# BOREAL CARIBOU HABITAT AND LAND USE PLANNING IN THE DEH CHO REGION, NORTHWEST TERRITORIES

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GOVERNMENT OF THE NORTHWEST TERRITORIES

YELLOWKNIFE, NT

2004

Manuscript Report No. 153

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# ABSTRACT

Boreal caribou *Rangifer tarandus* are nationally listed as Threatened. Land use jurisdictions, including communities and land claim organizations, will have to identify, steward and monitor boreal caribou habitat both for land use planning in the Deh Cho Region (southern Northwest Territories (NWT)) and for recovery planning in the NWT. Mapping current distribution (occupation) and potential habitat use (occurrence) for boreal caribou is a first step for both land use planning and recovery planning. We modeled occurrence at the landscape scale using generalized additive model analysis and Akaike Information Criterion with habitat information from spectral classification and habitat attributes such as cutlines, fire -history and elevation. The Deh Cho First Nations database of lifetime harvest kill sites and sightings from an aerial survey in March 2002 revealed that boreal caribou occupation has not changed at the regional level. Observations of boreal caribou fit relatively well with occurrence predicted from the modeling. Boreal caribou were strongly associated with black spruce and lichen on uplands and in lowlands.

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# INTRODUCTION

COSEWIC lists boreal caribou *Rangifer tarandus* in Canada as Threatened, and categorizes boreal caribou within the NWT as Data Deficient (Thomas and Gray 2002). Based on local information and data from the provinces, boreal caribou are likely distributed in the boreal plains ecozone. About 40% of the NWT's boreal plains are in the Deh Cho region. As the Deh Cho region's coniferous-lichen forests are relatively productive, the region may hold a large proportion of the NWT's boreal caribou. Residents of the Deh Cho communities have extensive information on where boreal caribou are found (Deh Cho First Nations 2002). That information can be used in an initial step towards mapping boreal caribou occupancy and potential habitat use (occurrence). Describing occupancy and occurrence are tasks identified in national recovery planning and in the Department of Resources, Wildlife and Economic Development's (RWED) priorities for boreal caribou. The federal Species at Risk Act requires jurisdictions to identify critical habitat. In this report, we use the term 'critical habitat' as habitat of high value (high probability of occurrence) to boreal caribou, however, we recognize that further definition and justification will be needed.

In 2001, we began a project with Deh Cho First Nations to enable land use jurisdictions (including communities and land claim organizations) to identify, steward and monitor boreal caribou habitat as a conservation contribution to land use planning in the Deh Cho region and recovery planning in the NWT and Canada. The projects' goal was met through the following objectives:

1) To map boreal caribou occupied habitat and occurrence (potential habitat) in the Deh Cho region (this report).

2) To predict and identify high value boreal caribou habitats and boreal caribou habitats at risk in the Deh Cho region (this report).

3) To complement and support land use planning in the Deh Cho region.

4) To develop outreach materials (brochures, posters) about boreal caribou and the significance of their habitat stewardship in community-based land use planning in the Deh Cho region and as a model for elsewhere in the NWT.

Our approach is to use Geographic Information Systems (GIS) modeling to relate caribou location data to environmental data. A combination of information from the Deh Cho First Nations (DCFN) and field sampling for caribou locations provided caribou location data. Environmental data included forest cover types classified from Landsat imagery; elevation; buffered distances from linear developments such as roads and seismic lines; and forest stand age classes. The output data is polygon maps with ordinal categories of high to low value habitat and the relative degree of risk to those habitats. The approach is inductive and analytical as we did not assume to know caribou habitat requirements but instead used the Deh Cho First Nations knowledge, forest cover mapping and field validation to objectively determine the ecological requirements for boreal caribou at a landscape scale.

Initially, we were going to hold a workshop in February 2002 with Deh Cho community representatives to discuss the project, obtain boreal caribou information and receive nominations for follow-up interviews in March 2002. We realized however, that this task was inappropriate given the existing demands on the communities for meetings and workshops on accelerated land and self–

government negotiations and oil and gas development in the Deh Cho region. Additionally, Deh Cho elders had already contributed their information through traditional land use mapping and we heard that it was more appropriate to return to the communities when this mapping project was further advanced.

In this report, we describe mapping historic and current caribou occupation and how we have used the available information and GIS modeling to describe boreal caribou occurrence in the Deh Cho region. We describe a broad-scale model to predict boreal caribou distribution in the Deh Cho region. This model integrates habitat variables (vegetation), geographic variables (land elevation), and observations from Deh Cho residents.

**METHODS**

We divided the Deh Cho study area into approximately 1700 10X10 km cells.  For each cell, we used RWED's Forest Management's Standard Maximum Likelihood Supervised Classification type to classify habitat from Landsat Tm 5 & 7 acquired between the summer of 1993 and 2000 (RWED-Forest Management's Northwest Territories Land Cover Classification Version 1:2002).  In some cases, full analysis of cells was not possible due to cloud cover.  We used only the cells in which at least half of the area was classified in the analysis.  Of the remaining cells, the proportional abundance of each habitat class was determined by dividing the area of each habitat type by the total area classified for each cell.

The Deh Cho First Nations contributed a database identifying 1070 boreal caribou harvest sites from within living memory (covering about 60 years) for Fort Simpson, Nahanni Butte, Trout Lake, Jean Marie River, Kakisa, and West Point. The database identified harvest sites within 304 of the 10 x 10 km cells.

A preliminary model for the Deh Cho study area was based on boreal caribou sightings from the 2001 surveys of the Bison Surveillance Zone that covered 194 of the 10X10 km cells.  We used the caribou sightings from the 2001 Bison Surveillance Zone (John Nishi pers. comm.) as input to a logistics model. The sightings were overlaid on the 10 km x 10 km grid with the RWED Forest Management vegetation layer to assess cell vegetation attributes.  The logistics model took the vegetation attributes associated with the presence or absence of caribou sightings and extrapolated across the Deh Cho region to produce a draft

'occurrence' map ranking the probability of the presence of caribou as low, medium or high.

In March 2002, when snow cover would allow us to record tracks, we tested the preliminary model by sampling the area for boreal caribou presence or absence. We systematically sampled across the Deh Cho region. We also sampled the 10x10 km cells roughly in proportion to the stratification based on high, medium, and low probability of caribou presence. We standardized the sampling by flying across the center of each cell at about 75 m above ground level at 150 km/h, which gave us approximately 10% coverage of each cell. Two back seat observers passed observations to a front seat recorder and navigator. The front seat recorder also visually averaged each cell as having either uniform or patchy cover, and closed or open cover. We recorded caribou sign as feeding craters, tracks and single trails and also noted when we saw moose and bison or their tracks.

**Habitat Variables**

The variables considered for prediction of boreal caribou occurrence can be broken down into five types: survey, habitat, geographic, ecological, and anthropogenic (Table 1). Each variable was summarized in terms of area (habitat variables) or related measures for each of the study area cells.

**Table 1:** Habitat variables used in the boreal caribou occurrence model.

| Variable | Description |
|---|---|
| *Survey* | |
| Canopy closure | Canopy closure observed in cells |
| *Habitat* | |
| blacksp | black spruce-lichen |
| decid | deciduous |
| firereg | fire regeneration/sparsely vegetated |
| herb | herbaceous |
| jackpine | jackpine |
| lichen | lichen |
| low shrub | low shrubland |
| sphag | Sphagnum moss with scattered spruce |
| mixfor | mixed forest |
| tallshrub | tall shrub or young deciduous |
| wet | wetlands |
| whitespr | white spruce |
| firelshr | fire regeneration/low shrub |
| *Geographic* | |
| Elevation | elevation in meters |
| *Ecological* | |
| Years since fire | |
| bimoose | presence/absence of bison or moose |
| *Anthropogenic* | |
| Seismic line length per cell | |
| harvest-site | harvests found per grid cell |

The data for some variables (canopy closure, years since fire, seismic line length) was incomplete with data missing for some cells (see Results). Incomplete variables were considered after a model was developed for the variables for which we had information for all cells. Cutline information was derived from National Topographic Database (NTDB) data, which was variably available at 1:250K and 1:50K scales. The 250K scale was used first then filled in with 50K where available. Sixteen 250K sheets and twenty-five 50K sheets

were used.  An additional five 50K sheets were available but contained no cutline layer.  The data used does not reflect all current/recent intensive seismic activity in the Deh Cho region, nor does it reflect that some of the cutlines in NTDB are quite grown over due to their age.

**Data screening**

One potential concern with the data set was that some habitat variables were correlated.  This could create issues of multicollinearity and redundancy if correlated variables were used in similar model runs.  Of these issues, variable redundancy was most topical since the procedures in SAS had automatic routines to detect strong cases of multicollinearity (Tabachnick and Fidell 1996). Redundancy causes more predictor variables to be entered into the model than is necessary given that the variables are structurally related.  We used Principal Components Analysis to assess the degree of independence among habitat predictor variables (Tabachnick and Fidell 1996), and to assign variables to potential groups based upon relatedness.  If predictor variables were determined to be similar, they were potentially pooled in subsequent analyses.

