

**LONG-TERM DISTRIBUTION RESPONSES OF THE PORCUPINE CARIBOU HERD TO
HUMAN DISTURBANCE**

Report Prepared by

Chris Johnson
University of Northern British Columbia (johnsoch@unbc.ca)

And

Don Russell

Introduction

The responses of animals to human developments and disturbance are commonly observed, but such responses are varied and complex. Individual animals, for example, may choose not to use habitats near a road or mine because the forage has changed. Likewise, human presence may be perceived as a threat to survival, once again forcing an individual to move away from such areas (Frid and Dill 2002). These responses can result in increased energetic costs resulting from greater vigilance and movement as well as habitat loss through the abandonment of portions of a seasonal range (Bradshaw et al. 1998, Seip et al. 2007). Thus, understanding the distribution of caribou relative to human developments can provide key insights on the costs to individual animals and ultimately populations.

Species distribution models are now a common and well-accepted technique for quantifying the responses of animals to human disturbance. Defined by Guisan and Thuiller (2005) as "... empirical models relating field observations to environmental predictor variables, based on statistically or theoretically derived response surfaces." this "model" takes many forms depending on study objectives and available data (Johnson and Gillingham 2005). Most approaches are premised on a set of empirical data or the knowledge of experts that describe the current or past distribution of a species, a set of environmental variables that might explain spatiotemporal variation in distribution, including human disturbances, and a statistical model to correlate observed distribution with predictor covariates. Choice of technique or model is dependent on the type of occurrence data for the species of interest, sampling strategy, and the modelling question or application (Johnson et al. 2006).

There are a number of direct and indirect applications of species distribution models to cumulative impacts analyses and associated regulatory frameworks. This can include the identification of important habitat resources or features and the avoidance of infrastructure or other disturbance events. In particular, species distribution models are a useful technique for identifying zones of influence around human developments. These zones represent the area where wildlife respond negatively to a proposed or existing development. An observed impact might correspond with an avoidance response, where animals shift their distribution away from a development, altered behavior in the vicinity of a facility, or changes in the types or quality of habitat used by animals (Johnson and St-Laurent 2010). As examples, woodland caribou (*Rangifer tarandus caribou*) in Quebec avoided a zone of 1250 m around paved roads (Leblond et al. 2011). Nelleman et al. (2001) reported a zone of avoidance of 2.5 – 5.0 km for reindeer (*R. t. tarandus*) responding to powerlines, resorts, and roads. Working within the confines of environmental assessment studies and regulation, the zone of influence can determine the total area of effect, serve as a metric for regional measures of cumulative effects, or help guide monitoring and mitigation strategies.

Although an intuitive concept, the zone of influence and measures of significance are difficult to quantify (Quinonez-Pinon et al. 2007). Recent research has focused on

developing techniques that indicate statistically meaningful responses of animals to human activities or facilities that can then be translated to zones of influence used for regulatory decisions or mitigation (Bennett et al. 2009, Boulanger et al. In Press). When empirical data are absent or there is less scientific rigour in the review process, expert opinion is used to estimate probable zones (e.g., AXYS and Penner 1998). Often, the processes to collect such ecological data are flawed (Johnson and Gillingham 2004), making a strong case for the application of formal and repeatable species distribution models for such purposes.

In this study, we used a type of species distribution model, a resource selection function (RSF), to quantify the influence of roads and other human disturbances on the distribution of caribou from the Porcupine herd during winter (*R. t. granti*). The resulting RSF allowed us to identify the strength of selection by caribou for particular vegetation communities and avoidance of portions of the winter range that were adjacent to human developments (Johnson et al. 2005). We used those responses to identify a zone of influence around settlements, major roads and other less used features such as wells, trails, and seismic lines. Also, the RSF allowed us to determine if those developments had a continuous influence on caribou distribution over time (1985-1998 and 1999-2012).

Methods and Data

Resource Selection Functions are generated using a collection of animal locations that are contrasted with a set of locations that represent the availability of habitats or random distances to some feature, such as a road. Variation in the distribution of caribou locations, relative to random locations, results in statistically derived (weighting) coefficients. A positive coefficient suggests that the animal or population is selecting a particular categorical resource, such as a landcover type. Likewise, a positive coefficient for a measured distance from a human feature suggests that an animal is more likely to be found in a habitat as the distance from that feature increases (Figure 1).

Location Data for Caribou

When developing the RSFs, we applied nearly 27 years of location data collected by satellite collars deployed on 97 caribou. Typically, collars were scheduled to record 1 location every 7 days, although some duty cycles resulted in locations as frequent as 1 per day. We restricted our analyses to the winter season (December 1 – March 31; Russell et al. 1993). In total, we used 3520 caribou locations to develop resource selection functions for Porcupine caribou during winter.

