Draft guidance for monitoring the zone of influence (ZOI) of anthropogenic disturbance on barren-ground caribou

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Presented at:
Slave Geological Province Regional
Wildlife Monitoring Workshop

Date:
March 10, 2015

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1. Introduction

Communities are concerned about the impact of human disturbance on barren-ground caribou. As such, monitoring the distribution and abundance of caribou in the vicinity of mines and associated roads is commonly included as a requirement for development projects in the NWT. Both academic studies and industry monitoring programs on the central barrens of the NWT have identified areas of lower caribou abundance within a certain distance of established diamond mines than would be expected given available habitat. This effect is termed the "Zone of Influence" or ZOI. Predictions on the size of this area can help to quantify the costs to caribou of avoiding these areas or, if they occur within them, to characterize disturbance impacts.

In the NWT, the three major operating diamond mines (Ekati, Diavik, Snap Lake) have in the past used aerial surveys as the primary means to monitor the distribution and abundance of barren-ground caribou around their operations. Data collected during these surveys have been reported upon and analysed in a number of comprehensive reports produced by the mines (Golder Associates Ltd. 2005; Golder Associates Ltd. 2008a; Golder Associates 2008b; Golder and Associates Ltd. 2011). Using aerial survey data Boulanger et al. (2012) estimated the ZOI around the Ekati and Diavik mines at around 14 km. The same study using GNWT collar data found a weaker ZOI of 11 km, although previous analyses (e.g. Johnson et al. 2005) of collar data suggested it might be as much as 30 km or more. A ZOI has also been demonstrated for roads in barren-ground caribou range, with avoidance of up to 4-6 km (reviewed by Wolfe et al. 2000). As with mines, the degree of avoidance depends on the size of the road and traffic levels; larger roads with higher traffic volumes are avoided more than simple roads with little traffic. These studies suggest that the ZOI is likely to be dynamic, depending on the size, location and nature of the development (e.g. open pit versus underground; mines versus roads; etc.), the level of industrial activity or volume of traffic, and herd characteristics (population status, demographic makeup, etc.).

While the existence of a ZOI has been generally accepted, questions remain as to its significance for a herd's demographics, causative mechanisms, and the extent to which it can be mitigated. Addressing such questions is critical to our understanding of the effects of anthropogenic disturbance impacts on caribou and our ability to minimize them at both a local project scale and a cumulative effects scale. Moving forward on some of these key questions requires that we can accurately measure ZOI and produce high quality data that will be valid and useful to support further investigations. This document aims to provide some guidance regarding approaches to monitoring ZOI that will maximize the quality of monitoring data, when such monitoring is appropriate.

A secondary aim for this document is to provide some guidance on when ZOI monitoring is operationally and technically appropriate. The need for such guidance emerged during wildlife monitoring workshops hosted by GNWT- ENR between 2009 and 2013 and over the course of annual stakeholder reviews of wildlife monitoring programs conducted by the mines. Workshops held in 2009 and 2010 (Marshall, R. 2009, Handley, J. 2010) reviewed monitoring programs conducted by the diamond mines on the central barrens. Questions were raised regarding the utility and efficiency of carrying out expensive aerial survey programs as a matter of routine, particularly when a ZOI had already been established. Rather, participants felt that in such cases resources were better allocated to programs that monitor large mammals such as caribou, grizzly bears and wolverine at a scale more appropriate to these species. However, further study of ZOI around mines might be appropriate if it fell within agreed-upon guidelines and for well-defined purposes. For example, if herd status changes, if mine activity levels change substantially or if enhanced mitigation is applied that may decrease the extent and magnitude of the ZOI, recalibration of the ZOI may be warranted. Further, the Ekati-Diavik ZOI determination (Boulanger et al. 2012) involves a single example under specific circumstances (summer range of the declining Bathurst herd), and additional cases of ZOI determination would strengthen the parameter. The workshops held in March and November 2013 focused on regional monitoring for cumulative effects. Again, participants expressed an interest in having operators contribute to regional monitoring or other research programs that improve our understanding of cumulative effects on wildlife. With fewer caribou being observed around the mines and growing concerns regarding cumulative effects at the scale of the annual herd ranges, aerial survey programs conducted by the diamond mines have been suspended in recent years, with mines seeking guidance regarding alternatives to ZOI monitoring and several stakeholders seeking clarity as to under what conditions ZOI monitoring might be expected to resume.

At the November 2013 Slave Geological Province Regional Wildlife Monitoring Workshop hosted by ENR, it was agreed that a group of technical experts would convene to develop guidance around when ZOI monitoring is appropriate and how best to monitor it. A ZOI Technical Task Group (TTG) was struck and met three times between June 2014 and February 2015. The ZOI TTG membership included:

Core Members:

- John Boulanger - Integrated Ecological Research
- Kim Poole – Independent Environmental Monitoring Agency
- Daniel Coulton – Golder & Associates
- Harry O'Keefe – Dominion Diamonds Ekati Corporation
- Mark Wiseman – Avalon Rare Metals
- Sarah McLean – DeBeers Canada
- Karin Clark – ENR-Wildlife
- Jan Adamczewski - ENR-Wildlife
- Andrea Patenaude – ENR-Wildlife

Supporting/Alternate members:

- John Virgl – Golder & Associates
- Damian Panayi - Golder & Associates
- Greg Sharam – ERM Rescan
- Brian Milakovic – ERM Rescan

This draft document is a product of that group's work up until March 2015. Further analyses will be conducted to refine recommendations on samples sizes, after which a final document will be produced and distributed.

2. Why monitor ZOI?

Measuring the size of the area where caribou abundance is less than would be expected based on habitat alone using well-developed, standardized study designs can be of value for several purposes, including:

- Quantifying impacts to caribou
- Verifying impact predictions made during an environmental assessment process,
- Evaluating mitigation effectiveness,
- Supporting investigations into causative mechanisms of ZOI,
- Providing a metric to compare across projects and scale up to a landscape level in support of cumulative effects assessment, and
- Providing a tool for application of adaptive management at a project and range scales.

3. Objective

The purpose of this guidance document is to:

- Foster a greater understanding among participants in the regulatory process in the NWT as to when ZOI monitoring for barren-ground caribou is appropriate and how it can be used.
- Provide guidance to operators on best practices regarding key design and technical considerations for common methods of ZOI monitoring of mines and/or roads.
- Provide preliminary guidance on alternative methods than can be used to monitor ZOI.
- Provide guidance on alternative activities that can be undertaken instead of ZOI monitoring in cases where it is deemed not appropriate.

4. Who should monitor ZOI on barren-ground caribou?

1. Operators of projects that overlap the range of one or more barren-ground caribou herds in one or more seasons and can reasonably expect caribou to occur near their operation during the life of the project based on traditional or local community knowledge and/or historical collaring datasets.