**Habitat modeling**

The 2002 aerial search for caribou presence and absence was relatively standardized and we assume that each cell received a similar degree of effort. The actual sample unit used to determine the presence and absence of caribou was the area of each cell surveyed, which was a 0.5 km strip on either side of the

plane for a total sample area of approximately 1 km X 10 km ().  The principal

analysis considered availability of habitat for caribou to be the entire 10X10 km

cell, which assumes that caribou select habitat at a broader scale than the area

surveyed for presence and absence.  An additional analysis limited availability to

the area sampled (1 km X 10 km) to assess the sensitivity of the analysis to the

definition of availability.

The presence/absence data was modeled using logistic regression

(McCullagh and Nelder 1989).  The proportional abundance data for each habitat

variable was standardized by its associated mean and variance to ensure that

each predictor was on the same scale.  As an initial step, generalized additive

models were used to assess the linearity of the relationship between habitat

predictor variables and the response presence/absence data (Bio et al. 1998).

Generalized additive models attempt to fit a linear term and a cubic spline term in

which the data is smoothed to the best fitting non-linear curve (Hastie and

Tibshirani 1990).  The significance of the linear and spline terms was evaluated

to determine if non-linear trends existed.  A generalized cross validation

procedure was used to select values for smoothing parameters.  If non-linear

trends existed, the general shape of the non-linear curve was noted for future use

in building the logistic model.  Each predictor variable was evaluated separately

in the analysis.  SAS PROC GAM was used for this analysis (SAS Institute

2000).

Generalized additive modeling provides a useful tool to explore data for

non-linear terms.  However, it is more difficult to evaluate overall model fit.  For

this reason, logistic regression with linear and higher order polynomial terms was used to produce estimated probabilities of occurrence and provide robust evaluation of predictor significance (Manly et al. 1993). A type 3 analysis, which is not sensitive to the order of predictor terms in the model, was used to evaluate parameter significance (SAS Institute 2000). The general method of model building was based upon significant terms from the generalized additive model analysis. In addition, linear terms and higher order polynomial terms were re-evaluated using the logistic model to verify generalized additive model findings.

The building of the model was complex in that there were habitat, geographic (elevation), ecological (presence of bison and moose), as well as human–related variables (historic harvest locations observed by the Deh Cho) that all could potentially predict caribou distribution. In many cases there were a priori hypothesis about predictor variables allowing the building of several "candidate" models that potentially explained caribou distribution. We used Akaike Information Criterion (AIC) to evaluate the sets of candidate models. The AIC or information theoretic approach is a different paradigm for model selection than traditional model selection based on significance tests (Anderson et al. 2000) and uses completely different methods to evaluate the usefulness of models. The AIC approach is basically an optimization score that attempts to minimize model bias while maximizing model precision. It evaluates model terms in regard to how much they contribute in terms of minimizing bias while not sacrificing precision.

Models were evaluated using the sample size corrected Akaike Information Criterion (AICc) index of model fit. The model with the lowest AICc score was considered the most parsimonious thus optimizing the tradeoff between bias and precision (Burnham and Anderson 1992). The difference between any given model and the most supported ($\Delta$AICc) was also used to evaluate the relative fit of models when their AICc scores were close. In general, any model with an $\Delta$AICc score of less than 2 was most supported by the data. SAS PROC GENMOD and LOGISTIC were used for this analysis (SAS Institute 2000).

The degree of significance of model parameters and the AIC criteria do not evaluate how well the model predicts caribou distribution. Receiver Operating Characteristic (ROC) curves were used to compare the predictive ability of models (Cummings 2000). A ROC curve considers how well a model predicts presence or absence through a range of probability cutpoints. A cutpoint was the probability level in which presence or absence was declared in each cell. The ROC score varies between 0.5 and 1. A score of 0.5 would correspond to a model with no predictive ability and a score of 1 would correspond to a model with perfect predicative ability. Models with scores of greater than 0.7 are considered to be of "useful" predictive ability (Boyce et al. In press). In addition, the goodness of fit test of Hosmer and Lemeshow (2000) was used to evaluate overall fit.

One potential issue with the data set was spatial autocorrelation due to sampling neighboring cells. Two strategies were used to confront this issue.

First, variograms which offer a spatial representation of the degree of correlation as a function of distance between sampling units, were plotted to allow graphical evaluation of the degree of autocorrelation in the data set (Isaaks and Srivastava 1989).  If spatial autocorrelation was evident, a generalized linear mixed model with a spatial covariance model was used (in lieu of generalized linear models) to adjust variances, compute over–dispersion parameters, and test the statistical significance of the observed autocorrelation (Gumpertz et al. 2000; Milliken and Johnson 2002).  In this case the GLIMMIX macro in program SAS was used for data analysis (Littell et al. 1996).  Second, the most supported AICc model was further evaluated for significance using bootstrap methods (Manly 1997).  For this, the data was randomly re-sampled 1000 times to allow estimation of standard errors of regression parameters and further evaluation of parameter significance.

The model's output was seven probability classes for predicting the occurrence of caribou.  We combined the classes that had a probability of occurrence of higher than 50 % to identify and predict high-value boreal caribou habitat.  Combining the classes was based on assigning any observation (cell) with a probability above the 75th quantile as having a relatively high probability of caribou occurrence (i.e. 75% of the observations are below this cutoff point and 25% are above).  The cutoff for the 75th quantile is 0.513, which is close to the value of 0.5.  We also aggregated cells into contiguous blocks based on probability class with the Dissolve geoprocessing operation of ArcGIS 8.2.

**RESULTS**

**Mapping boreal caribou occupation**

We sampled 618 of 1478 possible cells between 5 and 15 March 2002 using a fixed-wing aircraft and community observers from Ft Simpson, Wrigley, Trout Lake, Kakisa and Ft Providence. Flying time including ferry times was 57 hours. Of those cells, 605 had adequate habitat data for consideration in the model. Caribou sign (tracks, trails, feeding craters and caribou themselves) occurred in 33% of cells. We counted 86 caribou in 14 cells and 111 cells had caribou feeding craters. We used feeding craters and caribou sightings in the model but not tracks or trails. Feeding craters were distinctive and likely represent selection of a habitat rather than just traveling through an area.

The map of occupation (Figure 1) suggests that boreal caribou are widespread across the Deh Cho region. In the northeastern part of the Deh Cho region, extensive sign (tracks, feeding craters) from barren-ground caribou likely masked the presence of the boreal caribou. Boreal caribou are known in the area based on local ecological knowledge of people from Wrigley. It was the first time for some 20 years that barren–ground caribou had wintered in the area (T. Lennie pers. comm).

**Figure 1:** The Deh Cho, NWT, with the 10 x 10 km grid, the high (dark), moderate (medium) and low (light) probability of occurrence based on the preliminary model, flight lines for March 2002 and caribou sightings (circles).

**Predicting boreal caribou occurrence**

**Data screening:** To apply the habitat model to the entire study area we have to demonstrate a similar relative abundance of habitat types in areas surveyed and areas not surveyed. A comparison of the proportional abundance of habitat types in each cell for the areas surveyed and not surveyed revealed a general correspondence for most habitat types (Figure 2). Proportional abundance is the proportion of each cell occupied by a given habitat type.
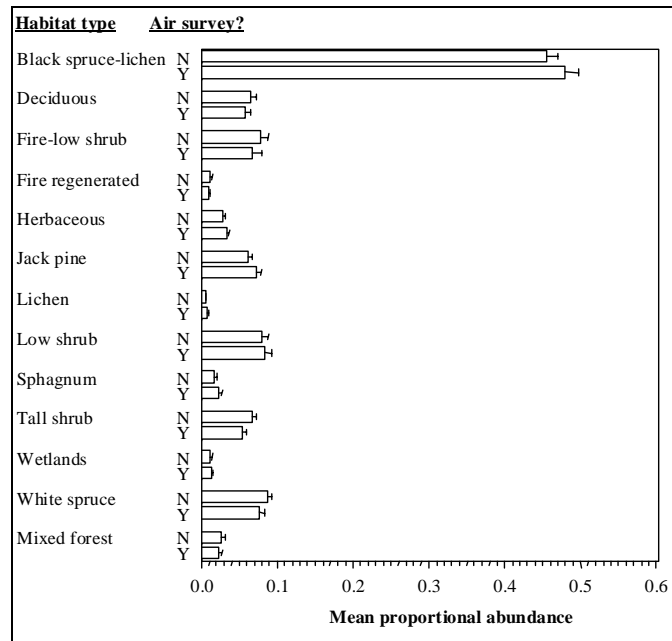
**Figure 2:** Proportional abundance of habitat types for areas surveyed and not surveyed in the Deh Cho study area, NWT, March 2002.

Black spruce and low shrub categories are the most common categories in the Deh Cho Study area (Figure 2). Abundance of different habitat types were likely interrelated and thus we used principal components analysis to minimize the degree of correlation of habitat types (when entered in the logistic model) and help guide the pooling of model parameters. For this, the proportions of habitat type in each cell were used as model inputs and similarities were assessed graphically using principal components plots. From this it was found that low shrubland-wetlands-jackpine, fireregeneration/sparsely vegetated-lichen-fire regeneration/low shrub, white spruce-mixed forest, and tall shrub-herbaceous were related to some degree. The analysis also suggested that sphagnum, black spruce-lichen and deciduous types were unique. These poolings of variables were used to guide the formulation of parsimonious habitat models.

