HABITAT SELECTION

FORTY MILE CARIBOU IN THE DAWSON REGION

LATE WINTER

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Summary

The Forty Mile caribou herd once numbered in the hundreds of thousands, and had an annual home range that extended from Fairbanks, AK, to Whitehorse, YT. Through a combination of harvest, predation, climate and habitat change, the herd declined to 4,000 caribou by the 1970s. Since then, the herd has rebounded, and they are expanding their annual movements into their former ranges, including portions of the Dawson region.

Using late-winter aerial survey data from 2008 and 2010, we modeled late winter habitat selection by Forty Mile caribou in the Dawson region. We then extrapolated model results beyond the study area, to predict selection patterns under scenarios of future winter range expansion.

Late winter habitat selection by Forty Mile caribou appears to rely on preferences for lichen abundance, distance from old forest fire areas, and elevation. Patches of highly-selected habitats are centred on an area south of the Top of the World Highway; extrapolation of the model to a wider area predicts highly-selected habitat patches southeast of Dawson, and along the southern margins of the Ogilvie Mountains. Fire, the most dynamic factor affecting Forty Mile caribou winter habitat, could have a large impact on future habitat selection and range expansion.

Key Findings

- Caribou selected for areas of high lichen abundance, moderate elevations, and for areas distant from old forest fires.
- Models performed well at predicting late winter caribou occurrence.
- Habitat selection values across the Dawson region were heterogeneous; patches of highly-selected habitat were interspersed within large areas with low selection values.
- Areas of highly-selected habitat coincided with areas of high lichen abundance. These were also areas that had not experienced forest fires since fire records began in 1952.

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Introduction

The Forty Mile caribou herd

The Forty Mile caribou herd once numbered in the hundreds of thousands, and had an annual range that stretched from Fairbanks to Whitehorse (Urquhart and Farnell 1986). Caribou from the Forty Mile herd provided food, clothing and other materials for many First Nations within their range, and were an important source of food for the Klondike Gold Rush (Urquhart and Farnell 1986, FMCHWG 2009). Through what is thought to be a combination of overharvest, predation, harsh winters and changes in their habitat, the Forty Mile caribou herd declined during and after the Gold Rush at the turn of the century, only to rebound to nearly 600,000 animals by the 1920s (Urquhart and Farnell 1986, McDonald and Cooley 2004, FMCHWG 2009). By the 1940s, however, the herd had declined to tens of thousands of animals; increased access and overharvest, as well as wolf predation, were thought to be responsible. The creation of new roads into the Forty Mile caribou herd's range allowed the herd to be hunted by more people, at more points during their annual movements. The Forty Mile herd continued to rise and fall, peaking at 45,000 – 55,000 animals in the 1950s, and then declining drastically to 4,000 animals by 1974. It was in this last decline that the Forty Mile herd ceased to enter Yukon, and the attention of hunters and resource managers shifted to the Porcupine caribou herd, accessible along the newly-constructed Dempster Highway (Urquhart and Farnell 1986).

Beginning in 2002, caribou from the Forty Mile herd began returning to Yukon (Dorothy Cooley, pers. comm., FMCHWG 2009). The Forty Mile caribou herd's winter range now extends into areas west of Dawson, in the vicinity of the Forty Mile, Sixty Mile and Ladue rivers. The most recent estimate, from 2003, gives the Forty Mile herd size as 43,000 animals, on either a stable or slightly declining trend (FMCHWG 2009).

If the Forty Mile caribou herd is to grow, it is expected that they will require an expanded range in which to support themselves. While caribou from the Forty Mile herd currently winter in the area west of Dawson, it is hoped that they will continue to expand, and re-inhabit more of their former range in Yukon. Changes to their former habitat, such as forest fires, decreases in lichen abundance, and increased human infrastructure, may affect the ability of the Forty Mile herd to use their former range as they once did.

Methods

Caribou location data

We examined late winter habitat selection by Forty Mile caribou in the Dawson region by analyzing caribou locations recorded incidentally during late winter moose surveys in west-central Dawson region (Figure 1; Cooley and

Kienzler 2011, Cooley et al. 2011). Caribou were observed from a fixed-wing aircraft flown at low level in a grid pattern within the survey area, and their locations were recorded ± 200 m. Both surveys were conducted as stratification surveys, with a search intensity of 0.42 minutes per km^2. In 2008, surveys occurred 10 – 28 March, and observers located approximately 450 caribou in 69 groups. In 2010, surveys occurred 4 – 13 March, and observers located approximately 450 caribou in 54 groups. Of these 123 caribou groups, we excluded 12 as belonging to either the Porcupine or Hart River herds based on their location, leaving 111 groups remaining as Forty Mile caribou. To establish a Forty Mile late winter study area, we built a 100% minimum convex polygon around the observed Forty Mile caribou locations, and buffered it by 10 km (Figure 1). We restricted the study area to within Yukon.

Resource selection functions

We modeled late winter habitat selection by the Forty Mile caribou herd using resource selection functions (RSFs). RSFs use characteristics of samples 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. We used exponential RSFs, which 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 (Manly et al. 2002).

Ecogeographical variables

We built RSFs using ecogeographical variables from 111 caribou group locations (considered to be “used” locations) and 1000 “available” locations seeded at random within the Forty Mile study area (Figure 1). We buffered all locations by a minimum 250 m radius, to incorporate spatial inaccuracy inherent in fixed-wing survey locations. We measured ecogeographical variables relating to caribou’s habitat selection within these buffers. Because caribou’s selection of habitat may occur at scales larger than their immediate surroundings, we also considered values for some variables within circular buffers with 500, 1000, and 2000 m radii. We considered variables related to topography, water, fire history and anthropogenic disturbance, all of which are thought to have an effect on caribou distribution and habitat selection.

