Late Winter Habitat Selection by Moose in the Dawson Land Use Planning Region

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Late Winter Habitat Selection
by Moose in the Dawson Land Use Planning Region

Environment Yukon Comments
Heather Clarke

Regional land use planning occurs throughout Yukon under Chapter 11 of the First Nations Final Agreements. To assist with the Dawson regional land use planning process, the Yukon Department of Environment gathered information related to wildlife values and resources across the planning area. Habitat suitability models are used to identify features on the landscape that are selected by wildlife species and to map the relative probability of occurrence for a given species across an area. Habitat suitability models were developed for multiple focal species in the Dawson planning region including sheep, caribou, and grizzly. Dryas Research Ltd. and Mark Wong Consulting were contracted to complete a late-winter moose habitat suitability model in the Dawson Land Use Planning Region. Their report outlining methodologies used and results follows.

Key Points:

- Separate habitat suitability models were developed for adult moose and for cow moose with calf(s).
- Model inputs included moose point locations derived from moose surveys conducted in 2008, 2009, 2010, and 2012, habitat variables derived from a detailed ecological landcover classification, topographical features derived from a digital elevation model, and spatial data on fire history and surface disturbance.
- Models were calculated using Resource Selection Functions (RSF). These models were used to determine whether moose used areas proportionately more than they were available ("selected") or proportionately less than they were available ("avoided").
- Adult moose selected areas:
  - close to forest, treed riparian areas, wide linear disturbances (>8 m wide) and to moderately-aged burns (11-25 years old);
  - of intermediate elevation;
  - on north-facing slopes; and
  - with a high abundance of deciduous riparian forest.
- Adult moose avoided areas:
  - close to recent burns (<10 years old); and
  - with a high proportion of wetlands, shrub cover, coniferous forest, and mixed-wood forest.
- Cow moose with calf(s) selected areas:
  - close to riparian habitat and to moderately-aged burns (11-25 years old);
  - of intermediate elevations; and
  - on north-facing slopes
- Cow moose with calf(s) avoided areas:
  - with a high proportion of wetlands, shrub cover, conifer forest, and mixed-wood forest
- Model results suggest selection represents a trade-off among resources necessary to provide shelter, forage, ease of travel, and to reduce predation risk.

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Introduction

1.1 Background

Land use planning in the area surrounding Dawson, Yukon has led to an increased interest and need to understand regional wildlife habitat use. Moose are abundant throughout the area and are of ecological, cultural, social, and economic value. Habitat suitability models are used to identify features on the landscape that are selected by a wildlife population and to map the relative probability an individual will use an area in a particular region. We developed late-winter habitat suitability models for moose across a large portion of the area identified for the Dawson Regional Land Use Plan.

Habitat suitability models were developed for two separate functional categories, each of which was suspected to exhibit different habitat use and selection: adult moose, and cows with one or more calves. Habitat selection patterns of adult moose are known to differ from those of cow moose with calves (Dussault et al. 2005), with the latter being associated primarily with habitats that provide protection from predators (White and Berger 2001). This information is necessary to understand moose-habitat relationships and has important implications for land use planning in the region.

Methods

1.2 Moose location data

Late-winter aerial moose surveys were conducted by Environment Yukon in four areas within the Dawson Land Use Planning (DLUP) Region over four years: Dawson (2008), Klondike (2009), Forty Mile (2010), and White Gold (2012) (Fig. 1). Aerial survey data for an additional survey area (Tombstone) were also available, but were not included in this analysis because the area was substantially different from the other four regions (i.e., much higher in elevation). The study area was defined as a combination of moose survey locations, and the extent of habitat and ecogeographical variables of interest. Based on moose composition recorded during each survey, moose location data were stratified into two categories: adult moose, and cows with calves (cow/calf groups). The adult moose category included all locations where adult moose (without calves), regardless of sex, were observed. The cow/calf category included locations where a single adult moose and one or more calves were observed. An independent habitat selection model was built for each category. Within the study area defined above, there were 754 adult moose observations, and 119 cow/calf observations used in the analyses. For each group (adults, and cow/calf) the observation points for each survey location and year were pooled. We included all points that fell within the DLUP Region and within the area covered for linear and areal disturbance. For available locations, 250 points for each survey (region/year) were randomly selected for the cow/calf data. This was done to balance the number of available points that were intersected by fire classes for each survey year (i.e., replicate the used points). This resulted in a total of 1000 randomly generated points for the cow/calf group. The same was done for adult available points, but 1000 available points were randomly generated for each survey (region/year) for a total of 4000 randomly generated available points for the adult used points.

