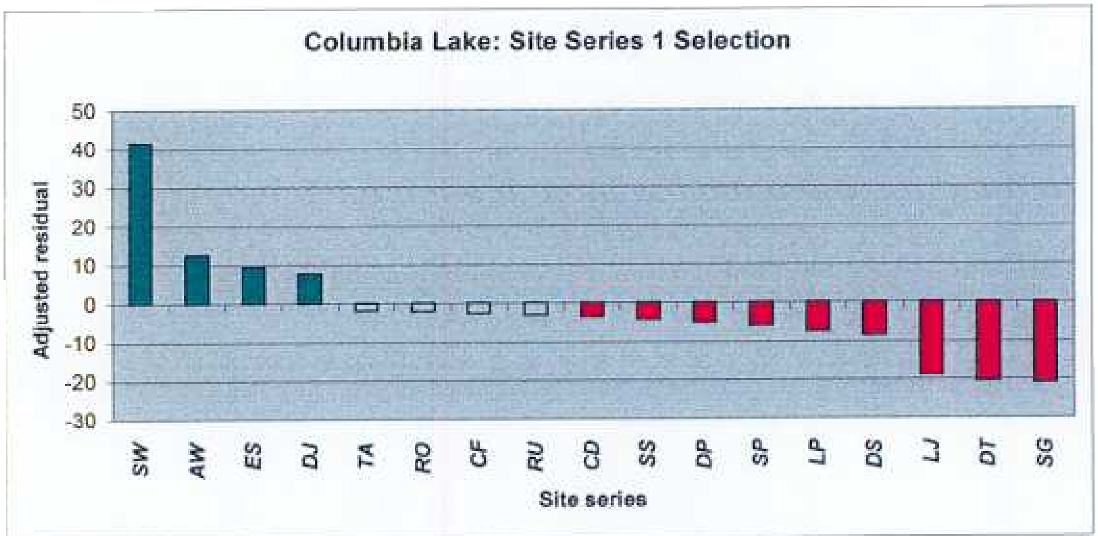

Figure 5. Selection for and against site series in the first decile by bighorn ewes at Columbia Lake as indicated by the adjusted residual statistic.

Pasture sage-bluebunch wheatgrass in the grass/forb structural stage is dominated by open grasslands of bluebunch wheatgrass. Antelope brush-bluebunch wheatgrass in the same structural stage is dominated by openings of bluebunch wheatgrass associated with several other species, primarily antelope brush, saskatoon, pasture sage, and Kentucky bluegrass.

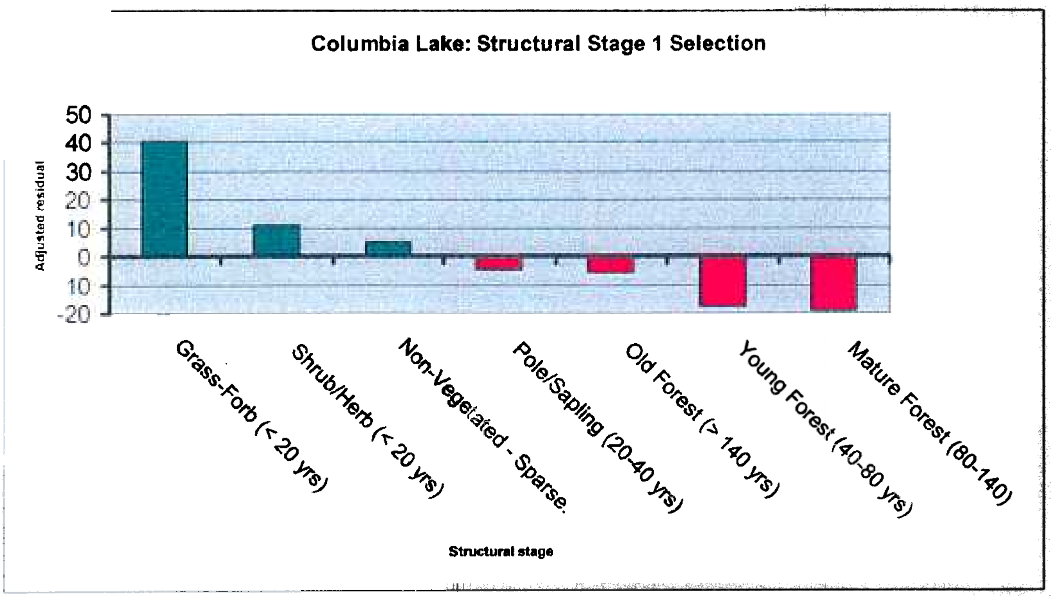

Figure 6. Selection for and against structural stages in the first decile by bighorn ewes at Columbia Lake as indicated by the adjusted residual statistic.

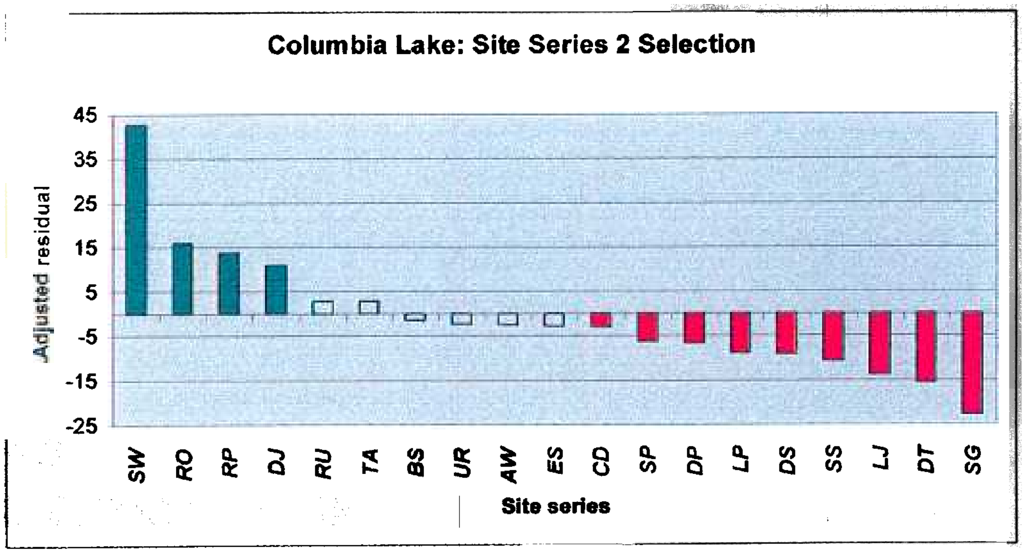

Figure 7. Selection for and against site series in the second decile by bighorn ewes at Columbia Lake as indicated by the adjusted residual statistic.

Rocky Mountain juniper-bluebunch wheatgrass ecosites selected for by bighorn ewes were primarily in the young and mature forest structural stages. These site series are dominated by open Douglas fir stands associated with Rocky Mountain juniper, bluebunch wheatgrass, nodding onion, kinnikinnik, and pine grass.

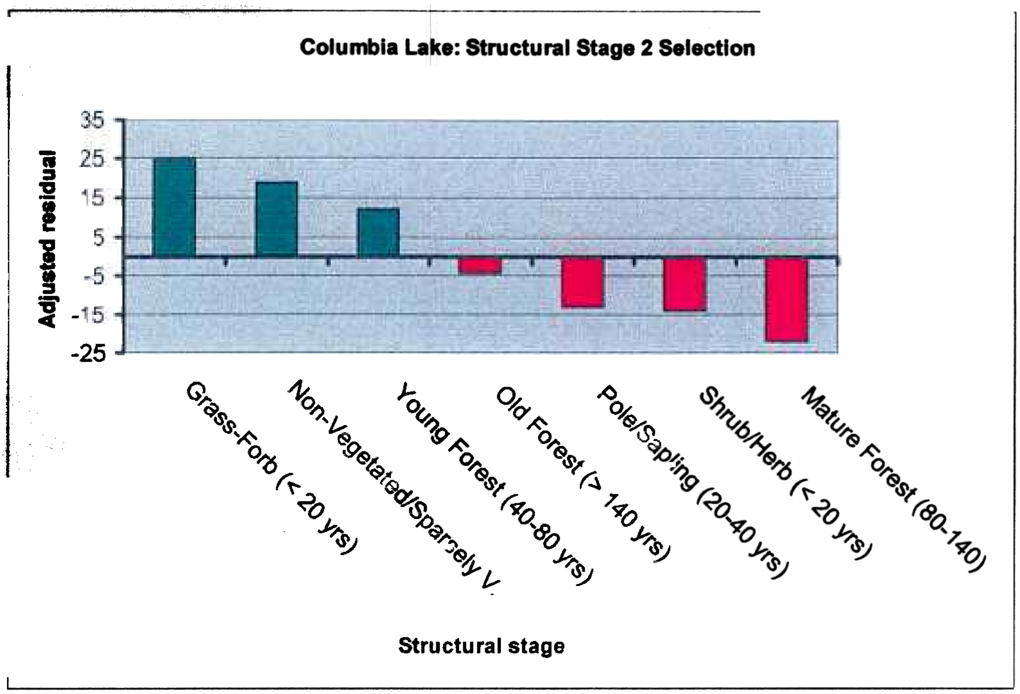

Figure 8. Selection for and against structural stages in the second decile by bighorn ewes at Columbia Lake as indicated by the adjusted residual statistic.

In the second decile, bighorn ewes again selected for pasture sage – bluebunch wheatgrass (SW) and Rocky Mountain juniper-bluebunch wheatgrass (DJ) site series, but in addition, they were also found more often than expected in areas where rocky outcrops (RO) and road surfaces (RP) were present (Fig. 7). All site series that were avoided in the first decile were also strongly avoided in the second.

Grass-forb, non-vegetated/sparsely vegetated, and young forest were strongly selected in the second decile, while old forest, pole sapling, shrub-herb, and mature forest stages were strongly avoided (Fig. 8). Vegetation on rocky outcrops accounted for less than 20% of the ground cover and was often dominated by low cover of saskatoon. However, plant cover could be very diverse in these communities depending on the microclimate.

Strongly selected ecosites were distributed at low elevations, primarily on the west side of the 100% MCP cumulative winter range (Figs. 9, 10). In particular, ecosites at the south end of the cumulative home range received more use that the same ecosites further north. Ecosites where rocky outcrops occurred in the second decile were most-commonly associated with pasture sage-bluebunch wheatgrass and antelope brush-bluebunch wheatgrass site series in the first structural stage (Figs. 9, 10).

