

STATISTICALLY-DERIVED EARLY WINTER MOOSE HABITAT SELECTION IN THE SOUTH CANOL REGION, YUKON

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Summary

I statistically derived moose habitat selection in early winter for the South Canol region, Yukon, using Resource Selection Functions. I used moose observation data collected during aerial surveys between 1994 and 2007, and various landscape variables including vegetation and topography. Using these results, I developed habitat suitability maps for 3 functional groups of moose: Single Moose, Group Moose, and Cow & Calf. I identified and discussed differences in the variables affecting suitability among the 3 groups. This information can be used to inform various resource and land-use planning processes in the Teslin area and will provide input into Yukon Environmental and Socio-economic Assessment Board processes during environmental assessments in the South Canol region.

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Introduction

Recent interest in habitat selection by moose in the Southern Lakes region has led to the development of moose habitat suitability maps based on local knowledge (McLeod and Clarke 2017). An abundance of historical moose survey data collected by Environment Yukon allowed for the development of statistically-derived habitat *selection* models, which in turn can also be used to map relative habitat suitability. To monitor moose populations, early winter stratification flights have been conducted between late-October and early-January in various locations throughout the South Canol Region between 1994 and 2007. I used the data collected during these flights and developed resource selection functions (RSFs) to determine early-winter habitat selection by moose.

I developed habitat selection models for 3 separate functional categories, each of which was suspected to exhibit different habitat use: *Single Moose*, *Group Moose*, and *Cow & Calf*. Habitat selection patterns of single 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). Locations of moose occurring in groups may also be indicative of an anti-predator strategy (Molvar and Bowyer 1994), however habitat

associations may differ from those exhibited by cows with calves; this has not been investigated.

My goal was to determine habitat selection (and ultimately, suitability) for each of these 3 functional moose categories in the South Canol region during early winter and to identify differences among groups. This information is necessary to understand moose-habitat relationships and has important implications for future habitat and moose management planning in southern Yukon.

Methods

Moose location data

I examined early-winter habitat selection by moose in the South Canol region by analyzing moose locations recorded during aerial survey stratification flights between 1994 and 2007 (figure 1). Each survey flight was conducted using either rotary-wing or fixed-wing aircraft flown at a low level in a grid pattern over the survey area. All locations were recorded ± 200 m and search intensity ranged from 0.16 min/km² to 0.58 min/km². Five distinct areas were surveyed and data were combined over all locations and years to form a single moose location data set. The study area was defined as the cumulative area covered by all 5 locations surveyed (figure 1). In total, it encompassed 17,856 km².

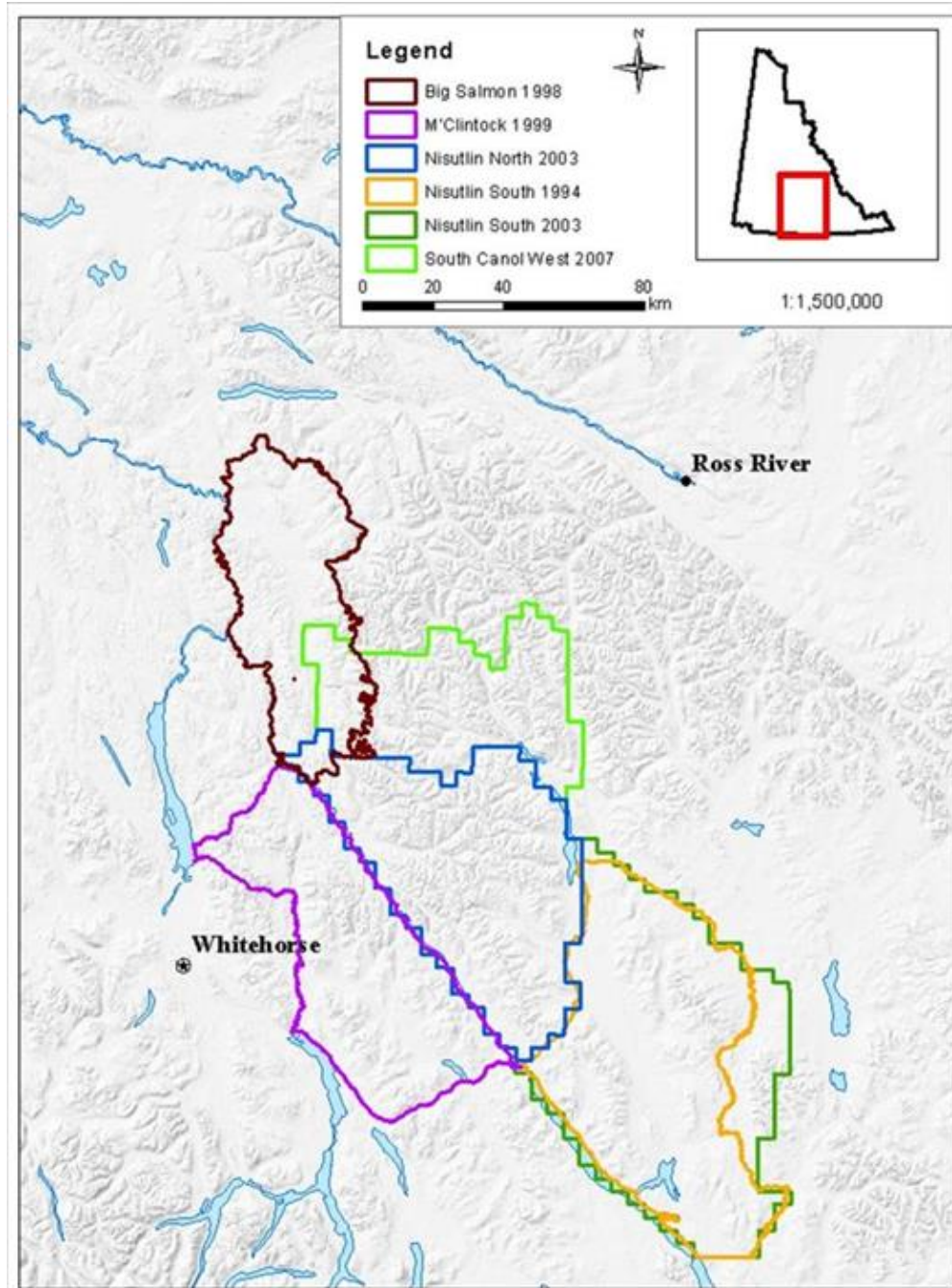


Figure 1. Map of study area showing boundaries for all aerial stratification surveys used in the habitat selection assessment.

The collective survey data were divided into 3 functional categories (i.e., Single Moose, Group Moose, and Cow & Calf moose) based on moose composition recorded during the survey. The Single Moose category included all locations where a solitary moose, regardless of sex, was observed. The Group Moose category included all locations where more than one adult moose, regardless of sex, were observed; calves may or may

not have been present. The Cow & Calf category included locations where a single adult moose and one or more calves were observed. In total, there were 531 Single Moose locations (figure 2), 373 Group Moose locations (figure 3), and 122 Cow & Calf locations (figure 4). An independent habitat selection model was built for each category.