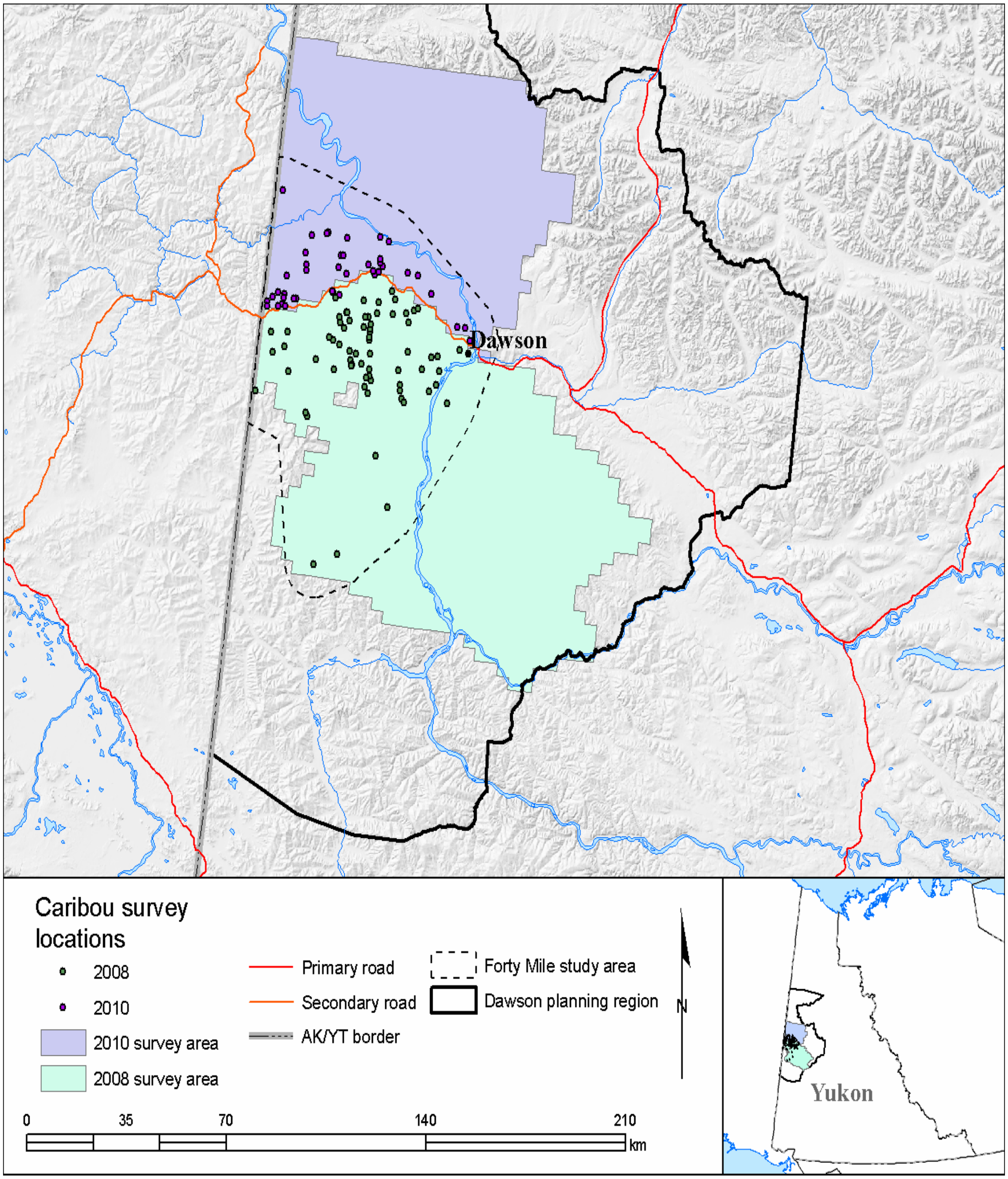

Figure 1. Map of southern Dawson region, showing caribou locations and survey extents from 2008 and 2010 late winter aerial surveys, as well as the Forty Mile late winter study area.

Caribou respond to topography in many ways. Snow depth, vegetation abundance, and climate, all important considerations for caribou, are highly influenced by topographic features. The topographic variables we used were derived from a 30 m resolution digital elevation model (DEM), and included:

Elevation = elevation (meters above sea level). We also considered a quadratic elevation term. We calculated mean elevation and mean squared elevation over a 250 m radius.

Slope = slope (degrees). We also considered a quadratic term for slope. We calculated mean slope and mean squared slope over a 250 m radius.

Eastness = a value representing the proximity of aspects to 90°, with cells with aspect 90° (due east) having the value 1, and cells with aspect 270° (due west) having the value 0. We calculated mean eastness over a 250 m radius.

Northness = a value representing the proximity of aspects to 0°, with cells with aspect 0° (due north) having the value 1, and cells with aspect 180° (due south) having the value 0. We calculated mean northness over a 250 m radius.

Ruggedness = a value representing the roughness of the terrain surface, calculated as the standard deviation of elevation values within a circular neighbourhood. We calculated ruggedness over circular neighbourhoods of 250, 500 and 1000 m radii.

Waterbody distance = distance (meters) from the closest waterbody, as depicted by 1:250,000 waterbody, wetland and watercourse layers (Geomatics Yukon). We calculated mean waterbody distance over a 250 m radius.

Lichen is the main winter forage for caribou, and their distribution and abundance is thought to be tightly linked to this resource. Caribou also rely on other vegetation for food and cover. The vegetation variables we considered were based on measures of lichen density and vegetative greenness, derived from satellite imagery, and included:

Lichen = percentage of lichen cover within a pixel, broken into nine classes from 0% through 80 - 100%, derived from a spectral mixing model developed by Chubey et al. (2010, 2011) applied to two 30 m resolution Landsat 5 images captured 3 July 2008 and 15 July 2009. We calculated mean lichen percentage over circular neighbourhoods of 250, 500, and 1000 m radii.

Greenness = normalized difference vegetation index values, derived from a 250 m resolution MODIS image captured 30 July 2006. We calculated mean greenness over circular neighbourhoods of 250, 500, and 1000m radii.

Fire history influences caribou distribution by reducing or removing lichen, and by resetting successional processes (Rupp et al. 2006, Joly et al. 2007, 2010). We examined fire history attributes using data from Environment Yukon's fire history shapefile, which contains fire footprints for the Dawson region for fires since 1952. Before deriving fire history variables, we removed fire footprints from any fires which occurred subsequent to caribou surveys in 2008 and 2010. We considered one fire history variable:

Burn distance = distance (meters) to the nearest fire footprint. We also considered a quadratic burn distance term. We calculated mean burn distance and mean squared burn distance over a 250 m radius.

The presence of anthropogenic features on the landscape can have a large effect on caribou distribution and abundance. Caribou have been seen to avoid human developments, such as roads, towns, and mines (Nellemann et al. 2001, Johnson et al. 2005, Weir et al. 2007). The presence of roads and trails on the landscape can also allow wolves to travel more efficiently, increasing wolf predation of caribou compared to unroaded areas (James and Stuart-Smith 2000). We considered one variable for anthropogenic disturbance:

Linear feature density = density of roads and trails (km/km^2) within a circular neighbourhood. We calculated mean feature density within a circular neighbourhoods with 1000 and 2000 m radii.

Model selection

As a preliminary step, we screened all variables for collinearity, and considered variables with Pearson correlations > 0.60 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, we built single-parameter RSF models for each variable, and compared their predictive abilities using Akaike's Information Criterion for small sample sizes (AIC_c; Burnham and Anderson 2002). We then chose the variable with the lowest single-parameter model AIC_c score for further consideration. When calculating AIC_c, we avoided artificial inflation of sample size by considering only the 111 used caribou locations (and omitting the 1000 available locations).

With our non-collinear set of variables, we began selection of RSF models representing late winter habitat selection by the Forty Mile caribou herd using backward and forward stepwise model selection (α-to-enter = 0.10, α-to-remove = 0.10; Hosmer and Lemeshow 2000). We then combined both models using a model averaging approach, combining parameters and error terms from both models, weighted by their AIC_c weight (ω_i; Burnham and Anderson 2002).

Model validation

We evaluated performance of the final model using k-fold cross-validation (Boyce et al. 2002). We randomly assigned used and available locations into 5 data subsets of equal size. We then used each data subset as a validation sample for RSFs trained using data from the remaining four subsets. We classed resulting RSF values derived from the validation data subset into 10 ranked bins, each containing roughly 1/10th of the pixel RSF values within the entire study area. For used locations in each data subset in turn, we calculated selection values using RSFs built from the remaining 4 subsets. We then binned used locations for each subset according to their selection value. We adjusted bin frequencies by dividing them by the actual area of the study area contained within each bin. A positive, significant Spearman rank correlation between bin rank and area-adjusted frequency rank denotes a model with good predictive performance.

Model application

We applied the final selected RSF model to the study area, producing a map of habitat selection values for Forty Mile caribou in late winter. We also extrapolated the final model beyond the bounds of the study area, to estimate potential patterns of late winter habitat selection by Forty Mile caribou under a scenario of winter range expansion.

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 Forty Mile caribou's potential late winter habitat selection patterns, with an unknown error term.