   -AND-

2. If so, operators for which a Wildlife Effects Monitoring Program is required in accordance with regulations under the Wildlife Act Section 95 once they have been developed, and Section 3 of the Wildlife and Wildlife Habitat Protection Plan and Wildlife Effects Monitoring Program Guidelines, in the interim.

   -OR-

3. Operators that have committed to such monitoring or been assigned such monitoring in measures or conditions delivered via regulatory process.

5. When is monitoring ZOI technically appropriate?

While certain operators may have requirements related to determining a ZOI estimate for their operation and/or monitoring ZOI over the life of their operation, it may not be necessary or appropriate for all developments and in all years, for a variety of reasons. Monitoring ZOI for barren-ground caribou is appropriate when:

1. Caribou are present in the ZOI study area during non-migratory periods when avoidance behaviour would be expected to more readily occur (i.e. may not be appropriate during spring migration if caribou are moving through an area quickly)
2. Monitoring can be conducted using a method that will have little to no impact during highly sensitive times in the life cycle (i.e. calving, post-calving, rutting).
3. It is determined using the recommended reconnaissance approach outlined in Section 7 that there is a sufficient number of caribou in the ZOI study area to generate statistically robust data, as outlined in Section 6.
4. Testing the effectiveness of a particular mitigation technique or suite of mitigations.
5. There is a method that can be applied with a reasonable level of certainty to generate a site-level ZOI.

6. Study design considerations for monitoring caribou ZOI

Monitoring frequency:

Projects for which ZOI monitoring is deemed appropriate are advised to produce an initial estimate of ZOI during the operations phase of their project. Repeat monitoring should be conducted when the project is expected to change due to a major shift in the project (e.g. mine phase change, expansion), a change in mitigation practices or other cause.

Sample size:

The main analytical approach to estimating of ZOI has been to use either aerial survey or radio collar data to derive a base habitat model (i.e. resource selection function, a.k.a RSF) that accounts for natural variation in caribou distribution and includes an additional predictor variable to assess distance from the development of interest (e.g. road, mine site, community etc.) as a way of characterizing avoidance. Recent advancements have been made in the methods available for estimating ZOI (Boulanger 2015, Appendix C), making ZOI calculations based on smaller sample sizes more computationally efficient and robust. As such, it is possible to estimate ZOI on a yearly basis if within-year sample sizes are adequate.

- ❖ The sample size requirements and analytical demands of such an approach are considerably less if analysts have access to pre-existing habitat models. Studies in areas without pre-existing habitat models may have a difficult time obtaining adequate sample sizes. There are current initiatives underway to develop commonly available RSF models that can be accessed by analysts for a number of applications including ZOI estimation; however, until such models are readily available, pre-existing models are listed in Appendix A. Some of these have been successfully used in the past to generate ZOI estimates. Analysts are encouraged to contact authors to make use of the best available habitat information at the time of their analysis.
- ❖ With substantial survey effort, a ZOI of magnitude similar to that of the Ekati-Diavik study area can be detected within a single year of surveys. Analysis of the 2008 data from the Ekati- Diavik study area suggest that at least 6 surveys (7,865 km of transect with caribou present in 140 or 1.75% of the 1 km cells) were needed to estimate the parameters of the underlying habitat model and the ZOI terms for a single year. After this sample size is achieved the main effect of increasing sample size is an improvement of precision of the ZOI estimates (Appendix A).

Considerations for aerial survey study design:

- ❖ The sampling unit is 1 km cells along the survey transect in which caribou are either present or not detected.
- ❖ The general design for aerial surveys should be based upon aerial transects centred on the development project, with graduated spacing (Figure 1) between transects as they extend out from the development. This design is recommended to increase the survey effort closer to the development, which can help offset lower sample sizes of cells closer to development within a potential ZOI.
- ❖ A study area for ZOI monitoring should be large enough to include sufficient areas beyond the expected ZOI where the probability of effects is low or nil. For barren-ground caribou, a recommended study area should extend approximately 35 km beyond the footprint of a development area.
- ❖ Sample sizes can be increased by pooling data from repeated surveys within and among years.
- ❖ Consistency and repeatability in aerial surveys can be promoted by having fewer persons participating in the survey.
- ❖ Protocols should record distance and direction to caribou groups.
- ❖ Preference is for aerial surveys to be conducted by small fixed-wing aircraft to minimize disturbance to caribou.