For each caribou location, we generated 5 paired random locations that quantified resource availability. Those locations were selected from within a circle that represented the potential movement distance of caribou. That circle was centered on the preceding caribou location and the radius was calculated from the 95th percentile movement distance for observed caribou (Johnson et al. 2005).

Habitat Data

As a necessary component of developing species distribution models that reflected the disturbance responses of caribou, we needed to understand and statistically ‘control’ for

variation in vegetation across the winter range. The study area was best described by the Northern Land Cover of Canada (Olthof et al. 2008). We used the “Class 2” summary classification developed for the seasonal ranges of the Porcupine caribou herd (Francis 2010). We aggregated the original 20-class legend into a simpler grouping of 15 landcover types. The majority of caribou locations (~67%) had a predicted error of 1000 m. Thus, we generated an error polygon with a radius of 1 km around each caribou and random location. We queried the percentage landcover type within the error polygon.

Human Disturbance Data

We identified a number of types of human disturbance features that are known to influence the distribution of caribou. Drawing from the methods of Johnson et al. (2005), the distance of each caribou and random location was calculated from existing human settlements, all-season roads, winter roads, trails, seismic lines, and well sites (Francis 2010; Figure 2). Not all disturbance features were active or experienced a constant level of human use through the 27 years of caribou locations. However, we had no supplementary data to record the age of features such as seismic lines or the activity and traffic on roads. Recognising that the activity near winter roads, trails, seismic lines, and wells had varied over time, we combined those features into one category with assumed low human use. Caribou distribution near roads may be influenced by snow depth. Thus, we fit an interaction term that represented distance to roads during deep snow years (>0.5 m). We generated a variable that consolidated all linear features as the density of main roads, winter roads, trails, and seismic lines within 1-km² cells across the winter range. We hypothesized that the avoidance response of caribou to human disturbance would decrease as distance from the disturbance feature increased. Thus, we fit a nonlinear quadratic (i.e., Gaussian) term for each disturbance variable (Table 1). The density of linear features was represented as the mean within the error radius of each location.

Resource Selection Function Models

We identified combinations of resource and disturbance variables that served as hypotheses to explain patterns in the distribution of Porcupine caribou. We used conditional (paired) logistic regression to generate the coefficients for each candidate RSF. Given the low density of human features across the winter range, we assumed that at some distance animal behavior and habitat selection would no longer be influenced by human activities. Clustered samples with the same value for a covariate are uninformative for estimation of that particular coefficient (Hosmer and Lemeshow 2000). Thus, we held the distance values (i.e., disturbance covariates) constant for use and random locations where the disturbance feature occurred outside the respective 95th percentile availability radius. This allowed the cluster to represent habitat effects, but statistically remove disturbance effects for animal locations that were at extreme distances from human facilities.

We identified a number of ecologically plausible RSF models that would explain the distribution Porcupine caribou. We used Akaike’s information criterion (AIC_c), corrected for small sample sizes, to identify the ‘best’ model: the model with the greatest explanatory power that minimised bias and maximised precision of the model parameters (Anderson et al. 2001). We reported the Akaike difference (AIC_c Δ), calculated as the

AIC_c score of each model subtracted from the model with the lowest score, and the Akaike weight (w), representing the approximate probability that the highest ranked model was the best model of the set.

Information-theoretic approaches are useful for identifying the most parsimonious model, but provide no information on absolute model fit or the predictive accuracy of the best model. Thus, we used k -fold cross validation to evaluate predictive success of the best model (Boyce et al. 2002). The k -fold procedure was performed 5 times withholding 20% of the data during an iteration; we repeated that process 6 times. We used a Spearman-rank correlation (r_s) to assess the relationship between predicted occurrence for withheld animal locations and their frequency within 10 equally sized classes of predicted values (Boyce et al. 2002). A predictive model will have a strong mean correlation indicating a greater number of withheld locations in higher ranked classes representative of more strongly selected habitats. We used 95% confidence intervals to assess the strength of effect of each predictor covariate. Selection or avoidance cannot be inferred from covariates with confidence intervals that approach or overlap 0. We used tolerance scores to assess variables within each model for excessive collinearity.