Results

Variable screening

Variables chosen for further consideration in the collinearity screening processed were Lichen_{1000}, $\text{Burn distance}_{250}$, $\text{Burn distance}^2_{250}$, Elevation_{250}, Elevation^2_{250}, Ruggedness_{1000}, Greenness_{500}, $\text{Linear density}_{2000}$, Eastness_{250}, Northness_{250}, and Waterbody distance_{250}. These variables were either non-collinear with other variables, or if they were found to be collinear, had lower AIC_c values for their single-parameter models than did the variables with which they had a collinear relationship (Table 1).

Table 1. AICc values and Pearson correlations for variable pairs with r > 0.60.

Variable	AIC_c	Variable	AIC_c	Pearson r
$Lichen_{1000}$	**669.80**	$Lichen_{250}$	687.15	0.776
$Lichen_{1000}$	**669.80**	$Lichen_{500}$	721.41	0.907
$Lichen_{250}$	**687.15**	$Lichen_{500}$	721.41	0.920
$Ruggedness_{1000}$	**720.54**	$Slope_{250}$	723.31	0.696
$Ruggedness_{1000}$	**720.54**	$Slope^2_{250}$	725.36	0.653
$Ruggedness_{1000}$	**720.54**	$Slope^2_{250}$	725.36	0.653
$Ruggedness_{1000}$	**720.54**	$Ruggedness_{250}$	723.35	0.670
$Ruggedness_{1000}$	**720.54**	$Ruggedness_{500}$	722.17	0.836
$Ruggedness_{500}$	**722.17**	$Slope_{250}$	723.31	0.903
$Ruggedness_{500}$	**722.17**	$Slope^2_{250}$	725.36	0.864
$Ruggedness_{500}$	**722.17**	$Ruggedness_{250}$	723.35	0.908
$Greenness_{500}$	**723.29**	$Greenness_{250}$	723.78	0.944
$Greenness_{500}$	**723.29**	$Greenness_{1000}$	723.45	0.951
Linear $density_{2000}$	**723.29**	Linear $density_{1000}$	723.78	0.909
$Slope_{250}$	**723.31**	$Ruggedness_{250}$	723.35	0.941
$Ruggedness_{250}$	**723.35**	$Slope^2_{250}$	725.36	0.924
$Greenness_{1000}$	**723.45**	$Greenness_{250}$	723.78	0.873

**Subscripts denote the radius of the circular neighbourhood over which the variable was calculated, and superscripts denote quadratic terms. The variables with the lowest AIC_c score (bold) associated with its single-parameter model are displayed in the left column. AIC_c scores were calculated for single-parameter exponential resource selection models containing the variable in question, except in the case of quadratic variables, where both the squared and untransformed variables were included as model parameters.

Model selection

We used the set of variables produced by the collinearity screening process as candidate variables in backward and forward stepwise model selection. The model selected using backward stepwise model selection included parameters for $Lichen_{1000}$, $Burn\ distance_{250}$, $Burn\ distance^2_{250}$, $Elevation_{250}$, and $Elevation^2_{250}$ (Table 2).

The model selected using forward stepwise model selection included only one parameter, $Lichen_{1000}$ (Table 3).

We calculated a final model using the model averaging approach, by combining parameters and error terms from both models, weighted by their Akaike weights (Burnham and Anderson 2002; Tables 4 and 5).

Model validation

The area-adjusted frequency of used caribou locations increased with bin rank in k-fold cross-validation (Figures 2 and 3). The Spearman rank correlation between mean area-adjusted frequency of caribou locations and bin rank was positive and significant ($\rho_{df=8} = 0.855$, $p < 0.0025$), indicating that the final model performed well at predicting caribou occurrence.

Model application

The map of late winter habitat selection by Forty Mile caribou, produced using the final model in Table 5, reveals a pattern of differential selection across the study area. The bulk of highly-selected habitat is located in a concentrated cluster of patches immediately south of the Top of the World Highway (Figure 4). Smaller patches of highly-selected habitat exist north of the highway and west of Dawson. The southern third of the study area contains little highly-selected habitat.

Using the habitat selection model developed within the study area (Table 5), we extrapolated beyond the study area as an estimate of late winter habitat selection by Forty Mile caribou under a winter range expansion scenario (Figure. 5).

Expansion of the model to the entire southern Dawson region was limited by the spatial extent of lichen data, which was not available for the entire region. Extrapolation of the late winter habitat selection model beyond the study area reveals patches of highly selected habitat south-east of Dawson, and a band of highly-selected habitat patches running along the southern margin of the Ogilvie Mountains. Much of the southern half of the region demonstrates low selection values.

Table 2. Exponential resource selection function model of late winter habitat selection by Forty Mile caribou in the Dawson region.

Parameter	Estimate	SE	Z	p
$Lichen_{1000}$	1.005	0.179	5.604	0.000
$Burn\ distance_{250}$	3.69E-4	1.81E-4	2.039	0.041
$Burn\ distance^2_{250}$	-5.96E-8	3.37E-8	-1.769	0.077
$Elevation_{250}$	8.00E-3	3.00E-3	2.510	0.012
$Elevation^2_{250}$	-5.08E-6	2.05E-6	-2.474	0.012
Log likelihood	**K**	**AIC_c**		
-328.397	5	667.365		

**Produced using backward stepwise model selection. AICc was calculated using only used caribou locations as the sample size (n used = 111).

Table 3. Exponential resource selection function model of late winter habitat selection by Forty Mile caribou in the Dawson region.

Parameter	Estimate	SE	Z	p
$Lichen_{1000}$	1.224	0.161	7.598	0.000
Log likelihood	**K**	**AICc**		
-333.233	1	669.801		

**Produced using forward stepwise model selection. AICc was calculated using only used caribou locations as the sample size (n_{used} = 111).

Table 4. AIC_c comparison of resource selection function models selected using backward and forward stepwise model selection.

Model	Log likelihood	K	AICc	ΔAIC_c	ω_i
Backward stepwise	-328.397	5	667.365	0	0.77
Forward stepwise	-333.882	1	669.801	2.435	0.23

Table 5. Final exponential resource selection function model of late winter habitat selection by Forty Mile caribou in the Dawson region.

Parameter	Estimate	SE	95% Confidence Interval	
			Lower	Upper
$Lichen_{1000}$	1.05	3.82E-2	0.978	1.127
$Burn\ distance_{250}$	2.85E-04	4.93E-08	2.85E-04	2.85E-04
$Burn\ distance^2_{250}$	-4.60E-08	1.50E-15	-4.60E-08	-4.60E-08
$Elevation_{250}$	6.17E-03	1.82E-05	6.14E-03	6.21E-03
$Elevation^2_{250}$	-3.92E-06	7.81E-12	-3.92E-06	-3.92E-06

**Produced by combining weighted models from Tables 2 and 3, following multimodel inference procedures in Burnham and Anderson (2002). Parameter estimates, SE and 95% CI are weighted by Akaike weights, and SE and 95% CI are unconditional, incorporating uncertainty in model selection as well as model uncertainty.