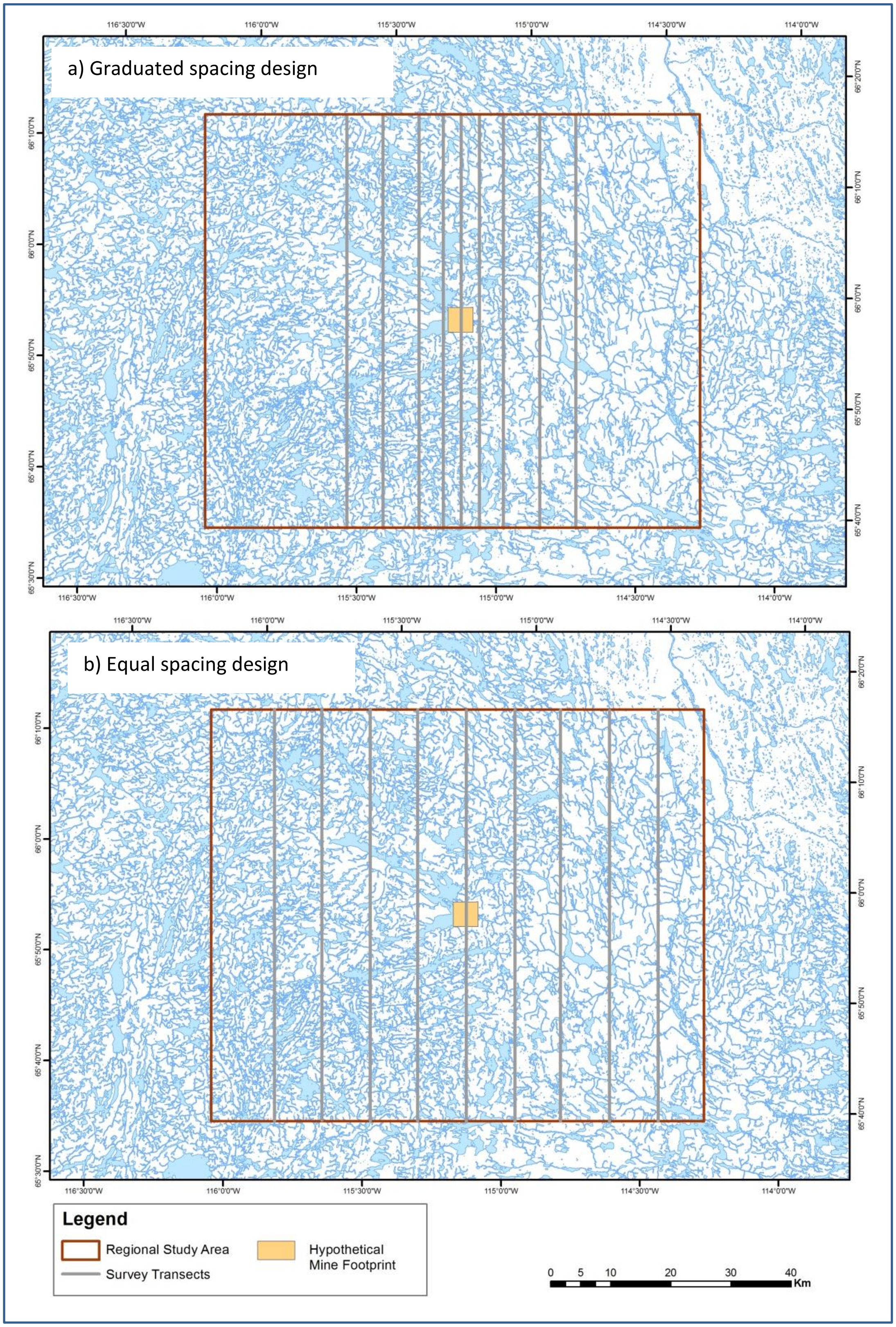

Figure 1: Example of aerial survey design with (a) graduated transect spacing and (b) equal transect spacing

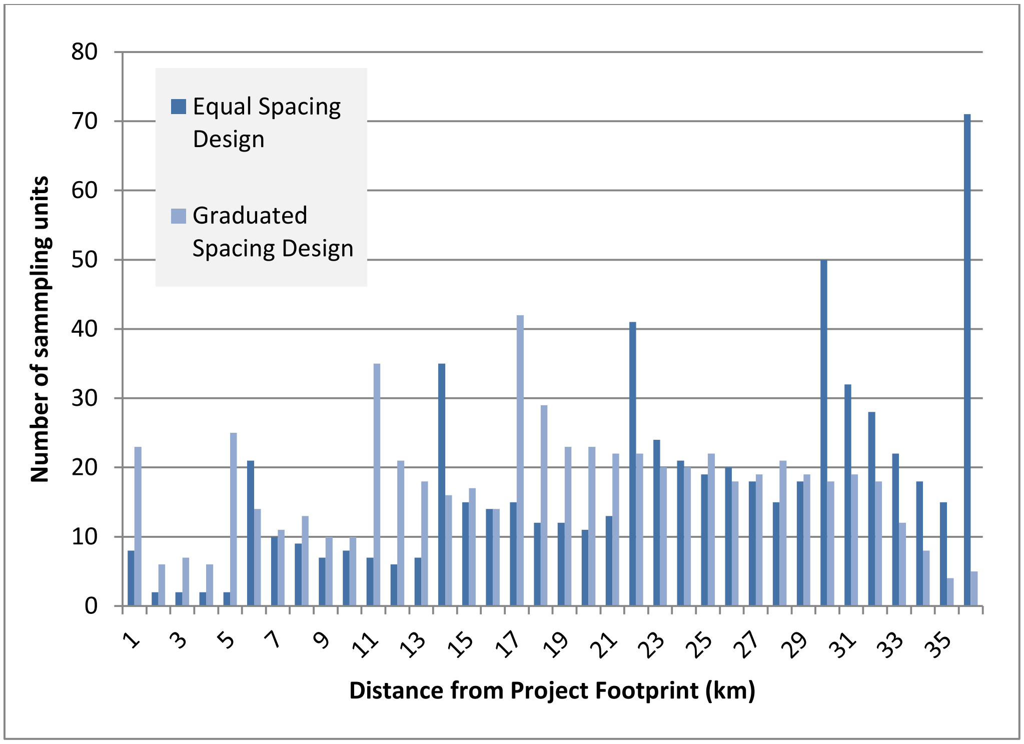

Figure 2: Comparison of frequency distributions of aerial survey sampling units for designs with equal and graduated transect spacing.

Considerations if using collar data

The effectiveness of using collar data to estimate ZOI depends in large part on the number of collared animals in a herd and the number of animals that approach the area around a project. On herds for which few collars are typically deployed, such as the Bathurst herd, ZOI estimates derived from collar data tend to be less precise than for aerial surveys. For example, Boulanger et al (2012) found that ZOI estimates from collars were less precise than aerial surveys given the low sample sizes of collars and resulting sparse distribution of collars relative to mine areas. However, data generated by collars may allow for analysis at various and larger scales of selection.

- For collar-based analysis, the sampling unit is the individual collared caribou rather than the number of locations used in the analysis. It is likely that locations from individual caribou will be spatially autocorrelated and using analysis methods that model individuals minimizes this issue.
- A recommended approach to assessing the sample of collared individuals would be to determine the 95th percentile of distances daily moved in a given year, buffering the caribou point with this distance and determining how many caribou encounter the mine at least once per year or season.
- The same general sample size guidelines will apply to collar-based analyses as aerial surveys. Therefore, on herds with few collars and/or few collared animals approaching the site, the only viable method to model habitat selection is to pool data among years.

- In general, the greater the number of collars on a herd, the greater the ability to detect a ZOI; however, it is difficult to predict sample sizes as collared caribou will not necessarily be within range of a development to allow modelling of ZOI. Therefore, the actual sample size of collared caribou for ZOI analysis will likely be lower than the number of collared caribou on a particular seasonal range.
- For many herds, collar data is often only available for adult cows and therefore there is no inference into sex-specific, age-specific or whole-population ZOI.
- Advances in collar technology can allow for geofencing functions in which the number of locations captured can be programmed to increase as collared animals approach within 35 km of a development or 20 km of a linear feature.

Considerations for monitoring ZOI of linear features

The need to consider the ZOI of a linear feature extending from a point feature (eg. a mine) arises when the linear feature extends well beyond the overall maximum recommended ZOI study area of the development itself (>35km).The principle for monitoring ZOI of linear features such as roads, pipelines or transmission lines is similar as for developments with a point source configuration in that equal sampling effort should be allocated throughout the distance range of the predicted ZOI with similar sample size considerations. The recommended study area should extend 20km beyond the either side of the linear feature.

Related monitoring

Comprehensive and consistent long-term monitoring of potential measurable driving factors of ZOI and continual efforts to minimize these factors should be undertaken over the course of the project. These factors include dust, noise and activity level indicators (e.g. number of aircraft flights, traffic levels, number of people in camp etc.).

