Estimating the Resource Selection Function and the Resource Selection Probability Function for Woodland Caribou

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Abstract:

An ability to understand how animals selectively use resources is essential to support conservation planning for many species. In evaluating resource selection, the exponential form of the resource selection function has become the common approach in practice and in present literature. We estimated the exponential form of the resource selection function and the Logistic form of the resource selection probability function using telemetry data from Woodland caribou. We showed that when applied in a geographic information system the Logistic form of the resource selection probability function provided a better fit to the caribou telemetry data than did the exponential form of the resource selection function. We suggest that multiple model forms should be considered and evaluated, using a method that is appropriate for the purpose, when estimating resource selection by animals. We further provide a useful and representative model for interpreting and displaying the types of resources that have been preferentially used and avoided by an at-risk caribou population during previous winters.

Key words: Telemetry data, GPS collars, Caribou, resource selection probability function, rspf, resource selection functions, rsf, use-available study-design.

Introduction

Woodland caribou (*Rangifer tarandus caribou*) are designated as either 'Endangered', 'Threatened', or of 'Special Concern' (COSEWIC 2002) in Canada. The Telkwa caribou herd of northwest British Columbia belongs to the 'Northern Woodland Caribou Population' which is designated as of 'Special Concern' (COSEWIC 2002).

Within the Northern Woodland Caribou Population, Telkwa caribou are of distinguishable conservation concern. Like many other 'at-risk' caribou herds, the Telkwa caribou herds' geographic distribution has recently (in the past 60 years) dwindled to a relatively small range. In relation the abundance of the Telkwa caribou population has also dwindled. In 1997, biologists could find only 8 remaining Telkwa caribou. Over the past decade since 1997, considerable management measures have been taken to recover this caribou population. These measures have included the translocation of 32 caribou to the herd, resource development and recreational mitigations to protect caribou and their habitats, and population and habitat-use monitoring. During the latest inventory of the Telkwa caribou population (October, 2006), 90 caribou including 24 calves were observed.

An ability to predict preferential habitat sites, especially in areas where previous occupancy is not known, is needed to support an ongoing mandate to recover the Telkwa caribou herd. In particular, resource managers are concerned about the effects that industrial and winter recreation activities may have on the caribou population and on their winter habitats.

The Resource Selection Function (RSF) and the Resource Selection Probability Function (RSPF) are functions that compute the probability (or relative probability if RSF is used) that a particular resource, as characterized by a combination of environmental variables, will be used by an individual animal (Manly et al., 2002). The exponential form of the Resource Selection Function (RSF) has recently been used to predict caribou habitat from telemetry data (Johnson et al. 2004, and 2005). More recently, Lele and Keim (2006) presented methods for estimating the Logistic form of the RSPF from telemetry data. However, the resource selection probability function has never been used to predict caribou resource selection.

In this study, we use aerial and GPS telemetry data from wintering Telkwa caribou to estimate the Exponential RSF and the Logistic RSPF, and hence to predict the locations of winter caribou habitat. Our objectives were:

1. To determine if there is a difference in the ability of the exponential RSF and the Logistic RSPF to predict winter caribou site selection,
2. To assess the resource preferences of wintering Telkwa caribou from GPS-telemetry and radio-telemetry locations, and
3. To determine if conservation areas can be identified from these telemetry locations and widely available geographic information system (GIS) data to help advance future research and recovery of the Telkwa caribou herd.

Data Description

Study Area

The study area is approximately 2,625 km^2 and occurs within watersheds of the Skeena River in northwest British Columbia, Canada (54.4ºN, 127.2ºW). The communities of

Smithers, Telkwa, and Houston are each located within 50 km of the study area. Anthropogenic disturbances in the area are primarily denoted by gravel roads and vegetation clearings related to recreation, forestry and mining activities. Topography in the study area is generally defined by rugged glacially formed relief in the Howson and the Telkwa Mountain Ranges and by broad U-shaped valley floors. Four biogeoclimatic (BEC) zones (Meidinger and Pojar 1991) occur within the study area. The Sub-Boreal Spruce (SBS) zone occurs at elevations between 550 m and 1200 m. It is characterized by severe and snowy winters and by climax forests of spruce (Picea engelmannii x glauca) and subalpine fir (Abies lasiocarpa). The Coastal Western Hemlock (CWH) zone has mild winters and occurs at low to mid elevations nearer coastal influences. The CWH zone occurs within only a small and discrete area in the northwest corner of the study area. The Engelmann Spruce-Subalpine Fir (ESSF) zone is the most common forested zone in the study area. It generally has long, cold and snowy winters and occurs at elevations above the CWH and SBS zones and below the alpine zone (850 m to 1650 m). Lastly, the Alpine zone occurs extensively at higher elevations (1300 m to 2300 m) above the ESSF zone. The alpine zone has the shortest growing season and harshest climate in the study area. Within alpine areas are jagged peaks and rolling windswept plateaus containing alpine sedges, grasses, and lichens.