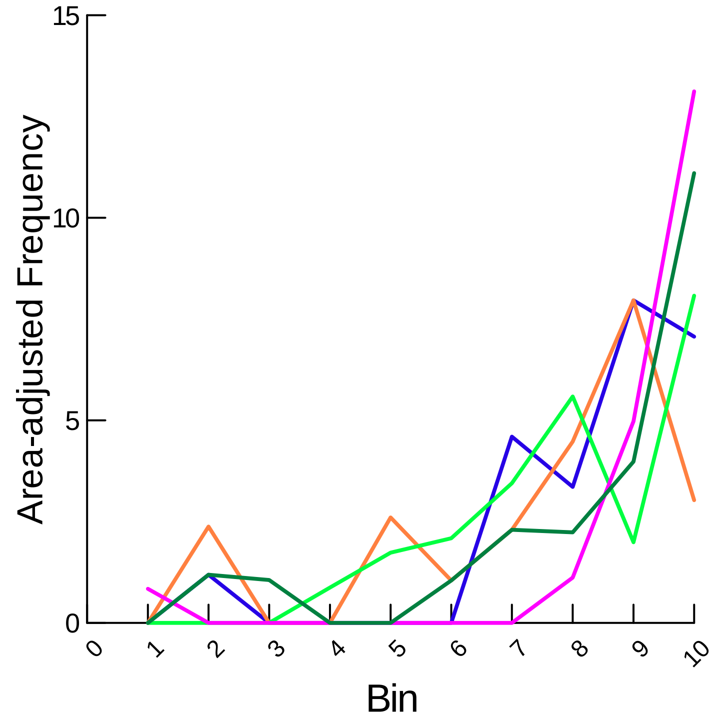

Figure 2. Individual area-adjusted frequencies of caribou locations (divided at random into five equal data subsets; depicted as individually-coloured lines) within 10 ranked RSF value bins.

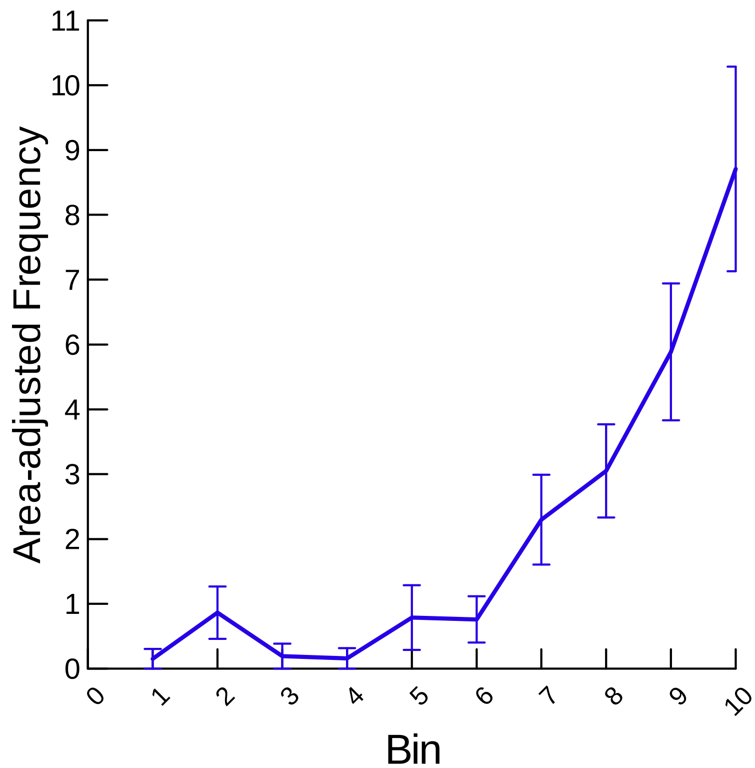

Figure 3. Mean (±SE) area-adjusted frequency of caribou locations (as determined individually for five randomly-selected data folds) within 10 ranked RSF value bins. Spearman rank correlation (ρ) for the mean data = 0.855, $p<0.0025$.

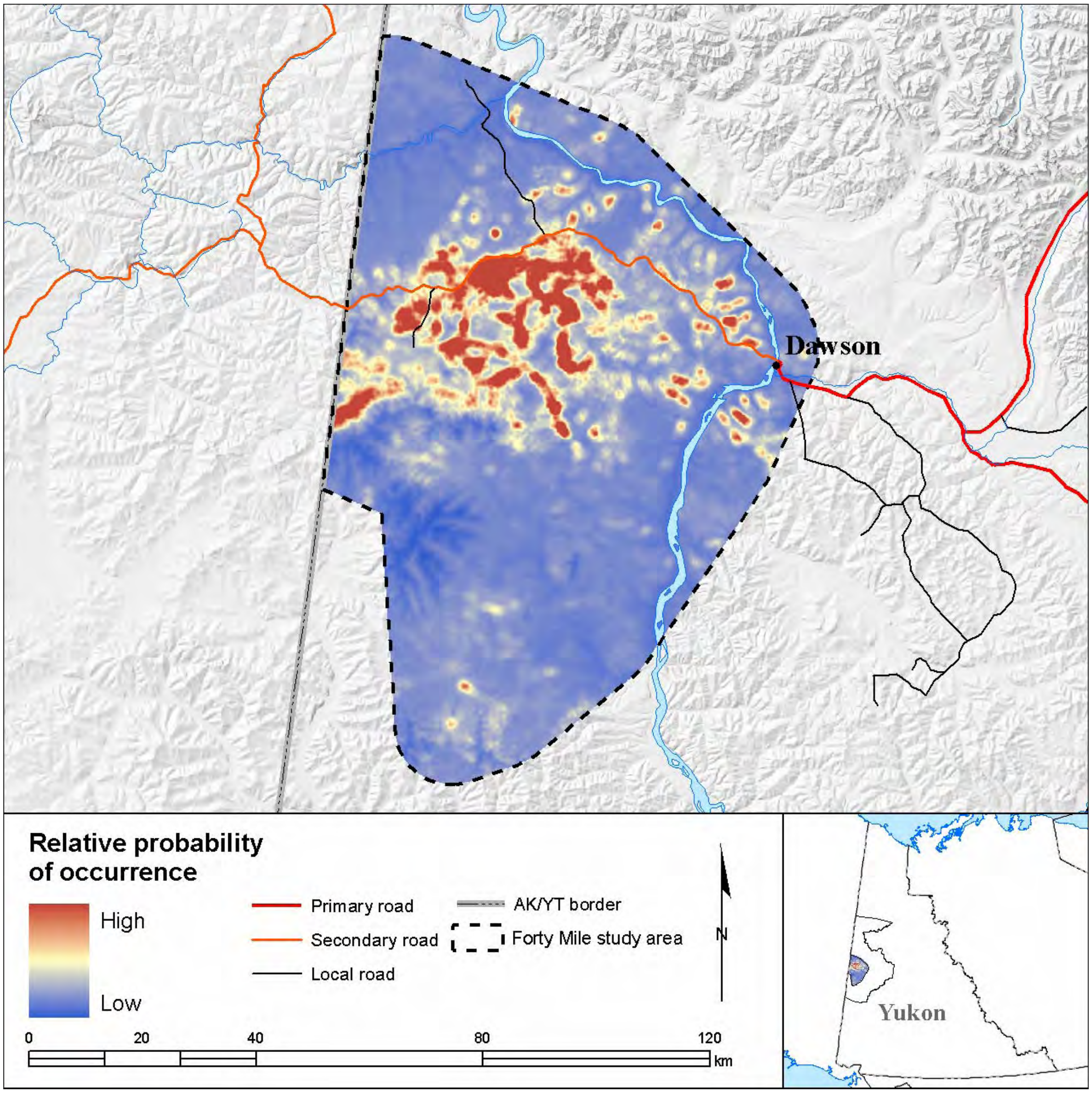

Figure 4. Relative probability of occurrence of Forty Mile caribou in late winter within the Forty Mile study area, as predicted by the final resource selection model in Table 5.