7. Recommended reconnaissance procedures for determining when to initiate aerial survey program

In order to determine whether there are enough caribou in the vicinity to launch an aerial survey program, an adaptive reconnaissance survey design that covers a representative sample of the survey area should be employed. An initial survey of 100- 200 km of transect can be flown at a wider reconnaissance level transect spacing. There are a variety of tablet computers with GPS interfaces that would allow on-the-fly calculation of the proportion of cells with caribou. Therefore this calculation could be done without having to land the plane. The proportion of cells could then be used to estimate the number of cells expected to have caribou. If this proportion was equal to or higher than the target proportion in survey planning, then the full survey would be flown. For example, for the Ekati/Diavik sampling design it took 7,865 kilometers of transect flying across 6 surveys to achieve the sample size requirement outlined in Section 6 (140 occupied cells). As a starting point in evaluation of survey design, the number of surveys required to meet this sample size could be estimated as 7,865 divided by the kilometers flown per survey. This general statistic could then be used to determine the feasibility of estimating ZOI of similar magnitude to Ekati and Diavik. From this exercise, a target proportion of cells with caribou needed per survey could be set and used as a basis for this adaptive survey design.

This approach would ensure that mines meet monitoring requirements without having to fly long surveys in which no caribou are detected,and thus there is no contribution to ZOI determination. Presence of collared caribou in the vicinity of the mine area, combined with local observations such as from pilots approaching site, could be a trigger for aerial reconnaissance surveys in some cases.

8. Alternative methods

Alternative means of estimating the caribou ZOI to augment or replace aerial surveys have been discussed. Proposed alternatives often include remote cameras, unmanned aerial vehicles (UAV) and satellite imagery to monitor caribou in the regional study area. Factors to consider in choosing a method to monitor ZOI include the merits of each technology, the resulting study design, spatial coverage of the study area, potential disturbance to caribou, ease to implement, human safety and community participation. A summary of advantages and disadvantages for each method, with respect to their applicability to estimating a ZOI, is provided in the table below. As some novel techniques are considered here, study design details are unclear in some cases, and there is uncertainty about their effectiveness to meet monitoring objectives. Pilot programs to further investigate the feasibility of novel approaches are encouraged.

Table 1. Considerations of different methods that could be used to monitor caribou ZOI.

Method	Target Parameter	Data Type	Sample Period	Sample Duration	Sample Area	Sample Efficiency	Scope	Cost	Disturbance	Analysis	Community Involvement
Ground Based Remote Cameras	presence/not detected locations	photos	24 hours	constant months/years	14.6 ha/camera	low capture rate/unit time	little info. on few individuals	Low	negligible	requires time to review photos; information not available in real time	photo interpretation
Air Based Remote Cameras (mounted to aircraft flying transects)	presence/not detected locations	photos	day	repeated snap shots in time	~1000km/day	high capture rate/unit time	Samples population, little info on variable # of animals	Moderate	negligible	requires time to review photos; some valuable information not available same day	photo interpretation
Air Based Remote Cameras (mounted to drones)	presence/not detected locations	photos	day	repeated snap shots in time	>4000km/day	high capture rate/unit time	Samples population, little info on variable # of animals	High	negligible	requires time to review photos; some information not available same day	photo interpretation
Satellite imagery	presence/not detected locations	photos	day, cloud limited	repeated snap shots in time	limited only by satellite coverage	variable depending on cloud cover	Samples population, little info on variable # of animals	High	none	requires time to review photos;	photo interpretation
GPS collars	locations (of cows in some herds; both sexes in others)	locations	24 hours	frequent repeated snap shots over months/years	unlimited	high value/unit time	lots of info on few animals	Moderate	high for short duration; negligible for long duration	provides information useful for a wide variety of analyses	
Aerial surveys with two observers	presence/not detected approximate locations	count	day	repeated snap shot in time	~1000km/day	variable /unit time	Samples population, little info on variable # of animals	High	Low with fixed wind; higher with helicopter	simple count	full participation

9. Reporting

While analysis and reporting of data on caribou distribution around individual mine sites will be the responsibility of the operating company, GNWT recommends that all data emanating from industry-led ZOI surveys should ultimately be centrally available through the GNWT's Wildlife Management Information System to facilitate assessment of results on multiple zones of influence at the regional and territorial scale. Access to and use of these data would be subject to data sharing agreements. Permission to publish findings of such analysis should be obtained from the operator.

10. What are alternative activities or forms of caribou monitoring to ZOI monitoring?

In some cases, ZOI monitoring may be deemed operationally appropriate (Section 5), however, it may be technically or logistically infeasible (Section 6). There is a nonetheless an expectation that operators will continue to allocate resources to understanding the impact of their operation on caribou within their wildlife management and monitoring plans. Possible alternatives to monitoring ZOI include:

- Pilot projects to investigate technical feasibility of other methods for monitoring ZOI.
- Development of commonly available regional habitat models to allow for future estimation of ZOI with lower sample sizes.
- Research into one or any combination of causative mechanisms of ZOI which may include dust, noise, light, smell, activity levels, viewscape, air travel corridor placement, smell, vibration, activity levels, palatability of forage.
- Contributions to monitoring objectives under GNWT's Barren-ground Caribou Management Strategy that directly support monitoring or minimizing ZOI such as purchase, deployment or upgrading of satellite-collars and collar data acquisition.
- Once a size estimate of ZOI has been generated by an operation, attention can be shifted to the magnitude and significance of ZOI at a local scale or regional scale. Support for cumulative effects assessment or modeling work run by other agencies may fulfill this.
- Other monitoring activities, research programs and/or partnership contributions may be acceptable as replacement components in wildlife management and monitoring plans. Operators can develop such plans in collaboration with GNWT-ENR, Aboriginal governments and groups and other authorities as appropriate.

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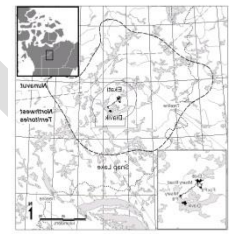
Wolfe, S.A.,Griffiths, B. & Wolfe, C.A.G. 2000. Response of reindeer and caribou to human activities. Polar Research 19: 63-73.