Identifying the Zone of Influence

We followed the methods of Boulanger et al. (In Press) and used an iterative model fitting procedure to identify the zone of influence for the Main Road, Settlement, and Low Use Human Feature variables. The boundary of that zone represents the distance at which caribou no longer demonstrate an avoidance response of the respective human feature. We used the paired logistic regression to incrementally include clusters of caribou and random locations as the distance from a feature increased. The statistical model initially was fitted with location clusters that occurred to a maximum of 1000 m distance from the nearest feature; we included additional clusters at 500-m intervals and successively refitted the model (i.e., 1000 m, 1500 m, 2000 m, etc.). This analysis is premised on a decay function where animal response to disturbance decreases with distance from the development. Such ecological responses are well established by other studies reporting disturbance thresholds for a wide range of species (Johnson and St-Laurent 2010). As measures of animal response, we recorded the change in the log likelihood statistic, a measure of model fit, and the coefficients for the disturbance feature at each 500-m interval.

We interpreted the zone of influence as the distance at which the log likelihood reached an asymptote revealing that additional more distant caribou locations did not improve model fit. This asymptote can be inferred as the point at which caribou no longer demonstrate a disturbance response or the caribou locations are not consistently more distant from the feature relative to the paired random locations. Similarly, the coefficient measuring the strength of the avoidance response should decrease in magnitude as the distance from the feature increases. Avoidance by caribou, as indicated by the coefficient, is stronger near the feature and decreases to some asymptote at successively larger distances from the feature.

Given the long time series of locations, we hypothesized that caribou disturbance responses and the zone of influence would vary over time. This could be interpreted as a habituation to non-permanent features such as roads and well sites or a decrease in activity at those features. As with the zone of influence analysis, we used the paired logistic regression to statistically control avoidance responses at two time intervals. We statistically removed disturbance data for the caribou location data collected from 1985 to 1998 and then 1999 to 2012. We interpreted a zone of influence for each disturbance feature, as explained above, for each time period. In theory, we could have determined a zone of influence for each year, while controlling the responses of caribou at all other years. However, a relatively infrequent collar duty cycle and a low density of human features resulted in few caribou locations within the immediate vicinity (< 50 km) of the disturbance types recorded on the winter range (Figure 3).

Results

We used 3520 caribou and 17 600 random locations to fit 11 RSF models describing the distribution of Porcupine caribou during the winter season. The best model of resource selection included a covariate for the 15 landcover classes, and nonlinear (quadratic) disturbance variables for the Main Road, Settlement, and Low Use Human Feature variables (Table 2, $AIC_w = 0.726$). The data suggested that caribou avoided areas of the winter range with a relatively high density of linear features, but that effect was largely subsumed into the individual disturbance covariates when a more complex model was fitted. The best model had good predictive performance with an average r_s of 0.805 (95% confidence interval = 0.780 – 0.829, $n = 30$).

During the winter season, Porcupine caribou most strongly selected the Sparse Mixed Forest, Wet Graminoid Tundra, and the Alpine Tundra landcover classes. Caribou avoided the Mixed Forest and Barren classes (Figure 4). There were relatively few caribou locations within 10 km of settlements as most of these features were at the periphery of the winter range (Figure 2, 3). Roads, wells, trails and seismic lines were more common and occurred in the areas occupied by caribou during winter. Despite the few settlements and roads, caribou demonstrated a strong nonlinear avoidance response to these human features. Although the coefficient was smaller in magnitude, the RSF suggested that caribou also avoided Low Use Human Features. The nonlinear (Gaussian) terms indicated that the avoidance response of caribou decreased as the distance from the nearest human feature increased.

For caribou on the winter range, the zone of influence of human features varied by time period and disturbance type. The change in log likelihood score and RSF coefficient revealed that the zone of influence was larger during the 1985 to 1998 monitoring period for the three disturbance types. This suggested that disturbance decreased over time or caribou became habituated to the footprint or disturbance activities associated with each type.

For Settlements, we observed a disturbance response that ranged from 34.5 to 38 km (Figure 5). However, the lack of a distinct asymptote and a gently declining slope for the log likelihood statistic suggested some imprecision in defining the exact zone of

influence. The observed relationship may be the function of few caribou locations in the vicinity of settlements or a large-scale disturbance response, where during winter caribou shift their distribution away from human settlements. This pattern of distribution is illustrated by the location of human settlements around the edge of the core winter range (80% kernel home range; Figure 2). The large fluctuations in the coefficient values at distances close to the nearest settlement revealed the sensitivity of the RSF fitting process to relatively few caribou locations (i.e., clusters). As the distance from the nearest settlement increased beyond 5000 m enough location clusters were included to fit a coefficient for that covariate (Figure 3, 5).