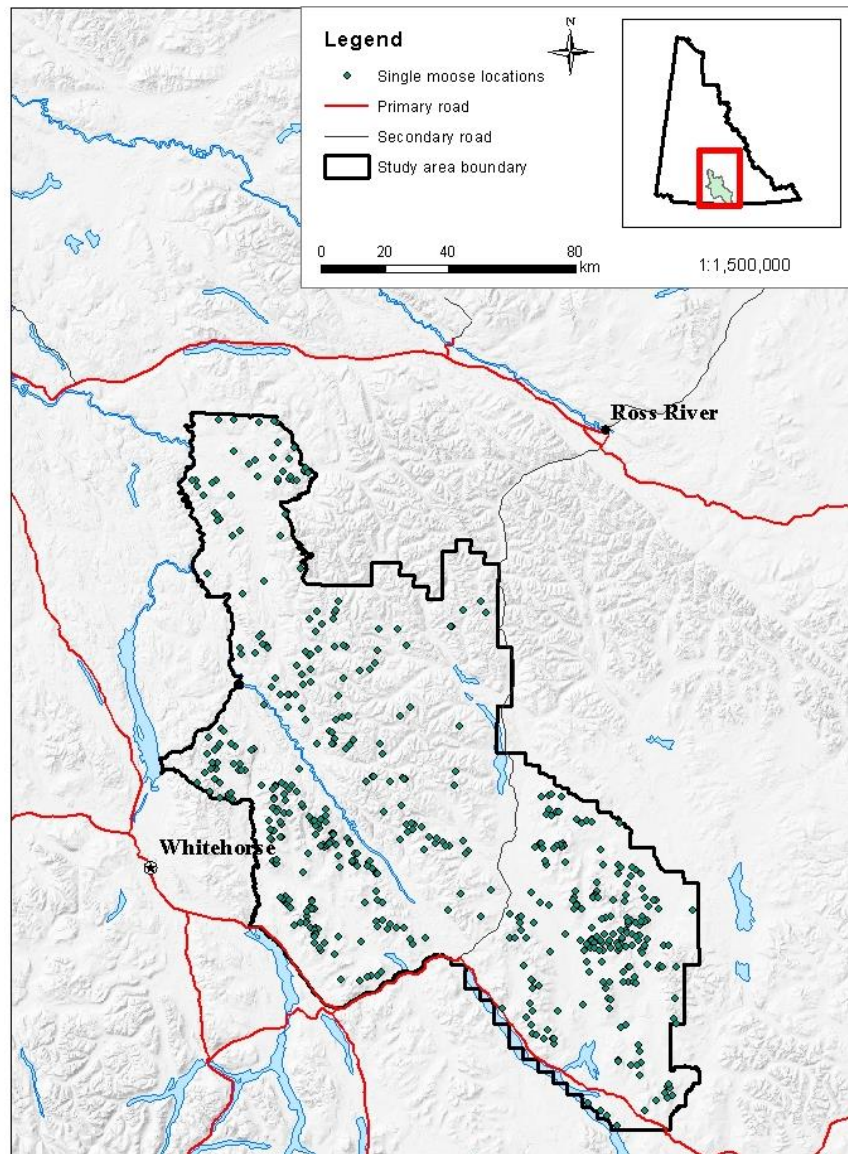


Figure 2. Map of study area, showing Single Moose locations.

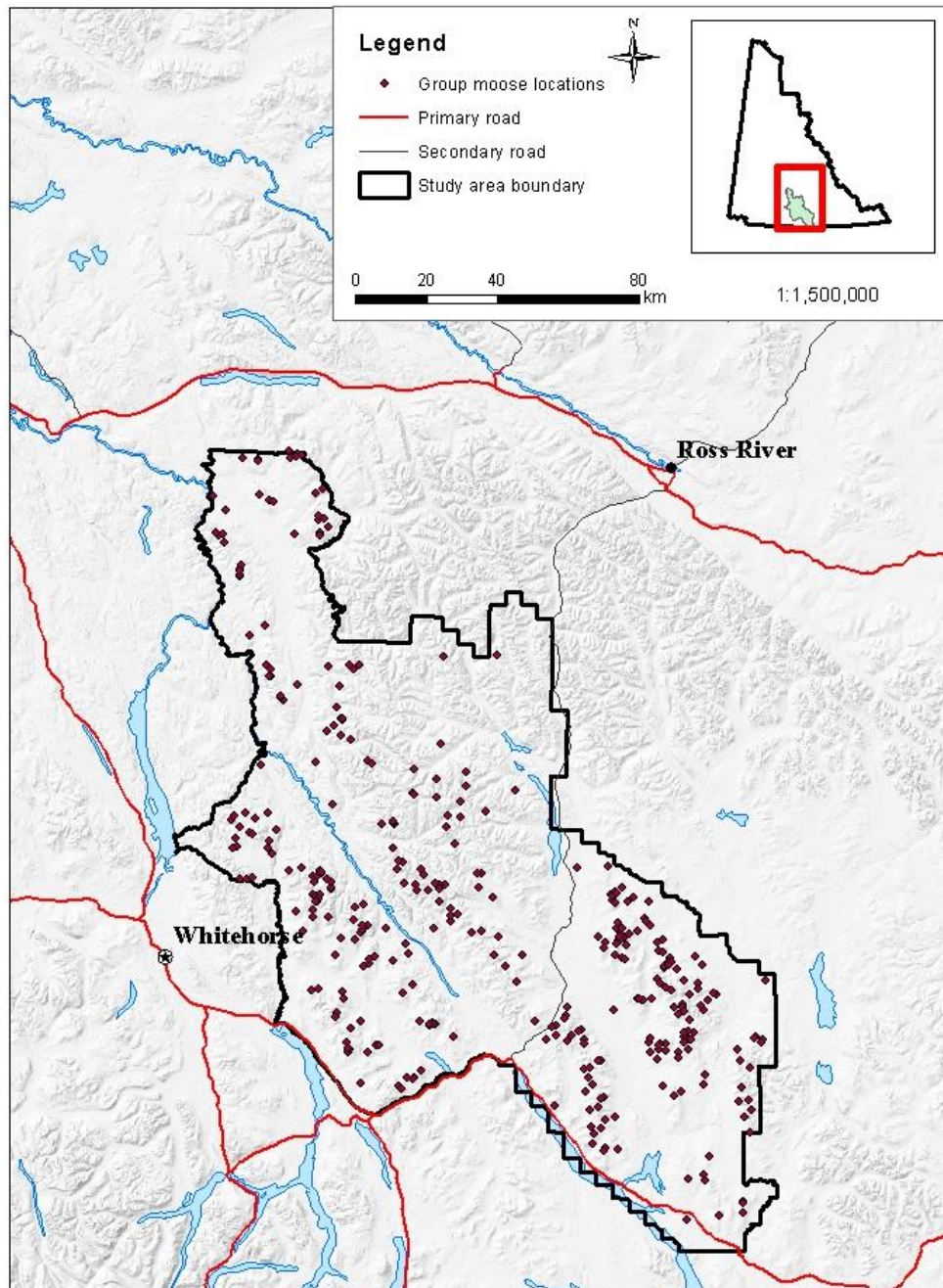


Figure 3. Map of study area, showing Group Moose locations.