APPENDIX A: Current Resource Selection Function Models for the Bathurst Range

RSF model developer/citation	Season	Base Habitat Layers	Statistical method	Extent	Caribou Data sources
BATHURST CARIBOU HERD					
Boulanger/Poole/Gunn RSF/ZOI analysis. Published in Wildlife Biology. (Boulanger et al. 2012) Contacts: John Boulanger (boulange@ecological.bc.ca Kim Poole kpoole@aurorawildlife.com	Summer (15 July to 15 October)	Land Cover Map of Northern Canada (NLC) Earth Observation for Sustainable Development of Forests (EOSD; http://cfs.nrcan.gc.ca/subsite/eosd/mapping) land cover classification. Esker coverage from 1:250,000 scale National Topographic Data Base maps (Natural Resources Canada; http://geogratis.cgdi.gc.ca/geogratis/en/product/search.do?id=8147). Layers combined/pooled as described in Appendix A of manuscript	Piecewise Regression (ZOI) and logistic regression (aerial surveys), conditional LR (collars). Table 1 in manuscript.	Bathurst summer range from collar data 1996-2008 (Fig 1 in manuscript) 	Ekati and Diavik aerial surveys (1998-2008) Collared caribou (1996-2008)
Johnson et al. RSF; Published in Wildlife Monographs (2005)	Migration /calving (April 15-June 14), Post calving (June 15-August 31), Autumn Migration (Sept 1-Oct 31)	WKSS landcover mapping Disturbance sources cobbled together from whatever was available.	Conditional logistic regression; ZOI based on inflection point of Gaussian disturbance function.	Bathurst seasonal ranges based on collar data from 1996 to 2000	GNWT collar data.
Nishi et al. Proof of Concept Cumulative Effects Report (In Prep – I think????)	post calving (14 June – 5 July),	Land Cover Map of Northern Canada (NLC) Earth Observation for Sustainable Development of Forests (EOSD; http://cfs.nrcan.gc.ca/subsite/eosd/mapping)	Conditional logistic regression; no ZOI	Bathurst seasonal ranges based on collar data	GNWT Collar Data NOTE: Also applied TK locations of hunting sites (Legat et

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RSF model developer/citation	Season	Base Habitat Layers	Statistical method	Extent	Caribou Data sources
	early summer (6 July – 18 July), and late summer (19 July – 22 August)	land cover classification. Esker coverage from 1:250,000 scale National Topographic Data Base maps (Natural Resources Canada; http://geogratis.cgdi.gc.ca/geogratis/en/product/search.do?id=8147). NDVI Various sources of disturbance features.		from 1996 to 2009	al. 2001)
Anderson and Johnson. Ecosphere In Press	Early winter (Nov – Dec), Late Winter (Jan – March)	GNWT Forest Management Land Classification GNWT Large Fire Database (burn boundaries) RSF of wolf habitat (GNWT wolf data)	Conditional logistic regression; no ZOI	Bathurst winter range based on collar data from 1996 to 2009	GNWT Collar Data
Golder Associates. 2011a. FORTUNE MINERALS LIMITED DEVELOPER'S ASSESSMENT REPORT	Winter (1 Nov. to 30 April)	Earth Observation for Sustainable Development (EOSD) data. For years prior to 2005, fire polygons in the NWT were from Mair (Department of Environment and Natural Resources, 2009, pers. comm.). Polygons defining the spatial extent of more recent fires were delineated using 80% volume contours around MODIS thermal anomaly data (USDA 2009, internet site) within a GIS platform using the Hawth's Tools extension (version 3.27; Beyer 2004) for ESRI ArcGIS 9.2. A spatially-explicit dataset describing the location and type of human developments within the study area was incorporated into	Fixed-effects exponential RSFs were used (Manly et al. 2002) with coefficients estimated from conditional logistic regression	Bathurst winter range from collar data 1996-2009 	GNWT Satellite and GPS radio-collared caribou data 1996-2009

RSF model developer/citation	Season	Base Habitat Layers	Statistical method	Extent	Caribou Data sources
		a GIS layer. Information for the development layer was obtained from the following sources: • Mackenzie Valley Land and Water Board: permitted and licensed activities within the NWT; • Indian and Northern Affairs Canada permitted and licensed activities within the NWT (INAC 2009); • Natural Resources Canada: obtained a GIS file on community locations from GeoGratis website; • Indian and Northern Affairs Canada contaminated sites database (INAC 2009); • Individual operators for project-specific information (e.g., component footprints and routes); • company websites; and • knowledge of the area and project status.			
Golder 2011b. Analysis of Environmental Effects from Diavik Diamond Mine on Wildlife in the Lac De Gras Region	summer to fall (July to October)	Landsat 2007 with veg classes of Matthews et al. (2001)	Piecewise regression (caribou occurrence ZOI) Logistic regression (nursery occurrence; quadratic function)	Ekati-Diavik Regional Study Area	Ekati and Diavik aerial surveys (1998-2009) for caribou occurrence, and nursery group occurrence
Rescan 2013. Back River Project: 2013 Habitat Selection by	Post-calving (June	Land cover: derived from vectorized classification of 30m resolution 2000 Landsat imagery classified by Canadian	Logistic regression	Four extents: Areas bound 50% and 95%	GNWT collar data 1996-2012

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RSF model developer/citation	Season	Base Habitat Layers	Statistical method	Extent	Caribou Data sources
Bathurst Caribou during the post-calving and summer periods. Prepared for Sabina Gold & Silver Corp.	16-July 20) and summer (July 20-August 31) ranges.	Centre for Remote Sensing. Derived Simple Ratio Vegetation Index (SRVI) Canadian Digital Elevation Data Eskers: Vanvec vector data by NRCan Predators: HSI modelling conducted for Back River Project Development layer, based on literature search.		kernal utilization distributions for each of post-calving and summer ranges.	

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APPENDIX B - *Previous work on potential causative mechanisms of ZOI within the NWT*

Mechanism	**Studies within Bathurst Caribou Range**	**Methods**	**Results**
<u>Dustfall:</u> TSP (total suspended particles) TSP; mean mass ; 10 lm in size).	Boulanger/Poole/Gunn RSF/ZOI analysis. Published in Wildlife Biology. (Boulanger et al. 2012) <u>Contacts:</u> John Boulanger (boulange@ecological.bc.ca Kim Poole kpoole@aurorawildlife.com *See RSF table for more details*	Logistic regression analysis of aerial survey and radio collar data. Base habitat model with estimated CALPUFF TSP concentration (Rescan 2006) added as a covariate to describe caribou distribution.	TSP correlated with avoidance of mine areas as related to estimated ZOI of mine areas of 14 km for aerial survey and collar data
Dustfall	Fugitive dust from mining activities (moving and crushing rock, vehicles, wind erosion, etc.) on vegetation can reduce photosynthesis or otherwise reduce forage quality for caribou. Monitoring of dustfall and of the associated effects to vegetation will be monitored at the Gahcho Kué Mine. Snap Lake Mine 2013 Vegetation Monitoring Program (March 2014) Gahcho Kué Mine Vegetation and Soils Monitoring Program (Version 3, September 2014)	Dustfall collectors will be installed along a 20 km transect from the Gahcho Kué and Snap Lake mines, and monitored monthly from May to September during operation. More intensive dustfall monitoring and associated vegetation assessment will occur every three years.	Vegetation monitoring at the Diavik mine has shown that mine construction and operation activities can change plant communities and it is suggested that dust may be one of the contributing factors (Naeth and Wilkinson 2008; Golder 2011). Results showed a distinct pattern of lower terricolous (ground dwelling) lichen cover, higher litter cover, and higher total vascular plant species richness in plots adjacent to the Mine site compared to reference plots. It is suspected that the Mine may be having local-scale effects on plant species composition as dust deposition rates at Mine plots were five times higher relative to reference plots. Studies at the Snap Lake Mine have shown that plant species