Bull River

Three site series, antelope brush-bluebunch wheatgrass (AW), cultivated field (CF), and river (RI) were strongly selected by radiocollared bighorn ewes (Fig. 11). Site series that they avoided most were snowberry-balsamroot (DS), pinegrass-twinflower (DT), and

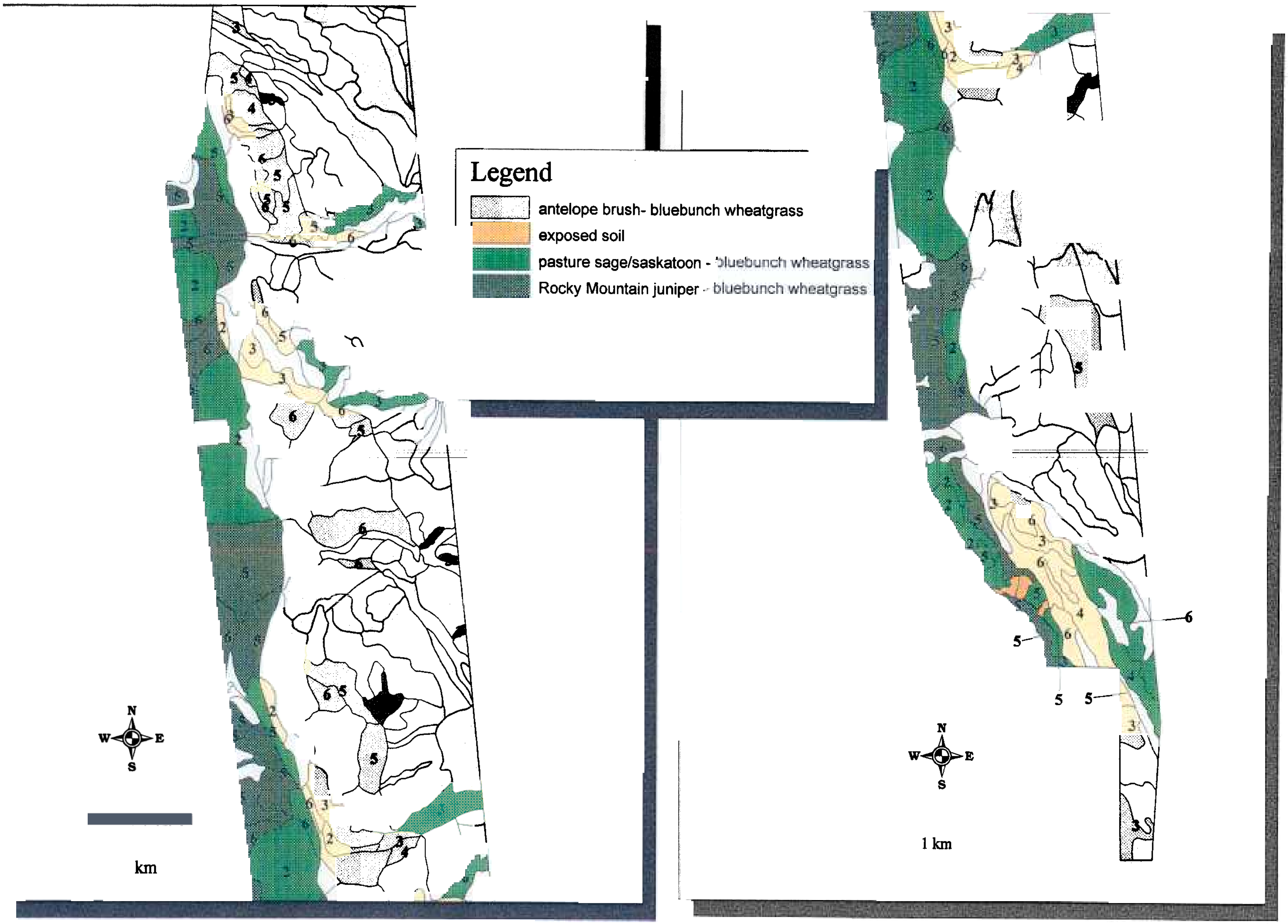

Figure 9. First decile site series strongly selected by bighorn ewes within their cumulative winter range at Columbia Lake. Numbers within each polygon refers to the associated structural stage of the site series.

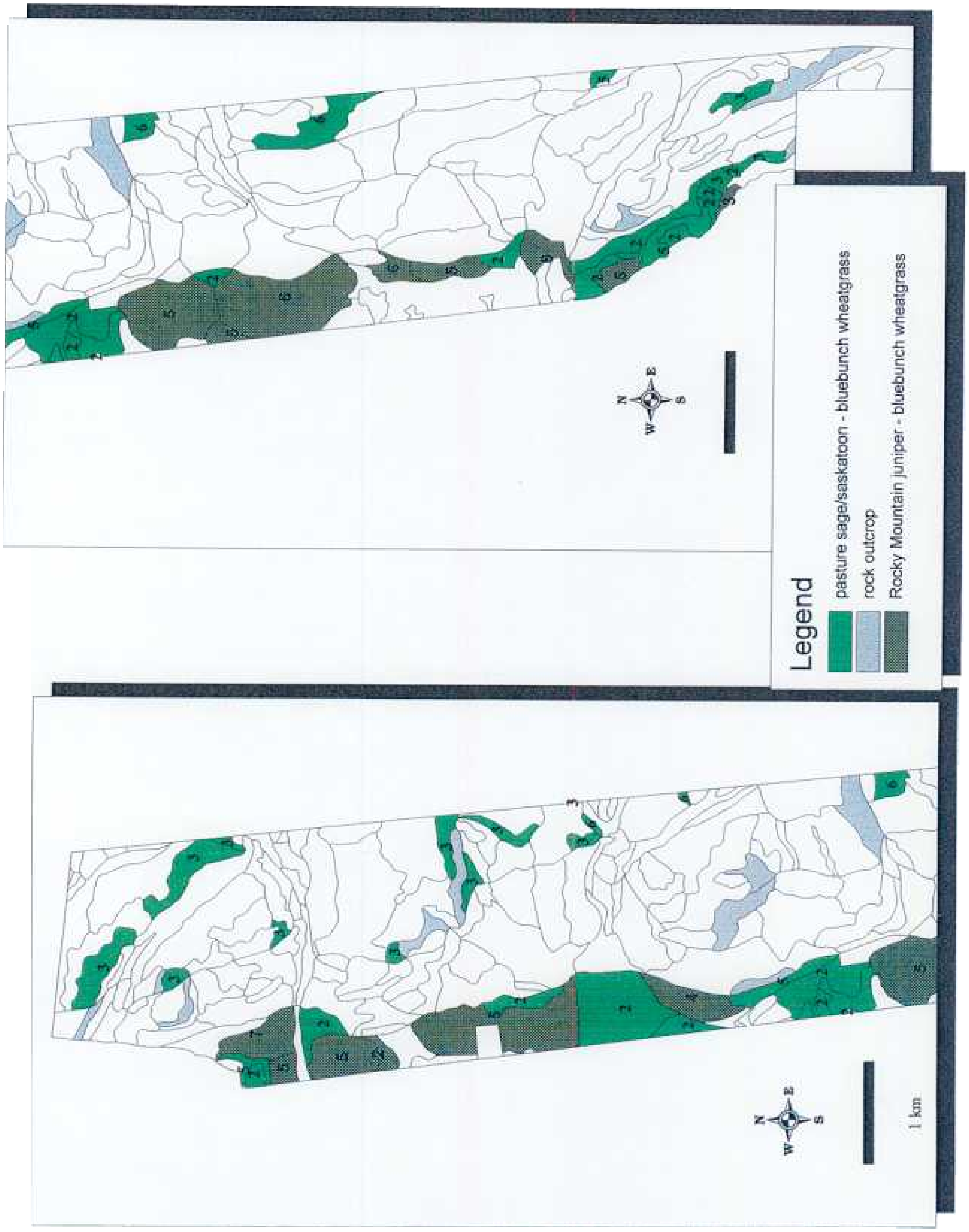

Figure 10. Second decile site series selected by bighorn ewes within their cumulative winter range at Columbia Lake. Numbers within each polygon refers to the associated structural stage of the site series.

spruce-pinegrass (SP). There was strong selection for one structural stage, low shrub, at Bull River. Bighorn ewes avoided all structural stages greater than low shrub (Fig. 12).

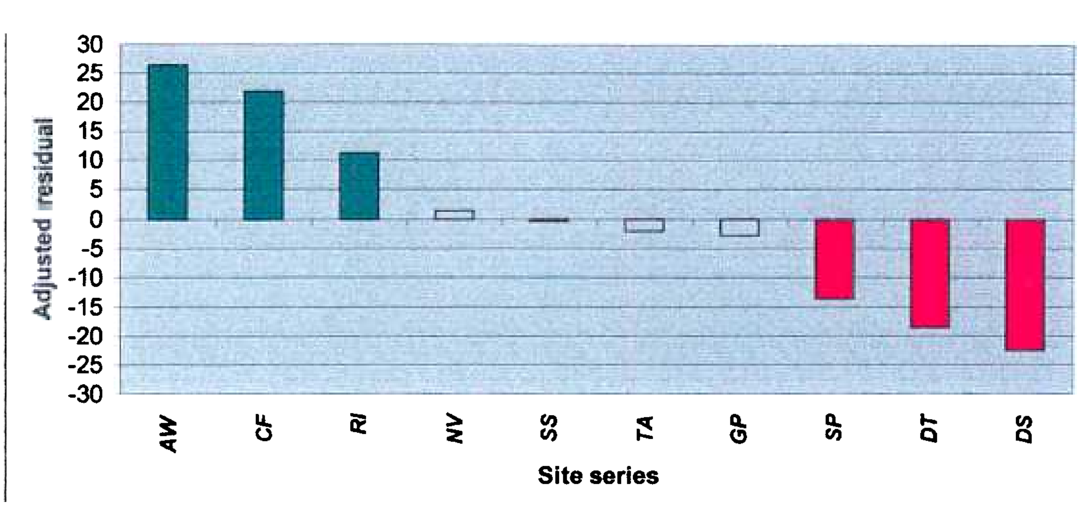

Figure 11. Selection for and against site series in the first decile by bighorn ewes at Bull River as indicated by the adjusted residual statistic.