Similar to the Settlement covariate, caribou demonstrated an avoidance response to Major Roads that occurred over relatively large spatial scales. The data suggested a zone of influence of 30 km during 1985 – 1998 followed by a reduced area of 18.5 km during 1999 – 2012. As with the response to human settlements, we did not observe a distinct asymptote where the disturbance response declined rapidly after some threshold distance to the nearest road was achieved. The zone of influence of Low Use Human Features was less than that observed for the Settlement and Major Road covariates. Also, we observed a distinct asymptote where caribou showed relatively little avoidance of wells, trails, winter roads, and seismic lines once they achieved a distance of 6 km during 1999 – 2012 and 11 km during 1985 – 1998 (Figure 5).

Discussion

The disturbance responses of *Rangifer* often scale to the intensity of the stimuli or the footprint of the human feature. For example, Seip et al. (2007) found that woodland caribou abandoned large portions of the winter range that were used frequently by loud and fast moving snowmobiles. Alternatively, Dyer et al. (2001) reported a zone of disturbance for woodland caribou in northern Alberta of 1000 m for oil and gas wells and 250 m for seismic lines (Dyer et al. 2001). Studying the Bathurst herd of barren-ground caribou (*R. t. groenlandicus*), Johnson et al. (2005) found a large area of avoidance near mines and communities that varied seasonally. Boulanger et al. (In Press) used the same set of caribou locations as applied by Johnson et al. (2005) to specifically identify the zone of influence around the Ekati and Diavik diamond mines. They reported a zone of influence of 14 and 11 km based on aerial survey and satellite collar data, respectively. Our findings were qualitatively consistent with those past works. The monitored animals of the Porcupine herd demonstrated a successively larger response distance and zone of influence in accordance with the level of disturbance assumed at each type of human feature.

Across the winter range of the Porcupine caribou herd, human settlements likely have the largest spatial footprint and the greatest magnitude of disturbance stimuli. This includes the normal business and activities of people found in northern communities as well as hunting that would occur at some distance from the immediate vicinity of the community. Consistent with the size of this disturbance area, we noted a large absolute and relative avoidance response by Porcupine caribou. However, there were few observations of caribou near settlements resulting in some uncertainty in the identification of the associated zone of influence. Few locations could be the result of avoidance by caribou

to those sites. Alternatively, the distribution of caribou during winter may not include human settlements that were clustered to the south and north of the observed range. We suspect that this is a real avoidance response as the technique we employed is robust to such sources of bias. We statistically controlled for habitat variation across the winter range and the matching of used and random locations permitted a measure of relative avoidance even where clusters of locations occurred at some distance from Settlements.

Relative to Settlements, we found a smaller zone of influence and a lesser avoidance response by caribou for Major Roads followed by human facilities that we assumed had a relatively low or inconsistent use over the period of monitoring. The Dempster Highway was the most influential Major Road. Although a single linear corridor, the Highway bisected the eastern portion of the winter range (Figure 2). The collar locations suggested that caribou spaced-away from this feature over a considerable distance.

Low Use Human Features had a relatively small footprint. Furthermore, the majority of seismic lines and wells were no longer active areas of human activity during the latter portion of caribou monitoring (Francis 2010); although there is likely a residual human footprint at most of those sites. Consistent with our definition of 'low use', caribou showed a lesser disturbance response and a relatively discrete, but smaller zone of influence around those features.

The time period of collar deployment and monitoring for the Porcupine caribou herd exceeds all other herds we are familiar with. Indeed, monitoring the distribution and movements of large mammals using satellite and later GPS collars has become common in the mid to late 1990s, a decade after caribou from the Porcupine herd were initially collared. This exceptional data set of animal locations allowed us to consider patterns of avoidance over time. Although sample size was not sufficient to compare more refined annual or even decadal time periods, we did note a relatively stronger response to sources of disturbance during the years 1985 – 1998. This temporal pattern was most apparent for the Low Use Human Features. Consistent with that result, oil and gas exploration and development was most active during the early period of monitoring. For this study, data limitations forced us to assume that all features had a similar and consistent influence on caribou distribution regardless of the history of activities at those sites. A more refined analysis would include spatial data that linked the activity history of each feature to the distribution of caribou during that period (Johnson et al. 2005).