As mentioned earlier, one potential issue with this data set was spatial autocorrelation potentially creating non-independence of sampling cells leading to negatively biased variance estimates and overfitting of the model to the data. The data were screened using a variogram to determine the relative degree of spatial autocorrelation. The variogram is an index of the relative spatial correlation of the presence and absence values of grid cells as a function of the distance they are separated. Theoretically it should be 0 at the origin, then increase as separation distance of cells increases and asymptote when there is no spatial autocorrelation.
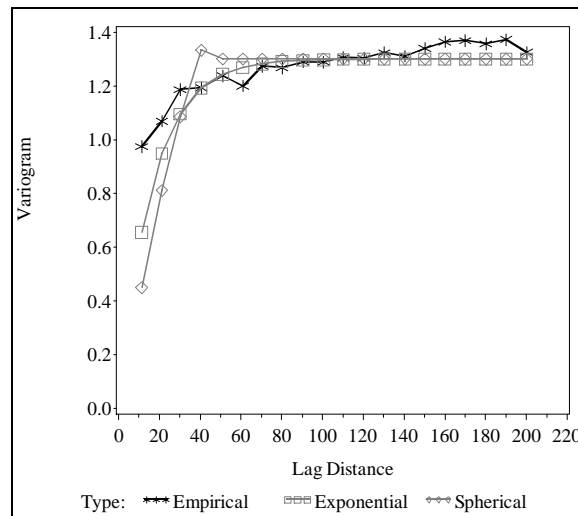


**Figure 3**: Variogram of spatial autocorrelation of caribou presence and absence as a function of distance (km) between grid cells. Variograms from the data (Empirical) and (Exponential and Spherical) theoretical models are also shown.

The empirical variogram suggests potential autocorrelation at distance of 40-80 kilometers; however, this effect is partially offset by the large value of the variogram (approximately 1) close to the origin (Figure 3). Failure of the variogram to intersect the origin (termed the nugget effect) usually is caused by a

great deal of short-scale variability in autocorrelation potentially due to both natural variation and sampling variation. If the nugget effect is large, as it is in this case, then the actual degree of spatial autocorrelation that can be measured or accounted for is compromised (Isaaks and Srivastava 1989; Littell et al. 1996).

Various theoretical spatial covariance models were fitted to the data using a generalized linear mixed model (GLMMIX macro in SAS). The exponential covariance model best fit the data, however, the degree of estimated dispersion in the data set was not large (with all over–dispersion parameter estimates being less than 1). Smaller scale sampling variation probably precluded efficient modeling of spatial variation using this approach. As an alternative, a more general bootstrap approach was used to partially account for autocorrelation. With this approach, the data was randomly resampled and the regression model (described next) rerun with each data set. Each resampled data set was a pseudo "random" sample of the data thereby partially mitigating non-independence of sample units (Manly 1997).

**Model Building**

The generalized additive model analysis revealed significant linear terms for black spruce, deciduous, lowshrub, tallshrub, wetlands, and white spruce habitat classes, elevation, and harvests per cell (at $\alpha=0.1$). Significant non-linear spline terms were found for the fire regenerated, herbaceous, lichen, sphagnum, mixed forest, and white spruce habitat variables, as well as for elevation and

harvests per cell.  The non-linear relationships were generally quadratic or cubic which was considered in subsequent model building.

We used a logistic regression model to further build the model and test for parameter significance.  All habitat terms were first entered into the model to test for correspondence with the generalized additive model analysis.  A general correspondence was evident using the Type 3 analysis except for lichen and low shrub classes.  Using the results of the generalized additive model analysis, higher order polynomial terms were added for the remaining terms that had significant spline terms in the generalized additive model analysis.  Of these, quadratic fire regeneration, herbaceous, sphagnum, and a cubic mixed forest term were significant.  From this a preliminary habitat model was derived (Table 2, Model 9).

At this time AICc model selection was used to determine if the model could be further reduced by pooling habitat classes identified to be related by the principal components analysis.  Similar terms were pooled and resulting AICc scores were evaluated to determine subsequent gains in model fit.  Only the pooling of herbaceous and tall shrubs improved model fit (Model 7).  This model became the base habitat model.  Non-habitat terms, namely elevation, harvests found per cell, and presence of bison and moose, were added to the model to determine if fit could be improved.  Of these, elevation improved fit the most with a significant linear term.  Presence of bison and moose did improve model fit as revealed by AICc model selection (Model 5) but addition of harvests per cell reduced model fit (Model 8).  The most supported AICc model included elevation

and presence of bison and moose (Model 1), however, models that contained

only elevation (Model 2), presence of bison and moose, harvests per cell, and

elevation were also supported (Models 3 and 4).  Because harvests per cell is a

variable of interest it was kept in the model to allow further graphical evaluation of

its predictive ability through interpretation of parameter estimates and

corresponding confidence intervals.

**Table 2:** AIC model selection results

| No. | Habitat variables[A] | Other variables | AICc | ΔAICc | k |
|---|---|---|---|---|---|
| 1 | Blacksp, firereg$^{1,2}$, sphag$^{1,2}$ (herb&tallshrub)$^{1,2}$, mixfor$^3$ | elevation, bimoose | 682.15 | 0.00 | 11 |
| 2 | Blacksp, firereg$^{1,2}$, sphag$^{1,2}$ (herb&tallshrub)$^{1,2}$, mixfor$^3$ | elevation | 682.27 | 0.11 | 10 |
| 3 | Blacksp, firereg$^{1,2}$, sphag$^{1,2}$ (herb&tallshrub)$^{1,2}$, mixfor$^3$ | elevation, bimoose, harvest-cell | 682.51 | 0.36 | 12 |
| 4 | Blacksp, firereg$^{1,2}$, sphag$^{1,2}$ (herb&tallshrub)$^{1,2}$, mixfor$^3$ | elevation, harvest-cell | 682.76 | 0.61 | 11 |
| 5 | Blacksp, firereg$^{1,2}$, sphag$^{1,2}$ (herb&tallshrub)$^{1,2}$, mixfor$^3$ | bimoose | 684.01 | 1.85 | 10 |
| 6 | Blacksp, firereg$^{1,2}$, sphag$^{1,2}$ (herb&tallshrub)$^{1,2}$, mixfor$^3$ | Elevation$^{1,2}$ | 684.33 | 2.17 | 11 |
| 7 | Blacksp, firereg$^{1,2}$, sphag$^{1,2}$ (herb&tallshrub)$^{1,2}$, mixfor$^3$ | | 685.68 | 3.53 | 9 |
| 8 | Blacksp, firereg$^{1,2}$, sphag$^{1,2}$ (herb&tallshrub)$^{1,2}$, mixfor$^3$ | harvest-cell | 685.98 | 3.83 | 10 |
| 9 | Blacksp, firereg$^{1,2}$, herb$^{1,2}$, sphag $^{1,2}$ tallshrub, mixfor$^3$ | | 690.54 | 8.39 | 10 |
| 10 | Blacksp, firereg$^{1,2}$, sphag$^{1,2}$ (herb&tallshrub)$^2$, mixfor$^3$ | | 692.29 | 10.14 | 8 |
| 11 | Blacksp, firereg$^{1,2}$, herb$^{1,2}$, sphag$^{1,2}$ tallshrub, (whitespr&mixfor)$^2$ | | 694.58 | 12.43 | 10 |
| 12 | Blacksp, firereg$^{1,2}$, herb$^{1,2}$, sphag$^{1,2}$ tallshrub, (firereg,fireshr,lichen)$^{1,2}$ | | 696.10 | 13.94 | 11 |
| 13 | Blacksp, firereg$^{1,2}$, herb$^{1,2}$, sphag$^{1,2}$tallshrub, (whitespr&mixfor)$^{1,2}$ | | 696.40 | 14.25 | 11 |
| 14 | PCA reduced model[B] | | 717.63 | 35.48 | 9 |
| 15 | Blacksp | | 721.93 | 39.78 | 2 |
| 16 | all habitat variables | | 724.65 | 42.50 | 14 |
| 17 | blacksp, decid, herb, jackpine$^2$, whitespr[C] | | 726.24 | 44.08 | 6 |
| 18 | harvest-cell | | 780.14 | 97.99 | 2 |

[A]A superscript implies a polynomial term or terms were added to the variable
[B]PCA-reduced model: (lowshr&wet&jackpine)$^{1,2}$, (whitesp&mixfor)$^{1,2}$, (firereg,lichen,firelshr)$^{1,2}$, (herb&tallshrub)$^{1,2}$[C]
[C]Preliminary habitat model

Hypothesis tests for individual parameters from Model 3 (Table 3) indicate that most parameters are statistically significant (at $\alpha=0.1$), with the exception of the linear herb and tall shrub term, presence of bison and moose, and harvest per cell. Bootstrapping allowed a randomization test of parameter significance through the percentile estimation of confidence intervals for model parameters. If the bootstrap confidence interval included 0, then the parameter is statistically non-significant. There was general agreement between type 3 $\chi^2$ tests and bootstrap results (p-value close to 0.1 or bootstrap CI near 0) except for the linear term elevation ($\chi^2$ test significant; bootstrap non-significant). A generalized mixed model analysis with an exponential spatial covariance model was also run to determine if spatial autocorrelation may affect test results. There was no difference in terms of parameter significance between the mixed model and the model results (Table 3).