Telemetry Data

Two types of caribou telemetry data were used in this study. They include GPS-collar location data and location data collected during aerial surveys of radio-collared caribou. These two data types provide extreme differences in data quality and representation. The GPS collar data represent a sample of locations from only a few individuals (3 caribou) and during only two winter seasons. However, the GPS collar data was attainable at hourly intervals (many locations per individual) and has a relatively small measurement error (locations are generally accurate to within 30 m). The radio-telemetry data on the other hand, is representative of a larger sample of individuals (44 caribou) in the population and was collected across 10 winter seasons. However the radio-collar data was available at only monthly to bi-weekly intervals (few locations per individual) and has a relatively large measurement error (locations are generally accurate to within 250 m in this study).

Only winter season telemetry data was considered in this study. The winter season was defined between December 01 and April 15 of the calendar year based on trends in climatic condition between 1996 and 2006. The GPS-collar data includes 2,682 winter locations collected from 3 female caribou during the 2001/02 and the 2002/03 winters. The radio-collar data includes 1,323 locations collected from 42 female and 2 male caribou for the winter years between 1996/97 and 2005/06.

GIS Data

To predict the site selection of wintering caribou a number of covariates were considered including: elevation (meters above sea level), slope steepness (sine of slope), a modification of Beer's aspect transformation (Beers et al. 1966), and a categorical covariate for the alpine BEC zone (Meidinger and Pojar 1991). All covariates are identifiable and can be easily derived in a GIS, using widely available data sources. A digital elevation model (DEM) at 25meter-pixel-resolution was used to derive the continuous topographic covariates of elevation, slope steepness, and aspect. Readily available ecosystem inventory from the province of British Columbia was used to code a covariate for the alpine BEC zone.

Data Analysis and Statistical Models

A use / available study design (Lele and Keim 2006; Keating and Cherry 2004; and Manly et al. 2002) was employed in the analysis of data and in the development of statistical models. In this analysis used sites are defined by the telemetry locations. Available sites are 95,000 locations that were randomly selected from within the study area. The available sites represent what kinds of habitats might be potentially available to caribou. Statistical analysis was conducted in the statistical software program: R Statistical Computing Version 2.2.1©. In the following sections we present an exploratory analysis of the data and a comparison of the Logistic RSPF and the exponential RSF as tools for modeling resource selection.

Exploratory Analysis

The first step in the analysis of data is to check for any anomalies in the data and to assess relationships of resource selection with individual covariates.

Selection index plots: We used a continuous version of the selection index (Manly et al. 2002) to study the relationship between resource selection and any individual covariate. To do this, we compute the non-parametric density function estimate for the values of an individual covariate (say, elevation) over the used sites and the non-parametric density function estimate of the same covariate over the available sites. If there is no selection, the two densities should be identical to each other in shape. In other words, if we take the ratio of these two density estimates, a constant ratio indicates no selection. We transformed the values of the selection index using the Log function to scale the selection index values as positive and negative numbers. A Log ratio larger than 0 indicates the resource is selected preferentially and a Log ratio less than 0 indicate the resource is not selected. The form of the selection index function, such as quadratic or exponential etc. can be determined from the plot and informs us about the possible form of the relationship between the resource and its preferential use.

We compiled selection index plots for the covariates elevation, sine slope and transformed aspect among three telemetry data sets considered:

1. GPS-collar data,
2. Radio-collar data, and
3. GPS-collar in combination with radio-collar data (herein referred to as the combined telemetry data set).