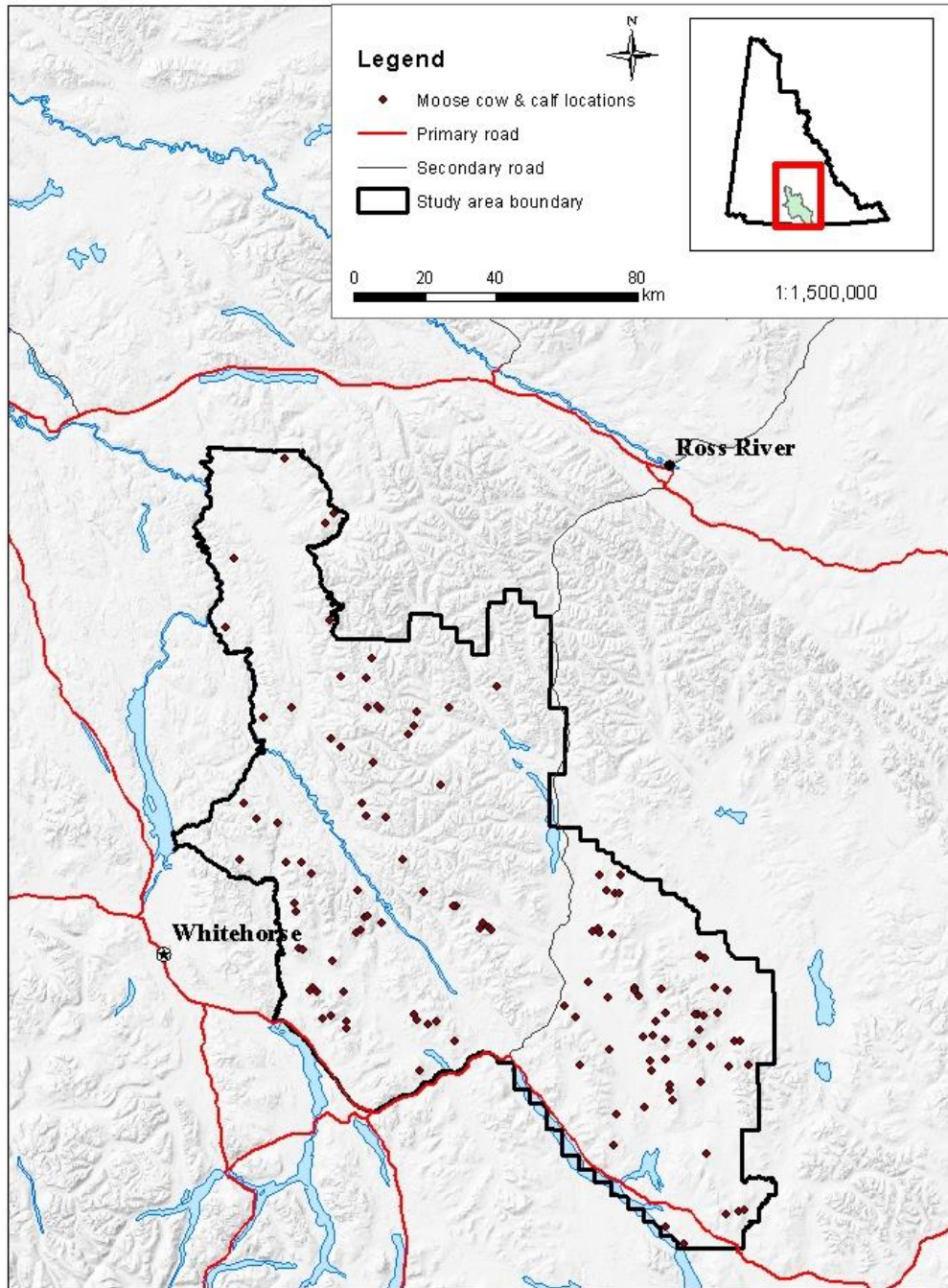


Figure 4. Map of study area, showing moose Cow & Calf locations.

Resource selection functions

I modeled early winter habitat selection by moose for each of the 3 functional moose categories using resource selection functions (RSFs). At the base of an RSF are ‘resource units’, which are locations across the landscape, each with a suite of associated physical and ecological characteristics, or ‘ecogeographical variables’. If the resource unit had a moose location (i.e., a moose was seen there during a survey) it is called ‘used’. If no moose location occurred in the resource unit, it is called ‘available’. An RSF uses the characteristics of known, used, and available resource units to ascertain which ecogeographical variables best predict where a moose is likely to be found (which resource unit it is selecting). Further, an RSF provides a value to each resource unit that is proportional to the probability of the resource unit being selected by the study organism; the output is a predictive model of moose habitat selection based on the ecogeographical variables considered. I used exponential RSFs, which took the form:

$$W(\chi) = \exp(\beta_1\chi_1 + \beta_2\chi_2 + \beta_3\chi_3 \dots + \beta_i\chi_i)$$

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 (Manly et al. 2002).

For each functional moose category, I built RSFs using

ecogeographical variables from the moose location data points (i.e. the “used” locations) and 3,500 “available” locations that I selected randomly from within the study area. Random points were not selected at elevations greater than 1,676 m (5,500 ft) as areas at this elevation are not considered moose habitat. I buffered all locations (used and random) by a 100 m radius to incorporate the spatial inaccuracy inherent in the data collection. All random points were located a minimum of 200 m apart to avoid overlap of buffers. I measured ecogeographical variables relating to moose habitat selection within these buffers. Because moose habitat selection may occur at scales larger than the buffer, I also measured some variables within circular buffers with 500 m and 1,000 m radii.

Ecogeographical variables

The type of ecogeographical variables to use in wildlife habitat modeling can vary considerably among studies. It is often driven by 1) the goal of the study, 2) the area of interest, and/or 3) a priori information on which landscape elements are suspected to be affecting a certain population. In the current study, it is the latter point that helped guide the selection of certain variables I used. Specifically, the landcover variables I selected for in the current study reflect those used in a local knowledge-based moose habitat suitability model developed for the same area (McLeod and Clarke, 2017). These variables were previously identified as potentially having an

effect on moose habitat selection and relate to 1 of the 3 main elements of habitat selection I chose to include: landcover composition.