**Table 3:** Analysis of logistic model terms.

| Parameter | DF | $\beta$ | Stderr ($\beta$) | CI (bootstrap) | | $\chi^2$ | P($\beta$=0) |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -0.59 | 0.22 | -1.01 | -0.16 | 7.39 | 0.0066 |
| Blacksp | 1 | 0.80 | 0.13 | 0.58 | 1.11 | 39.65 | <0.0001 |
| Firereg | 1 | 1.05 | 0.33 | 0.51 | 1.82 | 11.75 | 0.0006 |
| Firereg$^2$ | 1 | -0.16 | 0.07 | -0.33 | -0.07 | 6.20 | 0.0128 |
| Sphagnum | 1 | -0.45 | 0.25 | -0.99 | 0.00 | 4.35 | 0.0371 |
| Sphagnum$^2$ | 1 | 0.14 | 0.06 | 0.05 | 0.27 | 8.82 | 0.0030 |
| mixfor$^3$ | 1 | -0.04 | 0.03 | -0.13 | -0.01 | 2.96 | 0.0855 |
| herb&tallshrub | 1 | 01.23 | 0.19 | -0.13 | 0.61 | 1.84 | 0.1748 |
| (herb&tallshrub)$^2$ | 1 | -0.44 | 0.15 | -0.79 | -0.21 | 9.50 | 0.0021 |
| Elevation | 1 | 0.19 | 0.10 | *-0.01* | *0.39* | 3.75 | 0.0528 |
| Bimoose | 1 | 0.33 | 0.11 | *-0.05* | *0.39* | 2.31 | 0.1288 |
| harvest-cell | 1 | 0.12 | 0.12 | *-0.05* | *0.42* | 1.65 | 0.1994 |

Hypothesis testing is a subjective approach and the best method to consider parameter significance is though observation of estimates and associated standard errors presented in Figure 4 (Johnson 1999).

In terms of the predictive ability of the model, results of the Hosmer and Lemenshow (2000) goodness of fit test suggested adequate model fit ($\chi^2$=8.81, df=8, p=0.42). The ROC score was 0.77 (Bootstrap CI=0.73-0.81) indicating "useful" predictive ability (Cummings 2000; Boyce et al. In press).

The predicted relationships for each of the predictor variables (Figure 4) reveals that the strongest and most precise relationship is between caribou probability of occurrence and proportion of black-spruce/lichen in a grid cell. Relatively strong relationships exist between the probability of caribou occurrence and the proportion of sphagnum, the proportion of tall shrub and herbaceous habitat, and lower proportions of fire regeneration habitat. Less precise relationships exist between the probability of caribou occurrence and the proportion or mixed forest, elevation, and higher proportions of fire regeneration.

One variable not shown is the presence of bison and moose that was a binary variable. The predicted probability of occurrence for caribou when bison and moose were present was 0.35 (CI=0.26-0.44) whereas the probability of occurrence when bison and moose were absent was 0.43 (CI=0.35-0.51) suggesting that presence of bison and moose reduced the probability of boreal caribou presence.
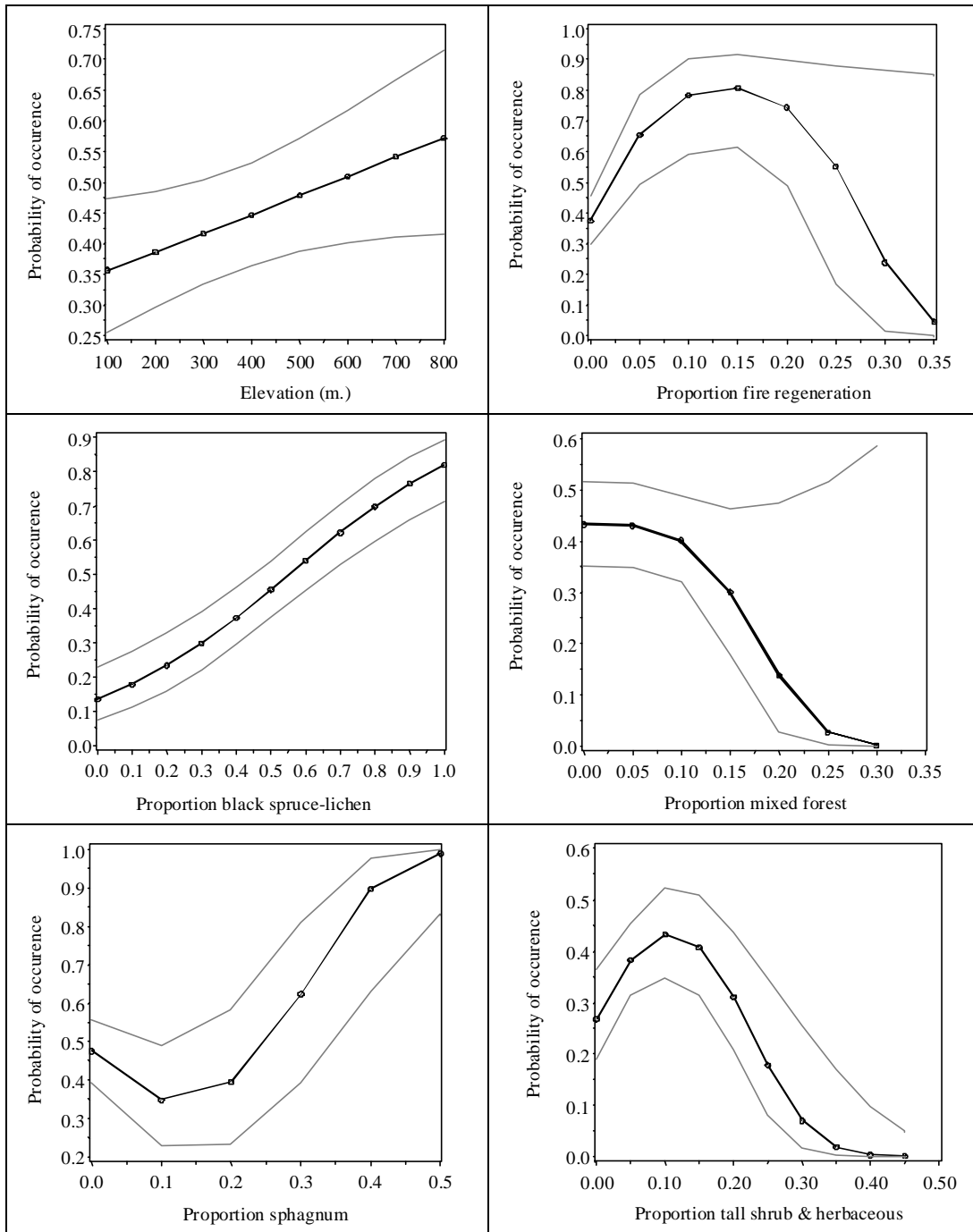
**Figure 4:** Predicted probability of occurrence for each of the significant habitat predictor variables. The range of the x-axis represents the approximate observed range of each variable. All values of other variables were standardized

to mean values for predictions (and absence of bison and moose).  95% confidence limits are given on predicted lines.

The predicted relationship between harvests per cell and probability of occurrence (Figure 5) reveals only a weak relationship where caribou are more likely to be found as a function of the number of harvests.  However, the precision of the relationship is low at higher harvest numbers.
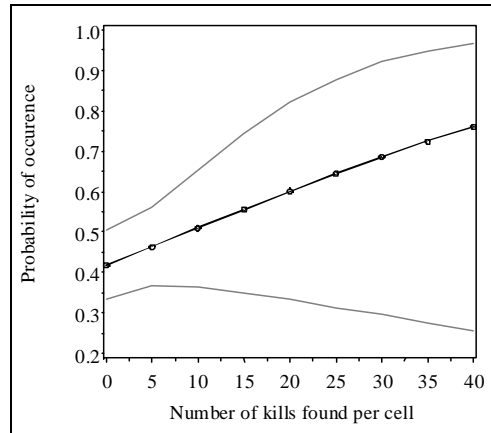


**Figure 5:**  Probability of occurrence as a function of number of harvested caribou found per grid cell from the model described in Table 3.  All other variables were standardized to mean values.

## Analysis of incomplete predictor variables

### *Canopy*
Of the 605 cells surveyed, 443 had ratings in terms of canopy closure. Ratings were reduced to open and closed with 242 open and 201 closed cells . This term was non-significant  ($\chi$=1.81, p=0.17, df=1) when added to the most supported AICc model.  In addition, interaction between canopy closure and black spruce was also non-significant.

**Fire history**

Of the 605 cells surveyed, 295 had data for the years since last fire. A linear years since last fire term was not significant ($\chi^2$=0.022, p=0.96, df=1) when added to the AICc chosen model. The years since fire variable was significantly correlated with the significant fire regenerated predictor variable with the highest proportion of fire regenerated habitat occurring in cells that had fires 7 years ago.