The identification of a zone of influence is important for land use planning, regulatory assessment, and mitigation (Quinonez-Pinon et al. 2007). Unfortunately, there is no clearly accepted technique for identifying the area around human activities that correlates with altered animal distribution or behaviour (Ficetola and Denoel 2009). The technique developed by Boulanger et al. (In Press) is statistically robust and logical. Where the distribution of caribou and associated random locations fails to show a pattern of differential distances (i.e., avoidance) the log likelihood statistic should asymptote and then decrease. The decrease in the statistic is the result of populating the function with data that have no directional pattern, but instead represent a random distribution of both used and available locations relative to the nearest disturbance feature. Although we are

confident in the technique, we did model zones of influence that exceeded avoidance responses reported in the literature. For example, working in northern British Columbia, Polfus et al. (2011) reported that during winter woodland caribou avoided high-use roads by 2 km, low-use roads by 1 km, and towns by 9 km. Such differences may be a function of the greater sensitivity of the technique we used or the particular ecology of the Porcupine caribou during winter. Also, we interpreted the asymptote of the log likelihood statistic as the extent of the zone of influence (Figures 6, 7, 8). The data suggested that the rate of decrease in model fit was not constant with perhaps some lesser distance representing an ecologically significant zone of influence. This consideration is especially germane when considering the modeled responses to Settlements and Major Roads.

Further Research and Monitoring

Quantifying the disturbance responses of caribou and the resulting zones of influence around human developments is complicated by the knowledge source (i.e., TK or science-based), sampling protocol for data collection, statistical technique, and scale of inference. Indeed, even well studied populations of caribou provide no simple answers to how much disturbance is acceptable or how animal responses to human disturbance can be measured in the context of natural variation in behaviour and population processes. After 40 years of impacts research for barren-ground caribou calving near the Prudhoe Bay oil facility, there is still much debate about the significance of observed disturbance responses (Joly et al. 2006, Noel et al. 2004, 2006).

We suggest a cautious interpretation of the results presented here. Change in the size of the herd over the past 27 years, variation in animal behaviour across the range of development types and associated activity at those sites over time, and a relatively small effect-size for caribou-disturbance responses all hint at a high-level of uncertainty when trying to determine a precise statistical finding. This is illustrated well by the avoidance response of caribou and the associated zone of influence around Settlements. That result is premised on relatively few caribou locations and a small proportion of the herd in the vicinity (< 5000 m) of those features during any one year. Other populations of caribou found across southern Canada are facing massive change in habitats and predator-prey relationships where the effects are much more easily documented (Festa-Bianchet et al. 2011). Further broad-scale monitoring using high-frequency GPS collars is warranted. Also, there are opportunities to combine the knowledge of people on the land with science-based collaring initiatives to better understand the distribution of Porcupine caribou (Gunn et al. 2011).

Despite some uncertainty in these findings, the results suggest that Porcupine caribou are demonstrating a disturbance response to human activities. Existing knowledge and data provide an opportunity to forecast and manage for future developments and importantly the cumulative impacts of disturbance across the seasonal ranges of the herd. Understanding changes in the distribution of caribou is an essential first step in documenting such impacts. However, the significance of those changes in distribution for population growth and ultimately the number of caribou will require more

mechanistic links to the productivity of individual female caribou (Johnson and St-Laurent 2010).

In addition to defining a zone of influence, species distribution models are easily adapted and applied to other resource management and conservation decision making tools and processes. These multi-model approaches often integrate maps, illustrating the location and amount of selected habitats, with predictive movement models, population viability analyses or habitat supply models. Johnson et al. (2005), for example, used maps of the distribution of high-quality habitats for a number of arctic species, including caribou, to quantify the impacts of possible development scenarios on the distribution and availability of habitats and population numbers (Johnson and Boyce 2004). Similarly, Carroll et al. (2003) linked species distribution and spatially explicit population models to understand the relative value of a range of reintroduction strategies for wolves under current and predicted future landscape conditions. In the case of the Porcupine herd, predictions of the distribution of caribou generated from a RSF can be linked to the foraging behaviour and activity of individual animals. Indeed, an existing energetics/population model was parameterised for the Porcupine herd (Russell et al. 2005). In combination, these methods can provide insights on the distribution and number of caribou that might be found across a landscape facing current and future development pressures at a range of spatial scales.

Acknowledgements

We thank the Porcupine Caribou Co-Management Board for funding this work. Shawn Francis kindly reviewed the report and assisted with the interpretation of the GIS data.