Moose respond to landcover composition primarily to meet foraging and cover requirements. The vegetation composition variables I used were derived from the 25 m resolution Earth Observation for Sustainable Development of Forest database (EOSD; Canadian Forest Service 2005). This landcover classification is circa 2000 and values for all landcover composition variables used in models represented the percent cover within the area of the site buffer (0.03 km²). Variables included:

- *Lowland non-vegetated* = areas that are non-vegetated occurring < 1,300 m in elevation.
- *Lowland shrub* = areas with a minimum of 20% ground cover, which is at least one third shrub, occurring < 1,300 m in elevation.
- *Upland shrub* = areas with a minimum of 20% ground cover, which is at least one third shrub, occurring ≥ 1,300 m in elevation.
- *Alpine* = areas that are non-vegetated or herbaceous (minimum 20% ground cover with one third of vegetation being herbaceous) occurring ≥ 1,300 m in elevation.
- *Riparian* = areas within a buffered region adjacent to open water. For waterbodies (lakes and wide streams), buffer = 100 m; for watercourses (smaller streams), buffer = 25 m.
- *Wetland* = areas with a water table near, at, or above the soil surface long enough to promote wetland or aquatic processes.
- *Lowland herbaceous* = areas of at least 20% ground cover, with one third of vegetation comprised of herbaceous species, occurring < 1,300 m in elevation.
- *Conifer forest* = areas where coniferous trees comprise a minimum of 75% of the total basal area.
- *Deciduous forest* = areas where deciduous trees comprise a minimum of 75% of the total basal area.
- *Mixedwood forest* = areas where coniferous and broadleaf trees are both present with neither accounting for 75% or more of the total basal area.
- *Open water* = areas of open water including lakes, rivers, and streams.

In addition to the above variables, I used topography and predation risk to produce the final variables.

Topographic variables can influence snow depth, vegetation abundance, and climate, and are important considerations for moose habitat selection (Lundmark and Ball 2008, Dussault et al. 2005, Maier et al. 2005). The topographic variables I used were derived from a 30 m resolution digital elevation model (DEM), and included:

Topographic Position Index (TPI) = a value representing landscape classification based on slope position and landform categories. Measured within circular buffers representing 3

spatial scales: 250, 500, and 1,000 m-radius. Negative values tend towards valley and canyon bottoms; positive values tend towards ridgetops and hilltops. Values close to zero tend toward flat areas or mid-slope areas (depending on slope value).

- *Elevation* = elevation (meters above sea level). I also considered a quadratic elevation term ($elevation^2$) to test for a non-linear relationship; this value was normalized prior to entering the models by dividing it by 10,000. I calculated mean elevation and mean squared elevation within the area of the site buffer.
- *Aspect* = Beer's aspect. A value representing the transformation of aspect to a continuous scaled variable. Maximum value represents a NE slope (i.e., coolest slope). I calculated mean aspect within the area of the site buffer.
- *Slope* = slope (degrees). I also considered a quadratic term for slope. I calculated mean slope and mean squared slope within the area of the site buffer.
- *Variation in elevation* = standard deviation of elevation values within circular buffers representing 3 spatial scales: 500 m-diameter, 1,000 m-diameter, 2,000 m-diameter.

Moose can respond to the risk of predation by selecting habitats in proximity to escape terrain (e.g. open water, forest cover) or by avoiding linear features (e.g. roads) where predator presence (wildlife and human) is often higher than the

remaining landscape (Stephens and Peterson 1984, White and Berger 2001, Yost and Wright 2001). Predation variables were derived from the EOSD and the National Road Network (NRN; GeoBase 2007):

- *Distance to open water* = value representing the Euclidean distance between a point and the edge of the nearest open waterbody. I calculated mean distance within the area of the site buffer.
- *Distance to forest* = value representing the Euclidean distance between a point and the edge of the forest (coniferous, deciduous, or mixedwood). I calculated mean distance within the area of the site buffer.
- *Distance to road* = value representing the Euclidean distance between a point and the nearest road (includes all mapped roads and trails). I calculated mean distance within the area of the site buffer.

Model building and selection

As a preliminary step, for each functional moose category, I screened all variables for collinearity, and considered variables with Pearson correlation coefficients (r) > 0.70 as collinear (except in the case of quadratic terms, which were expected to be highly correlated with their untransformed parent term). Where variables were found to be collinear, I built single-parameter RSF models for each variable and compared their respective predictive abilities using Akaike's Information Criterion (AIC;

Burnham and Anderson 2002). I then chose the variable with the lowest single-parameter model AIC score for further consideration and did not include the other variable.

I used backward and forward selection (α -to-enter = 0.10, α -to-remove = 0.10; Hosmer and Lemeshow 2000) to develop an RSF model representing early-winter habitat selection for each functional moose category. I selected either the backward or forward selection model as the final model using the lowest final AIC scores.

Model validation

I evaluated the performance of each final model using k-fold cross-validation (Boyce et al. 2002). For each functional moose category, used and available locations were randomly assigned into 5 data subsets of equal size. Each data subset was then used as a validation sample for RSFs created using data from the remaining 4 subsets. Selection values using RSFs built from the remaining 4 subsets were calculated and partitioned into 10 ranked bins, each containing roughly $1/10^{\text{th}}$ 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 1.0 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.

Model application

For each functional moose category, I applied the final selected RSF model to the study area and produced 3 maps of habitat suitability (based on selection values) for moose in early-winter: Single Moose, Group Moose, and Cow & Calf moose. The final model was not extrapolated beyond the study area boundary.

Results

None of the landscape composition or predation variables were collinear, therefore I included all the variables in initial models for all functional moose categories. Topographical variables chosen for further consideration following the collinearity screening for all 3 categories are summarized in Table 1. These variables were either non-collinear with other variables, or if they were found to be collinear, had lower AIC values for their single-parameter models than did the variables with which they had a collinear relationship.

Table 1. Variables retained and eliminated from habitat selection analysis for each functional moose category following collinearity assessment. TPI = Topographic Position Index.

Functional Moose Category	Variable Retained	Collinear Variables Eliminated
Single Moose	TPI 1000	TPI 500, TPI 2000
	Elevation	Non-collinear
	Elevation ²	Non-collinear
	Aspect	Non-collinear
	Variation in elevation 2000	Slope, Slope ² , Variation in elevation 500, Variation in elevation 1000
Group Moose	TPI 1000	TPI 500, TPI 2000
	Elevation	Non-collinear
	Elevation ²	Non-collinear
	Aspect	Non-collinear
	Variation in elevation 2000	Slope, Slope ² , Variation in elevation 500, Variation in elevation 1000
Cow and Calf Moose	TPI 1000	TPI 500, TPI 2000
	Elevation	Non-collinear
	Elevation ²	Non-collinear
	Aspect	Non-collinear
	Variation in elevation 2000	Slope, Slope ² , Variation in elevation 500, Variation in elevation 1000

Model selection

Backward-selection models were selected as the final RSF model for both Single Moose and Group Moose categories. Based on results from the k-folds model validation (see details below), both backward and forward selection Cow & Calf models were a poor fit. Due to a relatively low sample size (n = 124), this likely indicated the model was “overfit”, with too many variables included. To increase the fit of the data a final model was built using only landcover variables, and a combination of backward and forward selection (α -to-enter = 0.10, α -to-remove=0.10; Hosmer and Lemeshow 2000).