**Length of seismic lines**

Of the 605 cells surveyed, 534 had seismic line data. A linear length of seismic line term was significant when added to the AICc model ($\chi^2$=4.23, p=0.0397, df=1). A plot of this relationship (Figure 6) reveals a positive relationship between cutline length and probability of caribou occurrence. However, that apparent relationship could mean that caribou use the type of habitat in which cutlines occur or that caribou are attracted to cutlines as habitat. Given that we included cutlines regardless of the time since they were cut, the amount of vegetation regeneration is an unknown, which may affect caribou use.
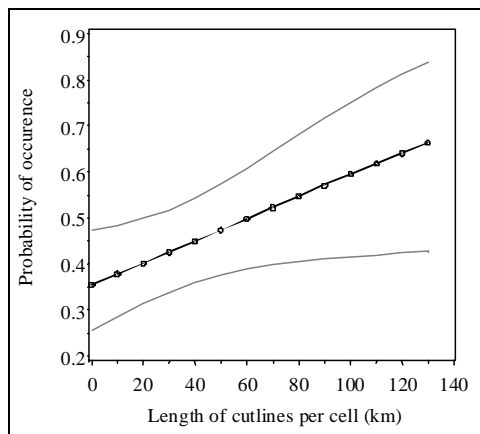
Length of cutlines per cell (km)

**Figure 6:** Probability of occurrence as a function of length of seismic cutlines from the model described in Table 3 (with seismic cutlines added). All other variables were standardized to mean values.

**Analysis with availability defined as the area visually sampled**

An analysis was conducted to determine the sensitivity of the most supported

model in Table 3 to the scale that habitat availability was defined in the

analysis. For this analysis, only the area visually sampled in March 2002 during

the aerial survey (approximately 1X10 km for each cell) was considered as

available habitat. A logistic analysis with bootstrapping of model parameters was

conducted in a similar fashion to the large-scale model. The results (Table 4) are

similar to the larger scale model. Slight exceptions to this are the non-

significance of the pooled herbaceous and tall shrub habitat terms. The ROC

score for this model was 0.79 (bootstrap percentile CI 0.75-0.82) suggesting

reasonable predictive ability.

**Table 4:** Logistic model results with availability defined by aerial survey strip width

| Parameter | DF | β | Stderr (β) | CI (bootstrap) | | $\chi^2$ | P(β=0) |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -0.84 | 0.16 | -0.94 | -0.30 | 14.89 | 0.0001 |
| Blacksp | 1 | 0.95 | 0.15 | 0.72 | 1.32 | 59.57 | 0.0000 |
| Firereg | 1 | -0.18 | 0.34 | 0.57 | 1.94 | 7.46 | 0.0063 |
| Firereg$^2$ | 1 | 1.16 | 0.07 | -0.33 | -0.08 | 12.81 | 0.0003 |
| Sphagnum | 1 | -0.41 | 0.30 | -1.05 | 0.12 | 3.24 | 0.0719 |
| Sphagnum$^2$ | 1 | 0.12 | 0.06 | -0.02 | 0.24 | 5.99 | 0.0144 |
| mixfor$^3$ | 1 | -0.04 | 0.04 | -0.17 | -0.02 | 3.86 | 0.0493 |
| herb&tallshrub | 1 | 0.05 | 0.19 | -0.28 | 0.46 | 0.06 | 0.8081 |
| (herb&tallshrub)$^2$ | 1 | -0.08 | 0.15 | -0.47 | 0.04 | 0.57 | 0.4520 |
| elevation | 1 | 0.23 | 0.11 | 0.03 | 0.44 | 5.20 | 0.0226 |
| bimoose | 1 | 0.40 | 0.12 | -0.04 | 0.43 | 3.22 | 0.0729 |
| harvest-cell | 1 | 0.15 | 0.14 | -0.03 | 0.49 | 2.67 | 0.1020 |

## Comparison with preliminary model

The main differences between the preliminary model and the 2002 model are the addition of fire-regenerated and sphagnum habitat classes and the deletion of white spruce, herbaceous and jackpine habitat classes. The addition of fire-regenerated and sphagnum classes is not surprising given that each of these classes were minimally present in the area surveyed in 2001. The full range of values found in the study area for white spruce, herbaceous, and jackpine was not represented by the area sampled in 2001 (see Figure 2 of preliminary model report), which may explain why these habitat classes did not appear significant when more thorough sampling was conducted.

The preliminary model was not supported by the full data set in terms of the AICc model selection criteria (Table 2, Model 17). However, the ROC value

for the model was 0.69 suggesting this model still provided useful predictive ability.  In addition, the ROC value for the preliminary model was 0.8 when applied to the 2001 data set that it was derived from, suggesting that the model had good predictive ability.

In contrast, the 2002 model was unable to converge when applied to the 2001 data set, presumably due to the non-presence of fire regenerated habitat variable.  If fire-regenerated habitat classes were removed, the 2002 full model displayed a ROC value of 0.75 suggesting good predictive power.  The main point here is that the 2001 model, while not being supported by the 2002 data set, was the best predictor of the 2001 data set and a reasonable predictor of the 2002 data set.  The main differences between models can probably be accounted for by differences in coverage and value ranges of habitat predictor variables.  This general conclusion highlights why ranges of predictor variables should always be compared when extrapolating model predictions to areas outside the original sampled area.

A related question is whether inclusion of the 2001 preliminary data in the 2002 data set would affect the fit or general relationships documented using the 2002 data set.  Statistically, this is tricky as cells that were surveyed both years will be over-represented in the data set leading to issues of psuedo-replication.  This could be partially accommodated by a repeated-measures analysis.  However, low sample sizes and the fact that only a proportion of cells in the 2002 data set were surveyed twice compromised this strategy.  For exploratory

purposes an analysis was run with data sets pooled.  The results in terms of

model parameter significance were the same as Table 3 except for non-

significance of the tall shrub and herbaceous category.

**Table 5:**  Presence and absence of caribou for cells surveyed in 2001 and 2002.

| 2002 survey | 2001 Survey Absent | Present |
|---|---|---|
| Absent | 22 | 15 |
| Present | 14 | 9 |

Of the 194 cells surveyed during the bison surveillance flights in winter

2001, 60 were also surveyed in March 2002.  Comparison of presence-absence

data from both years also shows a reasonable degree of variation in terms of

presence and absence of caribou in cells surveyed both years (Table 5).  For

example, in only 9 of the cells were caribou present both years, whereas in 29

cells caribou were present in one of the 2 years.

**Model predictions applied to study area**

The AICc model applied to the entire study area predicts a wide range of

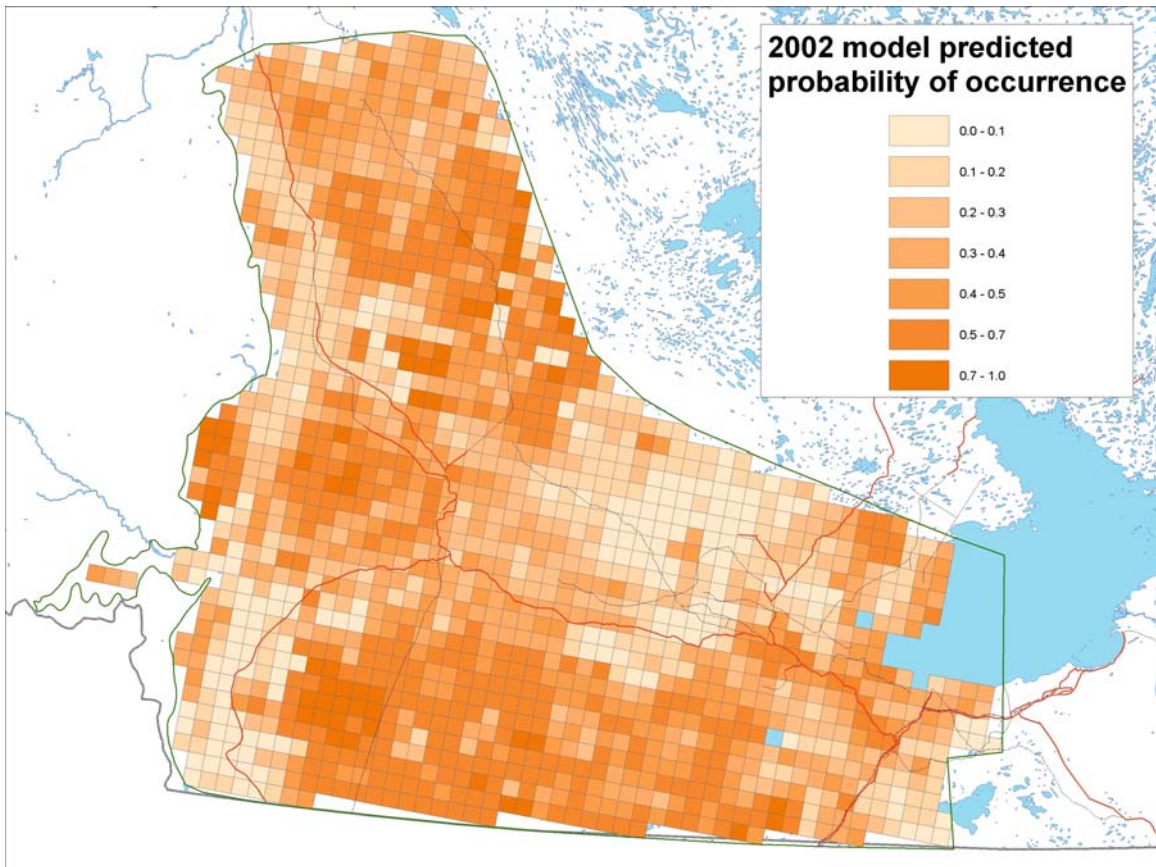probabilities of caribou occurrence (Figure 7).