APPENDIX B - *Previous work on potential causative mechanisms of ZOI within the NWT*

Mechanism	Studies within Bathurst Caribou Range	Methods	Results
			diversity have not changed between vegetation plots around the mine versus control plots based on changes in Ecological Land Classification (ELC). Vegetation monitoring at the Ekati Mine has primarily focused on air quality and metal concentrations in lichens as well as revegetation of disturbed areas. However, none of these studies have used a gradient approach using permanent vegetation plots (PVP), as proposed at Gahcho Kué.
Noise	Noise modelling has been completed for some mines as part of Environmental Assessment.	The NWT does not have environmental noise regulations. Therefore, the assessment of noise from Jay Project operations was based on Directive 038 (EUB 2007). Directive 038 stipulates that noise emissions from facilities under its jurisdiction be controlled to a permissible sound level (PSL) at each dwelling located within a 1.5 km criteria boundary. If there are no dwellings	For all receptors located 1.5 km from the Project boundary, the daytime PSL is 50 dBA and the nighttime PSL is 40 dBA. Noise modelling for Jay Project (including existing Misery Camp and Misery Road) at the 1.5 km AER criteria boundary (i.e., located at 1.5 km from the Project boundary) the daytime PSL is 50 dBA and the nighttime PSL is 40 dBA.

APPENDIX B - *Previous work on potential causative mechanisms of ZOI within the NWT*

Mechanism	**Studies within Bathurst Caribou Range**	**Methods**	**Results**
		within the AER 1.5 km criteria boundary (Directive 038 explicitly excludes worker camps as dwellings), Directive 038 requires noise levels form the Project to not exceed PSL at any point along the 1.5 km criteria boundary.	
Visual disturbance	Viewscape modelling has been done for some mines as part of Environmental Assessment.		
Odour	No existing studies	Two methods exist and include surveys from humans or a portable olfactometer	

APPENDIX C – Further Analyses

Estimation of zone of influence of mine sites on caribou populations: New analysis methods and sample size requirements

This analysis is currently in progress and this report will be updated in the future. Therefore, please contact the author before citing this report.

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1. Introduction

The main objective of this document is to update zone of influence estimates using newer analysis methods with a focus on estimating sample sizes needed to estimate zone of influence using aerial survey methods.

Boulanger et al (2012) estimated zone of influence for the Ekati and Diavik mine areas for the period of 1998-2008. The basic approach involved testing for a threshold distance from mine areas in which change in habitat selection occurred relative to distances further from the mine (Figure 1). This approach involved iterative fitting of logistic regression models over a wide range of distances followed by evaluation of the shape of log-likelihood curves to determine potential thresholds. The inherent complexity of this approach prevented analysis of yearly or within-year trends in zone of influence with most analyses pooling multiple years of data based upon mine operation phase.

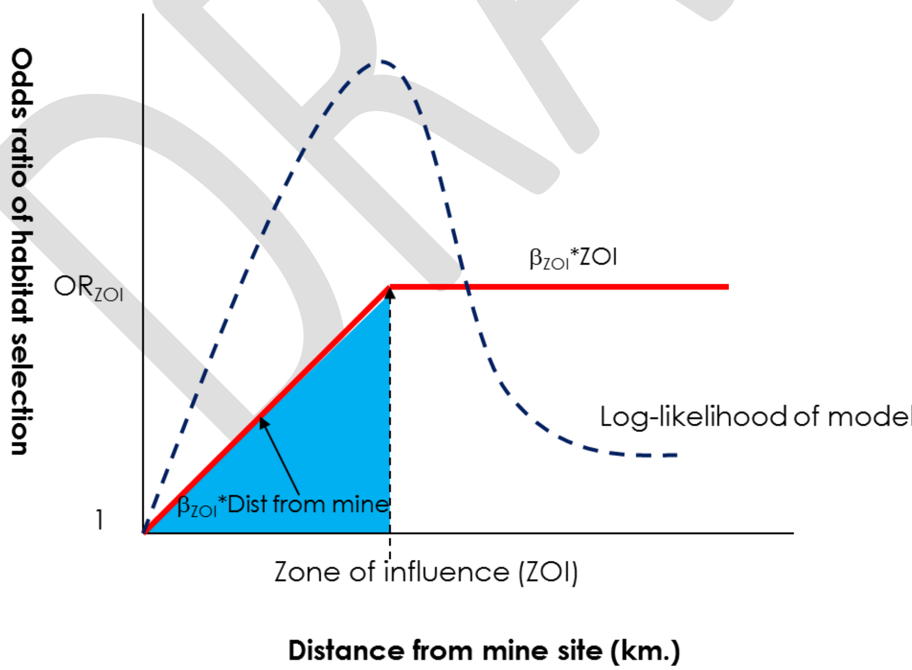

Figure 1: The underlying zone of influence model including the Bzoi parameter from Boulanger et al (2012).

APPENDIX C – Further Analyses

Subsequent to the Boulanger et al. (2012) analysis (which primarily occurred in 2008-09), a computer package in program R (R Development Core Team 2009) was developed to efficiently estimate breakpoints (Muggeo 2003;2008). Through correspondence with the author of the package *segmented* (Vito Muggeo, Institute of Social Statistics, University of Palermo, Palermo, Italy) this package was adapted to use generalized estimating equation logistic regression models used in the aerial survey zone of influence analysis. This analysis uses this new R method to further explore year to year variation in zone of influence and to explore sample sizes needed to estimate zone of influence from aerial survey data.

2. Methods

Aerial surveys methods

The general design for aerial surveys was based upon aerial transects around mine areas that contained the area around the mine and a "control" area that was far enough away from the mine where no effect of the mine could be assumed (Figure 2). The transects were then divided into 1 kilometer segments where caribou presence and habitat data were summarized (Boulanger et al. 2012).