Parameters in the final Single Moose model included: conifer, alpine, elevation, variation in elevation2000, and elevation². The final Group Moose model included the parameters: deciduous, upland shrub, TPI1000, elevation, variation in elevation2000, and elevation².

Parameters in the final Cow & Calf model included: *deciduous*, *upland shrub*, *lowland shrub*, and *mixedwood forest*. For summary statistics of final models for each functional moose category, refer to Table 2.

Table 2. Final RSF models of early-winter habitat selection by each functional moose category.

Functional Moose Category	Parameter	Estimate	Standard Error	Z	P-value	95% Confidence Interval	
						Upper	Lower
Single Moose	Conifer	-1.121	0.178	-6.303	0.000	-1.469	-0.772
	Alpine	-2.388	0.484	-4.931	0.000	-3.337	-1.439
	Elevation	0.024	0.003	6.861	0.000	0.017	0.030
	Variation in elevation2000	-0.004	0.002	-2.199	0.028	0.007	0.000
	Elevation ²	-0.085	0.015	-5.834	0.000	0.114	-0.057
Group Moose	Deciduous	2.222	0.398	5.588	0.000	1.443	3.002
	Upland shrub	1.225	0.251	4.884	0.000	0.733	1.716
	TPI1000	-0.012	0.003	-4.402	0.000	-0.017	0.007
	Elevation	0.041	0.004	9.869	0.000	0.033	0.050
	Variation in elevation2000	-0.007	0.002	-3.803	0.000	-0.011	-0.004
Cow and Calf Moose	Elevation ²	-0.156	0.017	-9.340	0.000	-0.188	-0.123
	Deciduous	2.404	0.588	4.089	0.000	1.252	3.557
	Upland shrub	1.744	0.380	4.581	0.000	0.999	2.488
	Lowland shrub	1.154	0.427	2.704	0,007	0.317	1.990
	Mixedwood forest	1.768	0.869	2.034	0.042	0.064	3.472

Model validation

The area-adjusted frequency of used moose locations increased with bin rank k-fold cross validation for all 3 functional moose categories (figures 5,

6, and 7). The Spearman rank correlation between mean area-adjusted frequency of moose locations and bin rank was positive and significant for all 3 functional categories (Table 3) indicating that all final models performed well at predicting moose occurrence

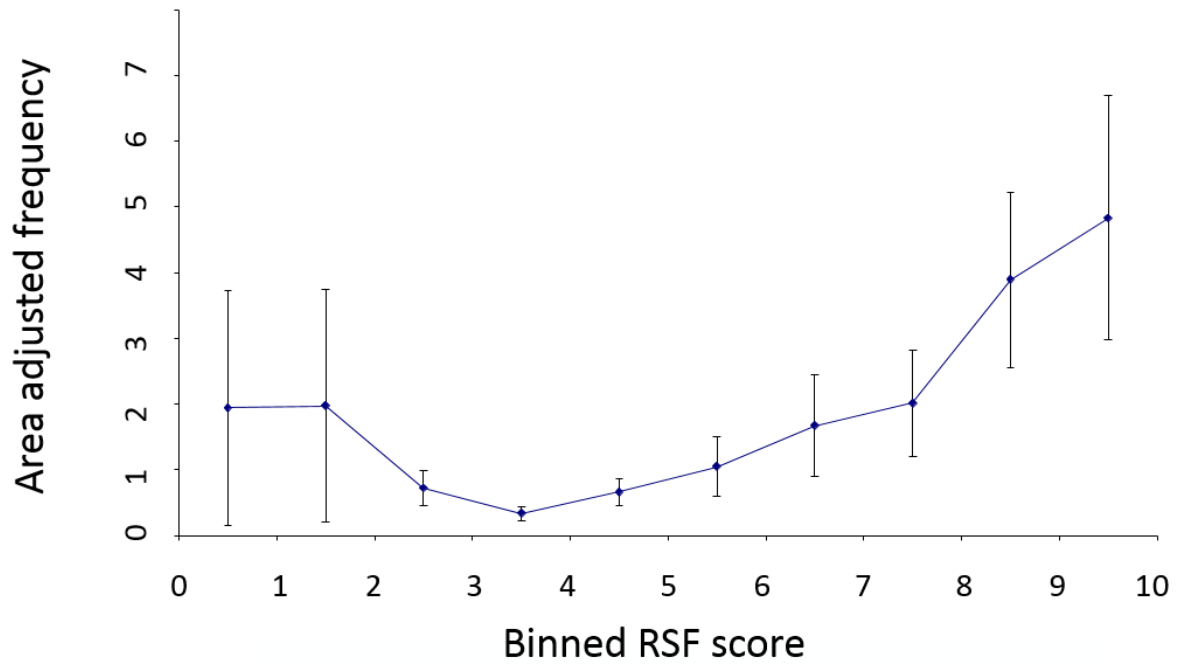


Figure 5. Mean (SE) area-adjusted frequency of categories (bins) of RSF scores for withheld locations in a validation series of 5-folds of the Single Moose habitat selection model.