**Figure 7:** Predicted probability of occurrence of boreal caribou from the 2002 model, Deh Cho, NWT.

One way to interpret the fit of the model is to overlay the original transect data on the predicted probabilities of occurrence (Figure 8). From this it can be seen that occurrence and model predictions correspond well with the possible exception of the far northern area where the model predicts moderate levels of caribou but none were observed. The presence of boreal caribou in this area was likely masked by the presence of barren–ground caribou. The model is able to predict pockets of low abundance such as those observed in the central

northern study area as well as pockets of high abundance such as those
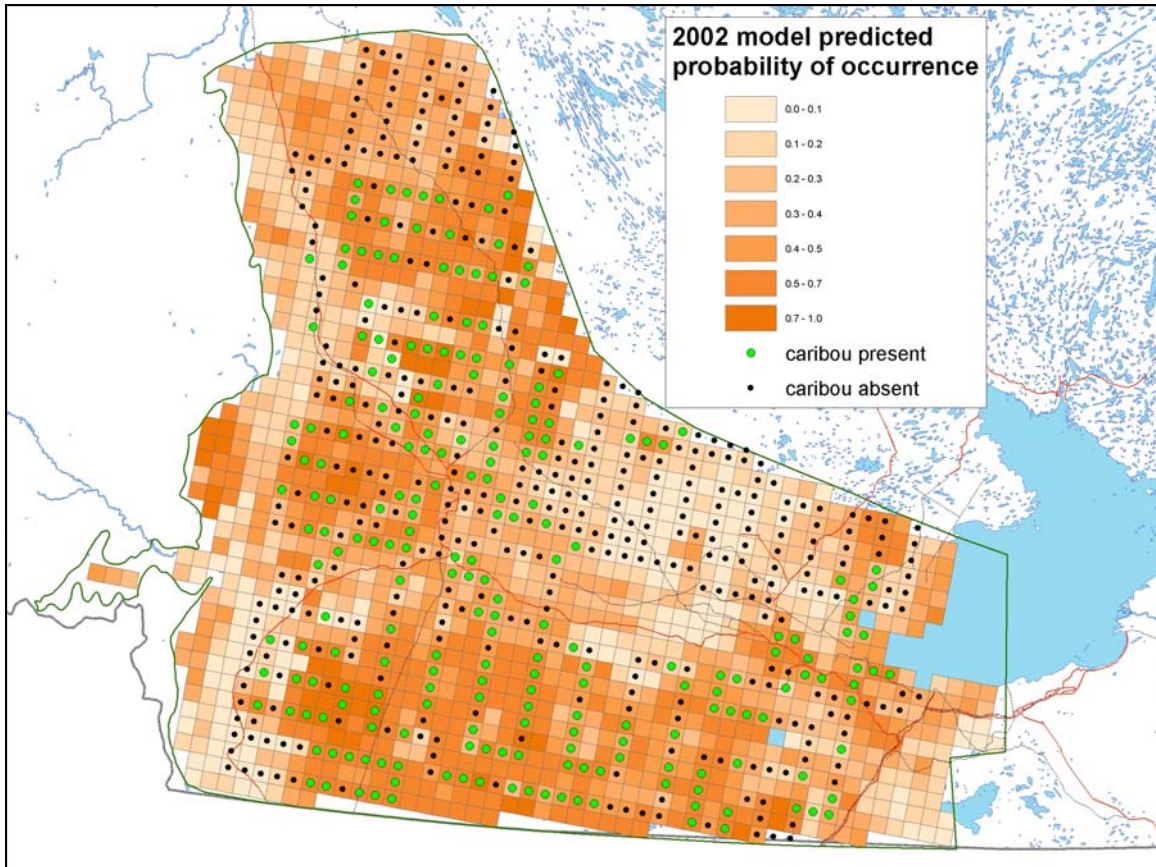
observed in the western study area.



**Figure 8:** Predicted probability of occurrence and observations from 2002 aerial transects, Deh Cho, NWT, March 2002.

The strongest predictor is the proportion of black spruce and lichen

present, which is exemplified when model predictions are compared with the

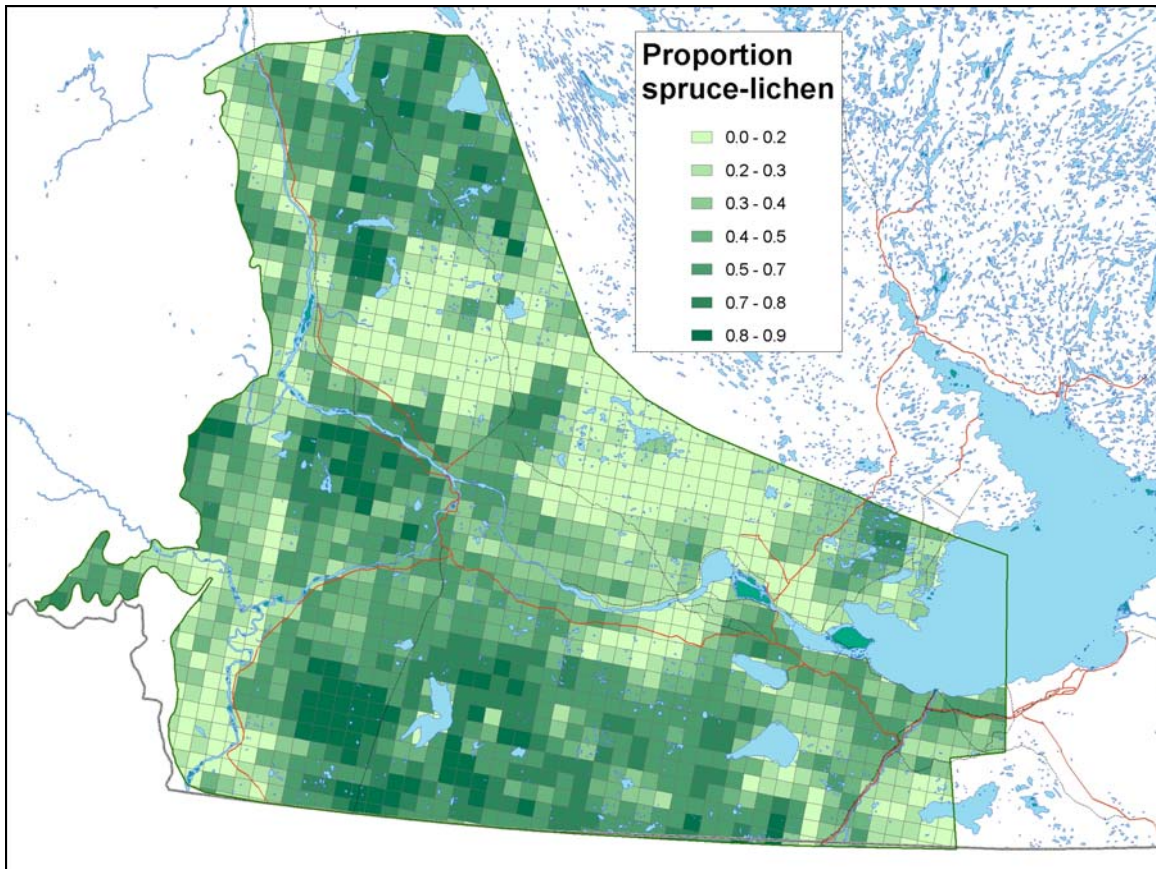distribution of black spruce and lichen in grid cells (Figure 9).