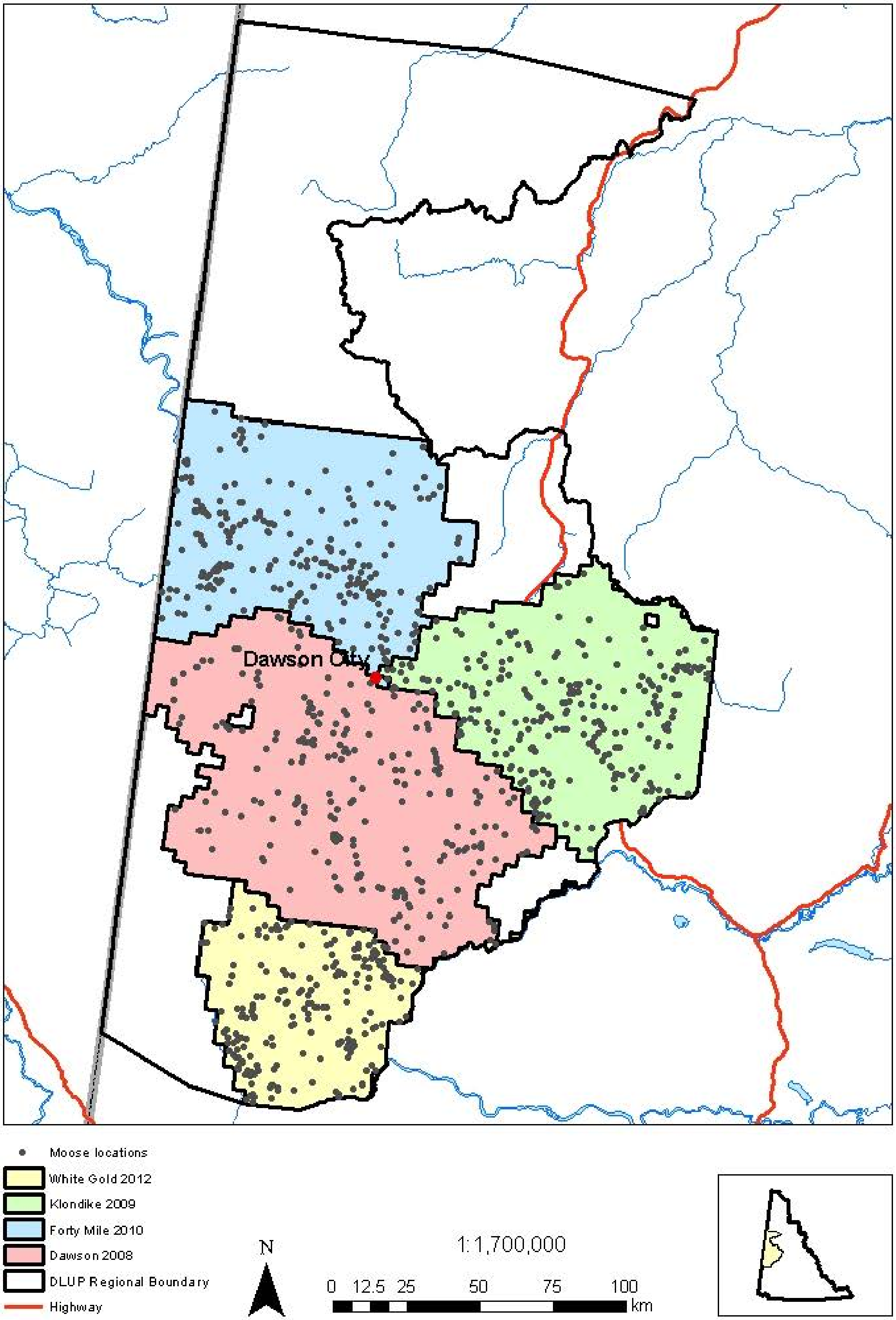

Figure 1: Map of the Dawson Land Use Planning Region, showing all moose locations and the boundaries of all four late winter aerial surveys.

1.3 Resource Selection Functions

Late winter habitat use was modeled using resource selection functions (RSFs). RSFs use characteristics of used and available resource units to provide values for resource units that are proportional to their probability of being used by the study organism. Exponential RSFs, were used and took the form:

$$W(x) = \exp(\beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \ldots + \beta_i x_i)$$

where x_i is the value of the i^{th} ecogeographical variable for each considered resource unit, and β_i is the coefficient value assigned to the i^{th} ecogeographical variable for each considered resource unit. Coefficient values were estimated using logistic regression (Faraway 2006; Hosmer and Lemeshow 2000; Manly et al. 2002).

1.4 Ecogeographical variables

Resource selection functions for each group (adults, and cow/calf) were constructed using ecogeographical variables that reflected landscape features such as disturbance (burn distance, areal disturbances, linear disturbances), topography (elevation, slope, aspect, ruggedness, water features), and vegetation (wetlands, shrub, conifer, mixed-wood, deciduous, distance to forest, and riparian areas). Used and randomly generated points were buffered by a 250m radius to incorporate any spatial inaccuracy inherent in fixed-wing survey locations. Moose may also select landscape features at larger scales, and we therefore measured some features using a 1km circular buffer around each point. The ecogeographical variables were estimated within these buffers.

The ecogeographical variables derived from various GIS layers were as follows (note that not all variables were entered into the model selection process due to screening processes described in Model selection):

1.4.1 Disturbance Variables

A. *Burn Distance* – Fire history data were stratified into three age classes (0-10 years old, 11-25 years old, and >25 years old) based on prior research that suggests that moose prefer forest 11-25 years after a burn (Maier et al 2005, Nelson et al 2008). Time since fire was relative to the year surveyed, so we created layers of each fire class for each survey year to ensure consistency. We then measured the mean distance to each burn class within a 250m radius. We also measured the proportion of fire class within 250m and 1km, but these variables were later found to be inappropriate due to linear separation (i.e. there were too many zeroes in the data set for used and available points) and were excluded from model development (d2_fire_<10_250, d2_fire_11-25_250, d2_fire_>25_250).

B. *Areal disturbance* – Mean distance to an areal disturbance using a 250m radius around each point, (d2_areal_250).

C. *Linear disturbance* – Linear disturbances may affect moose habitat use positively by facilitating travel, or negatively by increasing predation risk by wolves. Also, the effect of road proximity on moose habitat use may vary according to road width (i.e., wide highways versus single lane roads). We therefore classified road disturbance based on width (<4m=low, 4-8m = mid, >8m=high). We measured the mean distance to each road class within a 250m radius. We also measured the density of linear disturbance (all sizes) within a 1km buffer. However, further analysis revealed too many zeroes in the dataset which affect linear separation, so this variable was not entered into the global model (d2_low_250, d2_mid_250, d2_hi_250).

1.4.2 Topographic Variables

D. *Elevation* – meters above sea level, calculated as the mean elevation within a 250m radius of the point (elev_250).

E. *Elevation^2* – meters above sea level squared, calculated as the squared mean elevation value within a 250m radius of the point. Moose may prefer intermediate elevations, and the inclusion of this term would identify such selection behaviour (sq_elev_250).

F. *Slope* – degrees, defined as the mean slope within a 250m radius of the point (slope_250).

G. Slope^2 – degrees squared, defined as the squared mean slope value within a 250m radius of the point. Moose may prefer intermediate slopes, and the inclusion of this term would identify such selection behaviour (sq_slope_250).

H. *Eastness* – represents the proximity of an aspect to 90 degrees. Cells with an aspect of 90 degrees (east) get a value of 1, where as cells with an aspect of 270 degrees (west) get a value of -1. Mean eastness was calculated over a 250m radius (east_250).

I. *Northness* – represents the proximity of an aspect to 0 degrees (north). Cells with an aspect of 0 degrees (north) get a value of 1, where as cells with an aspect of 180 degrees (south) get a value of -1. Mean northness was calculated over a 250m radius (north_250).

J. *Ruggedness* – represents the unevenness of the landscape. Ruggedness was calculated as the standard deviation of elevation within 250m and 1km radii (rugged_250, rugged_1km).

K. *Watercourse distance* – distance from the closest water body. This was calculated as the mean distance within a 250m radius (d2_h2o_250).

1.4.3 Habitat Variables

L. *Wetlands* – mean proportion of wetland within 250m and 1km radii. The proportions within 250m or 1km radii were calculated based on wetland presence (1) or absence (0) (wetland_250, wetland_1km).

M. *Shrub* – mean proportion of shrub habitat within 250m and 1km radii. Shrubs are a primary forage source for moose (shrub_250, shrub_1km).

N. *Conifer* – mean proportion of conifer habitat within 250m and 1km radii. Coniferous forests may be selected by moose during late winter for shelter (conifer_250, conifer_1km).

O. *Mixed-wood* – mean proportion of mixed-wood habitat within 250m and 1km radii. Mixed-wood areas may be selected by moose in late winter because they provide a combination of shelter and browse (mixed_250, mixed_1km).

P. *Deciduous* – mean proportion of deciduous habitat within 250m and 1km radii. Deciduous forests provide trees, shrubs, and forbs that are a source of forage for moose (decid_250, decid_1km).