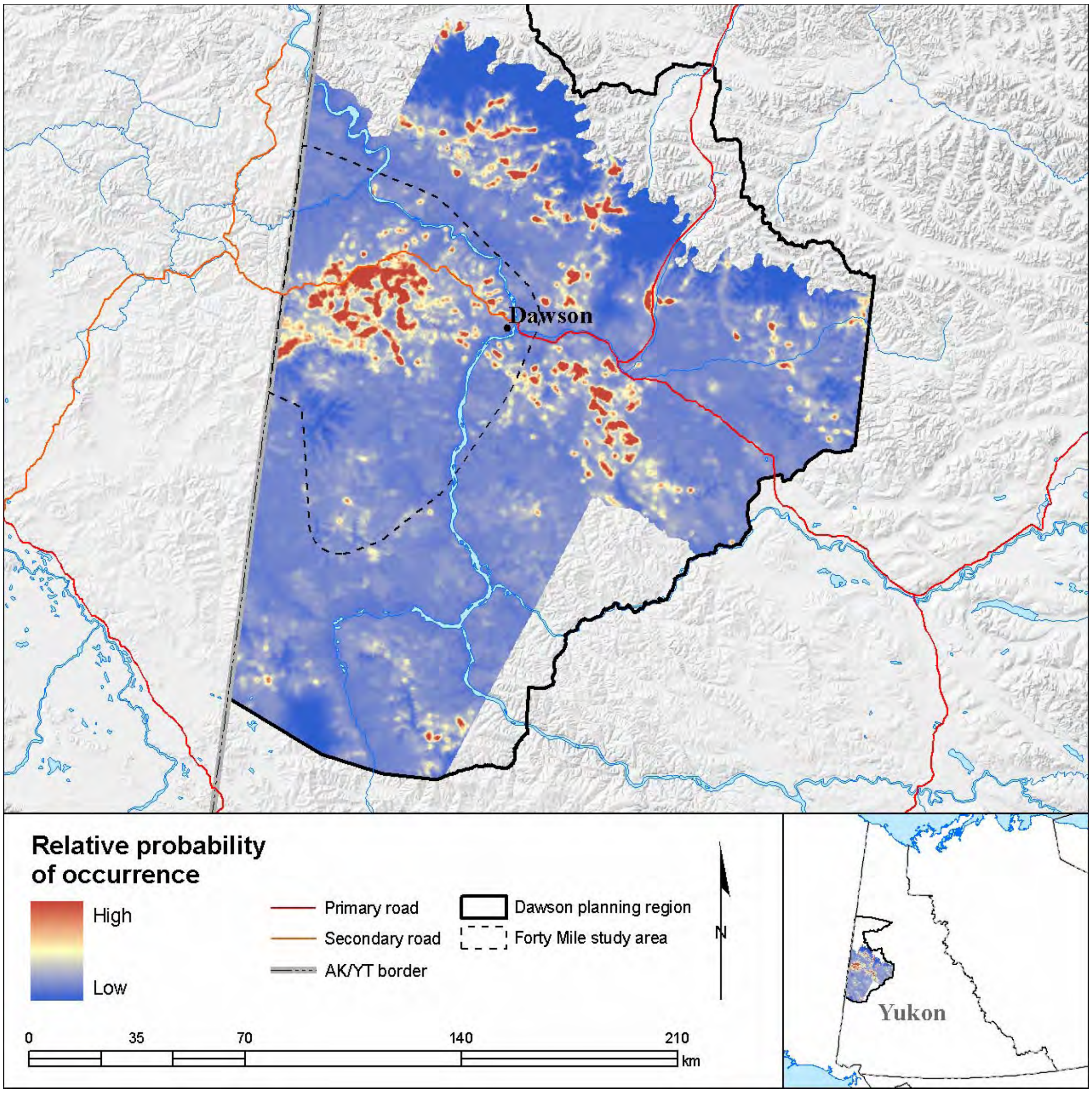

Figure 5. Relative probability of habitat use by Forty Mile caribou in late winter, predicted using the final model in Table 5, estimated for habitat beyond the study area to examine potential patterns of late winter habitat selection by Forty Mile caribou in an expanded winter range.

Discussion

Model selection and validation

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 model showed that it performed well at predicting caribou occurrence within the study area (Figures 2 and 3). 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 here (111 used caribou locations). As more late winter location data for the Forty Mile caribou herd are collected, they should be used to further validate this habitat model.

Model application

The final model predicted selection for high lichen proportion within a 1000 m radius (Table 5). Selection for lichen at this scale was shown to fit the data better than selection for lichen at the 250 and 500 m scales (Table 1). That caribou select for lichen abundance at scales larger than their immediate surroundings is not surprising; caribou are a mobile species, and selection of a lichen-rich neighbourhood with good foraging opportunities could be more important than selection of a single lichen-rich site. Lichen proportion was selected as a model parameter by both the forward and backward stepwise model selection procedures (Tables 2 and 3), confirming its importance as a driver of caribou habitat selection.

The final model included a quadratic relationship between selection and distance to burns (Table 5), with the predicted selection maximum occurring at a distance of 3094 m from a burn. The inclusion of the quadratic term for burn distance in the model suggests that, despite the widely-observed poor quality of burned forest as caribou habitat, some property of old burns, or the vicinity of old burns, is attractive to caribou in late winter. Caribou's late winter foraging patterns could incorporate occasional feeding on grasses, forbs or shrubs, which are plentiful in previously-burned areas. Lichen, caribou's main winter forage, is very low in protein, and occasional supplementation of caribou's diet with vascular plants could be a strategy to maximize foraging efficiency and nutritional intake (Storeheier et al. 2002, Joly et al. 2010). In such a case, caribou would be expected to select for proximity to burned areas, while spending most of their foraging time outside of burns themselves. Alternatively, the modeled quadratic relationship could be an approximation of a true pattern where the negative effect of proximity to burns on selection is attenuated once they are 3 km distant, with no perceivable effect of burns on caribou's habitat selection beyond that distance.

The final model also incorporated a quadratic relationship with elevation (Table 5), with the selection maximum occurring at 786 m above sea level. 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. In this case, a selection maximum at 786 m corresponds to caribou's use of mid-slopes and low hills, and selection against both valley bottoms and high elevations. Selection of mid-elevation areas could be a product of greater snow depths in valley bottoms, and low forage abundance and unsuitable climates at higher elevations. Caribou may also select for mid-elevation areas as a strategy to avoid higher predation risk from wolves associated with moose at lower elevations (James et al. 2004, Gustine et al. 2006).

Distance from waterbodies was also included in the final model, with selection increasing with increasing distance from waterbodies (Table 5). This result is surprising; caribou in other areas are known to spend time on frozen lakes during winter, drinking overflow water, feeding on lakeshore vegetation, and keeping vigilant for predators (Ferguson and Elkie 2005). Selection against proximity to water may relate to the habitats where waterbodies are found in the Dawson region, low-elevation areas where snow is likely to accumulate, and caribou's apparent selection against proximity to waterbodies may be a reflection of their avoidance of these habitats. Areas in close proximity to waterbodies may also harbour high densities of moose, which in turn support high wolf densities; caribou may avoid these areas as an anti-predator strategy (James et al. 2004).

The variable for linear feature density was not included in the final models. While the effects of linear feature density on caribou habitat selection have been well-documented elsewhere (e.g. Dyer et al. 2002, Apps and McLellan 2006, Fortin et al. 2008,), the relatively low density of linear features encountered by Forty Mile caribou west of Dawson may have been below the threshold for measurable effect. Under range expansion scenarios, as caribou encounter higher densities of linear features in the areas south and east of Dawson, linear features may play a larger role in their habitat selection.