References

- Anderson, D.R., K.P. Burnham, and W.L. Thompson. 2001. Null hypothesis testing: problems, prevalence, and an alternative. *Journal of Wildlife Management* 64:912-923.
- AXYS Environmental Consulting and Penner and Associates. 1998. Environmental effects report: wildlife. Prepared for Diavik Diamonds Project, Yellowknife, Northwest Territories.
- Bennett, V. J., M. Beard, P. A. Zollner, E. Fernandez-Juricic, L. Westphal, and C. L. LeBlanc. 2009. Understanding wildlife responses to human disturbance through simulation modeling: A management tool. *Ecological Complexity* 6:113-134.
- Boulanger, J. K.G. Poole, A. Gunn, and J. Wierzchowski. Estimating the zone of influence of industrial developments on wildlife: A migratory caribou and diamond mine case study. Accepted for *Wildlife Biology*, In Press.
- Boyce, M.S., Vernier, P.R., Nielsen, S.E., and Schmiegelow, F.K.A. 2002. Evaluating resource selection functions. *Ecological Modelling* 157:281–300.
- Bradshaw, C.J.A., S. Boutin, and D.M. Hebert. 1998. Energetic implications of disturbance caused by petroleum exploration to woodland caribou. *Canadian Journal of Zoology* 76:1319-1324.

- Carroll, C, R. Noss, P.C. Paquet, and N.H. Schumaker. 2003. Use of population viability analysis and reserve selection algorithms in regional conservation plans. *Ecological Applications* 13:1773-1789.
- Dyer, S.J., J.P. O'Neill, S.M. Wasel, and S. Boutin. 2001. Avoidance of industrial development by woodland caribou. *Journal of Wildlife Management* 65: 531–542.
- Ficetola, G. F and M. Denoel. 2009. Ecological thresholds: an assessment of methods to identify abrupt changes in species-habitat relationships. *Ecography* 32:1075-1084.
- Festa-Bianchet, M., J.R. Ray, S. Boutin, S.D. Côté, and A. Gunn. 2011. Conservation of caribou in Canada: an uncertain future. *Canadian Journal of Zoology*, 89:419-434.
- Francis, S. 2010. Porcupine caribou habitat and disturbance mapping. Prepared for Porcupine Caribou Management Board.
- Frid, A., and L. Dill. 2002. Human-caused disturbance stimuli as a form of predation risk. *Conservation Ecology* 6:11.
- Guisan, A., and W. Thuiller. 2005. Predicting species distribution: offering more than simple habitat models. *Ecology Letters* 8:993-1009.
- Gunn, A., Johnson, C.J., Nishi, J., Daniel, C.J., Russell, D.E., Carlson, M., and Adamczewski, J.Z. 2011. Addressing cumulative effects in the Canadian Central Arctic – Understanding the impacts of human activities on barren-ground caribou. P. Krausman, and L. Harris, editors. *Cumulative Effects in Wildlife Management: Impact Mitigation*. CRC Press.
- Hosmer, D.W., and S. Lemeshow. 2000: *Applied Logistic Regression Analysis*. Second Edition. Wiley and Sons, New York.
- Johnson, C. J., and M. S. Boyce. 2004. A quantitative approach for regional environmental assessment: application of a habitat-based population viability analysis to wildlife of the Canadian central Arctic. *Canadian Environmental Assessment Agency Research and Development Monograph Series*.
- Johnson, C.J., M.S. Boyce, R.L. Case, H.D. Cluff, R.J. Gau, A. Gunn, and R. Mulders. 2005. Quantifying the cumulative effects of human developments: a regional environmental assessment for sensitive Arctic wildlife. *Wildlife Monograph* 160.
- Johnson, C. J., and M. P. Gillingham. 2004. Mapping uncertainty: sensitivity of wildlife habitat ratings to variation in expert opinion. *Journal of Applied Ecology* 41:1032-1041.
- Johnson, C.J. and M.P. Gillingham. 2005. An evaluation of mapped species distribution models used for conservation planning. *Environmental Conservation* 32:1-12.
- Johnson, C.J., S.E. Nielsen, E.H. Merrill, T.L. McDonald, and M.S. Boyce. 2006. Resource selection functions based on use-availability data: theoretical motivations and evaluation methods. *Journal of Wildlife Management* 70:347-357.
- Johnson, C. J., and M-H. St-Laurent. 2010. A unifying framework for understanding the impacts of human developments for wildlife. D. Naugle, editor. *Energy Development and Wildlife Conservation in Western North America*. Island Press, Washington, D.C., USA.
- Joly, K., C. Nellemann, and I. Vistnes. 2006. A reevaluation of caribou distribution near an oilfield road on Alaska's North Slope. *Wildlife Society Bulletin* 34 866-869.