Q. *Distance to forest* – defined as the mean distance to forest habitat (regardless of type: conifer, deciduous, or mixed) within a 250m of the point. Moose may base their habitat selection on the proximity of forest cover, in addition to their immediate surroundings (d2_for_250).

R. *Moisture index* – mean moisture value within 250m and 1km radii. Values were 1 for dry, 2 for moist and 3 for wet (moist_250, moist_1km).

S. *Shrub riparian* - mean proportion of shrub-dominated riparian habitat within 250m and 1km radii. Riparian shrubs are a source of forage for moose.(shrubrip_250, shrubrip_1km).

T. *Deciduous riparian* - mean proportion of deciduous tree-dominated riparian habitat within 250m and 1km radii. Riparian deciduous trees area a source of forage and cover for moose (decrip_250, decrip_1km).

U. *Coniferous riparian* - mean proportion of coniferous-dominated riparian habitat within 250m and 1km radii. Conifer riparian areas may provide shelter in close proximity to foraging resources (conrip_250, conrip_1km).

V. *Total riparian* - mean proportion of total riparian habitat within 250m and 1km radii (totrip_250, totrip_1km).

W. *Distance to shrub riparian* – mean distance to any shrub-dominated riparian habitat within a 250m radius (d2_shrubrip_250).

X. *Distance to treed riparian* - mean distance to tree-dominated riparian habitat within a 250m radius (d2_treerip_250).

Y. *Distance to total riparian* – mean distance to any riparian habitats within a 250m radius (d2_totrip_250).

1.5 Model selection

Potential variables (above) were screened for collinearity using Pearson correlations (r, Zar 1999). Correlations in which |r| > 0.60 were deemed to be collinear (except in the case of quadratic terms, which were expected to be highly correlated with their untransformed parent term). In cases where |r| >0.90, the pair of variables were deemed to be virtually identical and we selected one based on logistical factors (i.e., a desire to include it as a squared term), or consistency (i.e., selected 250m scale to be consistent with other variables). For cases in which |r| was 0.60 to 0.90, single-parameter RSF models were created for each variable, and each model was evaluated using Akaike's Information Criterion (AIC; Akaike 1973; Burnham and Andersen 1998). The variable with the lowest single-parameter model AIC_c score was retained for further use in model construction.

The remaining variables were then used to construct a global RSF model for each category (adults, and cow/calf) that contained non-correlated variables. The global models were then simplified using a forward/backward step-wise approach using AIC values. This was implemented using the '*stepAIC*' function in Program *R* (R Development Core Team 2011). This iterative process used AIC values to determine which (if any) variables should be removed from the global model while simultaneously using AIC to determine whether previously removed variables should be returned to the model. The final models thus represented the most parsimonious late-winter habitat model for each group.

1.6 Model validation

The top model for each group (adults, and cow/calf groups) was validated using k-fold cross-validation (Boyce et al. 2002). Used and available locations were randomly assigned into five data subsets of equal size. Each data subset was then used as a validation sample for RSFs created using data from the remaining four subsets. Selection values using RSFs built from the remaining four subsets were calculated and partitioned into ten ranked bins, each containing roughly 1/10th of the RSF values. Used locations for the validation subsets were then binned according to their selection value. Frequencies of used locations within each bin were adjusted by dividing the area of that range of RSF values available across the landscape. Area-adjusted frequencies below 1.0 would indicate used locations occurred at rates less than expected, while values greater than one would indicate used locations occurred at rates greater than expected given the available area of that range of RSF score within the landscape. A positive and significant Spearman rank correlation (Zar 1999) between bin rank and area-adjusted frequency rank denoted a model with good predictive performance.

1.7 Model application

The final model for each category (adults, and cow/calf) was used to create a map of the study area that indicated the relative probability of occurrence during late winter. Models were constrained to the study area and DLUP boundaries.

Results

1.8 Variable screening

For both groups, the variables entered into the global model were either non-collinear with the other variables, or if they were found to be collinear, had lower AICc values for their single-parameter models than did the variables with which they had a collinear relationship (see Appendix 1 for adult moose and Appendix 2 for cow/calf groups). In other words, all variables entered into the global models (**Table 1**) were independent of each other.

Table 1: List of variables included in the global models for adult moose and cow/calf groups. See Section 1.4 for description of each variable.

Adult moose		Cow/calf groups	
d2_fire_>25_250	elev_250	d2_fire_>25_250	wetland_250
d2_fire_11-25_250	sq_elev_250	d2_fire_11-25_250	shrub_250
d2_fire_<10_250	east_250	d2_fire_<10_250	conifer_250
slope_250	north_250	elev_250	mixed_1km
sq_slope_250	d2_h2o_250	sq_elev_250	moist_1km
d2_hi_250	mixed_250	east_250	d2_for_250
wetland_250	mixed_1km	north_250	d2_totrip_250
shrub_250	d2_for_250	d2_hi_250	totrip_250
conifer_250	d2_treerip_250	d2_low_250	decrip_1km
decid_1km	totrip_250	d2_h2o_250	
moist_250	decrip_250		

1.9 Model selection

The set of variables produced by the collinearity screening process (**Table 1**) was used to parameterize global models for each group that were then refined using a forward/backward stepwise procedure using AIC values.

The resulting model for adult moose (Table 2) showed positive associations with distance to recently burned areas (<10 years old), intermediate elevations, north-facing slopes, and deciduous riparian habitats. Adult moose were negatively associated with the distance to areas burned 11-25 years ago, the distance to wide linear disturbances (such as roads >8m wide), distance to forested areas, distance to treed riparian areas, and the proportions of wetlands, shrub cover, coniferous, and mixed-wood habitat within a 250 m radius. Note that a negative association with distance (to 11-25 year old fires, and >8m wide linear features) implies selection for this feature (i.e., probability of use would increase as the distance to the feature decreased). Conversely, a positive association with distance (i.e., to 0-10 year old fires) indicates an area would be more likely to be used if it were further from that feature. In other words, adult moose appeared to avoid newly burned areas.

Table 2: Variables, beta coefficients, standard errors, z-scores, and p-values for the final model for late winter habitat selection by adult moose in the Dawson Land Use Planning Region.