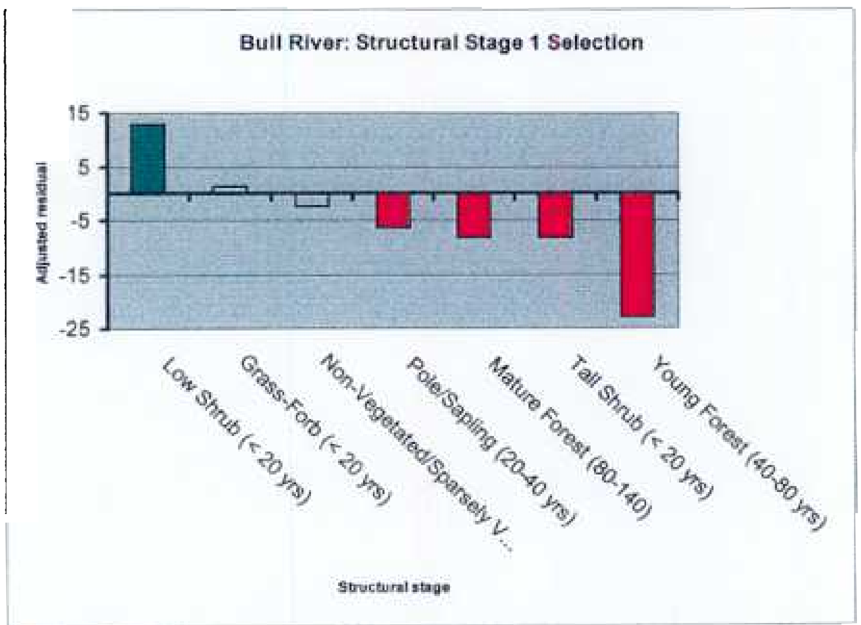

Figure 12. Selection for and against structural stages in the first decile by bighorn ewes at Bull River as indicated by the adjusted residual statistic.

Three site series were strongly selected in the second decile. In addition to antelope brush-bluebunch wheatgrass (AW), talus (TA) and pine grass-twin flower (DT) site series were strongly selected (Fig. 13). Site series strongly avoided by bighorn ewes were, in increasing order, river (RI), rock outcrops (RO), cultivated field (CF), sarsaparilla (SS), spruce-pine grass (SP), and snowberry-balsamroot (DS). Within the second decile, the young forest and sparsely vegetated structural stages were strongly selected while the grass/forb, pole sapling, and low shrub structural stages were avoided (Fig. 14).

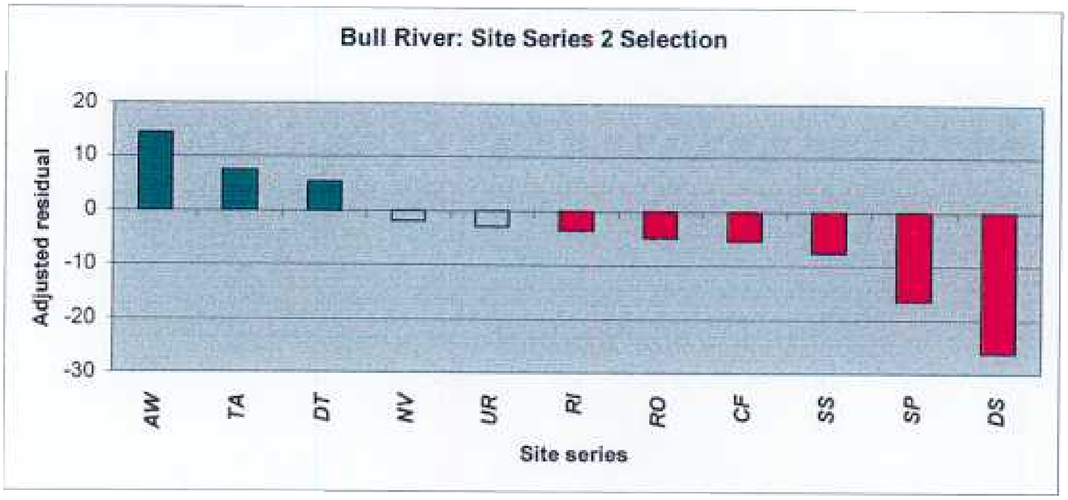

Figure 13. Selection for and against site series in the second decile by bighorn ewes at Bull River as indicated by the adjusted residual statistic.

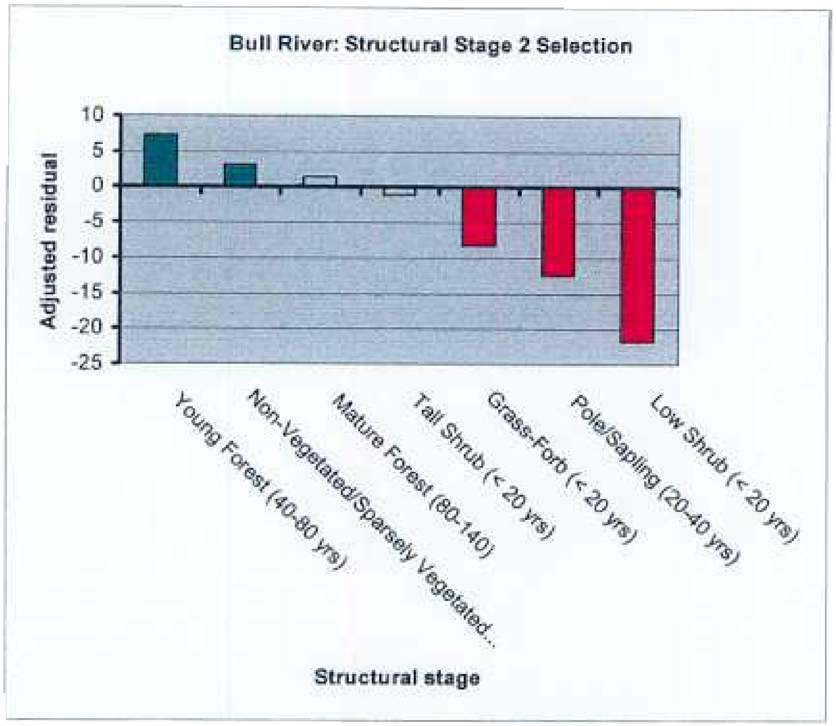

Figure 14. Selection for and against structural stages in the second decile by bighorn ewes at Bull River as indicated by the adjusted residual statistic.

Antelope brush-bluebunch wheatgrass site series in the low shrub structural stage are dominated by those species in addition to saskatoon. However, Douglas fir are often associated with the ecosites as well as ponderosa pine, pin cherry, snowberry, june grass, and Canada bluegrass. Most of these sites were found along the north side of the Bull River immediately east of the highway (Fig 15). The only cultivated field within the 100% MCP winter range was located in the same immediate area.

Wigwam/Mount Broadwood

Radiocollared ewes strongly selected 4 site series in the first decile at the Wigwam-Mount Broadwood study area and avoided 8 (Fig. 16). Abandoned field (AF), western larch-snowberry (WS), Douglas fir-bluebunch wheatgrass (DB), and non-vegetated (NV) site series were used significantly greater than expected. Site series strongly avoided by bighorn ewes were, in increasing order, bulrush-water weed marsh (BW), saskatoon-Douglas maple (SM), juniper-pinegrass (JP), talus (TA), grey frayed-cap feathermoss-bluegrass (GB), western larch-birch-leafed spirea (WB), Douglas fir-pinegrass (DP), tall oregon grape-velvet-leaved blueberry (OV), Douglas fir-red-stemmed feathermoss (DR), and bluebunch wheatgrass-jacob's ladder (BJ). No structural stages were strongly selected in the first decile although the shrub/herb and pole sapling structural stages were used more frequently than expected. (Fig. 17). Young forest was strongly avoided by radiocollared ewes.

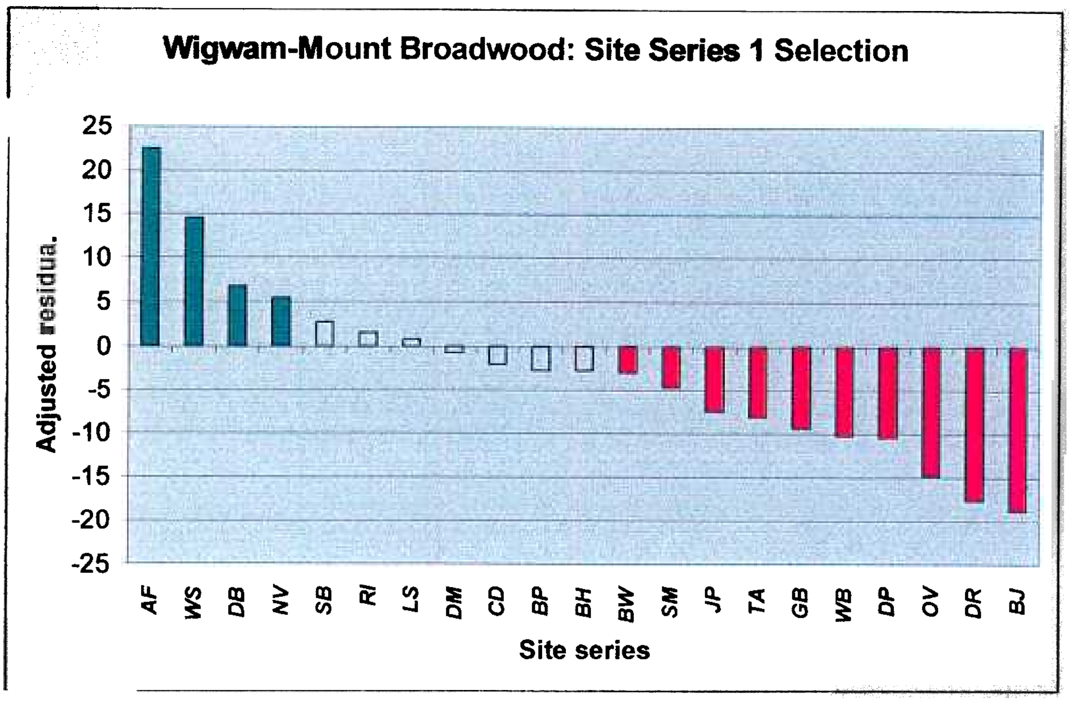

Figure 16. Selection for and against site series in the first decile by bighorn ewes at Wigwam-Mount Broadwood as indicated by the adjusted residual statistic.

Figure 15. Site series selected by bighorn ewes within their cumulative winter range at Bull River. Numbers within each polygon refers to the associated structural stage of the site series.