The selection index plots for each covariate are provided in Figure 1. The X-axis corresponds to the range of values of the covariate and the Y-axis corresponds to the Log of the selection index. The color of the plotted line varies by telemetry type.

a) Elevation: For woodland caribou and especially for the northern woodland caribou population that occupy mountain terrain, elevation has been documented as an important factor in winter site selection (Gustine et al. 2006, Johnson et al. 2004) presumably due to a relationship with snow cover and or vegetation. In the site index plot for elevation by Telkwa caribou the relationship resembles the quadratic form. Telkwa caribou preferred sites between 1400 m and 2400 m elevation, uniformly among all three telemetry data sets in the winter season. The preference of higher elevation ranges (1400 to 2400 m) is indicative of alpine and sub-alpine ecosystems within the study area.

b) Steepness of the slope: Next we considered the covariate for slope steepness. The values of slope steepness (in degrees) were transformed using the sine function (sin [slope]) to scale the slope data between 0 and 1. From the selection index plots, it appears the relationship with slope steepness also has a quadratic form. However, there is an obvious difference in the selection index for steep slopes by the telemetry data set considered. The data set for the GPS-collar and the combined telemetry data set indicate that caribou prefer sites that occur on slopes between (approximately) 5º and 25º steep. In contrast the radio telemetry data set does not appear to indicate a strong relationship between slope steepness and site selection. We infer that analysis of the slope steepness covariate using radio-telemetry data is confounded by measurement error since the slope steepness of a site can be highly variable within 250 m (and the accuracy of the radio-telemetry locations).

c) Aspect: The aspect of a slope, or the direction of slope exposure, may influence the snow cover, rate of snowmelt, and vegetation cover at a particular site. Such characteristics are more likely effects from the amount of solar energy and wind exposure a site receives (Mcune and Keon 2003). Within the study area slopes that face south, southwest, west, and northwest receive the greatest amount of solar energy and wind exposure. We used a modification of Beer's aspect transformation (Beers 1966) in considering aspect as a covariate for site selection by wintering caribou. The aspect transformation used takes the following form:

Transformed Aspect = sine (aspect + 225)

Where, aspect was derived from a DEM in degrees. The transformed aspect was thus scaled between -1 and 1, where slopes facing southwest (225˚) have a value of 1 and slopes facing northeast (45˚) have a value of -1. In the selection index plot for transformed aspect it is apparent that there is a difference in the level of selection given the telemetry data set considered. Similar to the slope covariate, we infer that analysis of the transformed aspect covariate using radio-telemetry data is confounded by measurement error since the aspect of a site can be highly variable within 250 m. A positive linear relationship among selection index and transformed aspect is apparent among the GPS-collar data set and the combined data set. These data indicate caribou have a preference for sites having a transformed aspect nearer 1.0.