Variable	Name	Coefficient	Std. Error	Z	P-value
Intercept	Intercept	-4.283	0.530	-8.08	6.50E-16
d2_fire_11-25_250	Dist. to 11-25 year fires, 250m	-3.97E-05	8.06E-06	-4.925	8.42E-07
d2_fire_<10_250	Dist. to <10 year fires, 250m	2.58E-05	6.33E-06	4.078	4.53E-05
d2_hi_250	Dist. to >8m linear disturb, 250m	-1.29E-05	6.52E-06	-1.973	0.048
wetland_250	Prop. wetland, 250m	-2.072	0.514	-4.033	5.50E-05
shrub_250	Prop. shrub, 250m	-4.59E-01	0.161	-2.851	4.36E-03
conifer_250	Prop. conifer, 250m	-1.903	0.206	-9.264	2.00E-16
mixed_1km	Prop. mixedwood, 1km	-2.495	1.162	-2.148	0.032
elev_250	Mean Elevation	1.03E-02	1.36E-03	7.592	3.16E-14
sq_elev_250	Mean Elevation squared	-6.92E-06	8.50E-07	-8.138	4.00E-16
north_250	Mean Northness, 250m	0.269	0.081	3.315	9.15E-04
d2_for_250	Dist. to forested habitat	-4.29E-04	2.40E-04	-1.787	0.074
d2_treerip_250	Dist. to treed riparian habitat	-1.08E-04	4.55E-05	-2.365	0.018
decrip_250	Prop. decid. riparian habitat, 250m	3.136	1.067	2.938	0.003

The final model for cow/calf groups (Table 3) indicated a positive association with intermediate elevations and north-facing aspects. They were negatively associated with the distance to areas burned 11-25 years ago, along with the proportion of wetlands, shrub cover, mixed-wood, and conifer areas within the buffer radius. Cow/calf groups also were negatively associated with the distance to riparian habitat. As for adults, note that a negative association with distance (in this case, to 11-25 year old fires, or distance to riparian areas) implies selection for this feature such that the probability of use would increase as distance to the feature decreased.

Table 3: Variables, beta coefficients, standard errors, z-scores, and p-values for the final model for late winter habitat selection by cow/calf groups in the Dawson Land Use Planning Region.

Variable	Name	Coefficient	Std. Error	Z	P-value
Intercept	Intercept	-2.999	1.053	-2.847	0.004
d2_fire_11-25_250	Dist. to 11-25 year fires, 250m	-5.64E-05	2.00E-05	-2.820	0.005
d2_low_250	Dist. to smaller roads	-1.57E-05	8.77E-06	-1.795	0.073
wetland_250	Prop. wetland, 250m	-2.004	1.089	-1.840	0.066
shrub_250	Prop. shrub, 250m	-1.054	0.381	-2.770	0.006
conifer_250	Prop. conifer, 250m	-2.538	0.497	-5.113	3.17E-07
mixed_1km	Prop. mixedwood, 1km	-7.044	2.950	-2.385	1.71E-02
elev_250	Mean Elevation	8.63E-03	2.90E-03	2.976	0.003
sq_elev_250	Mean Elevation squared	-5.85E-06	1.79E-06	-3.264	0.001
north_250	Mean Northness, 250m	5.54E-01	0.203	2.736	0.006
d2_totrip_250	Dist. To riparian habitat, all types	-3.04E-04	1.83E-04	-1.662	0.097

1.10 Model validation

In general, and as expected, the area-adjusted frequency of used moose locations increased with bin rank in k-fold cross-validation (see Figure 2 and Figure 3). For adult moose, the Spearman rank correlation between mean area-adjusted frequency of moose locations and bin rank was positive and significant ($\rho = 0.988$, $p < 0.001$, Figure 4), and ranged between 0.927 and 0.988 for each of the five individual subsets (with each being significant at $P<0.001$). Similarly, for cow/calf groups, the Spearman rank correlation was positive and significant ($\rho = 0.855$, $p < 0.01$, Figure 5), although it ranged between 0.547 and 0.828 for each of the five individual subsets. Thus, both RSF models appear to fit the data well, although there was more variation in the cow/calf data (i.e., a larger range), possibly a result of a lower sample size than the adult model.

1.11 Model application

We applied the final selected RSF models to the study area, producing a map of late-winter habitat selection values for adult moose (Fig. 6) and cow/calf groups (Fig. 7). Model results extrapolated beyond the study area should be interpreted with caution; habitat selection values calculated using RSFs are dependent on habitat availability, and as availability changes (as it does when the area over which the model is applied is changed), selection values also change. As a consequence, the predictive ability of the model beyond the study area over which it was built is not quantifiable. The results of model extrapolation beyond the study area should be interpreted as an educated guess of potential cow/calf late winter habitat selection patterns, with an unknown error term.

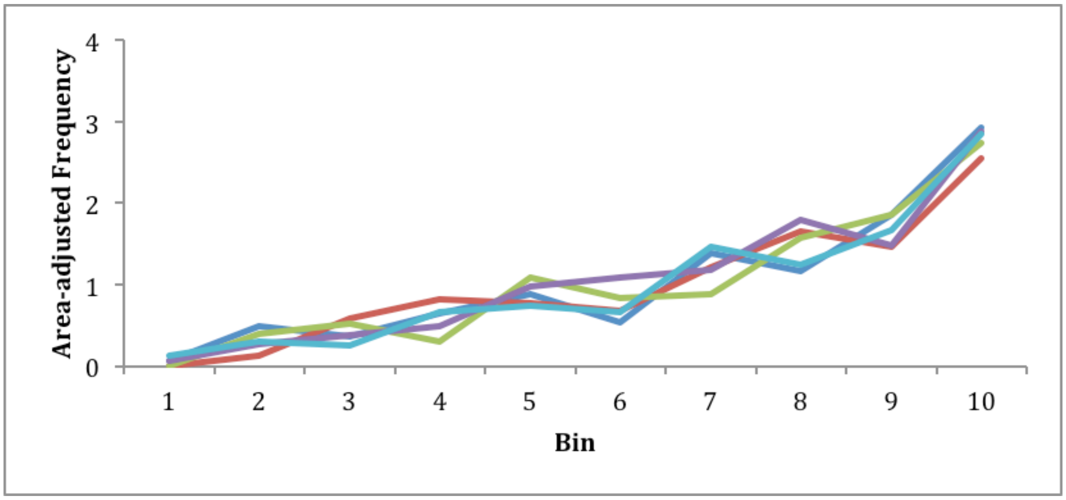

Figure 2: Individual area-adjusted frequencies of adult moose locations (divided at random into five equal data subsets; depicted as individually-coloured lines) within 10 ranked RSF value bins.

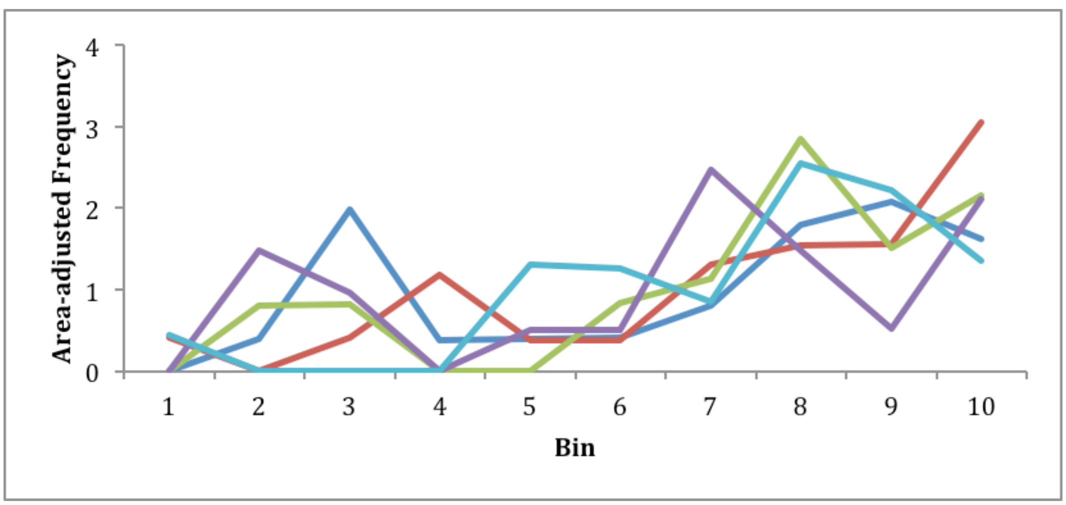

Figure 3: Individual area-adjusted frequencies of cow/calf moose locations (divided at random into five equal data subsets; depicted as individually-coloured lines) within 10 ranked RSF value bins.