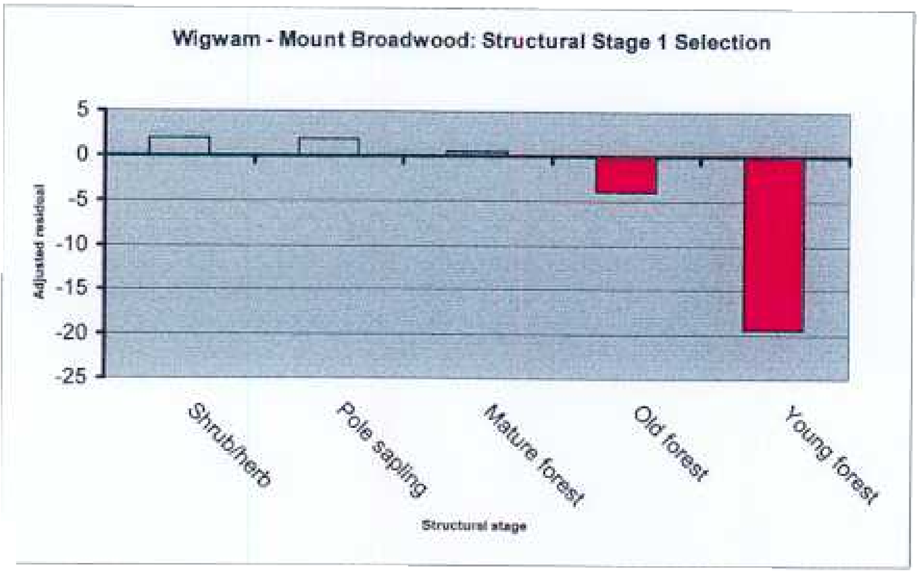

Figure 17. Selection for and against structural stages in the first decile by bighorn ewes at Wigwam-Mount Broadwood as indicated by the adjusted residual statistic.

Within the second decile, Douglas fir-bluebunch wheatgrass (DB), western larch-snowberry (WS), and snowberry-arrowleaved balsamroot (SB) were strongly selected while 8 other site series were strongly avoided (Fig.). Site series strongly avoided by bighorn ewes were, in increasing order, paper birch-red osier dogwood (BD), rock outcrop (RO), western larch-birch-leafed spirea (WB), bluegrass-pussytoes (BP), bluebunch wheatgrass-jacob's ladder (BJ), grey frayed-cap feathermoss-bluegrass (GB), Douglas fir-red-stemmed feathermoss (DR), tall oregon grape-velvet-leaved blueberry (OV). Among structural stages, young forest and pole sapling were strongly selected within the second decile, while old growth forest was used significantly less than expected (Fig. 19).

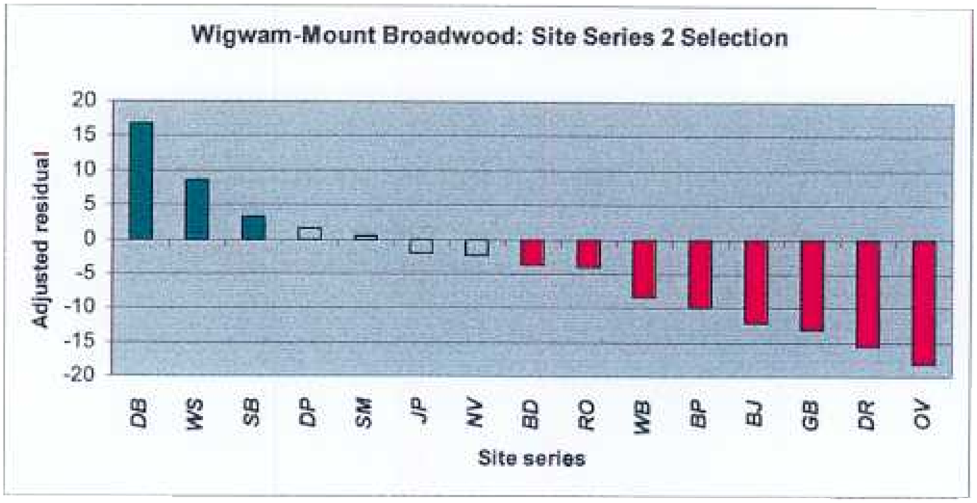

Figure 18. Selection for and against site series in the second decile by bighorn ewes at Wigwam-Mount Broadwood as indicated by the adjusted residual statistic.

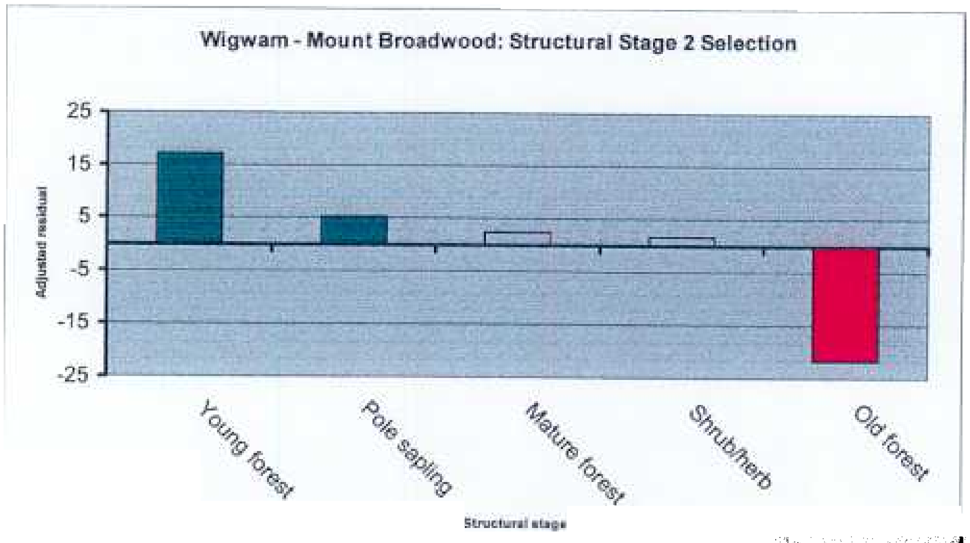

Figure 19. Selection for and against structural stages in the second decile by bighorn ewes at Wigwam-Mount Broadwood as indicated by the adjusted residual statistic.

The most frequently-used of the strongly selected site series were along the Wigwam and Elk Rivers. This was particularly true for the Douglas fir-bluebunch wheatgrass site series in both structural stages. Although the type was located throughout the southern third of the MCP (Fig. 20), it was used by bighorns only in close proximity to the two rivers.

The Douglas fir-bluebunch wheatgrass site series was most frequently associated with the shrub/herb structural stage, particularly in the first decile. This ecosite is dominated by bluebunch wheatgrass grassland. Other grasses that occur include junegrass and other bluegrass species. In the pole sapling and young forest structural stages, it changes from a grassland to an open Douglas fir forest with a grassland understory. Western larch-snowberry types in the shrub/herb structural stage consisted primarily of dense stands of snowberry, but with several bighorn forage plants associated with it. Saskatoon, buckbrush, western fescue, and oregon grape are found here.

3.2.2 Discriminant Function Analysis-including all variables

The discriminant function analysis (DFA) using all variables discriminated well between used and unused habitat within the 100% MCP winter ranges at the 3 study areas. Relatively high Canonical Correlation Coefficients (0.756-0.624), low Wilk's lambda values (0.611-0.428), high Eigenvalues (0.637-1.334), and finally, very good percent classification success (79.9-87.5%) all indicate the strength of the DFA to differentiate between land that was selected by bighorn ewes and those areas that were avoided within the winter ranges (Fig. 21). The Bull River and Columbia Lake DFA's were stronger than the Wigwam DFA in all cases.

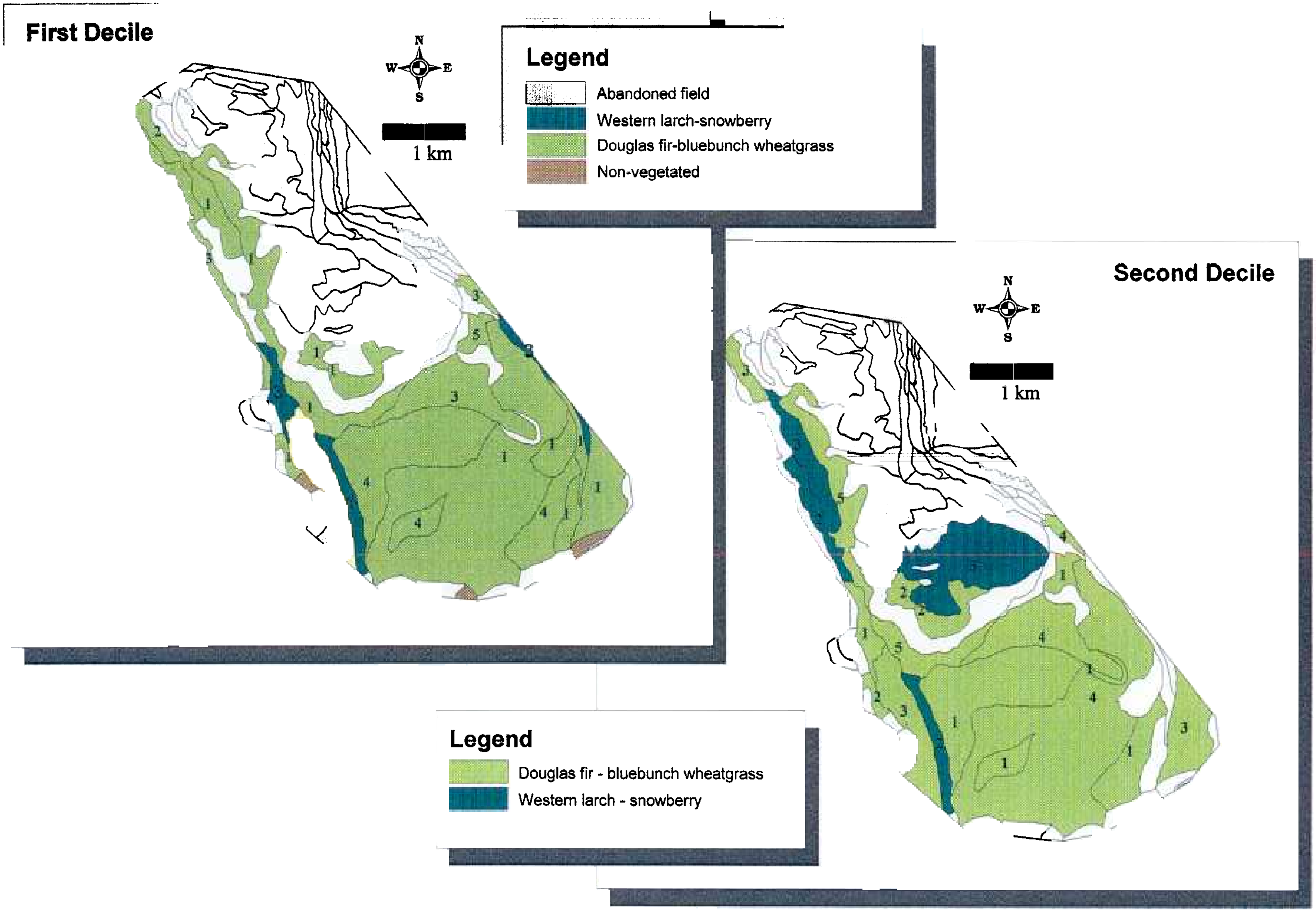

Figure 20. Site series selected by bighorn ewes within their cumulative winter range at Wigwam/Mount Broadwood. Numbers within each polygon refers to the associated structural stage of the site series.