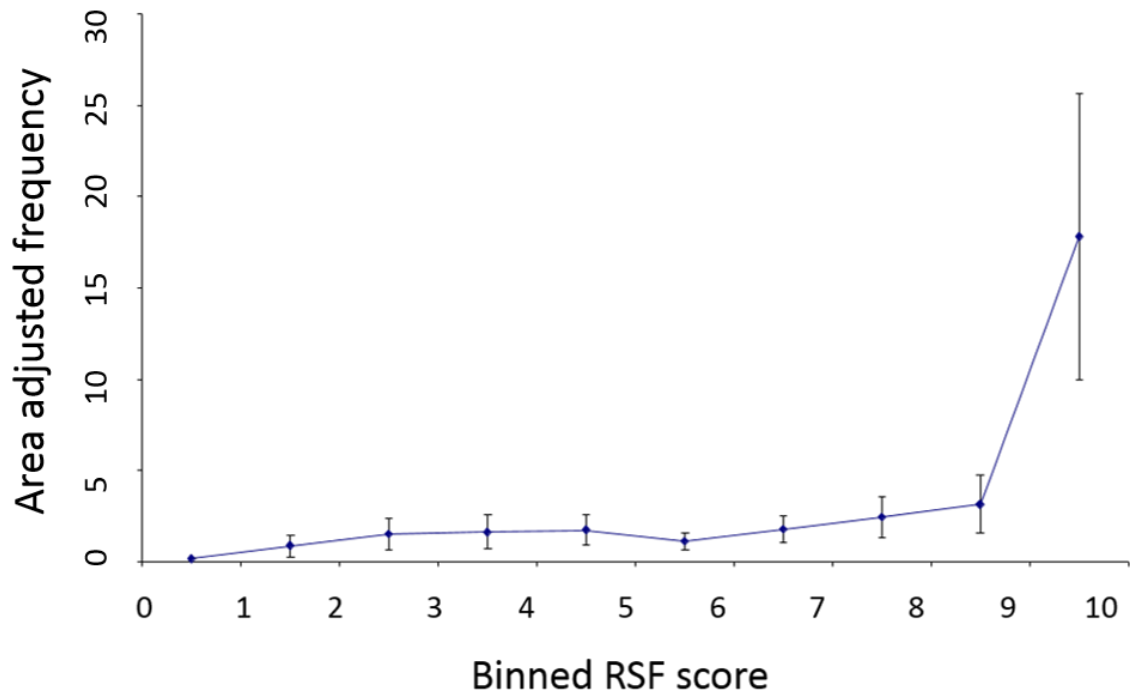


Figure 6. Mean (SE) area-adjusted frequency of categories (bins) of RSF scores for withheld locations in a validation series of 5-folds of the Group Moose habitat selection model.

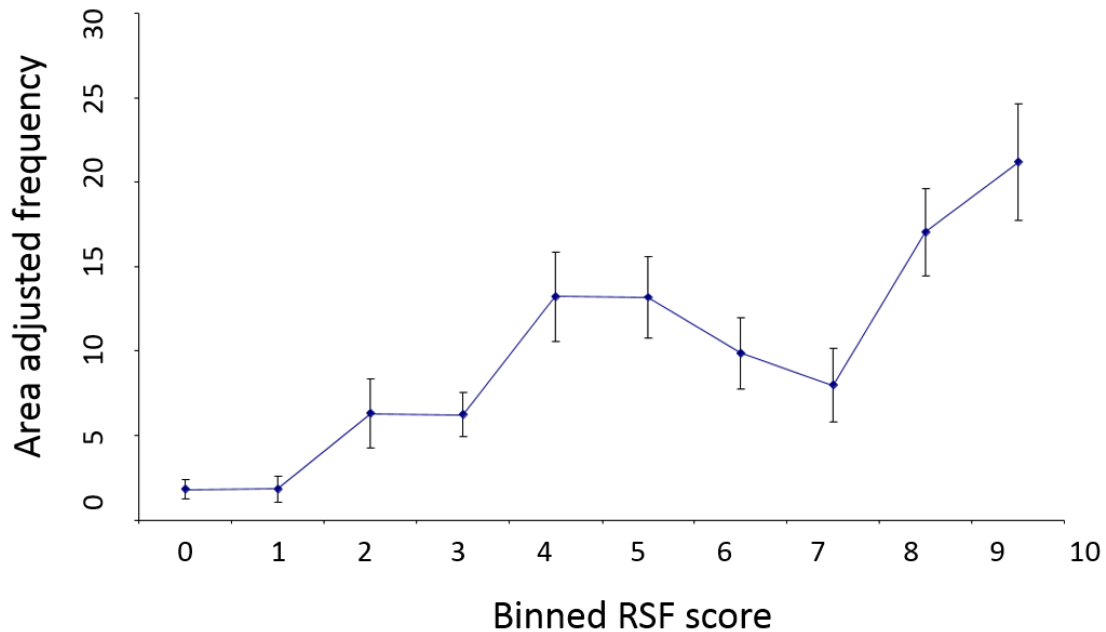


Figure 7. Mean (SE) area-adjusted frequency of categories (bins) of RSF scores for withheld locations in a validation series of 5-folds of the Cow & Calf moose habitat selection model.

Table 3. Results of Spearman rank correlation between area-adjusted frequency and binned RSF scores for each functional moose category.

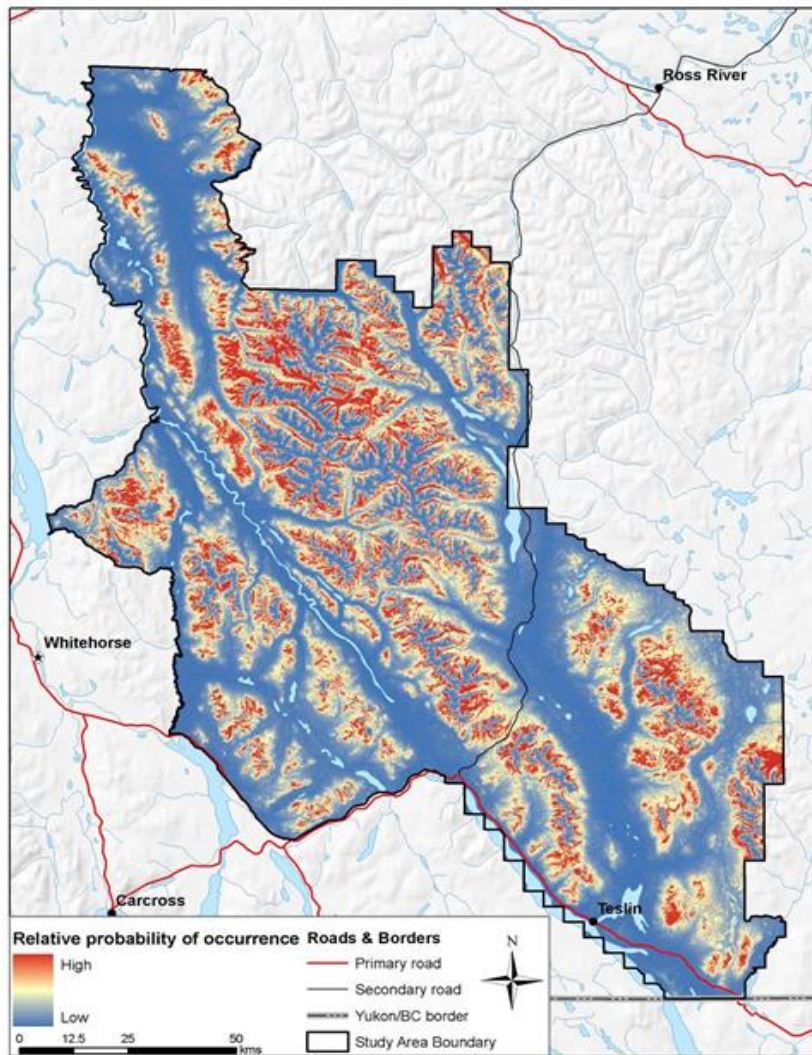
Functional Moose Category	<i>r_s</i>	<i>r_{crit}</i>	p-value
Single	0.383	0.279	<0.05
Group	0.402	0.279	<0.05
Cow & calf	0.719	0.279	<0.05

Model application

The maps of early winter habitat suitability by Single, Group, and Cow & Calf moose reveal a pattern of differential selection across the study area.