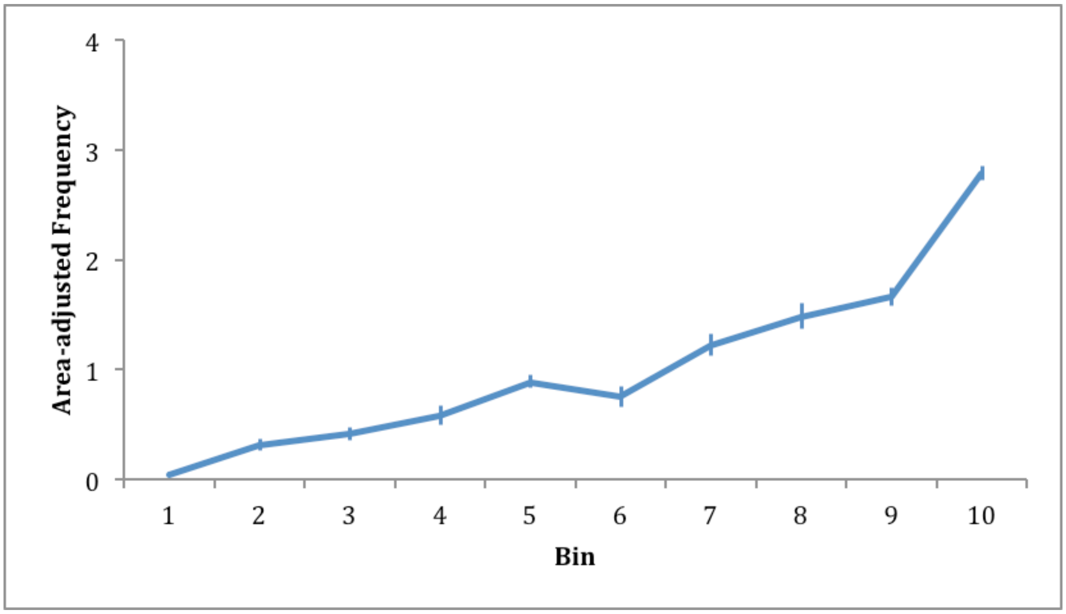

Figure 4: Mean (±SE) area-adjusted frequency of adult moose locations (as determined individually for five randomly-selected data folds) within 10 ranked RSF value bins. Spearman rank correlation (ρ) for the mean data = 0.988, P<0.001 (range of 0.927 to 0.988 for the 5 subsets).

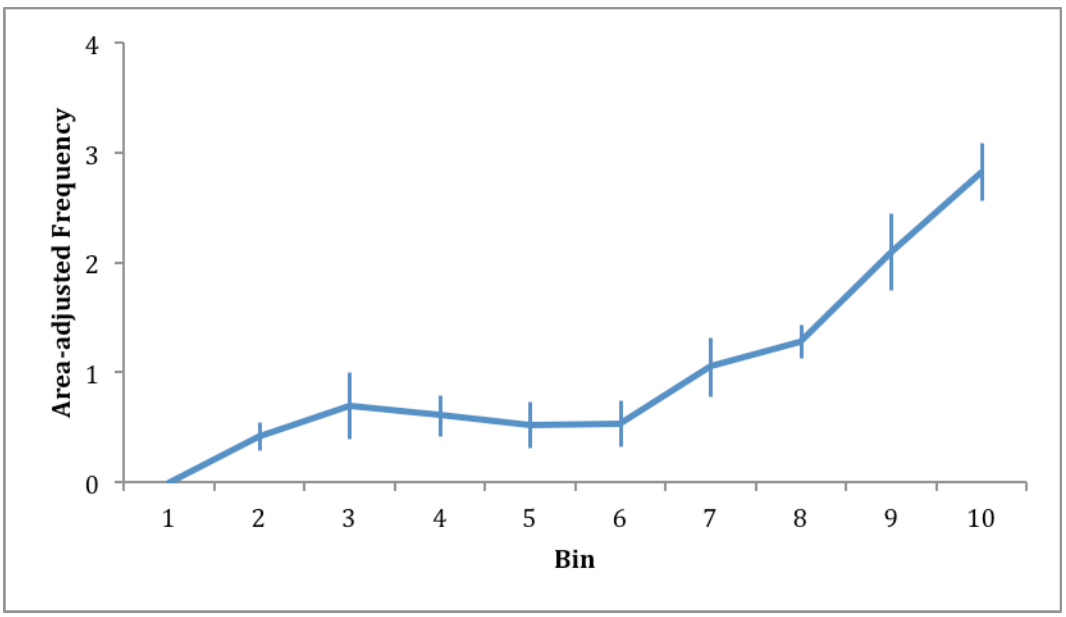

Figure 5: Mean (±SE) area-adjusted frequency of cow/calf moose locations (as determined individually for five randomly-selected data folds) within 10 ranked RSF value bins. Spearman rank correlation (ρ) for the mean data = 0.855, p<0.01 (range of 0.547 to 0.828 for the 5 subsets).