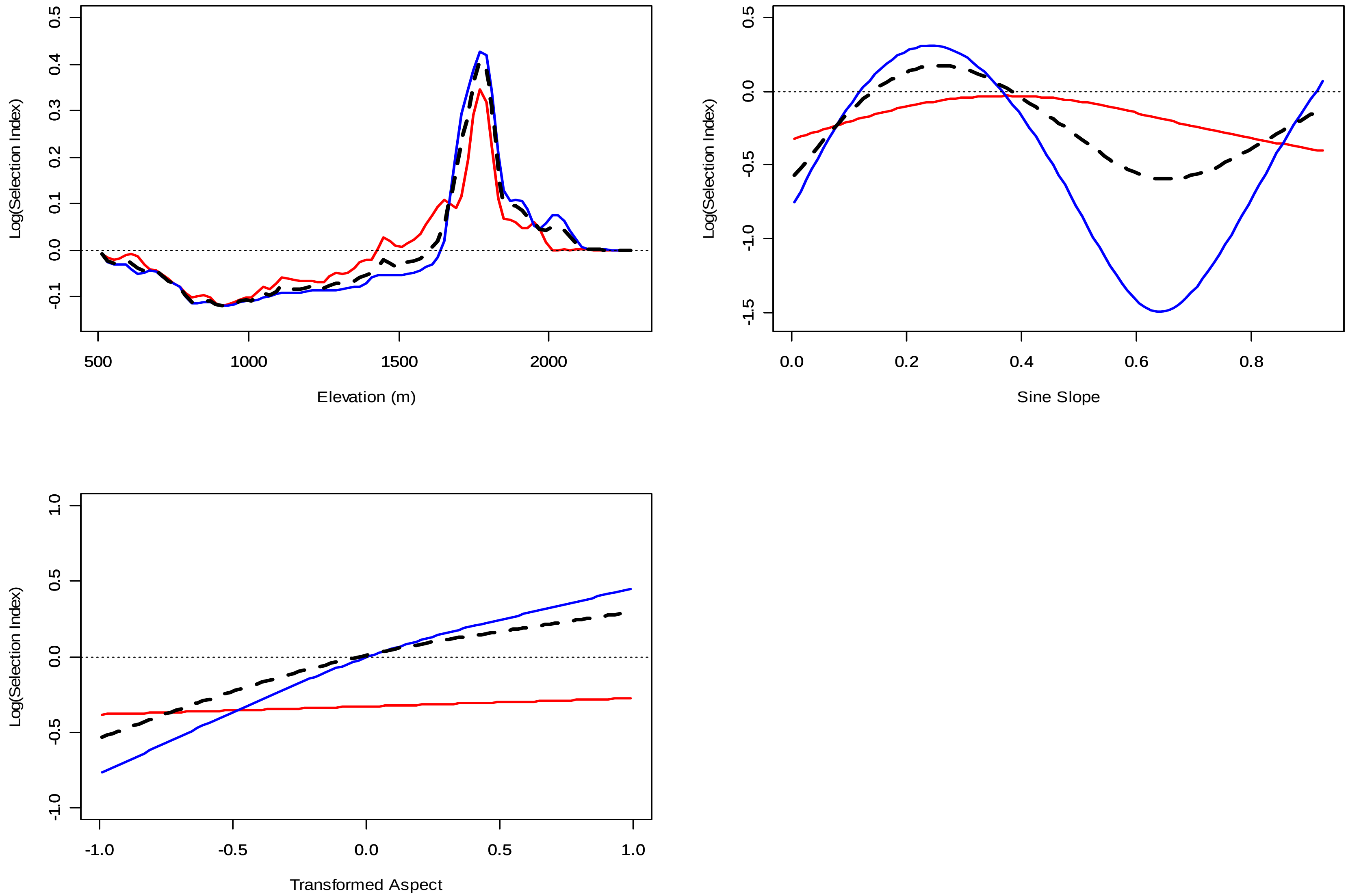

Figure 1: **Selection index plots for the caribou telemetry data. A red line indicates radio-telemetry data, a blue line GPS telemetry data, and a black-dashed line indicates the combined radio and GPS telemetry data. Log transformed selection index values greater than the dashed line at 0.0 of the y-axis are preferred sites. Values less than the dashed line at 0.0 of the y-axis are avoided sites.**

4) Alpine: Northern woodland caribou populations are documented to preferentially winter in alpine and sub-alpine ecosystems (Johnson et al. 2004b, Johnson et al. 2003, Poole et al. 2000, Terry et al. 2000), presumably due to forage access of terrestrial lichens in alpine ecosystems and arboreal lichens in sub-alpine forests. We define alpine areas as the Alpine BEC zone. The alpine BEC zone primarily occurs at elevations above which trees grow, but may include patches of krummholz trees. Table 1 provides the Log of the selection index for alpine ecosystems among the three telemetry data sets. The telemetry data indicate that Telkwa caribou strongly preferred sites in alpine ecosystems in the winter season (among all three data sets).

Table 1: Log value of the selection index for the Alpine BEC zone from Telkwa caribou telemetry data.

	Radio-Telemetry	**GPS-Telemetry**	**Combined GPS and Radio Telemetry**
Log [Selection Index for Alpine]	0.79	0.98	0.92

<u>Statistical Models</u>

Two statistical models, both applicable to the use / available study design (Lele and Keim 2006; Keating and Cherry 2004; and Manly et al. 2003), were employed in analysis of the Telkwa caribou telemetry data. The first model, the exponential form of the RSF is the most common modeling approach for estimating the relative probability of resource selection by animals, including caribou (Johnson et al. 2004, 2005, 2006). The second, the Logistic RSPF, was recently identified as an alternative approach for estimating the probability of resource selection by animals and has not previously been applied to caribou telemetry data.

We considered identical telemetry data sets, available distributions, and covariates to estimate resource selection by Telkwa caribou using both statistical models. In these models we consider only the combined telemetry data set, since among the data available this data set provides the most robust representation of resources used by the herd. In Table 2 we provide the Bayesian information criterion (BIC) value (Burnham and Anderson 2002) for the fitted exponential RSF and the fitted Logistic RSPF models for the combined telemetry data set.