**Figure 9:** Proportion black spruce and lichen in grid cells, Deh Cho, NWT, March 2002.

One other factor that might explain absence of caribou from certain areas is the presence of bison and moose (Figure 10). The main clusters of bison and moose were in areas of low caribou sign. Many of these areas are also lower in elevation and therefore it is difficult to determine if this relationship is due to habitat or other factors such as predation.
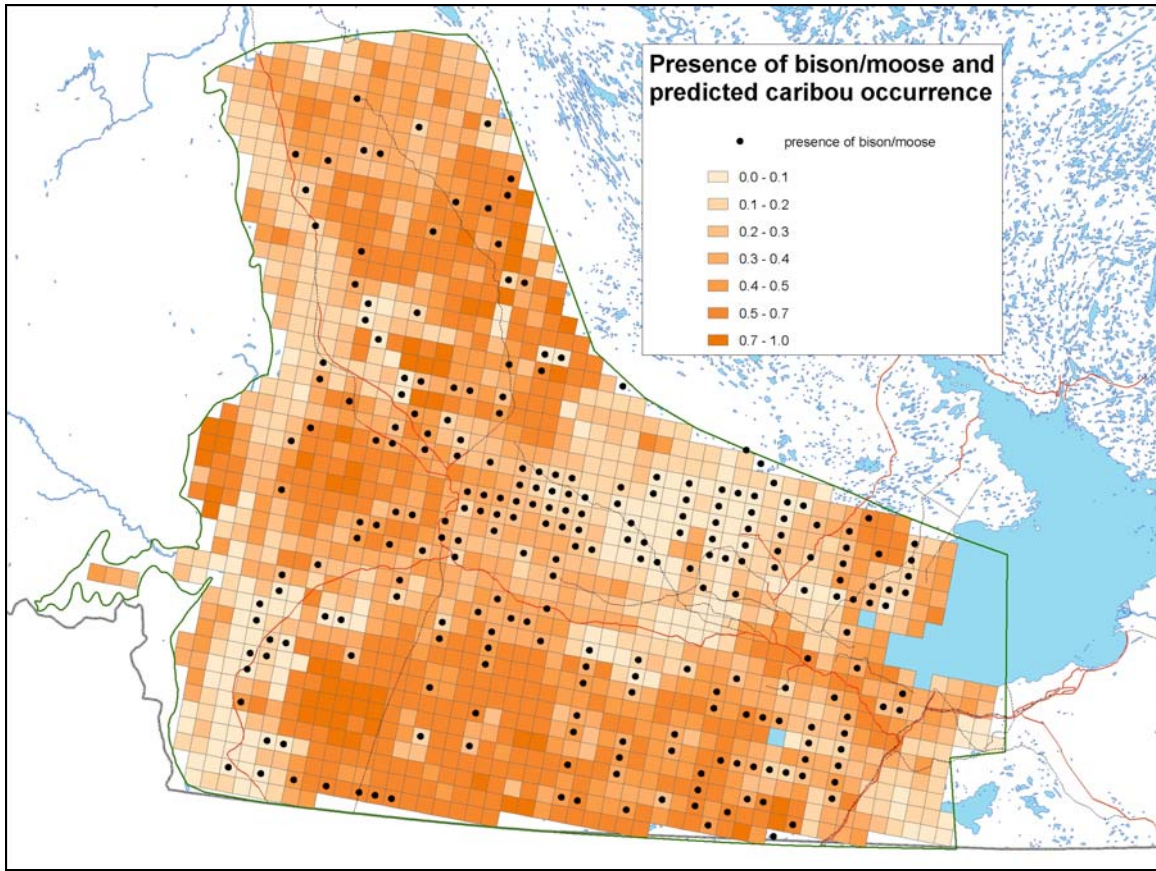
**Figure 10:** Presence of bison and moose compared to predicted caribou distribution, Deh Cho, NWT, March 2002.

## DISCUSSION

Habitat occupied by boreal caribou and habitat where boreal caribou are predicted to occur (potential habitat) are widespread across the Deh Cho. Lifetime memory harvest sites and the March 2002 sampling reveal that current and longer–term boreal caribou occupation does not appear to have changed greatly at the regional scale (Figure 11). One apparent difference west of Fort Simpson is appears because we did not sample for caribou occupation in March due to turbulence.
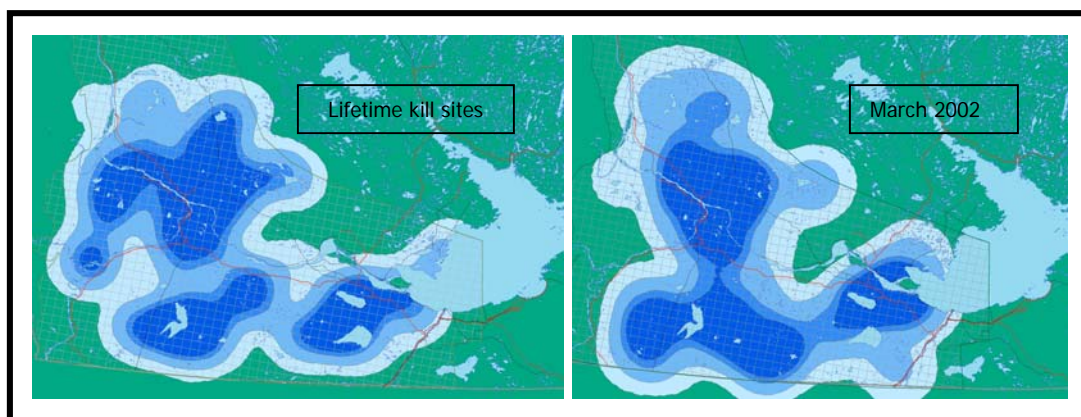


**Figure 11:** Boreal caribou occupation based on fixed kernal analysis of lifetime kill sites (left map) and March 2002 aerial survey (right map), Deh Cho, NWT, March 2002.

During the aerial survey northeast of Fort Providence, we saw plentiful sign of moose and bison but less sign of boreal caribou, although the area had relatively high quality habitat. Local knowledge and Tom Chowns (pers. comm.) identified the area as where boreal caribou used to occur. The model suggests that moose and bison presence is less likely to coincide with the occurrence of

boreal caribou.  Boreal caribou may avoid the habitat preferred by moose and bison or may be spacing themselves away from an increased risk of predation as wolves or black bears may be more abundant where there are moose and bison. Avoidance of predation is the key factor driving caribou habitat selection at the scale of seasonal range use (Rettie and Messier 2000).

Although the habitat model predicted that boreal caribou would occur northeast of Wrigley, we saw large numbers of barren–ground caribou tracks which would have obscured any boreal caribou sign.  We saw groups of barren-ground caribou and at least one of those groups included a conspicuously long-legged dark bull – possibly a boreal caribou.  The barren-ground caribou were likely the Bluenose East herd and it was their first reappearance in the area for some 20 years (Tim Lennie pers. comm.).

The occupation map based on lifetime kill sites underestimates caribou distribution in the vicinity of Wrigley, Fort Liard and Fort Providence as data were unavailable at the time the map was produced.  We also lack information from aboriginal people living in northern Alberta who may have traditional knowledge about areas along the NWT Alberta border such as the Cameron Hills. The lifetime kill sites had, in the model, more predictive power at the lower probabilities of caribou occurrence.  This is likely a consequence of hunting for boreal caribou being opportunistic, influenced by ease of access and hunting for moose.

Boreal caribou were strongly associated with black spruce and lichen on uplands and in lowlands. The uplands include the uplands west and east of Trout Lake, the uplands west of Fort Simpson (Martin and Ebbut Hills, Sibbeston Lake) and the Horn Plateau. Lowlands include the vicinity of Fort Simpson and Antoine Lake and the lowlands north of Kakisa extending to the southern shore of Great Slave Lake west of Hay River.

The Mackenzie and Liard Rivers and associated lowlands seemingly divide caribou distribution into a southern central block (Trout Lake and Kakisa), a western block and a northeast block (Figure 11). Recent findings in northern Alberta suggest that the likely role of major rivers in dividing distribution has implications for population structure. McLoughlin et al. (2002) used microsatellite markers to quantify genetic diversity within and among boreal caribou in northern Alberta and northeast British Columbia. Their analyses identified a region of relatively low gene flow, which corresponded to the valley of the Peace River.

The modeling described in this report is more a snapshot of factors associated with the distribution of caribou during late winter than a definitive study of habitat selection by caribou, which would have to consider several scales (Johnson et al. In Press, Johnson et al. Submitted). One assumption of this model and of the field sampling is that a snapshot of caribou abundance in late winter is an adequate representation of seasonal caribou distribution within the study area. The amount this assumption is violated depends on how much

the caribou seasonally migrate between habitat types throughout the year. However, published papers on boreal caribou refer to their lack of seasonal migrations and relatively small home ranges (for example, Rettie and Messier In Press).

The associations documented in this study should not be interpreted as a causal relationship between predictor variables and caribou distribution.  An experimental-based approach with treatment and control sampling such as the BACI design (Underwood 1997) would have to be undertaken to document causation between predictor variables and caribou distribution (Bradshaw et al. 1997).

Two factors that we had thought might influence boreal occurrence were fire history and density of cutlines.  We had fire history for just under half the 10 X 10 km cells surveyed, and the term 'years since last fire' was not significant when added to the AICc chosen model.  However, the years since fire variable was significantly correlated with fire regenerated vegetation with the highest proportion of fire regenerated habitat occurring in cells that had fires 7 years ago. Caribou occurrence was predicted to increase with lower proportions of fire-regenerated vegetation but decrease with higher proportions.  Possibly, the higher proportions of fire-regenerated vegetation provide attractive forage for moose.  Caribou likely space themselves away from moose to reduce predation risk.  In northern Alberta research currently underway (J. Dunford pers. comm. 2002) suggests that caribou used burned areas in a proportion greater than their

availability.  The research has also determined that lichens in northern Alberta grow more rapidly after fires than on barren–ground caribou ranges.

We had expected that predicted caribou occurrence would decrease with increasing cutline density as boreal caribou in Alberta tend to avoid seismic lines and roads (Dyer et al. 2001, 2002).  Caribou may avoid seismic lines because of increased travel by wolves on seismic lines.  Caribou in close proximity to seismic lines are at higher risk of being killed by wolves (James 1999, James and Stuart-Smith 2000).  Our model was at a landscape scale and the cut lines were mostly older lines with varying amounts of vegetation regrowth.  These two reasons may explain why the model predicts higher probability of caribou occurrence with increasing cut line length. During the aerial survey in March we could see tracks where caribou traveled along some lines.