Variables for greenness and aspect appeared to have little predictive ability for caribou habitat selection, and were likewise excluded from the final models.

Within the Forty Mile study area, the largest patches of highly-selected habitat were located immediately south of the Top of the World Highway, in the vicinity of the Sixty Mile River (Figure 4). Lichen proportion, as derived from Landsat 5 imagery, was very high in this area compared to other parts of the study area, and lichen proportion appeared to have a very strong influence on caribou's habitat selection. Smaller, more isolated patches of highly-selected habitat occurred elsewhere (northwest and southwest of Dawson, south of Top of the World Highway at the Alaska border), all of which corresponded to patches of lichen abundance derived from satellite imagery.

While it should be interpreted with caution, the extrapolation of study area results to the wider area of the southern Dawson region reveals some interesting predictions about potential caribou habitat (Figure 5). Under predicted habitat selection values, habitats with high selection value have a very heterogeneous distribution across the southern Dawson region, with large areas in the south and through the Tintina Trench having low predicted selection values. If Forty Mile caribou late winter range were to extend eastward, the model predicts that caribou would encounter a cluster of high selection value habitat patches southeast of Dawson. These patches correspond to areas of high lichen proportion. This area is located in the heart of the Klondike Goldfields, however, and has a very high density of roads, trails, placer mines, and other anthropogenic disturbances. Depending on the level of human activity this area supports in winter and the caribou's degree of aversion to this infrastructure or activity, the Forty Mile caribou herd may or may not be able to use this area as late winter habitat. If caribou's use of this area is impeded, the density of human development in this area could act as a block to further eastward expansion of the Forty Mile caribou herd into their traditional home range. Other patches of habitat that are predicted to be of high selection value to Forty Mile caribou exist on the southern slopes of the Ogilvie Mountains; if Forty Mile caribou expand their winter range to areas north of the Tintina Trench, they may encounter these patches of habitat.

The most dynamic factor affecting Forty Mile caribou winter habitat now and into the future is fire. Forest fires, depending on their severity, can reduce or eliminate lichen across large areas, and because it is slow-growing, lichen can take many decades to regrow after fire (Morneau and Payette 1989, Jandt et al. 2008, Joly et al. 2010). Areas predicted to be highly selected by Forty Mile caribou are those high-lichen patches that exist in areas that have remained unburned since fire records began in 1952. Areas of highly-selected habitat in the Dawson region are limited; one or two large fires within these habitats could have a large impact on the distribution and abundance of Forty Mile caribou in their Yukon range. Forest fire frequency is thought to be increasing, through a combination of climate change and increased human activity in the Dawson region. As Forty Mile caribou habitat is burnt, their use of the landscape is likely to change, and future forest fires within the Forty Mile caribou winter range will need to be incorporated into habitat models as they occur.

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APPENDIX 1. Model revision based on updated lichen cover data.

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The lichen coverage data used in the original late-winter Forty Mile caribou habitat suitability analysis were updated in early 2012. As lichen cover represents one of the 5 variables in the final habitat suitability model, I recalculated model parameters by applying the new data to the final model and produced new habitat suitability maps.

Relative to the original lichen coverage data, the updated product predicted a broader distribution and greater abundance of the lichen across the Forty Mile herd range (Figures 1.1, 1.2). This difference is a result of the updated data being a direct classification of lichen across the entire herd range whereas the original data was extrapolated across a portion of the range (Chubey et al. 2011, 2012). When the data were extrapolated, a conservative predictive approach was taken in an attempt to maximize the classification of true “lichen” and minimize “false classification”. When the data were revised and classified directly (i.e. no extrapolation), this predictive approach was unnecessary and the coverage data provided a less conservative, but more accurate, depiction of true lichen presence.

Using the updated data, I calculated the mean percentage of lichen cover within a pixel, broken into 9 classes from 0 to 80% over a circular neighbourhood of 1000 m radius. Because the original final model represented an average of the 2 models produced using both backward and forward stepwise selection, I parameterized both models using the new data. Results indicated more support for the model resulting from backward stepwise selection (Table 1.1) than that resulting from forward stepwise selection (Table 1.2). The AICc value of the model using backward stepwise selection was lower than that of the model using forward stepwise selection and the delta AICc was >2 (Table 1.3). Thus, I used only the backward stepwise selected model to calculate the updated resource selection function.

Parameter estimates in the updated model indicated the moose-habitat relationships outlined in the results based on the original model remain; however, specific values differed (Table 1.1). This difference between models can be explained by multiple factors: 1) the mean percentage of lichen within the circular neighbourhood of both the used and available points changed, altering the lichen selection coefficient, 2) when the coefficient of one variable in a logistic regression changes (i.e. lichen), it will affect the coefficient values of the remaining variables, and 3) the original final model was weighted, reflecting an averaged coefficient value of two models.

The updated model was used to map habitat suitability within the Forty Mile Caribou winter range (Figure 1.3) and to extrapolate habitat suitability across a large portion of the Dawson Land Use Planning Region (Figure 1.4). Maps created using the updated model should be used in place of any maps developed from the original analysis.

Table 1.1. Exponential resource selection function model of late winter habitat selection by Forty Mile caribou in the Dawson region.

Parameter	Estimate	SE	Z	95% Confidence Interval		p
				Lower	Upper	
Lichen$_{1000}$	0.644	0.161	4.01	0.329	0.958	0.000
Burn distance$_{250}$	5.66E-04	2.30E-04	2.463	1.15E-04	1.01E-03	0.014
Burn distance$^{2}_{250}$	-7.00E-08	4.00E-08	-1.737	-1.60E-07	1.00E-08	0.082
Elevation$_{250}$	8.93E-03	4.37E-03	2.043	3.63E-04	1.75E-02	0.041
Elevation$^{2}_{250}$	-5.68E-06	2.77E-06	-2.046	-1.11E-05	-2.40E-07	0.041
Log likelihood	**K**	**AIC$_c$**				
-235.580	5	483.731				

**Produced using backward stepwise model selection. AICc was calculated using only used caribou locations as the sample size (nused = 111).

Table 1.2. Exponential resource selection function model of late winter habitat selection by Forty Mile caribou in the Dawson region.

Parameter	Estimate	SE	Z	p
Lichen$_{1000}$	0.868	0.145	5.971	0.000
Log likelihood	**K**	**AICc**		
-242.316	1	488.670		

**Produced using forward stepwise model selection. AICc was calculated using only used caribou locations as the sample size (nused = 111).

Table 1.3. AIC$_c$ comparison of resource selection function models selected using backward and forward stepwise model selection.