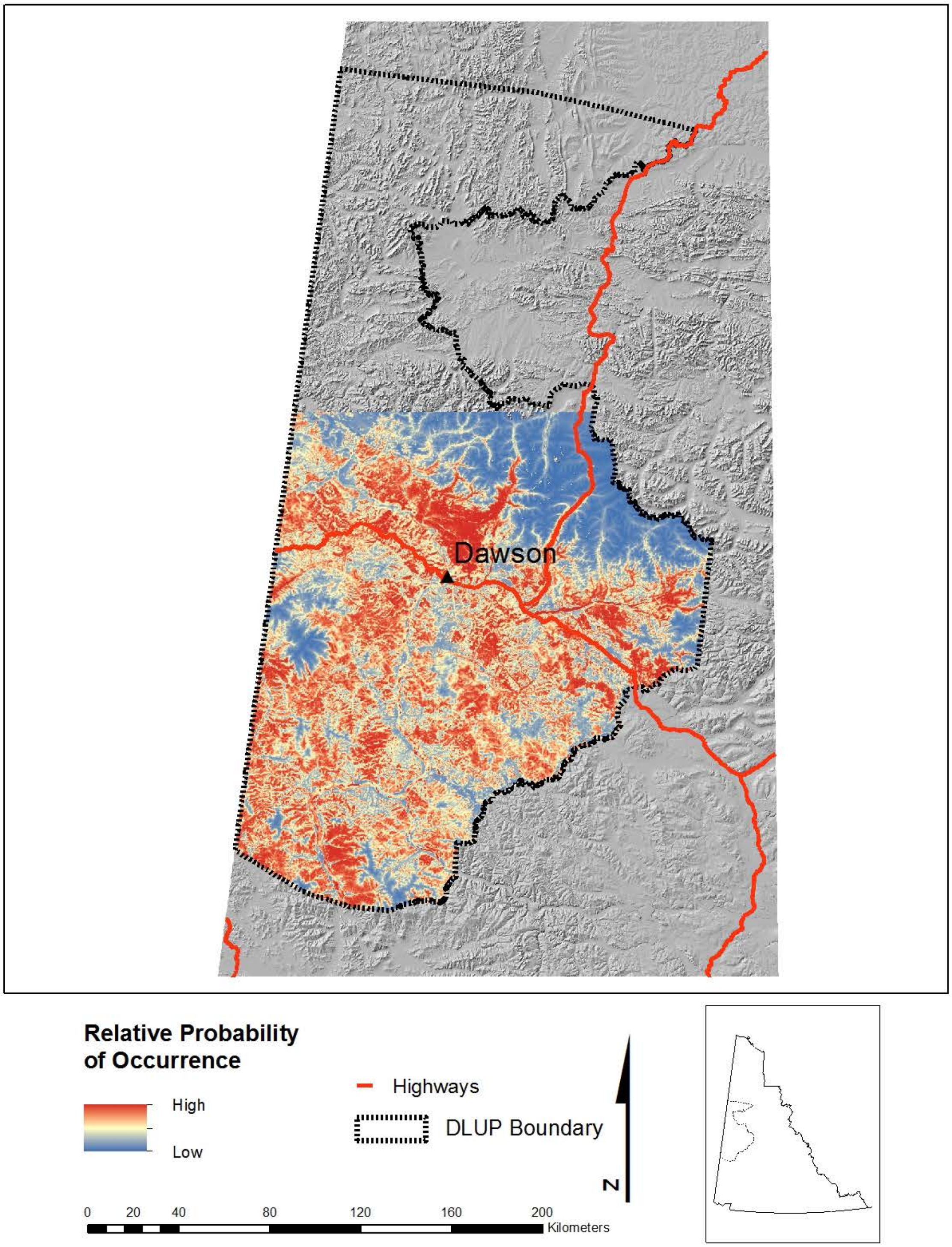

Figure 6: Relative probability of occurrence of adult moose in late winter within the Dawson Land Use Planning Region study area, as predicted by the final resource selection model summarized in Table 2.

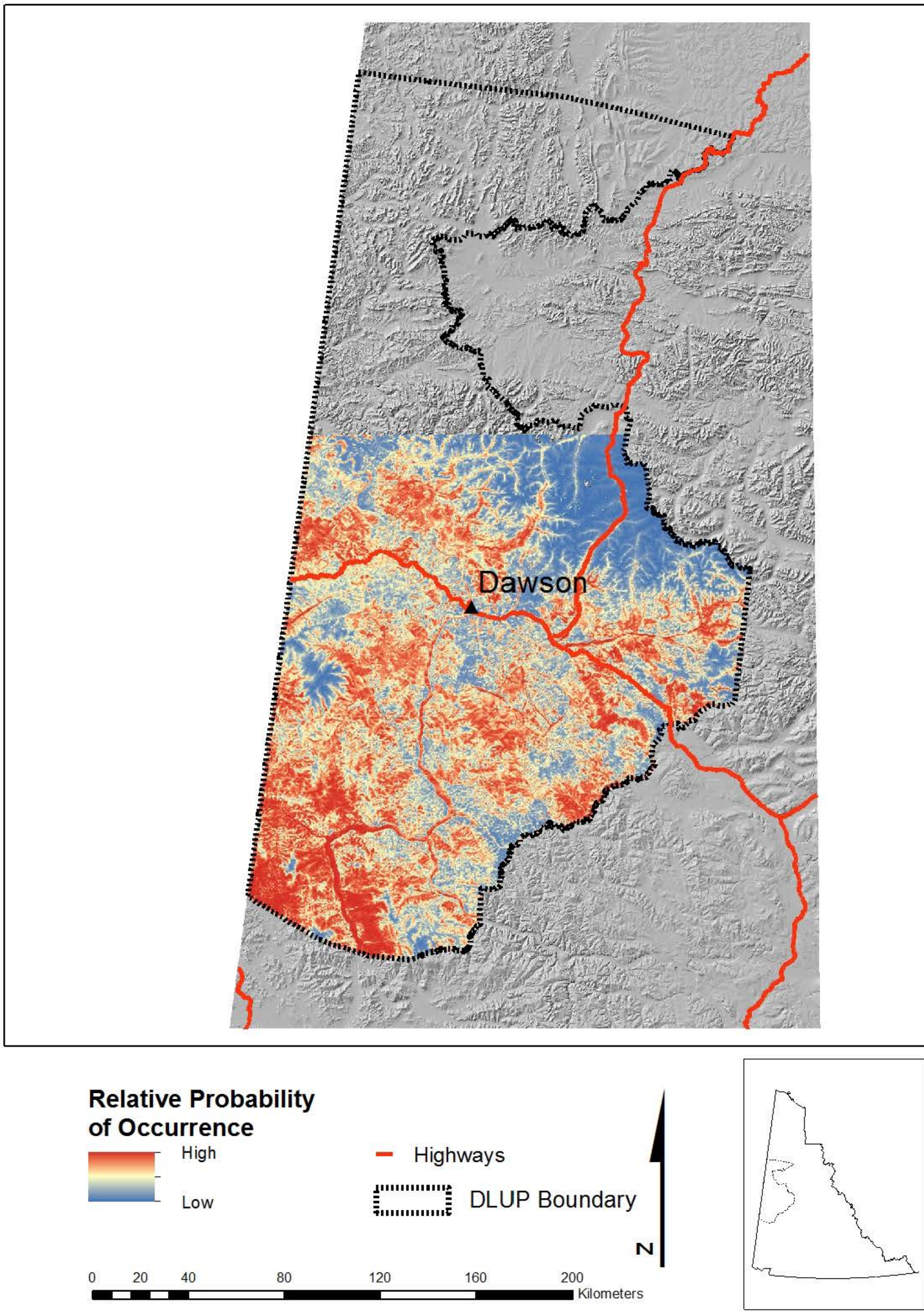

Figure 7: Relative probability of occurrence of cow/calf groups in late winter within the Dawson Land Use Planning Region, as predicted by the final resource selection model summarized in Table 4.