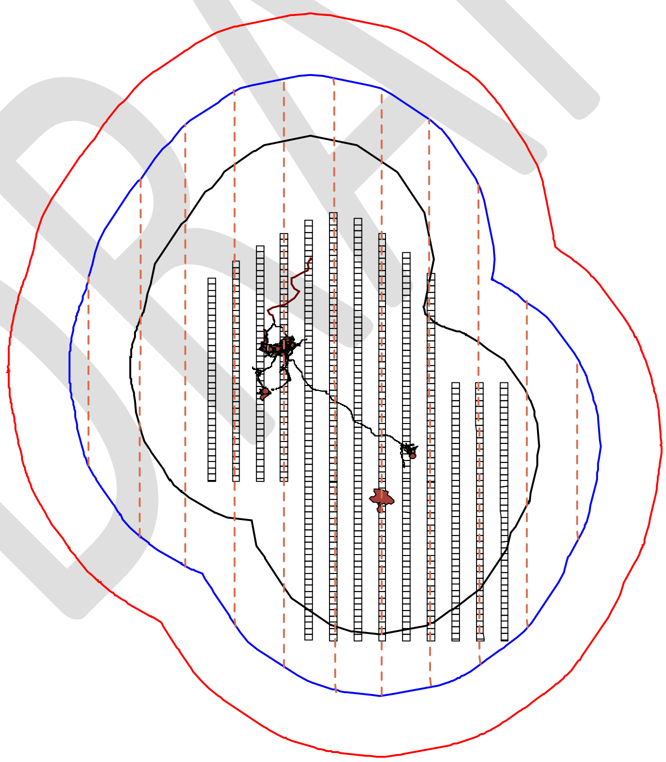

Figure 2: The Ekati mine site, Misery Road and camp, Diavik mine site, and Sable Road, and aerial survey transects flown prior to 2006, with buffers of 20 km (black), 30 km (blue), and 40 km (red) beyond current and near-future (Sable Road) development. Transects flown beginning in 2006 within the 30 km buffer are shown as red broken lines.

APPENDIX C – Further Analyses

Analysis methods

The analysis used the base habitat model developed in Boulanger et al. (2012) as well as the same general estimation methods for all analyses. This model included terms for relative occupancy (relative population size of caribou on the grid during the survey), sedge/wetlands, water, low shrub, tundra, and seasonality as indexed by NDVI (Table 1). It is suggested that readers review Boulanger et al. (2012) which provides details of the input data sets as well as analyses.

Table 1 Base habitat model for aerial survey analysis for the Ekati and Diavik mine area aerial surveys. Standardized slope estimates are given for habitat variables (from Boulanger et al. 2012).

Parameter	Estimate	SE	CI	χ^2	*P*
Intercept	-3.33	0.04	-3.40 - -3.26	8737.26	<0.0001
Esker	0.04	0.02	0.01 - 0.07	5.52	0.0188
Relative occupancy	0.58	0.01	0.56 - 0.61	2656.08	<0.0001
Lowshrub^2	-0.06	0.03	-0.11 - -0.01	6.28	0.0122
Sedge wet	0.15	0.04	0.08 - 0.23	15.71	<0.0001
Tundra^2	-0.10	0.02	-0.14 - -0.06	28.18	<0.0001
Tundra*NDVI	0.49	0.25	0.00 - 0.97	3.87	0.0492
Water	-0.14	0.08	-0.29 - 0.02	2.97	0.0848
Water^2	-0.23	0.05	-0.32 - -0.14	25.70	<0.0001

Base models were run using the *glm* (R_Development_Core_Team 2009) or *geepack* (Yan 2002) packages in R. Once a base model was developed, it was run through package *segmented* (Muggeo 2003; 2008) to estimate zone of influence and associated magnitude of zone of influence (as determined by the odds ratio (OR)). The coding in *segmented* was manipulated to constrain the relationship so that slope to the right of the estimated zone of influence was equal to 0 (Boulanger, *In prep*., *Rangifer*). Naïve generalized linear models, which did not account for autocorrelation in the data set, were run to provide initial estimates of zone of influence in *segmented*. These estimates were then used as starting points in the more complex generalized estimating equation analyses. For the generalized estimating equation approach, models were fit based upon minimizing the standardized Pearson residuals which indexes fit of the model and observed data.

One additional question was whether zone of influence models adequately fit the data. To test this the final segmented models were tested for goodness of fit using ROC tests. If a model adequately fit the data then the ROC area under the curve should be 0.7 or more (Boyce et al. 2002, Boulanger et al. 2012). The *pROC* package (Robin et al. 2014) was used for ROC estimation.

For an initial step in the analysis, estimates of zone of influence using the segmented method were compared with previous estimates conducted using the log-likelihood method in Boulanger et al. (2012). Theoretically, estimates should be similar for these 2 methods. However, the segmented method uses a more efficient estimator of thresholds as well as method of estimating variance that may provide a better estimate than the profile-likelihood method used in Boulanger et al. 2012. In addition, estimates from program *segmented* are not constrained by the 0.5 kilometer increment used in the Wildlife

Biology paper. However, analyses in program *segmented* were conducted independently for each mine phase period whereas Boulanger et al. (2012) ran analyses with mine phase as factors in a comprehensive model (to increase sample sizes for the base habitat model). Therefore, differences in estimates may result given the different underlying models. Given this, it was essential to compare the estimates from *segmented* and previous methods to ensure that the comparison of zone of influence estimates was not influenced greatly by differences in underlying models.

Year-specific zone of influence analyses were then conducted to determine if zone of influence could be estimated using yearly data as well as to assess yearly variation in zone of influence. Of most interest was the minimal sample size required for a zone of influence estimate given the low present abundance of caribou in the Bathurst herd. For this analysis, data from 2008 were incrementally subsampled to provide a general assessment of minimal sample size. Successive surveys were pooled to increase sample size starting with a single survey (which was comprised as one survey for Diavik and one for Ekati using closest date for pairing) up to the ten surveys conducted for each mine in 2008. The base habitat model parameters (Table 1) were used for all model runs with slopes for each parameter being estimated for each model run. Estimates of zone of influence, slope, and model goodness of fit were then incrementally assessed.

A zone of influence estimate was considered significant if the confidence limits of the zone of influence estimate and the corresponding slope estimate did not overlap 0.

3. Results

Comparison of program *segmented* with previous estimates

Comparison of estimates suggested that in all cases zone of influence estimates were very close (Table 2). For example, in 2000-02 the zone of influence estimate and OR estimates were not significant, similar to the previous method that did not detect a zone of influence. Odds ratio estimates were also similar especially when confidence limits were considered. Estimates of zone of influence from *segmented* were slightly less precise for 2003-08 and pooled years as indicate by confidence limit width relative to the zone of influence estimates (CI/ZOI). Difference in odds ratio estimates as well as slightly lower precision of estimates was potentially due to the “stand alone” analysis for each period for the *segmented* analysis compared to the pooled approach used in Boulanger et al. (2012), which increased overall sample size (as discussed later).

APPENDIX C – Further Analyses

Table 2: Estimates of zone of influence (ZOI) using program *segmented* and likelihood based methods in Boulanger et al. (2012). The zone of influence estimate, confidence limit (CI) relative precision (CI divided by estimated ZOI), significance of zone of influence model term (ZOI), goodness of fit (GOF; ROC score), and the magnitude of zone of influence effect as described by the odds ratio (OR_{ZOI}) are given.