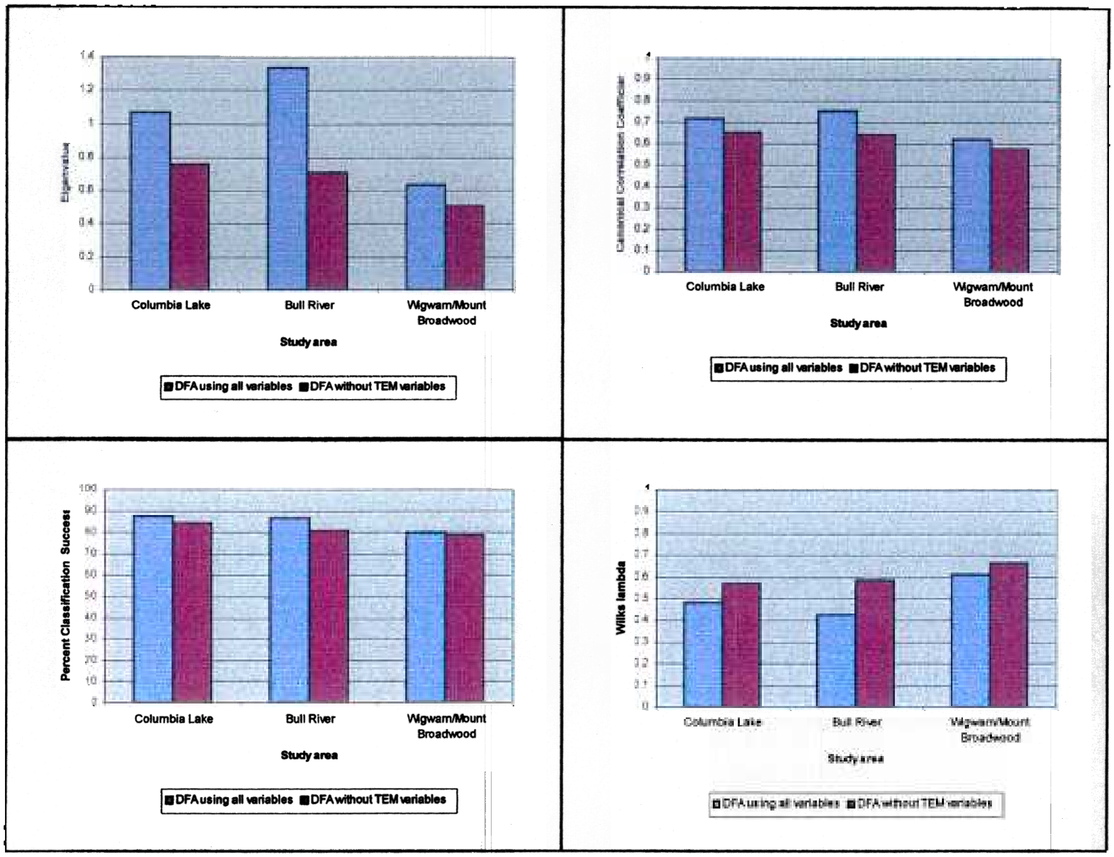

Figure 21. A comparison of Eigenvalues, Canonical Correlation Coefficients, Wilk's Lambda, and percent classification success associated with discriminant function analyses conducted with and without TEM variables in the 3 bighorn ewe winter ranges in the East Kootenay Trench.

Columbia Lake

Table 4 lists the top 10 variables in the DFA based on the absolute value of the Standardized Canonical Coefficient. The group centroid for selected habitat was 1.79 and for available habitat was –0.59. A positive group centroid for selected habitat and a negative value for available habitat means that for TEM variables, a positive Standardized Canonical Coefficient represents selection for that site series while a negative value indicates avoidance. Among topographical variables, elevation, distance to steep terrain, terrain ruggedness, and southwest aspect were important contributors to the multivariate model. Bighorns selected for lower elevations, land closer to areas of steep terrain (≥30°), increased terrain ruggedness (i.e., land with many changes in slope and aspect), and land facing southwest within the winter home range. Among TEM variables, pasture sage-bluebunch wheatgrass (SW2), Rocky Mountain juniper (DJ2), juniper-pine grass (LJ2), and the soopolallie-grouseberry (SG2) site series all in the second decile (i.e., when a site series was the second most prevalent within an ecosite), were top 10 contributors to the multivariate model. In addition, the antelope brush-bluebunch wheatgrass site series (SW) and structural stage in the first decile were also in the top 10 variables. Antelope brush-bluebunch wheatgrass (SW) in the second decile was strongly selected. The other 4 site series were used significantly less than expected in the multivariate model. Lower structural stages, the earlier seral stages in succession, were also selected.

Table 4. The top 10 variables contributing to the multivariate model of bighorn ewe winter range at Columbia Lake based on the Standardized Canonical Coefficient.

Variable	Standard Canonical Coefficient
Elevation	-0.57772962
SW2	0.56016889
Distance to Steep Terrain	-0.494542955
Terrain Ruggedness	0.385756546
DJ2	0.287826381
LJ2	0.284178467
AW	0.280483227
SG2	0.216335916
Structural Stage 1	-0.214474607
SW aspect	0.211515879

Table 5 lists the top 10 contributors to the DFA based on the absolute value of the Structure Matrix Coefficient. Bighorn ewes selected for land with lower greenness values and lower structural stages in the first decile. Among site series, pasture sage-bluebunch wheatgrass was selected for in both the first and second deciles (SW, SW2), although ecosites in which the site series occurred in the second decile were more important. In addition, both pinegrass-twinflower (DT) in the first decile and soopolallie-grouseberry (SG) in the second decile were selected against. In order of importance to the DFA, the following topographical variables were included in the top 10: elevation, distance to steep terrain, terrain ruggedness, and slope.

Table 5. The top 10 variables contributing to the multivariate model of bighorn ewe winter range at Columbia Lake, based on the absolute value of the Structure Matrix.

Variable	Structure Matrix
Greenness	-0.453708596
[illegible]	-0.433976731
[illegible]	0.421779929
[illegible]	0.409845719
[illegible]	-0.372959397
Distance to Steep Terrain	-0.329099766
Terrain Ruggedness	0.264402046
Slope (degrees)	0.234291628
SG2	-0.210910714
[illegible]	-0.190830669

Bull River

Table 6 lists the top 10 variables based on the absolute value of the Standardized Canonical Coefficient in the DFA. The group centroid for selected habitat was –1.15 and for available habitat was 1.16. A negative group centroid for selected habitat and a positive value for available habitat means that for TEM variables, a negative Standardized Canonical Coefficient represents selection for that site series while a positive value indicates avoidance. Among TEM variables, site series from the second decile, snowberry balsamroot (DS2), antelope brush-bluebunch wheatgrass (AW2), and spruce-pine grass (SP2), and the structural stages associated with the second decile were major contributors to the multivariate model. All 3 site series were avoided. Among structural stages, there was selection for higher successional stages in both deciles. Within the first decile site series, spruce-pine grass (SP), and pine grass-twin flower (DT) site series were avoided. Among topographical variables, elevation was the most important, with ewes selecting for lower elevations.

Table 6. The top 10 variables contributing to the multivariate model of bighorn ewe winter range at Bull River based on the Standardized Canonical Coefficient.

Variable	Standard Canonical Coefficient
DS2	0.857870903
AW2	0.727329998
Structural stage 2	-0.71857415
CF	-0.660457881
SP2	0.589695451
Structural stage 1	-0.48337025
SP	0.444812267
RI	-0.436718351
DT	0.354179471
Elevation	0.34281743

Table 7. The top 10 variables contributing to the multivariate model of bighorn ewe winter range at Bull River, based on the absolute value of the Structure Matrix Coefficient.

Variable	Structure Matrix
Elevation	0.469582256
Structural stage 1	0.373241456
AW	-0.312120852
DS2	0.310782381
Greenness	0.302115244
DS	0.265133815
CF	-0.25372364
Terrain ruggedness	-0.245003227
SW aspect	0.240886313
DT	0.214983509

Table 7 lists the top 10 contributors to the DFA based on the absolute value of the Structure Matrix Coefficient. Six of the top 10 were TEM variables. Ewes selected for older seral stages within structural stages of the first decile. Snowberry-balsamroot (DS, DS2) was avoided in both deciles. Within the first decile, antelope brush-bluebunch wheatgrass (AW) and cultivated field (CF) site series were selected for, while pinegrass-twinflower (DT) was avoided. Elevation was the most important topographical variable, with ewes selecting for lower elevations. Increased terrain ruggedness and southwest aspects were also favoured. Finally, greenness was included in the top 10 variables. Ewes selected for locations with lower greenness values than expected by chance.

Wigwam/Mount Broadwood

Table 8 lists the top 10 variables based on the absolute value of the Standardized Canonical Coefficient. The group centroid for selected habitat was 0.688 and for available habitat was –0.926. The 4 most important variables based on the Standard Canonical Coefficient were all topographical. Ewes were found more than expected on south, southwest, and southeast aspects. In addition, they selected for lower elevations and areas closer to steep terrain. Among site series, they selected for Douglas fir-bluebunch wheatgrass in both the first and second deciles (DB, DB2), and abandoned fields (AF) in the first decile. The larch-birch leafed spirea site series (WB) was avoided in the first decile. In addition, ewes selected for lower structural stages in the second decile.

Table 9 lists the top 10 contributors to the DFA based on the absolute value of the Structure Matrix. Five were topographical variables. Lower elevations, decreased distance to steep terrain, southwest aspects, and increased terrain ruggedness were all selected. Flat terrain was avoided. Abandoned fields (AF) and Douglas fir-bluebunch wheatgrass (DB) site series in the first decile were used more than expected, while Douglas fir-red-stemmed feathermoss (DR) was avoided. Tall oregon grape-velvet-leaved blueberry (OV, OV2) was avoided in both deciles.

Table 8. The top 10 variables contributing to the multivariate model of bighorn ewe winter range at Bull River based on the Standardized Canonical Coefficient.