The Single Moose (figure 8) and the Group Moose (figure 9) maps are quite similar, with high suitability habitat being dispersed fairly evenly north-to-

south and east-to-west across the study area. The highest abundance of high suitability habitat for both Single and Group Moose is in the top-center of the study area on high elevation shrubby areas; high alpine areas and valleys appear to be avoided. Overall, low-elevation conifer forest habitats tend to be avoided while deciduous forests are of higher suitability. Riparian corridors represent a low suitability habitat.

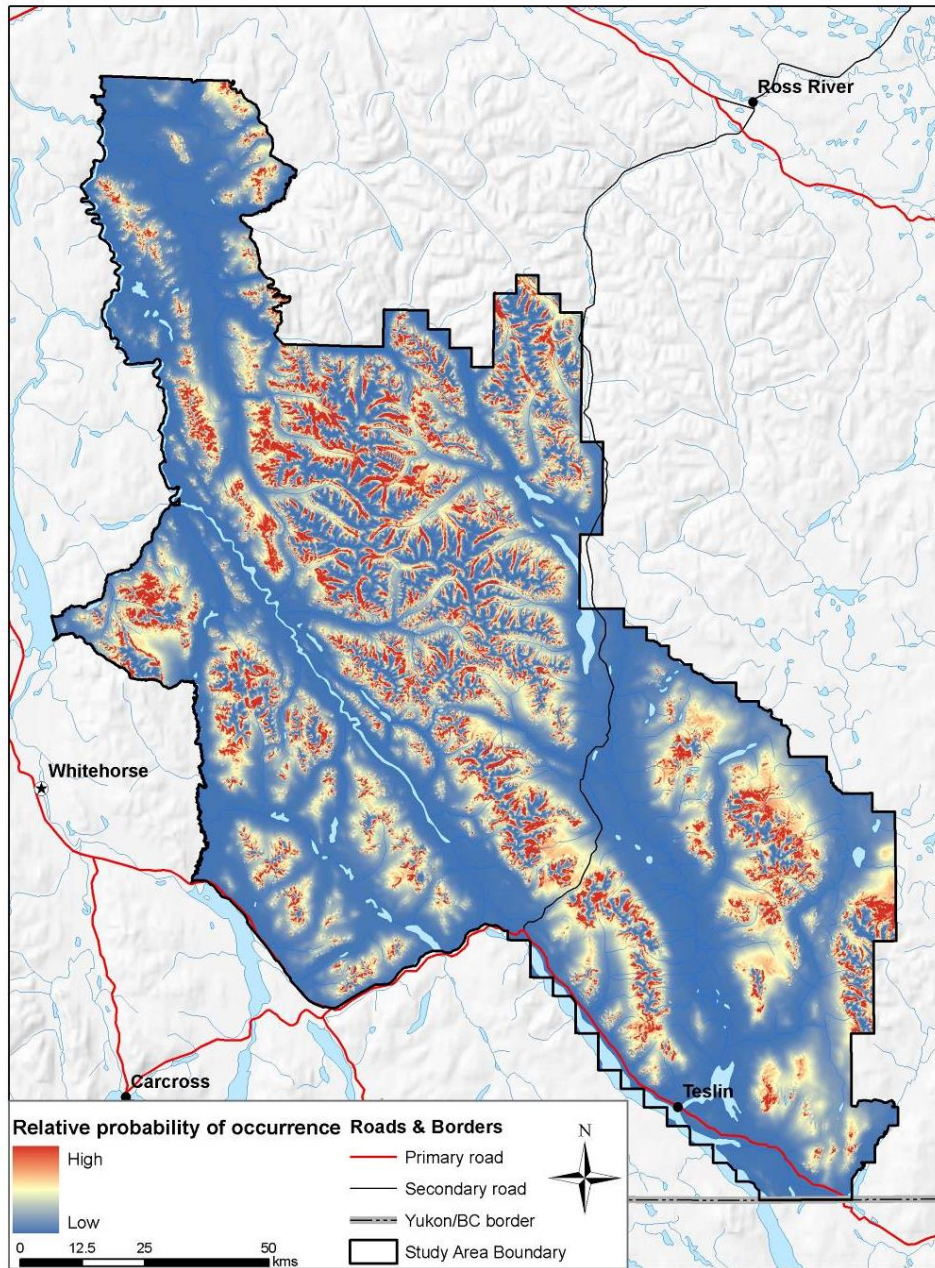


Relative probability of habitat use by single moose in early winter in the South Canol study area.

Figure 8. Relative probability of habitat selection by Single Moose in early winter in the study area.

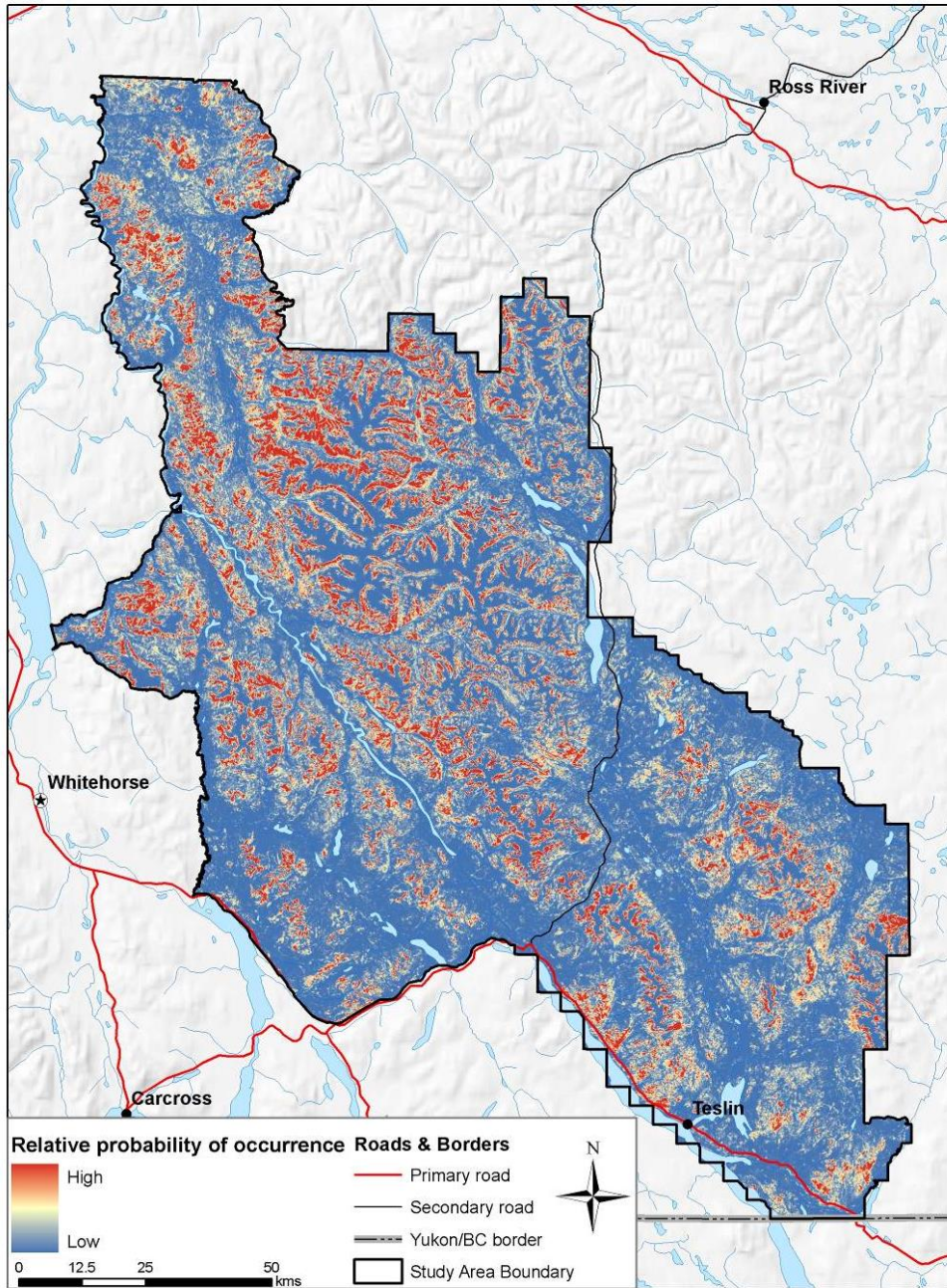
Compared to the Single and Group Moose maps, the Cow & Calf map (figure 10) appears fairly distinct. High and low suitability areas for cows with a calf(s) are more interspersed across the study area, while areas of moderate suitability are rare. Because the Cow & Calf model was derived using only landcover variables, the map does not reflect any relationship