- Leblond, M., J. Frair, D. Fortin, C. Dussault, J.-P. Ouellet, and R. Courtois. 2011. Assessing the influence of resource covariates at multiple spatial scales: an application to forest-dwelling caribou faced with intensive human activity. *Landscape Ecology* 26:1433–1446.
- Nellemann, C., I. Vistnes, P. Jordhøy, and O. Strand. 2001. Winter distribution of wild reindeer in relation to power lines, roads and resorts. *Biological Conservation* 101:351-360.
- Noel, L.E., K.R. Parker, and M.A. Cronin. 2004. Caribou distribution near an oilfield road on Alaska's North Slope, 1978-2001. *Wildlife Society Bulletin* 32:757-771.
- Noel, L.E., K.R. Parker, and M.A. Cronin. 2006. Response to Joly et al. (2006), A reevaluation of caribou distribution near an oilfield road on Alaska's North Slope. *Wildlife Society Bulletin* 34:870-873.
- Olthof, I., R. Latifovic, D., and Pouliot. 2008. Circa-2000 Northern Land Cover of Canada. Earth Sciences Sector, Canada Centre for Remote Sensing, Natural Resources Canada.
- Polfus, J.L., M. Hebblewhite, and K. Heinemeyer. 2011. Identifying indirect habitat loss and avoidance of human infrastructure by northern mountain woodland caribou. *Biological Conservation* 144:2637-2646.
- Quinonez-Pinon, R., A. Menoza-Duran, and C. Valeo. 2007. Design of an environmental monitoring program using NDVI and cumulative effects assessment. *International Journal of Remote Sensing* 28:1643-1664.
- Russell, D., R.G. White, and C.J. Daniel. 2005. Energetics of the Porcupine Caribou Herd: a computer simulation model. Technical Report Series No. 431. Canadian Wildlife Service. Ottawa.
- Seip, D.R., C.J. Johnson, and G.S. Watts. 2007. Displacement of mountain caribou from winter habitat by snowmobiles. *Journal of Wildlife Management* 71:1539-1534.

Table 1: Description of variables used to construct RSF models quantifying the resource selection and distribution of Porcupine caribou during winter (Francis 2010).

| Variable Name | Description |
|----------------------------|---|
| Landcover | Percent landcover for 15 vegetation classes within a 1000-m error radius surrounding satellite collar locations. |
| Major Road | All season roads; relative to other linear features and roads Major Roads had the greatest volume of traffic and largest assumed impact on caribou distribution; included Dempster Highway (Yukon) and Dalton Highway (Alaska). |
| Settlement | Community footprints including associated air strips and surrounding infrastructure (e.g., waste disposal facilities). |
| Winter Road | Periodically used winter roads; these features may include trails and may occur on frozen water bodies; this disturbance feature was represented as Low Use Human Feature. |
| Trail | Trails used for transportation; assumed to have higher levels of use and greater longevity compared to seismic lines; this disturbance feature was represented as Low Use Human Feature. |
| Seismic Line | Seismic lines of various widths used for geophysical exploration of oil and gas deposits; lines are of unknown age and regrowth; this disturbance feature was represented as Low Use Human Feature. |
| Well | Oil and gas well sites and pads; all sites in the Yukon and Northwest Territories portion of the range are abandoned and in various stages of regrowth; this disturbance feature was represented as Low Use Human Feature. |
| Density of Linear Features | Density of all linear features (trails, seismic, winter road, pipeline, major road) across the study area within a 1-km ² window. |

Table 2: Results of information theoretic model selection procedure to select the most parsimonious resource selection function for Porcupine caribou during the winter season.

| <i>Model Covariates</i> | <i>Model Selection Metric</i> | | | |
|--|-------------------------------|------------------------|---------------------|----------|
| | <i>K</i> | <i>AIC_C</i> | Δ <i>AIC</i> | <i>w</i> |
| Landcover | 15 | 12234.2 | 606.7 | <0.001 |
| Landcover + Main Road ² | 17 | 12049.3 | 421.8 | <0.001 |
| Landcover + Main Road ² + Road ² XSnow ² | 19 | 11998.2 | 370.7 | <0.001 |
| Landcover + Density Linear Feature | 16 | 12234.3 | 606.8 | <0.001 |
| Landcover + Density Linear Feature ² | 17 | 12233.5 | 606.0 | <0.001 |
| Landcover + Main Road ² /Settlement ² | 17 | 11795.3 | 167.8 | <0.001 |
| Landcover + Main Road ² /Settlement ² + Density Linear | 18 | 11795.8 | 168.3 | <0.001 |
| Landcover + Low Use Human Feature | 17 | 12054.2 | 426.7 | <0.001 |
| Landcover + Low Use + Settlement ² + Main Road ² + Density Linear | 22 | 11666.6 | 39.2 | <0.001 |
| Landcover + Low Use + Settlement ² + Main Road ² + Road ² XSnow ² | 23 | 11627.5 | 0.0 | 0.726 |
| Landcover + Low Use + Settlement ² + Main Road ² + Road ² XSnow ² + Density Linear | 24 | 11629.4 | 2.0 | 0.274 |