Discussion

1.12 RSF model selection, validation, and limitations

Stepwise model selection techniques can select models that fit very well to the data used to build them. This is the case here; k-fold cross-validation of the final models showed that they performed well at predicting adult and cow/calf moose occurrence within the study area. The risk in using stepwise model selection, however, is that the selected models may reflect patterns in the data that are a feature of the specific dataset, and do not reflect patterns within the general population. This is particularly true when the sample size is small, as is the case for cows with calves (119 observations).

A relatively large number of variables were used in the development of each RSF. Although variables were pre-selected for their potential to affect moose habitat use, it is possible that the final models include some variables simply through chance alone. Thus, one should consider these RSFs as a search for habitat use patterns rather than a formal test of specific hypotheses.

Over-fitting a model may be a problem in some step-wise procedures and lead to a more complex model than otherwise warranted. However, our use of AIC methodology to refine the global model rewards a model for goodness-of-fit, but penalizes it for increasing the number of variables, thereby preventing the problem of over-fitting (Anderson et al. 2000; Burnham and Andersen 1998).

In general, as more late winter location data for this moose population are collected, they should be used to further validate and refine these habitat models.

1.13 Model application

Northern moose populations show patterns of seasonal habitat use that reflect a trade-off among shelter, forage, ease of travel, and predation risk. The relative importance and availability of each of these factors changes throughout a given year, and among years. To further compound the issue, moose are known to use different habitats based on sex and stage of their life history. Therefore, one must consider both the time of year as well as the segment of the population (e.g., adults versus cow/calf groups) when investigating habitat use and selection to aid in habitat management planning.

In this study of late winter habitat use, the final models for adult moose and cow/calf groups were well supported by the data and performed well during cross-validation tests. This suggests that both models provide a reasonable ability to predict habitat selection patterns during late winter in the DLUP Region. These models were then used to create predictive maps of late winter habitat use within the DLUP Region that visually highlighted areas of higher (and lower) probability of use by both adult moose, and cows with calves.

Both categories (adults and cows with calves) avoided wetland, shrub, conifer, and mixed-wood vegetation types within their immediate surroundings, measured as the proportion of each within a 250m or 1km buffer of the observed moose location. To account for the effects of scale, we considered both 250m and 1km buffers for each of these features; however some were a) removed during the collinearity screening process due to their correlation to other variables, or b) were removed from the final model during the stepwise process.

It was anticipated that one or more of these features would be selected for by moose in late winter due to requirements for shelter (conifer), forage (shrub), or a combination (mixed-wood) (Lundmark and Ball 2008; Poole and Stuart-Smith 2005, 2006). The reasons for the avoidance are unclear, but one possible explanation is that age of the vegetation type was unknown, and thus all age classes were pooled. Therefore, young conifer stands that contain little browse and provide no overhead shelter were pooled with older age class that would provide shelter (e.g., Lundmark and Ball 2008; Poole and Stuart-Smith 2005). Alternatively, certain error may have existed in the vegetation inventory used in the analysis with particular areas of the landscape being misclassified. It is unlikely however, that this would have led to the clear, significant relationships identified in the model. A third possibility is that moose were selecting for a variety of vegetation types and thus avoided areas dominated by any individual type. Note, however, that adult moose selected areas closer to forested habitat - both upland and riparian. This indicates (as expected) that moose distribution is affected by the proximity to shelter. The apparent discrepancy between variables expressed as ‘proportion of’ and ‘distance to’ may be interpreted as moose preferring areas that are near cover but which have a variety of vegetation types (i.e., not dominated by a particular type).

As anticipated, elevation was an important predictor of adult and cow/calf habitat selection. Moose in Yukon may move to higher elevations in early winter before descending to lower elevations in late winter, primarily to avoid deep snow (Johnston et al. 1984). A review of other studies showed wide variation in the response of moose to elevation during winter (O'Donovan and Morrison 2010). The inclusion of the quadratic term in the final models indicates that both groups selected for intermediate elevations. Quadratic relationships with elevation are common in ecology, existing where organisms select for elevations that are neither at the minimum nor maximum of those available. This result also parallels the work of Maier et al. (2005) who showed the density of female moose in Alaska was highest at moderate elevations during winter. Selection of mid-elevation areas could be a trade-off between greater snow depths in valley bottoms, and lower forage abundance and unsuitable climates at higher elevations.

Both groups also selected for north-facing aspects. Previous studies (Maier et al. 2005) have shown no association with aspect. The reasons for this association with north-facing aspects are unclear, but may be related to the distribution of habitat features not captured by the variables used in this analysis.

Riparian areas affected the distribution of adult and cow/calf groups; moose in both classes selected areas closer to riparian habitats. This pattern of association with riparian areas is also seen in moose populations in other jurisdictions. For example, Jung et al. (2009) showed that moose in Labrador used riparian areas during winter more than would be expected based on availability; numerous other studies have reported similar results (see references within Jung et al. 2009). Riparian areas offer moose an abundance of forage (woody browse such as willow (*Salix* spp.) and aspens (*Populus* spp.)) during late winter while providing both wind protection and exposure to sunlight for warmth (Jung et al. 2009; Maier et al. 2005; Peek 1998; Seaton et al. 2011). Similarly, nearby forested areas would provide areas of lower snow-cover on the ground and protection from storms. It is unclear why the distance to riparian areas was selected in the final model rather than the proportion of riparian area. Nevertheless, the selection of this feature indicates the importance of riparian habitat for moose during late winter.

Human disturbance features (areal disturbances, or linear features) affect the habitat selection of both adults, and cows with calves. Adult moose appeared to use areas closer to wider (>8m) linear features, whereas cow/calf groups selected habitats closer to small roads. The reasons for this selection are unclear, however, adult moose may have used the features for ease of movement through the landscape. Moose are known to use cleared roads, railroad tracks, and similar features during periods of deep snow because movement along them is energetically less costly. The models did not reveal any avoidance of linear features, suggesting that moose were not avoiding them due to predation pressure by wolves.

Fire is one of the main drivers of landscape pattern in northern forests (Bonan and Shugart 1989; Nelson et al. 2008; Viereck 1973), and both groups were affected by the distance to the nearest burned area. Both adult moose and cows with calves had a negative relationship with the distance to areas burned 11-25 years ago. Such a negative relationship implies the probability of use decreases as the distance to this feature increases. Thus, moose appeared more likely to use an area if it were closer to a fire in the 11-25 year age category. This result is consistent with results from Alaska in which moose were associated with areas burned within the past 11-30 years (Maier et al. 2005). Other evidence from Alaska also indicates that moose densities increased 5-26 years following a fire, further suggesting the importance of this feature on moose populations (Nelson et al. 2008). Adult moose (but not cows with calves) were positively associated with the distance to areas burned within 10 years. Following the rationale above, this implies adult moose were more likely to use an area as the distance to a relatively new fire increased (i.e., avoidance of areas burned within the past 10 years).