Model	Log likelihood	K	AICc	ΔAIC$_c$	ω_i
Backward stepwise	-235.580	5	483.731	0	0.92
Forward stepwise	-242.316	1	488.670	4.939	0.08

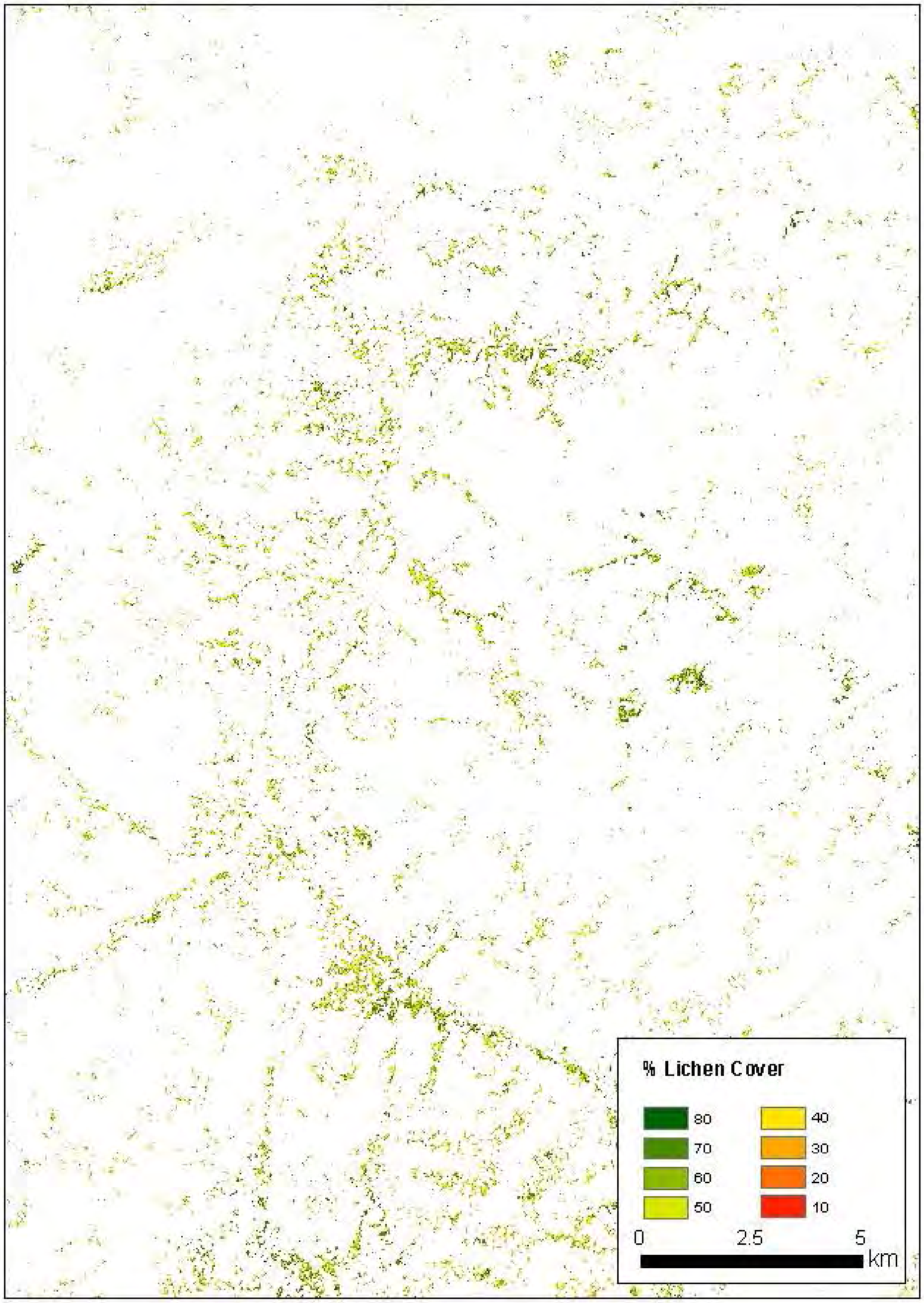

Figure 1.1. Original lichen coverage data in a portion of the study area (Chubey et al. 2011).

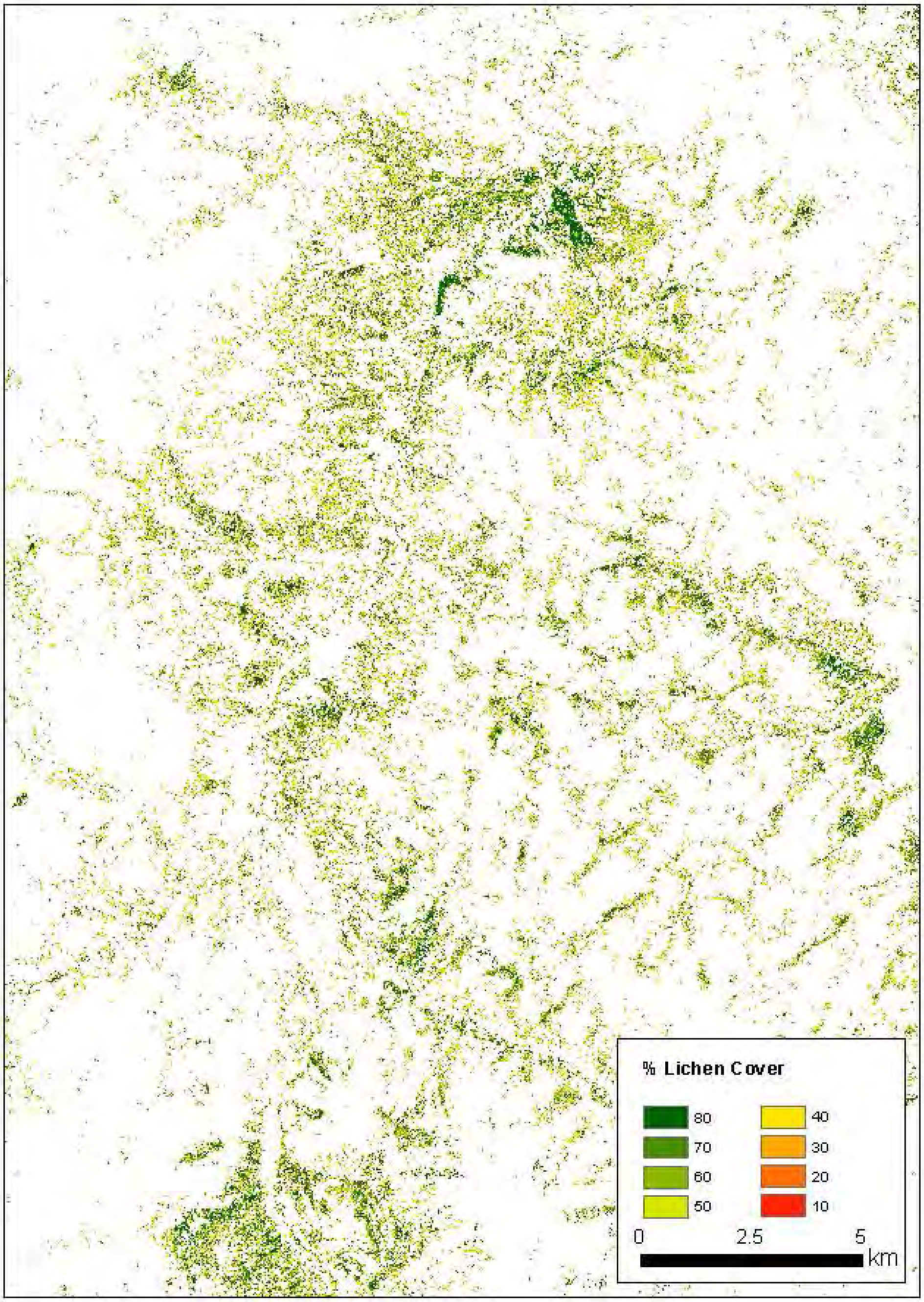

Figure 1.2. Revised lichen coverage data in the same portion of the study area represented in Figure 1.1 (Chubey et al. 2012).