between habitat suitability and topological factors such as elevation. Rather, suitability is related to landcover composition, with areas characterized by deciduous forest, mixedwood forest, or shrub (lowland and upland) being most suitable. High alpine areas, valleys, and riparian corridors have low suitability.



Relative probability of habitat use by grouped moose in early winter in the South Canol study area.

Figure 9. Relative probability of habitat selection by Group Moose in early winter in the study area.



Relative probability of habitat use by cow & calf moose in early winter in the South Canol study area.

Figure 10. Relative probability of habitat selection by Cow & Calf moose in early winter in the study area.

Discussion

Model selection and validation

Stepwise model selection techniques can select models that fit very well to the data used to build them. In this case, models for all 3 functional moose categories fit the data well; k-fold cross-validation of each final model showed that it performed well at predicting 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 populations. This is particularly true when the sample size is small; in the current study sample sizes for the Single and Group Moose models were relatively high ($n = 397$ and $n = 361$, respectively), reducing this risk. However, for the Cow & Calf model, sample size was lower ($n = 122$), thus the risk was higher. When more survey data for cows with calves become available, they should be used to further validate the Cow & Calf model.

Single Moose

The final model for Single Moose predicted selection for high elevation. This result is not surprising given that moose tend to migrate up to higher elevations following the fall rut and remain in these regions throughout early winter (LeResche 1974, Johnston et al. 1984). I found that moose preferred habitat with little variation in elevation (i.e., flatter terrain when using a 2,000 m

diameter area). This indicates that Single Moose select for the degree of unevenness in the surrounding landscape at a scale larger than their immediate surroundings. This is understandable given that the average home range of Single Moose is much larger than the smaller scales tested (i.e., 1,000 m diameter and 500 m diameter; LeResche 1974). The model also included a negative quadratic elevation parameter suggesting that some intermediate value of elevation is selected for by Single Moose in early winter. That is to say, highly suitable habitat is not situated too low down, or too high up. The most preferred elevation was predicted to be 1,411 m. Finally, Single Moose appear to select against both conifer forest and alpine areas habitats known to be avoided by moose in early-winter (Johnston et al. 1984).

Group Moose

The final model for Group Moose indicated that groups of moose share similar preferences for elevation and variation in elevation as Single Moose. The most preferred elevation was slightly lower, however, at 1,314 m. The model also predicted selection against the topological position index (TPI) over a 1,000 m diameter area. This indicates that at this scale, groups of moose prefer flat or slightly lower areas (i.e., tending toward valleys and canyon bottoms) to higher ridgetops and hilltops. Finally, groups of moose prefer deciduous forests and upland shrubs, habitats commonly known to provide forage resources for moose (Dussault et al. 2005).

Cow & Calf Moose

Cow and calf moose select for deciduous and mixedwood forest and upland and lowland shrub habitats. These areas are likely attractive to cows and calves because they provide both foraging resources and cover from predators and inclement weather (Stephens and Peterson 1984, Kunkel and Pletcher 2000, Dussault et al. 2005). Due to concerns over small sample size, the final Cow & Calf model was designed to only indicate relationships between moose and landcover features; relationships with topographical features such as elevation and TPI were not identified. As a result, details on habitat selection as they relate to landscape topology may be missing and the description of habitat suitability for cows and calves may be incomplete. Caution should be made when interpreting and applying this model and when possible the model should be re-assessed using topological variables.

Considerations and Limitations

The models developed for all 3 functional moose categories were unique in that they were based on moose occurrence data spanning 13 years (1994 to 2007). While certain habitat conditions may have changed during that time due to succession, the effect of these changes on perceived moose habitat and associated selection was assumed to be minimal. Further, any effects would be minimized by the fact that the landcover data used in the analyses reflected habitat conditions circa 2000 and differences in actual habitat conditions at the time

occurrence was recorded would therefore only reflect a range of 6-7 years (i.e., 1994 to 2000 = 6 years prior; 2000 to 2007 = 7 years after). Additionally, while wildfires can alter habitats, often making them more suitable for moose (Nelson et al. 2008), only 0.1% of the study area has been burned since 2000 (when the land cover classification was generated) making any effect of wildfire on moose habitat selection negligible.

If a given model is extrapolated beyond the study area boundary in the future, results 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 a model beyond the study area over which it was built is not quantifiable.

Model results are also limited by error associated with input variable data. The EOSD used to describe landcover attributes across the study area has a degree of error associated with it, and overall classification accuracy is estimated at 78%. Specifically, mixedwood forests are classified with the lowest degree of accuracy and are frequently misidentified as conifer (38%) or shrub (22%) habitats. Shrub habitats are also classified with a relatively low level of accuracy, often misclassified as deciduous forests (20%) or herbaceous areas (14%). While these sources of error do not preclude the use of these models, model interpretation and application should

be done with these limitations in mind. Models should be re-assessed and validated with newer and more accurate data as it becomes available. This study highlights landcover features that are important in defining moose habitat in early winter in the South Canol region. Furthermore, it reveals differences in habitat selection among different functional categories

of moose, reflecting a relationship between moose behaviour and habitat use. The identification of areas of high habitat suitability can inform future decisions on moose and habitat management and aid in the development of land use and resource planning.

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