Variable	Standard Canonical Coefficient
Distance to Steep Terrain	-0.553991113
SW aspect	0.545442475
S aspect	0.417968399
Elevation	-0.39087221
DB2	0.3631968
AF	0.260629652
SE aspect	0.258250718
WB	-0.190328801
Structural Stage 2	-0.156097238
DB	0.152120853

Table 9. The top 10 variables contributing to the multivariate model of bighorn ewe winter range at Wigwam/Mount Broadwood, based on the absolute value of the Structure Matrix Coefficient.

Variable	Structure Matrix
Elevation	-0.63274313
Distance to Steep Terrain	-0.47709605
SW aspect	0.43624271
AF	0.271738688
Flat	-0.22783986
OV2	-0.21790325
Terrain ruggedness	0.214206776
DR	-0.21269764
DB	0.199766732
OV	-0.17728074

3.2.3 Discriminant Function Analysis-excluding Terrain Ecosystem Mapping variables

The discriminant function analysis (DFA) excluding TEM variables discriminated well between used and unused habitat within the 100% MCP winter ranges at the 3 study areas. Relatively high Canonical Correlation Coefficients (0.656-0.579), low Wilk's lambda values (0.664-0.570), high Eigenvalues (0.506-0.756), and good percent classification success (78.8-84.7%) all indicate the strength of the DFA to differentiate between land that were selected for by bighorn ewes and those areas that were avoided within the winter ranges (Fig. 21). All 3 DFA's without TEM variables were not as strong as DFA's using all variables in their ability to differentiate used and unused habitat within the 3 winter ranges. As was the case with the DFA using all variables, the Wigwam/Mount Broadwood DFA was the weakest of the 3.

Columbia Lake

Table 10 lists the top 5 variables based on the absolute value of the Standardized Canonical Coefficient. The group centroid for selected habitat was –1.509 and for available habitat was 0.501. Bighorn ewes selected for lower elevations, increased terrain ruggedness, land closer to steep terrain, steeper terrain, and lower greenness values.

Table 10. The top 5 variables contributing to the multivariate model of bighorn ewe winter range at Columbia Lake, based on the absolute value of the Standard Canonical Coefficient.

Variable	Standard Canonical Coefficient
Elevation	0.792750913
Terrain Ruggedness	-0.475472523
Distance to Steep Terrain	0.529848846
Greenness	0.350532946
Slope (degrees)	-0.234421898

The Structural Matrix Coefficient produced a similar picture of the DFA, although the relative importance of the variables changed somewhat (Table 11). Greenness became the most important contributor to the DFA, followed by elevation, distance to steep terrain, terrain ruggedness, and slope.

Table 11. The top 5 variables contributing to the multivariate model of bighorn ewe winter range at Columbia Lake, based on the absolute value of the Structure Matrix Coefficient.

Variable	Structure Matrix
Greenness	0.539141251
Elevation	0.443187098
Distance to Steep Terrain	0.391068763
Terrain Ruggedness	-0.314188559
Slope (degrees)	-0.278408394

Bull River

Table 12 lists the top 5 variables based on the absolute value of the Standardized Canonical Coefficient. The group centroid for selected habitat was –0.841 and for available habitat was 0.848. Bighorn ewes selected for lower elevations, increased terrain ruggedness, steeper slopes, and southwest-facing aspects. However, in contrast to the other 2 study areas, bighorn ewes selected for habitats further from steep terrain than would be expected by chance. Greenness contributed little to the DFA based on the Standardized Canonical Coefficients.

Again, the Structure Matrix Coefficient showed similar relationships among the variables and the distribution of bighorn ewes on their winter ranges. Four of the 5 variables included in the top 5 using the Standardized Canonical Coefficient were also in the top 5 when the Structure Matrix Coefficients were examined. Ewes selected for lower elevations, increased distances to steep terrain, decreased greenness values, increased terrain ruggedness and greater than expected use of southwest aspects.

Table 12. The top 5 variables contributing to the multivariate model of bighorn ewe winter range at Bull River, based on the absolute value of the Standard Canonical Coefficient.

Variable	Standard Canonical Coefficient
Elevation	0.510151885
Terrain ruggedness	-0.360096506
Distance to steep terrain	-0.342084877
Slope (degrees)	-0.283070559
SW aspect	0.260317968

Table 13. The top 10 variables contributing to the multivariate model of bighorn ewe winter range at Bull River, based on the absolute value of the Structure Matrix Coefficient.

Variable	Structure Matrix
Elevation	0.642302497
Distance to steep terrain	-0.516955107
Greenness	0.413238306
Terrain ruggedness	-0.335119529
SW aspect	0.329488345

Wigwam/ Mount Broadwood

Table 14 lists the top 5 variables based on the absolute value of the Standardized Canonical Coefficient. The group centroid for selected habitat was –0.613 and for available habitat was 0.826. Based on the absolute value and sign of the Standard Canonical Coefficient, bighorn ewes selected for south, southeast, and southwest aspects, lower elevations, and areas closer to steep terrain. Landsat imagery was not available for the Wigwam/Mount Broadwood study area so correlations between greenness and bighorn ewe distribution could not be made.

Table 14. The top 5 variables contributing to the multivariate model of bighorn ewe winter range at Wigwam/Mount Broadwood, based on the absolute value of the Standard Canonical Coefficient.

Variable	Standard Canonical Coefficient
SW aspect	0.674362895
Elevation	-0.600084407
Distance to steep terrain	-0.53737405
S aspects	0.47596382
SE aspects	

The importance of variables changed when the Structure Matrix Coefficients were ordered (Table 15). Two variables included among the top 5 when the Standard Canonical Coefficient was considered were not within the top 5 based on the absolute value of the Structure Matrix Coefficient. Elevation became the most important

Table 15. The top 5 variables contributing to the multivariate model of bighorn ewe winter range at Wigwam/Mount Broadwood, based on the absolute value of the Structure Matrix Coefficient.

Variable	Structure Matrix
Elevation	-0.71039562
Distance to steep terrain	-0.53564697
SW aspect	0.489779967
Flat	-0.25580118
Slope (degrees)	0.2501185

variable, with SW aspect and distance to steep terrain remaining in the top 5. As was the case in all other models, lower elevations, decreased distances to steep terrain, and greater than expected use of southwest aspects characterized bighorn ewe use of the study area. In addition, avoidance of flat terrain and greater than expected use of steeper slopes were added and S and SE aspects were dropped.

3.2.4 Comparison of Habitat Selection between Study Areas

General linear modeling was used to examine the similarities and differences in availability and use of habitat between the 3 study areas. Topographical variables were contrasted between Columbia Lake, Bull River, and Wigwam/Mount Broadwood to test whether habitat availability and use were significantly different. TEM variables could not be used because classification of site series and structural stages were not consistent across the 3 study areas. Significant differences were found between all 3 study areas, both in the types of habitat available and in the use of habitat by the radiocollared bighorn ewes. However, trends in use by radiocollared ewes were almost all in the same direction in the 3 study areas. In all 3 study areas, bighorns used lower elevations (Fig 22). Lower greenness values were selected for in Columbia Lake and Bull River (Fig. 23). The greenness layer was not available for the Wigwam/Mount Broadwood study area. Among slope variables, sheep selected for steeper slopes as well as for areas with greater terrain ruggedness (Figs. 24, 25). The only exception to similar use trends across the 3 study areas was with the variable, distance to steep terrain. At Columbia Lake and Wigwam/Mount Broadwood, ewes were closer to steep terrain than would be expected by chance (Fig 26). However, at Bull River, the opposite was true. The definition of steep terrain was land >30° slope. The 100% MCP winter range at Bull River did not contain steep terrain, producing this result.

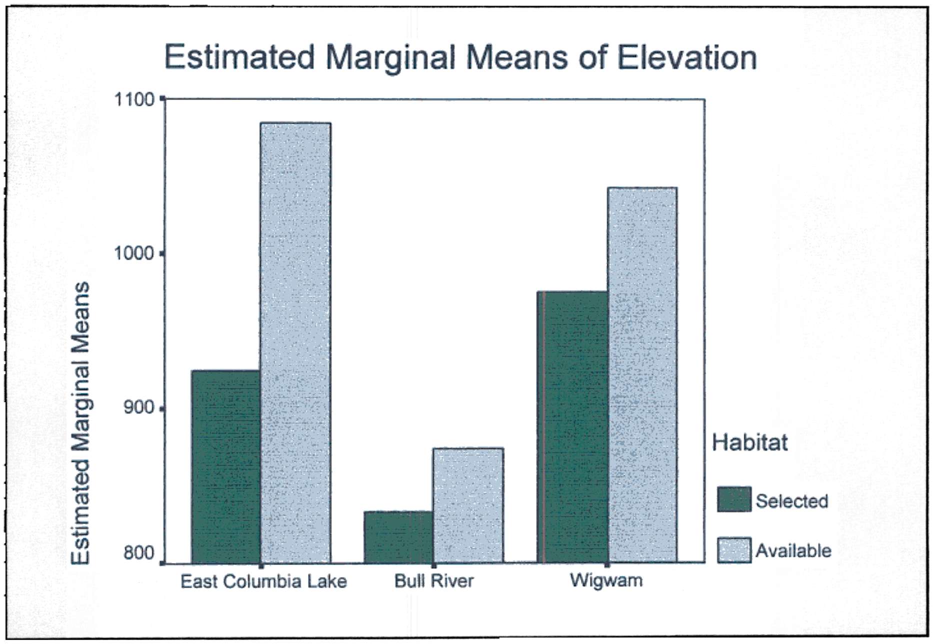

Figure 22. Estimated marginal means of elevation across 3 bighorn ewe winter ranges in the East Kootenay Trench.

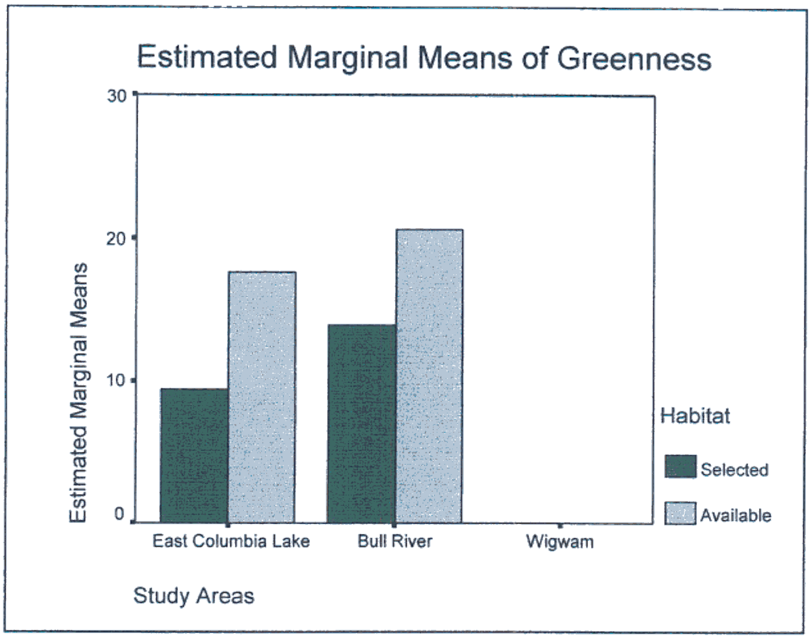

Figure 23. Estimated marginal means of greenness across 3 bighorn ewe winter ranges in the East Kootenay Trench.