Using 10 X 10 km cells as the unit of habitat availability while only surveying a 1 km x 10 km area of the cell carries the assumption that caribou select habitat on a broad scale.  The degree to which this assumption is met is related to the typical area traversed by caribou (i.e. their home range area).  The analysis of data at smaller scales (the transect strip width 1X10km for each cell) suggests a relationship similar to that suggested by the larger-scale model.  The agreement of models defined at the large and small scale suggests that either caribou may select habitat on a broader scale or that the resolution of habitat classification limits the resolution of finer-scale habitat types.

Another potential issue is the non-independence of sample units, since adjacent cells were sampled during aerial surveys. Non-independence usually causes increased autocorrelation of observations and negatively biased variance estimates of model parameters. Ideally, non-adjacent cells would be sampled in a systematic fashion (i.e. checkerboard) to minimize issues with non-independence. This sampling design is more complex and less cost effective. To confront this issue, both spatial covariance models and bootstrapping was used to assess and account for non-independence issues. These analyses suggest that results are reasonably robust. However, a simulation-based approach would provide a more definitive conclusion about this sampling issue.

Differences in visibility of caribou as a function of habitat type might result in habitats being excluded from the habitat selection model where caribou are obscured by vegetation. To confront this, the canopy closure was measured for a subset of cells with no significant difference detected. However, this only provides a partial test, especially if the visibility of caribou is low in certain habitat types. There are documented ways to estimate sightability bias if a segment of the caribou population has radio collars (Krebs 1998). This would provide further evaluation of aerial based survey techniques for modeling distribution.

Significance tests are useful for evaluating model terms but they are very limited for model fitting. There are a variety of reasons for this. One main reason is that the alpha level (0.05) chosen for significance tests is subjective. For example, a term can still be helping a model in

terms of prediction even though its alpha level is greater than 0.05.

The model has potential application elsewhere in the NWT to generate a standardized map of occurrence, but given the latitudinal differences in vegetation, caution is warranted in extrapolating this model beyond the Deh Cho study area.  As shown in comparing the preliminary to the subsequent full model, the actual best fitting model is partially determined by the distributions and ranges of values of predictor variables in the data used when the model is built. For example, proportions of some predictor variables in the full model (i.e. fire-regenerated, mixed forest, and sphagnum) were low in cells, and had limited range of occurrence across the study area.  Therefore the relationship between caribou presence/absence and higher abundance of these habitat variables is unknown.  Comparison of the ranges of predictor variables used for the full model and the ranges of predictor variables found in other areas is a good first step if the model is to be considered in other areas.  Additionally, a cross-validation exercise that samples new areas for caribou could also be used to validate the predictive ability of the model (Boyce *et al.*  In press).

The federal Species At Risk Act requires that critical habitat be identified for Threatened and Endangered species.  Building habitat models is a preliminary step toward identifying critical habitat (Scott et al. 2001).  This project identified boreal caribou habitat through mapping boreal caribou occurrence (potential habitat) and occupied habitat in the Deh Cho.  Our initial step in identifying critical habitat is to predict high value boreal caribou habitat in the Deh

Cho (Figure 12), based on the probability of occurrence classes higher than 50%.
Our ranking of habitat importance with a higher likelihood of occurrence is based
on the logic that habitat use is related to selection and preference, which in turn
relate to resource-dependent fitness. This chain of logic allows us to equate
patterns of use with habitat importance. Disproportionate use is assumed to
demonstrate selection of habitat. However, we are also aware of methodological
pitfalls in describing those relationships (Garshelis 2000).
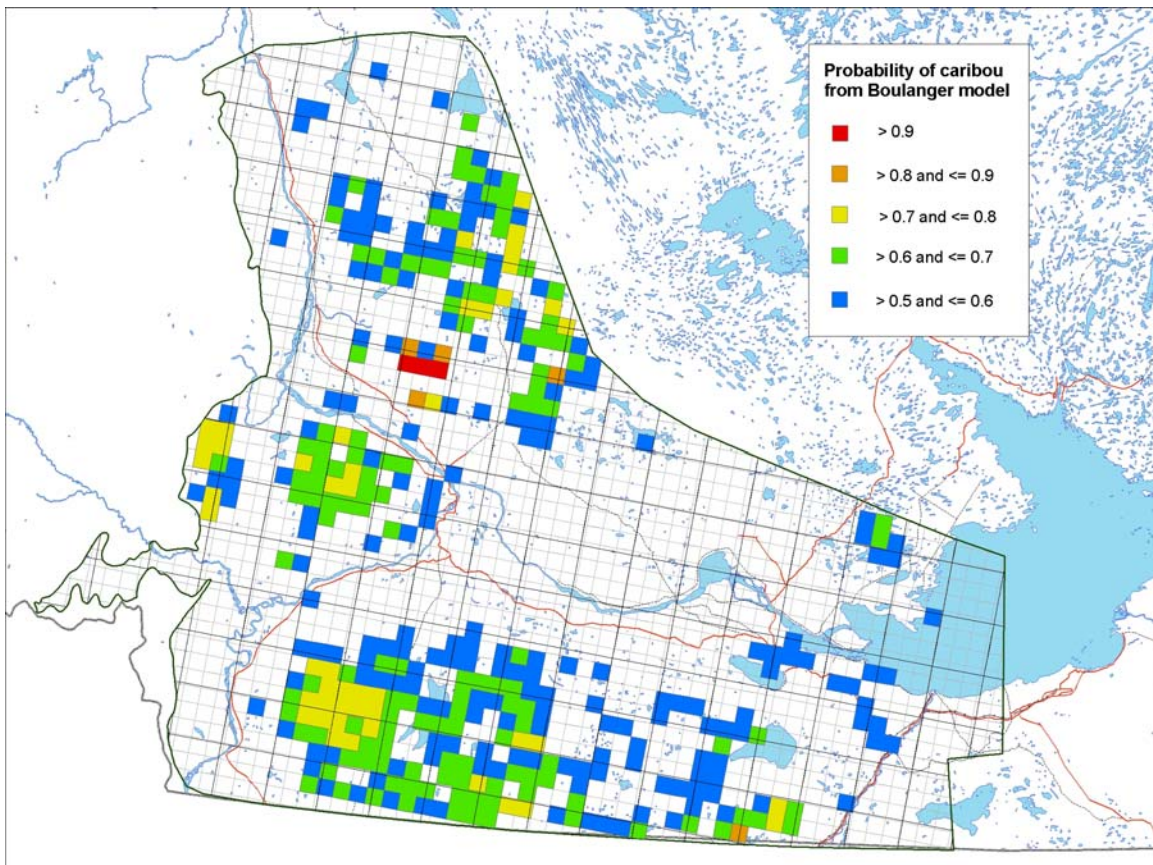


**Figure 12:** Predicted high value boreal caribou habitat, Deh Cho, NWT, March
2002 (based on the probability of occurrence classes (50 – 100%) and with 10 x
10 km and 100 km x 100 km grids

Our designation of high value caribou habitat based on the model requires further investigation of both habitat attributes and the survival of caribou in those areas.  In the meantime, it can be considered as advice for land–use planning where, for example, particular measures may be necessary.  One illustrative example is that, within a 900 km$^2$ block centered on an oil company's 2002 request to undertake 3–D seismic line cutting in the Cameron Hills, two thirds of the area is high value boreal caribou habitat according to our model.  The risk of increased predation by wolves or black bears is a possibility given the high density of existing cutlines and the presence of moose.  The predicted high quality caribou habitat in the area and the likely risks to boreal caribou that would result from additional cutlines are strong arguments for requiring the use of best practices such as hand cut lines and reduced line of sight along the lines rather than allowing 4 or 6 m wide cutlines.

The project's goal is to enable land use jurisdictions (including the local communities and regional organizations) to identify, steward and monitor critical habitat for boreal caribou as a conservation contribution to land use planning in the Deh Cho and recovery planning in the NWT and Canada.  Our results, describing caribou at the landscape rather than finer scales, is appropriate for land–use planning as it is based on findings elsewhere.  Research in Alberta, Saskatchewan and Ontario suggests that it is necessary to conduct resource management at the landscape scale to maintain large blocks of contiguous habitat and avoid creating corridors favourable to moose thereby increasing the risk of predation (Rettie and Messier In Press, Racey et al. 1991, James

and Stuart–Smith 2000).  We have mapped (Figure 12) the predicted high quality

habitat with a 1000 km$^2$ grid to emphasize the larger blocks.

Mapping boreal caribou occurrence and occupation in the Deh Cho is a first step

in both land use and recovery planning.  We suggest that we now need to ensure that

traditional land use information from Fort Providence, Wrigley and Fort Liard is included

in the mapping.  Other follow–up steps would be to measure caribou survival in what we

predict is high–quality caribou habitat and to investigate lichen and herbaceous plant

growth relative to fire–history.  Radio–collars are used in Alberta to determine both adult

and calf survival.  Using those collars would be useful to describe seasonal habitat use

and identify habitat types where sightability prevented inclusion in the model.  Our

predictions for boreal caribou occurrence are based on modeling at a relatively coarse

(landscape) scale.  Although testing the model with the two independent data sets

(lifetime memory kill sites and an aerial survey) gives us confidence in the model

predictions, we will need different models using other approaches and validation to

further investigate boreal caribou relationships with their habitat (for example, Wilson et

al. 1998).

# ACKNOWLEDGEMENTS

PERSONAL COMMUNICATIONS

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