Table 2: Log-likelihood values for best fit multiple covariate models. A model with a larger log-likelihood value is considered to provide a better fit.

Exp RSF	L RSPF
-15958	-16460

The Logistic RSPF provides a better descriptor of the data, under assumptions of the BIC.

Final Model

We estimate both the Logistic RSPF and the exponential RSF for evaluation in a GIS to the extent of the study area.

The best fit Logistic RSPF model takes the form:

$$\pi(\underline{x};\beta) = \frac{\exp(\underline{x}\beta)}{1+\exp(\underline{x}\beta)}$$

The best fit exponential RSF model takes the form:

$$\pi(\underline{x};\beta) = \exp(\underline{\chi}\beta)$$

The parameter estimates (β) and the standard errors for both models are provided in Table 3. All covariates are significantly different form zero.

Table 3: The estimated coefficients (β) and the standard errors (SE) for the model covariates used in each of the exponential RSF and the Logistic RSPF.

Covariate	Logistic RSPF		Exponential RSF	
	B	SE	B	SE
Intercept	-36.09	1.42	-	-
Elevation	3.22	0.16	1.18	0.08
Elevation ^2	-0.08	0.004	-0.022	0.002
Sine Slope	5.36	0.60	-1.527	0.38
Sine Slope ^2	-17.34	1.14	-5.127	0.64
T. Aspect	0.16	0.02	0.179	0.023
Alpine	1.38	0.06	1.536	0.059

The final Logistic RSPF and the exponential RSF models can be applied in a GIS to plot the models geographically. We applied both model functions in a GIS raster format at 25 m pixel resolution to the extent of the study area. Each 25m by 25m pixel is assigned a probability value of site selection using the Logistic RSPF model (Lele and Keim 2006) and a relative value of site selection from the exponential RSF model (Johnson et al. 2004, and 2005). The range of RSPF probabilities within the study area ranged from 0 to 0.076.

Model Evaluation

We used a measure of the residual sum of squares (RSS) to determine the fit of the final models within the study area. In this approach we compared each model, as applied in a GIS to the extent of the study area, to the combined telemetry location data. Since the combined telemetry data was used to derive both the Logistic RPSF final model and the exponential RSF final model, a good fit is expected in both cases.

To calculate the RSS each model (RSPF and RSF) needed to be categorized into a grouping of ordinal bins where the highest ranked bin contained the most preferred sites and visa versa. Each model was converted into an index in a GIS by dividing each pixel value by the maximum model value attained within the study area. This conversion allowed both models to be identically scaled between 0 and 1.0, where a value of 1.0 represents the most preferred sites. We then classified both scaled models into 12 equally distributed bins, in increments of 0.083. For each bin we then calculated the area (number of pixels) and the number of telemetry locations predicted by each respective model in the study area. Using these data we were then able to compute the used proportion of telemetry locations and the predicted-value (expected) for each bin using the following calculations.

[1] Used Proportion = # of telemetry locations / ∑ telemetry locations in all bins

[2] Predicted-value = the bin mid-point value * (Area / ∑ Area in all bins)

To derive the predicted value we used the mid-point value of the model interval at each bin as per Johnson et al. (2005) and Boyce and McDonald (1999). We note that bin 1 (least preferred sites) can be sensitive to the midpoint value since it contains sites with a predicted probability of "0" resource selection. The RSS was calculated using the Log transformation of the predicted-value and the used proportion using the following function for each model (RSPF and RSF).

$$J = \sum_{i=1}^{K} \{(y_i - x_i) - (\overline{y} - \overline{x})\}^2$$

Where; *K* is the total number of bins, y_i is the logarithmic transformation of the proportion of predicted use, x_i is the logarithmic transformation of the proportion of observed use.

The RSS is provided for the exponential RSF model and the Logistic RSPF model in Table 4. A plot of the residuals for each model is provided in Figure 3. If the model has a good fit, one would expect:

1. A RSS value approximate to zero, and
2. A linear relationship between the used proportion and the predicted value on the Log scale, to have a slope of 1.0 (with an intercept defined by the relationship).

Table 4: Residual Sum of Squares (RSS) calculated for the Logistic RSPF Model and the exponential RSF model. A RSS value nearer zero indicates a better model fit.