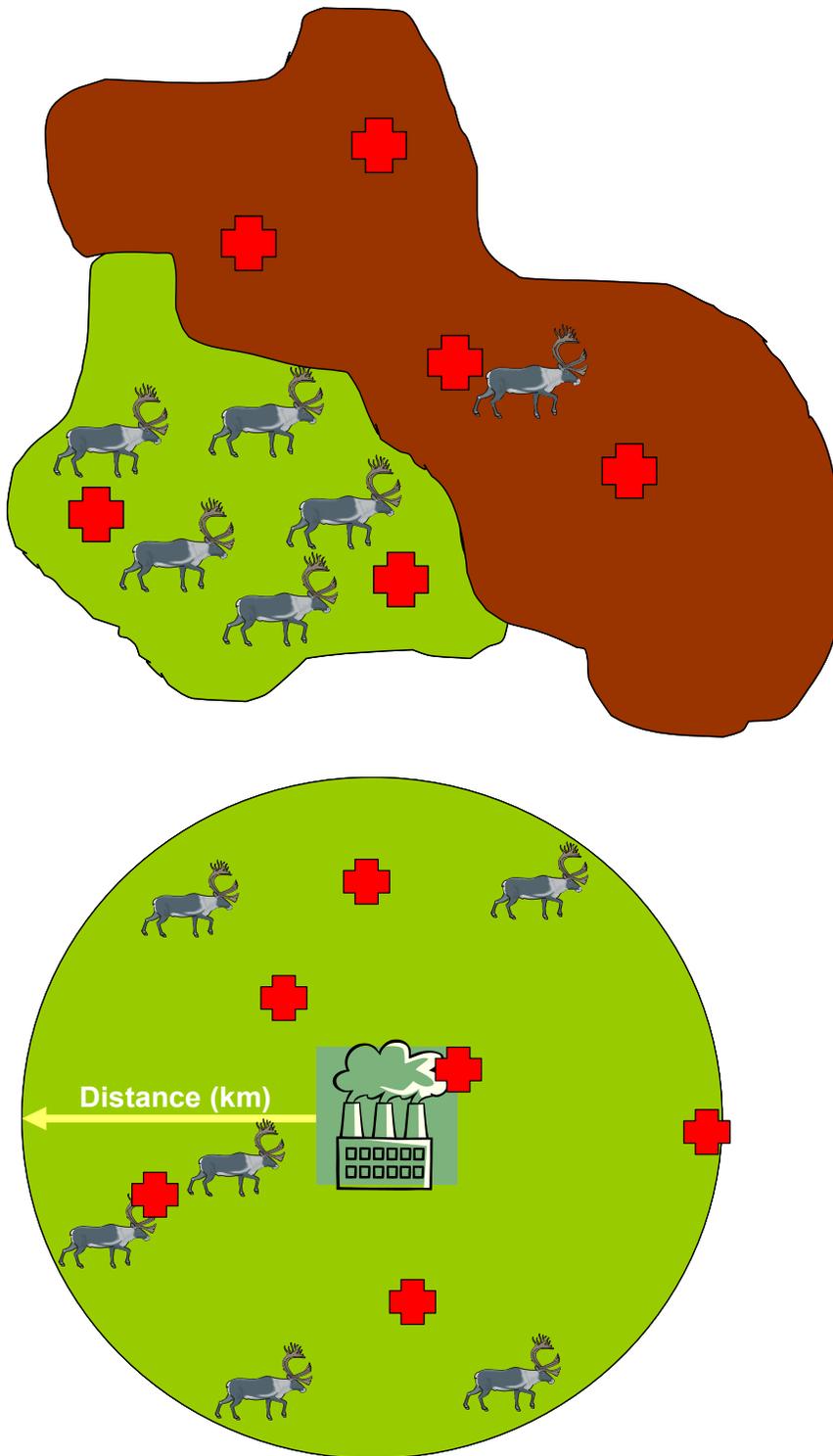


Figure 1: Distribution of caribou quantified using a hypothetical Resource Selection Function. In the top panel, a greater proportion of caribou locations in the green habitat would reveal habitat selection and a positive weighting coefficient. In the bottom panel, caribou are distributed farther from the factory relative to the random locations (red cross) suggesting avoidance of that feature.