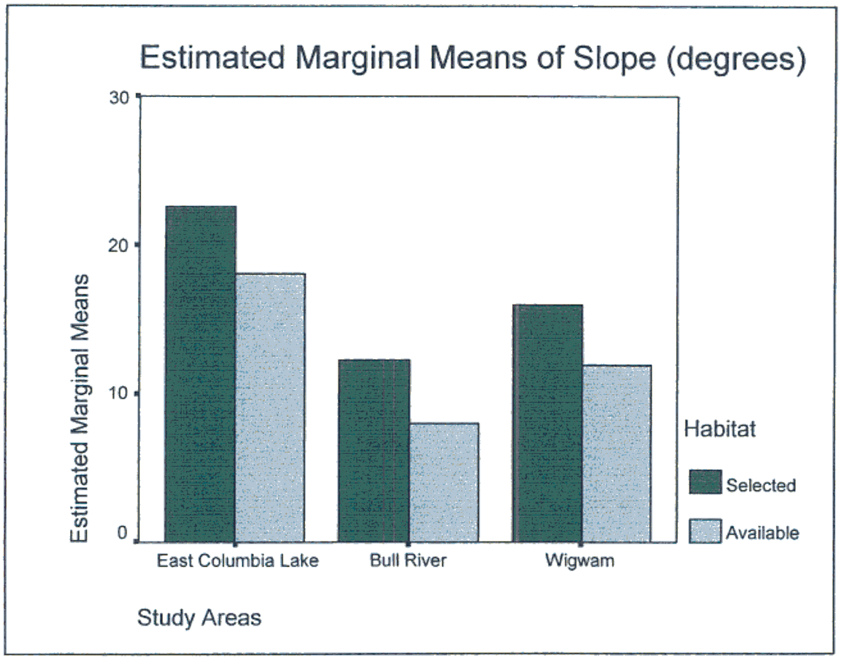

Figure 24. Estimated marginal means of slope across 3 bighorn ewe winter ranges in the East Kootenay Trench.

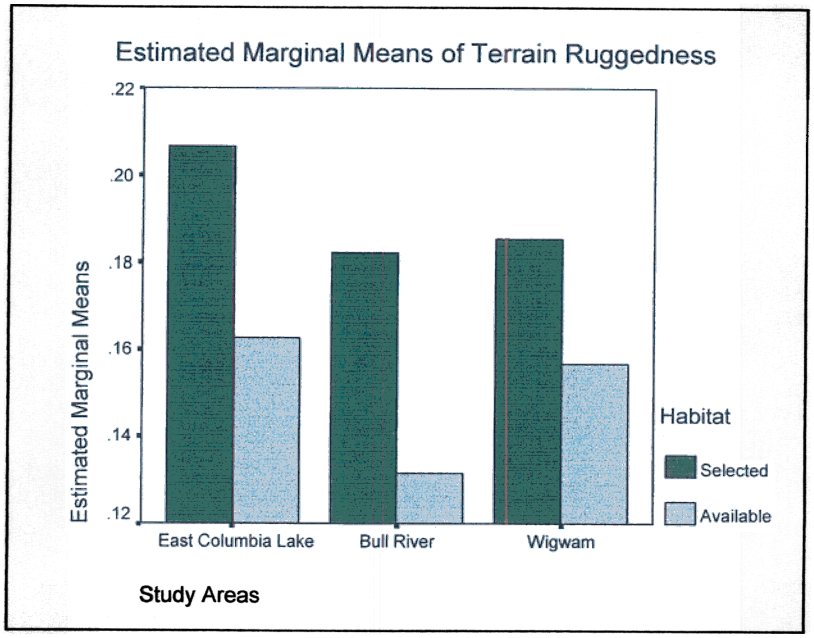

Figure 25. Estimated marginal means of terrain ruggedness across 3 bighorn ewe winter ranges in the East Kootenay Trench.

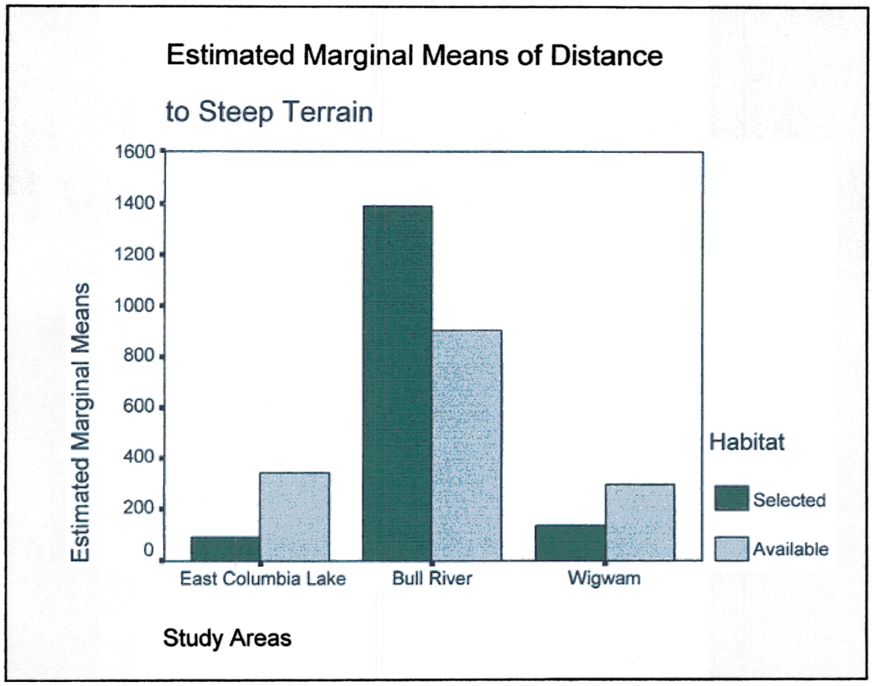

Figure 26. Estimated marginal means of distance to steep terrain across 3 bighorn ewe winter ranges in the East Kootenay Trench.

4.0 DISCUSSION

Radiocollared bighorn ewes used habitat in a predictable fashion in all 3 study areas. Results from the different univariate and multivariate analyses of the bighorn ewe radio telemetry data showed strong correlations between ewe distribution and several habitat types that provided life requisites: forage, security, and thermal cover. Over all 3 study areas, bluebunch wheatgrass site series were selected for, typically in the earlier seral stages such as grass/forb and shrub/herb. Selection for these within the second decile (the second most abundant site series within an ecosite) was sometimes directed toward older structural stages in which open stands of Douglas fir occurred with understories of bluebunch wheatgrass. In addition, the attraction to artificial opening was evident at 2 of the 3 study areas. Abandoned fields at Bull River and Wigwam/Mount Broadwood were strongly selected in the first decile. All site series strongly selected by bighorn ewes contained forage in the form of grasses, herbs, and/or shrubs. This emphasized the generalist foraging strategy of bighorn sheep. They are capable of digesting a wide variety of plant species and many different forage species contribute to their diet. Comparisons of availability and use of individual plant species within these selected site series will determine whether bighorn ewes on these winter ranges are selecting for particular plant species. This aspect of the analysis will be addressed in the final report.

Site series in the second decile were an important part of bighorn ewe habitat selection. The DFA using all variables demonstrated this; site series in the second decile were contributors to the multivariate model in all 3 study areas. In some cases (e.g., Columbia Lake), a bluebunch wheatgrass site series from the second decile was ranked higher in importance to the model that the same site series in the first decile. These site series may be smaller inclusions of preferred habitat in a matrix of less suitable habitat. Crosstabulations of use versus availability showed the importance of escape terrain in the second decile at Bull River and Columbia Lake. Rock outcrops were strongly selected for at Columbia Lake while at Bull River, talus was strongly selected in the second decile.

In several cases, strong selection for site series was documented that did not appear to make sense ecologically. River (RI) site series appeared in several instances as did road surface (RP). This is a consequence of the sampling procedure wherein each radio location was buffered with a 100 m radius circle and the areas within the buffered circles were randomly sampled. For radio locations that were within 100 m of a river or a road surface, it was possible to have selection for these site series even though it is unlikely that these site series were used very much or at all, as in the case of river site series.

A greenness band derived from Landsat 5 TM satellite images appear to be well-correlated with ewe winter range use in the East Kootenay Trench (Fig. 27). Radiocollared bighorn ewes strongly selected lower greenness values than would be expected by chance within the two 100% MCP winter ranges where the layer was available. The variable ranked first and fifth in the DFA using all variables, and fourth and third in the DFA without TEM variables based on the Structural Matrix Coefficients at Columbia Lake and Bull River, respectively. Lower greenness values correspond well with early seral stage grasslands (i.e., younger structural stages) that were selected by