RSS: Logistic RSPF Model	RSS: Exponential RSF Model
0.5511092	76.38691

The smaller RSS value for the Logistic RSPF model, as compared to the exponential RSF model, indicates that a better fit with the caribou telemetry locations is attained by the Logistic RSPF model.

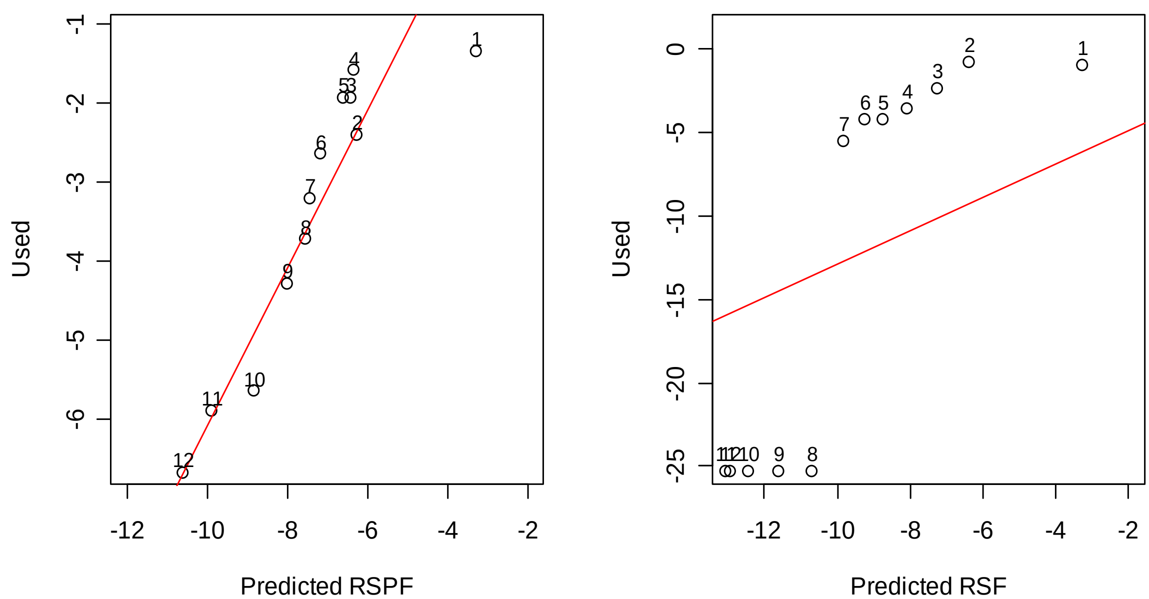

Figure 2: Plots of model fit for both the Logistic RSPF model and the exponential RSF model on the Log scale. A red line indicates the expected model fit. The bin number is denoted above each point, where a larger bin number represents a grouping of more preferred sites.

The effect of the residuals is displayed as the vertical distance between each point (bin) and the expected fit, in each plot (Figure 2). In the plot for both models, bin 1 provides a slightly skewed measure. We presume that this is largely due to an inflation of the predicted-value that occurs at bin 1 when sites with a predicted selection probability of “0” (sites with no selected resources) assume the mid-point value. The residuals in the RSPF model are relatively consistent among the 12 bins, with the exception of bin 1. In the RSF model the bin residuals indicate that use is greater than expected among sites that are predicted to be least preferred (bins 1 to 7), and visa versa. Actually, we noted that no telemetry locations occurred in bins that are estimated to represent the most preferred resource sites (bins 8 to 12) by the RSF model. The plot of the model fit)and the bin residuals) indicate that in this case the exponential function provides a relatively poor fit with resource selection and the Logistic RSPF provides a better fit with resource selection among the collared caribou in this study (and given the data, of course). We provide the area estimates from the 12-bin Logistic RSPF model to the extent of the study area in Appendix A (at the end of the report).

Discussion

We have presented a detailed analysis of radio-telemetry and GPS-telemetry data in estimating resource selection models using both the exponential RSF and the Logistic RSPF approaches. In our analysis we used readily available GIS data and statistical software to evaluate resource selection from caribou telemetry data. The analysis presented is simple, intuitive and allowed a quantitative evaluation of resource selection by caribou using multiple telemetry datum, multiple covariates, and multiple modeling approaches. The final model was easily applied in a GIS across a broad geographic area as an efficient and effective tool for land use managers and researchers.