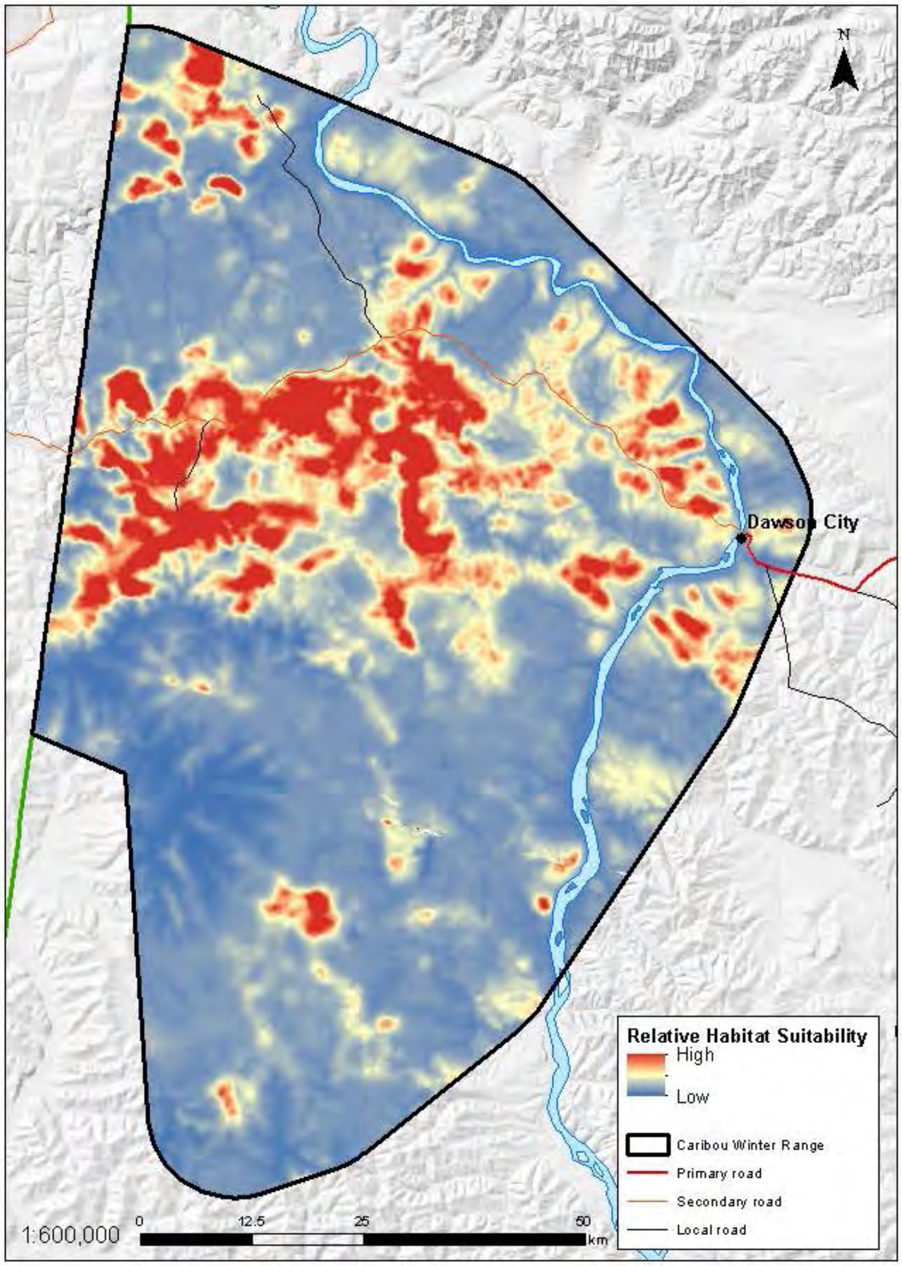

Figure 1.3. Relative late-winter habitat suitability of the Forty Mile Caribou Herd within the caribou herd winter range boundary.

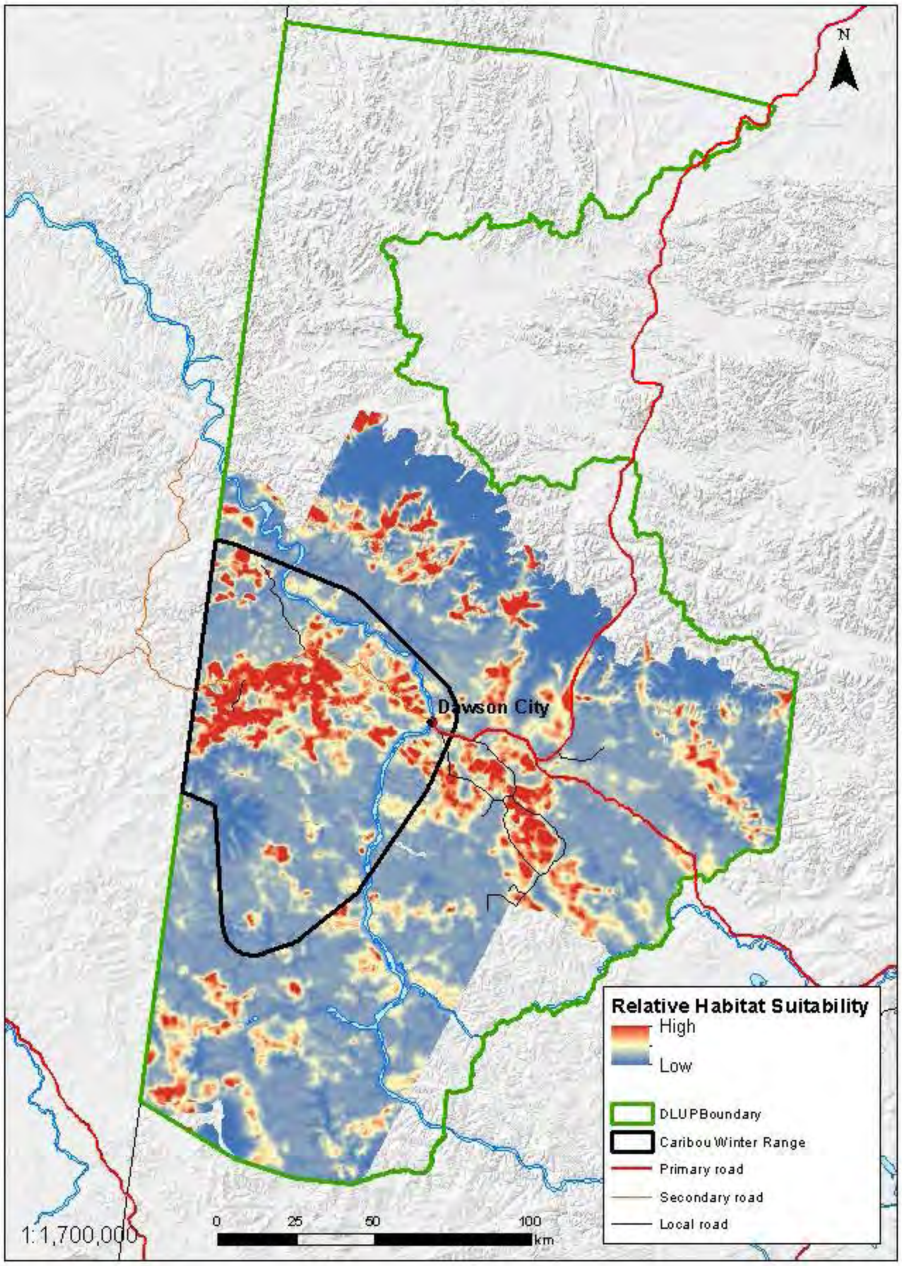

Figure 1.4. Relative late-winter habitat suitability of the Forty Mile Caribou Herd extrapolated across a large portion of the Dawson Land Use Planning Region.

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