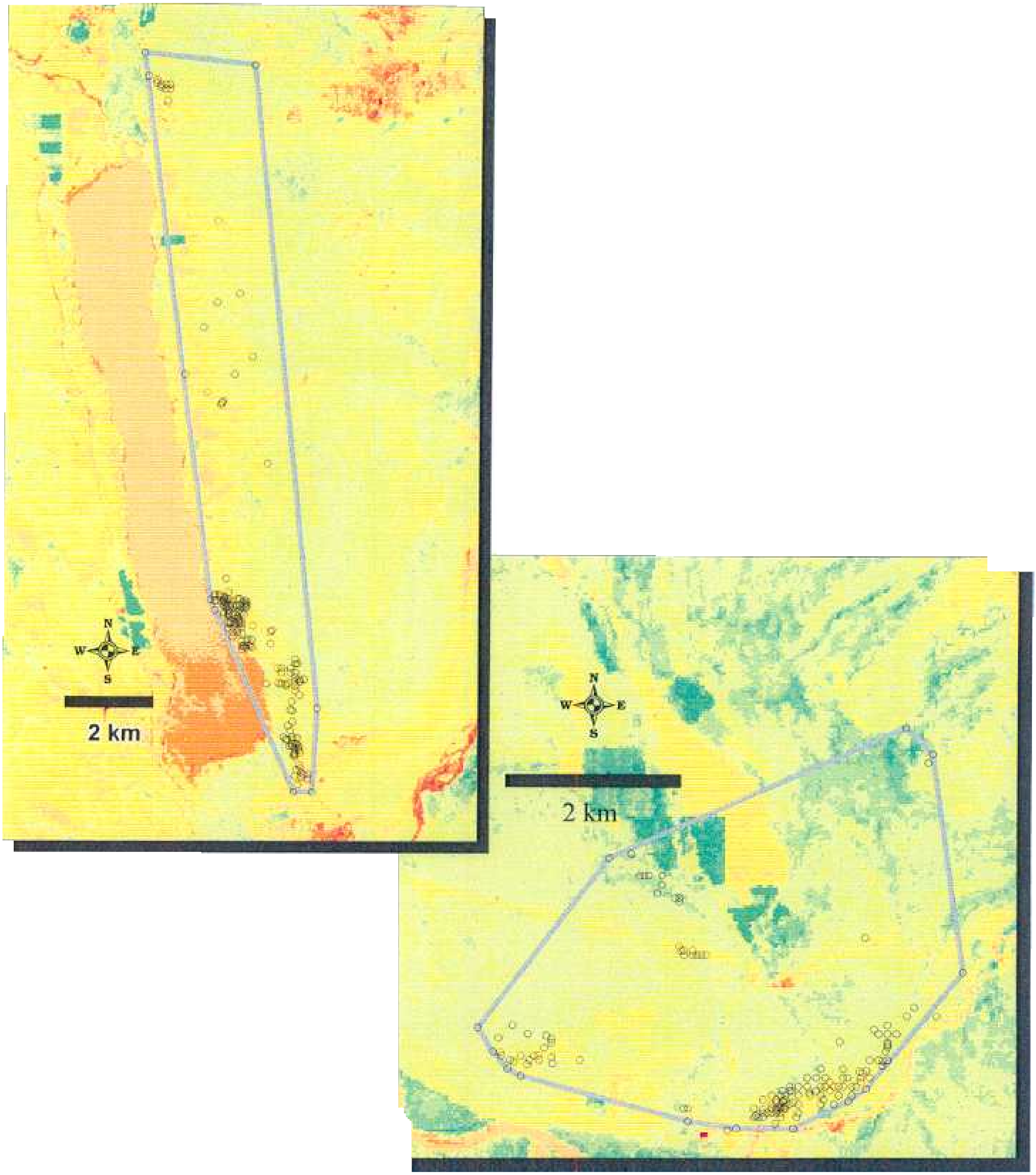

Figure 27. Greenness values derived from Landsat 5 TM satellite images at Columbia Lake and Bull River in relation to radio locations of bighorn ewes during winter.

bighorn ewes. The reduced strength of the DFA's for the Wigwam/Mount Broadwood study area relative to the other 2 study areas (Fig. 21) is likely due to the lack of a greenness layer in those analyses.

Topographical variables demonstrated the importance of terrain attributes to bighorn ewe habitat selection. Within the DFA's, these variables were significant contributors to the models. Elevation, and bighorns' selection for lower elevations within their winter ranges, was ranked among the top 10 variables in the DFA using all variables in all study areas, and in 2 cases, it was ranked first. In DFA's conducted without TEM variables, elevation ranked first or second among all variables. Lower elevations within the winter ranges likely have less snow accumulation through the winter than higher elevations making for easier foraging by bighorns. Steep terrain, distance to steep terrain, and terrain ruggedness all provide some measure of ewe habitat selection for security. These attributes appear to correlate well with escape terrain. In most DFA's, at least one of these variables was a significant contributor to the model. Increased terrain ruggedness, increased slope, and decreased distance to steep terrain characterized ewe habitat selection. Aspect, another topographical variable, was another frequent contributor to the DFA's. In particular, southerly aspects tended to be strongly selected. Southerly aspects have greater exposure to solar radiation in the winter and as such accumulate less snow. In the same manner as lower elevations, southerly aspects are more efficient feeding sites since bighorns have to dig less to gain access to forage.

The topographical variable, distance to steep terrain, provided the only case in which trends in habitat selection were not consistent across the 3 study areas. At Columbia Lake and Wigwam/Mount Broadwood, ewes strongly selected areas closer to steep terrain than would be expected by chance. However, the inverse was true at Bull River. Steep terrain was identified as land with a slope in excess of 30°. However, the 100% MCP cumulative winter range at Bull River enclosed very little land identified as steep terrain using this criterion with the result that bighorn habitat use within the MCP did not follow the trend in the other 2 study areas.

This analysis emphasizes some of the strengths and weaknesses of using TEM as a tool to examine bighorn sheep habitat relationships. The TEM variables showed strong correlations with bighorn sheep habitat use. By identifying site series and structural stages that are strongly selected as well as those strongly avoided by bighorn ewes, habitat manipulations can be specifically targeted to increase the ability of the winter range to support sheep. In particular, ecosites with preferred site series (e.g., a bluebunch wheatgrass type) but occurring in structural stages that are avoided by bighorns can be targeted for habitat enhancement. These sites could be manipulated to bring them back to an earlier seral stage (i.e., a lower structural stage), one that is preferred by sheep. These management prescriptions can be very specific so that only those ecosites that are occurring in proximity to ecosites that are heavily used by bighorns are manipulated. This should increase the likelihood that habitat enhancement sites will be discovered quickly by bighorns on the winter range.

A weakness of the TEM data is its limited areal extent. Even though sheep populations at the 3 study areas are currently low relative to historic numbers, the 100% MCP winter

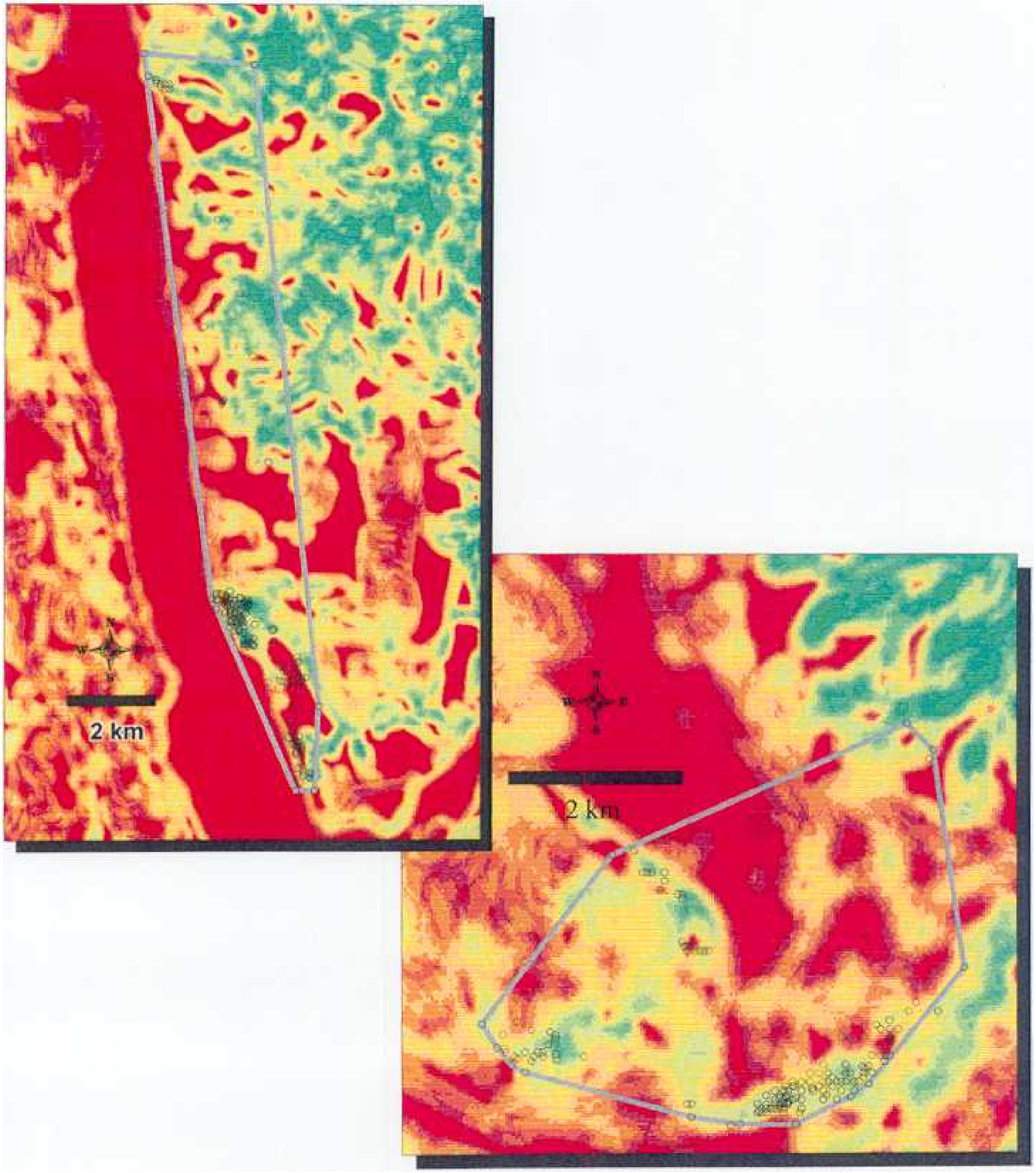

Figure 28. Terrain ruggedness values derived from digital elevation models at Columbia Lake and Bull River in relation to radio locations of bighorn ewes during winter.

range in each study area extended beyond the boundaries of the TEM area. Data regarding habitat selection of ewes outside the TEM boundaries couldn't be used. Similarly, the results of the habitat selection analysis can only be applied to areas with TEM data in place. Bighorn winter ranges without TEM data cannot benefit from the analysis.

The topographical and satellite image based variables do not suffer from this problem. They are available across the landscape and relationships developed in the 3 study areas can be applied throughout low elevation sheep range on the east side of the Trench. In addition, although the DFA's which excluded the TEM variables were weaker than DFA's which used all available variables, they were not significantly weaker. Differences in classification success ranged from 1.1% at Wigwam/Mount Broadwood to 6.0% at Bull River. Since the DFA's which did not incorporate the TEM variables used fewer variables that are more widely available and yet did not have significantly lower classification success, they are the preferred model from an regional perspective. However, TEM provides additional detailed ecosite data that is beneficial for habitat enhancement planning.

5.0 LITERATURE CITED

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