Both aerial radio-telemetry locations (Johnson et al. 2004, 2005, 2006) and GPS-collar telemetry locations (Gustine et al. 2006) from woodland caribou have recently been used to estimate resource selection models. We considered both aerial radio-telemetry locations and GPS-collar telemetry locations in estimating resource selection models for Telkwa caribou. In this particular study the radio-telemetry locations were thought to be accurate to within approximately 250 m. Conversely the GPS collar locations are generally accurate to within 30 m of the true animal location. We presume that the larger measurement error in the radio-telemetry locations may have masked site selection when considering resources, as slope steepness and aspect, which can be highly variable within the 250 m distance. In contrast we considered a covariate that had considerably less relative variability within 250 m distance, elevation, and found that the selection index relationship did not strongly vary between the telemetry data sets. We suggest that it is important to consider the variability in the resource units at a scale equivalent to the accuracy of the telemetry locations when evaluating and estimating resource selection from telemetry data.

In our final model, we found that caribou foremost selected sites at mid to high elevations primarily near or above tree line within the study area. Secondarily they preferred sites that were moderately steep to almost flat. Lastly, they preferred sites nearer warmer aspects (225 degrees) that were exposed at an angle between 150 and 300 degrees. We believe that the sites predicted by the model are consistent with known wintering caribou ecology in mountainous terrain like: windswept, solar exposed, and relatively snow free, sites near or within the alpine (Poole et al. 2000, Edmonds 1988); relatively vast and open plateaus that provide advanced detection of predators (Terry et al. 2000); alpine plateaus that may offer an abundance of terrestrial lichen forage (Terry et al. 2000 and Edmonds 1988); and or high elevation sub-alpine forest patches that may offer an abundance of arboreal lichen forage (Johnson et al. 2000, Terry et al. 2000).

In this case for estimating resource selection by wintering caribou, we showed that the Logistic form of the resource selection probability function (Lele and Keim 2006) provides a much stronger fit than did the exponential form of the resource selection function (Johnson et al. 2004, and 2005). We do not suggest that the exponential form of the resource selection function should not be considered in modeling resource selection (as the exponential model may be a better model in certain situations). We do however suggest that multiple model forms (including models as probit and the log-log link) be considered and evaluated, using a method that is appropriate for the purpose, when estimating resource selection by animals. We emphasize this need given the poor interpretation estimated by the exponential RSF model in this case.

Lastly, we showed that the Logistic RSPF model provides a strong representation of the caribou telemetry data when applied in a GIS. The maximum probability attained by the model in any 25 m by 25 m pixel within the study area is 0.076. We stress that a low maximum probability estimated by the RSPF model does not indicate a poor model fit. Each RSPF probability indicates the probability that a particular resource, as characterized by a combination of environmental variables (defined at each 25m by 25m pixel in this case), will be used by an individual animal (Lele and Keim 2006, Manly et al. 2002). A low maximum probability value can be achieved when there are multiple combinations of environmental variables that lead to the maximum probability and or when maximum probability sites are not strongly selected for in comparison to other combinations of environmental variables (E.g. not a unique and specifically preferred resource type). We conclude that given the data used the Logistic RSPF model provides a useful and representative model for interpreting and displaying the types of resources that have been preferentially used and avoided by the Telkwa caribou during past winters.

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Appendix A – Logistic RSPF Model Area Analysis

Area Analysis of the 12-Bin Logistic RSPF Model for Wintering Telkwa Caribou as applied in a GIS to the extent of the Study Area (Telkwa Caribou Recovery Area).

Winter Habitat Suitability	**RSPF BIN**	**Area Analysis**		**Telemetry Location**	
		Area (km^2)	**Percent of Study Area**	**Number of Locations**	**Percent of Total**
Low	1	2508.12625	95.56	1042	26.02
	2	41.89813	1.60	361	9.01
	3	21.66313	0.83	580	14.48
	4	21.18875	0.81	818	20.42
	5	14.01563	0.53	578	14.43
↓	6	6.81813	0.26	283	7.07
	7	4.47563	0.17	162	4.04
	8	3.39625	0.13	96	2.40
	9	1.92688	0.07	55	1.37
	10	0.76313	0.03	14	0.35
	11	0.24000	0.01	11	0.27
High	12	0.10563	0.00	5	0.12
	Total	**2624.61750**	**100.00**	**4005**	**100.00**