These patterns in habitat association most likely derive from the successional patterns of browse following a fire such that browse levels are most attractive to moose 10-25 years post-fire (Maier et al. 2005). If distance to fire is truly a driving factor in late winter habitat selection by moose, then future fire patterns have the potential to greatly affect the winter distribution of moose throughout the DLUP Region. Forest fire patterns, and their likelihood of occurrence, should be a consideration in any late-winter moose habitat management planning in the DLUP Region.

Overall, the RSFs developed in this study captured the late-winter habitat use patterns of adult moose and cows with calves in the DLUP Region. As such, the models may be used to predict the relative probability of occurrence of these groups with the study area. As with all predictive models, these should be revised and re-validated accordingly when new data becomes available.

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Appendix 1: Summary of variable screening for adult moose.

This appendix provides AIC_c values and Pearson correlations for pairs of variables where |r| > 0.60 for the adult moose data set. Suffixes of '250' or '1k' indicate 250m and 1km buffer radii, respectively. For pairs of variables with |r| > 0.90, we selected the variable that was most consistent and logical based on the rest of the variables included in the global model. For pairs of variables with 0.60 < |r| < 0.90, we selected the variables with the lowest AIC_c. AIC_c scores were calculated for single-parameter exponential resource selection models containing the variable in question. Bolded variables represent the selected variable from the correlated pair and do not necessarily represent variables that were included in the global model.

Variable #1	AIC_C	Variable #2	AIC_C	Pearson r
slope_250	4483.8	moist_1km	4489.7	-0.682
slope_250	---	rugged_250	---	0.960
slope_250	4483.8	**rugged_1km**	4482.1	0.811
sq_slope_250	---	rugged_250	---	0.925
sq_slope_250	4478.3	rugged_1km	4482.1	0.743
rugged_250	4481.7	rugged_1km	4482.1	0.784
rugged_250	4481.7	moist_1km	4489.7	-0.630
rugged_1km	4482.1	moist_1km	4489.75	-0.705
d2_areal_250	4489	**d2_hi_250**	4477.4	0.760
d2_areal_250	4489	**d2_mid_250**	4487.3	0.850
d2_hi_250	4477.4	d2_mid_250	4487.3	0.811
wetland_250	4482.1	wetland_1km	4484.9	0.812
wetland_1km	4484.9	moist_1km	4489.7	0.650
shrub_250	4487.1	shrub_1km	4489.1	0.822
conifer_250	4451.3	conifer_1km	4461.4	0.802
decid_250	4474.6	**decid_1km**	4470.9	0.790
moist_250	4468.1	moist_1km	4489.7	0.706
d2_totrip_250	---	d2_shrubrip_250	---	0.936
d2_totrip_250	4455.2	d2_treerip_250	4461.6	0.669
shrubrip_1km	4462.3	shrubrip_250	4464.5	0.677
shrubrip_1km	4462.3	**totrip_250**	4460.7	0.649
shrubrip_1km	4462.3	totrip_1km	4464.4	0.801
shrubrip_1km	4462.3	conrip_1km	4464.5	0.657
shrubrip_250	4464.5	**totrip_250**	4460.7	0.703
totrip_250	4460.7	totrip_1km	4464.4	0.807
totrip_250	4460.7	conrip_1km	4464.5	0.760
totrip_250	4460.7	conrip_250	4463.9	0.878
totrip_1km	---	conrip_1km	---	0.938
totrip_1km	4464.4	**conrip_250**	4463.9	0.705
totrip_1km	4464.4	**decrip_1km**	4458.0	0.683
conrip_1km	4464.5	**conrip_250**	4463.9	0.752
decrip_1km	4458.0	decrip_250	4447.9	0.796

Appendix 2: Summary of variable screening for cow/calf groups.

The table below provides AIC_c values and Pearson correlations for pairs of variables where |r| > 0.60 for the cow/calf data set. Suffixes of '250' or '1km' indicate 250m and 1km buffer radii, respectively. Bolded variables represent the selected variable from the correlated pair as described in Table 1. These variables do not necessarily represent the variables used in the global model.

Variable #1	AIC_C	Variable #2	AIC_C	Pearson r
slope_250	---	**rugged_250**	---	0.960
slope_250	750.78	**rugged_1km**	750.7	0.795
slope_250	750.78	**moist_1km**	750.3	-0.699
sq_slope_250	---	rugged_250	---	0.928
sq_slope_250	750.38	rugged_1km	750.7	0.727
rugged_250	750.76	**rugged_1km**	750.7	0.756
rugged_250	750.76	**moist_1km**	750.3	-0.648
rugged_1km	750.67	**moist_1km**	750.3	-0.733
d2_areal_250	750.92	**d2_hi_250**	750.6	0.782
d2_areal_250	750.92	d2_mid_250	751.0	0.857
d2_areal_250	750.92	**d2_low_250**	748.9	0.605
d2_hi_250	750.63	d2_mid_250	751.0	0.800
wetland_250	750.25	wetland_1km	750.9	0.814
wetland_1km	750.93	**moist_1km**	750.3	0.636
shrub_250	750.07	shrub_1km	750.6	0.821
conifer_250	740.51	conifer_1km	744.4	0.779
mixed_250	750.75	**mixed_1km**	750.2	0.604
mixed_1km	750.17	decid_1km	750.7	0.609
decid_250	750.95	**decid_1km**	750.7	0.815
moist_250	750.76	**moist_1km**	750.3	0.711
d2_shrubrip_250	---	**d2_totrip_250**	---	0.938
d2_totrip_250	746.47	d2_treerip_250	750.4	0.672
shrubrip_1km	750.95	**shrubrip_250**	750.9	0.801
shrubrip_1km	750.95	**totrip_1km**	750.8	0.808
shrubrip_1km	750.95	**totrip_250**	750.8	0.703
shrubrip_1km	750.95	**conrip_1km**	750.8	0.621
shrubrip_250	750.90	**totrip_1km**	750.8	0.630
shrubrip_250	750.90	**totrip_250**	750.8	0.777
totrip_1km	750.80	**moist_1km**	750.3	0.627
totrip_1km	750.80	**totrip_250**	750.8	0.843
totrip_1km	---	conrip_1km	---	0.932
totrip_1km	750.80	conrip_250	750.9	0.638
totrip_1km	750.80	**decrip_1km**	750.2	0.712
totrip_250	750.79	conrip_1km	750.8	0.764
totrip_250	750.79	conrip_250	750.9	0.793
totrip_250	750.79	**decrip_1km**	750.2	0.601
conrip_1km	750.82	conrip_250	750.9	0.703
conrip_1km	750.82	**decrip_1km**	750.2	0.643
decrip_1km	750.24	decrip_250	750.3	0.858