Period	ZOI (km)	CI	CI/ZOI	Significance of β_{ZOI}		GOF ROC	OR_{ZOI}	
				χ^2/Z	*P*		Est.	CI
<u>Program *segmented*</u>								
1998-99	3.8	0-7.7	202.2%	0.47	*0.49*	0.75	8.4	-44.9-61.8
2000-02	1.01	-0.3-2.3	258.2%	1.45	*0.47*	0.79	1.6	-1.6-4.8
2003-08	14.6	12.8-16.4	25.0%	65.60	<0.0001	0.79	4.3	2.4-6.3
Pooled	15.2	13.1-17.4	29.1%	63.75	<0.0002	0.79	2.3	0.3-4.3
<u>Likelihood/WB approach</u>								
1998-99	4	3.0-7.0	100%	9.12	0.002	0.79	5.8	1.6-10.0
2000-02	-[a]							
2003-08	14	13.0-15.0	14.3%	-9.91	<0.001	0.79	9.9	5.7-14.1
Pooled	14	12.0-15.5	25.0%	10.94	<0.001	0.78	4.2	1.4-8.4

[a] No peak in the likelihood curve was observed making estimation of zone of influence not possible

Yearly estimation of zone of influence

Sample size summary

Yearly sample sizes for the analysis are given in Table 3. It can be seen that the proportion of 1 km transect segments with caribou varied from 1.6 to 10% from 1998 to 2008. The number of cells in which caribou were present varied, however, this was also due to change in study area configuration as discussed in Boulanger et al. (2012).

Table 3: Summary of yearly sample sizes for zone of influence surveys

Year	Number of surveys		Cells (1 km) surveyed	Cells (1 km)with caribou	
	Ekati	Diavik		count	percent
1998	17		6,715	268	4.0%
1999	18		7,110	410	5.8%
2000	12		4,740	120	2.5%
2001	11		4,345	448	10.3%
2002	8	8	5,416	339	6.3%
2003	9	9	6,093	260	4.3%
2004	9 combined		6,093	168	2.8%
2005	10 combined		6,770	446	6.6%
2006	10	8	10,432	311	3.0%
2007	9	10	13,157	332	2.5%
2008	10	10	12,643	206	1.6%

APPENDIX C – Further Analyses

Year-specific estimates of zone of influence did not detect a significant zone of influence until 2003 with both zone of influence and the odds ratio overlapping 0 for years prior to 2003. Beginning in 2003, zones of influence with a mean level at approximately 15 km were estimated for all years except 2007 where a zone of influence of 7 km was estimated. The effect size of the zone of influence increased with year after 2004 (Figure 4). ROC score suggested reasonable fit for yearly models (as indicated by a ROC score of 0.7 or greater).

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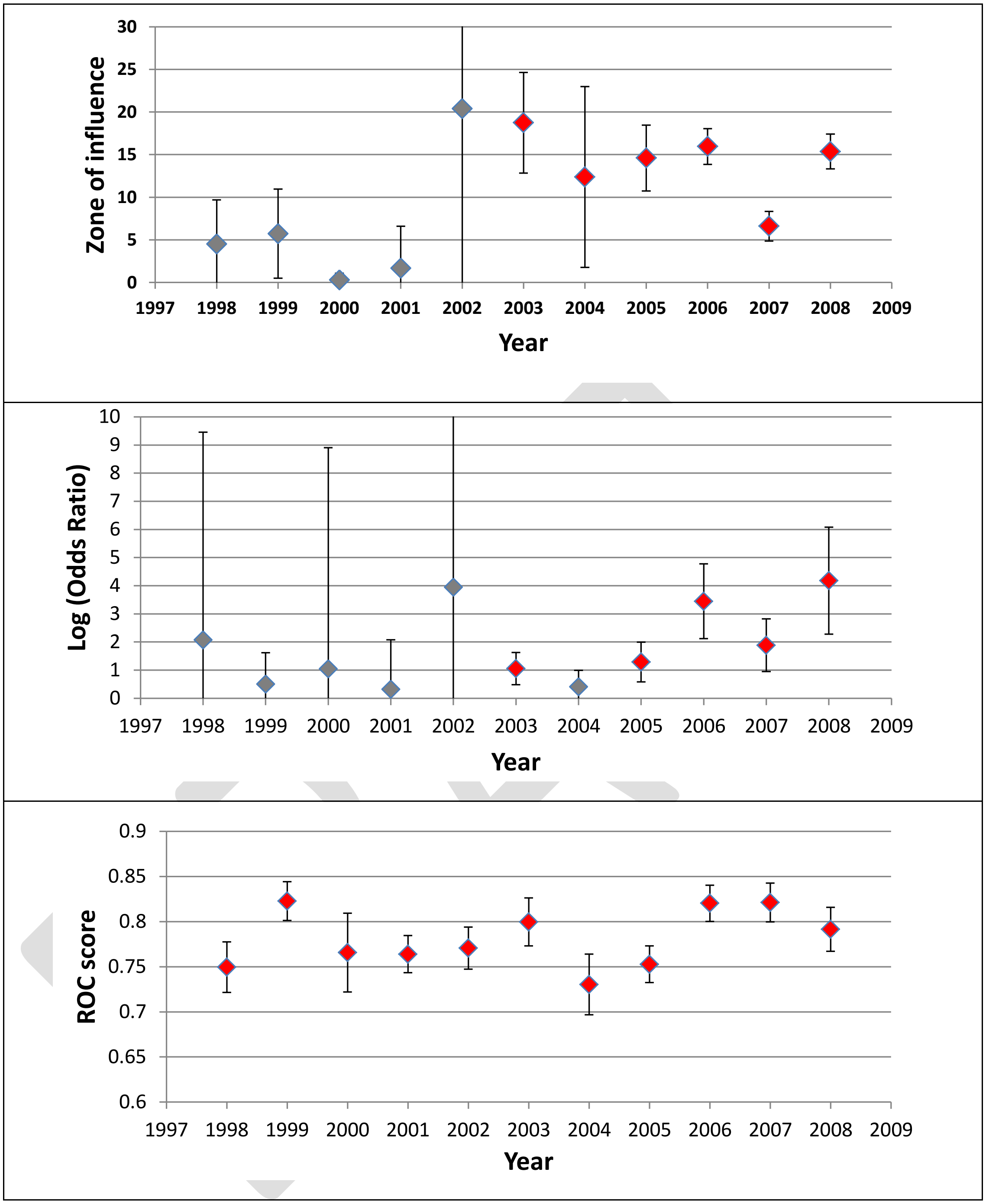

Figure 3: Estimated zone of influence, magnitude of zone of influence (Log(Odd ratio) and goodness of fit (ROC score) for yearly zone of influence estimates for Ekati and Diavik. Confidence limits are given as error bears. Estimates that were not statistically significant are shown in grey.

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Single year (2008) analyses

Results from yearly analyses suggest that yearly zone of influence estimates are feasible. Data from 2008 were subsampled to determine the threshold sample size needed to estimate the zone of influence within a single year. The range and average percentage of caribou detected declined in relation to overall herd size (Boulanger et al. 2014). In 2008, caribou groups were only detected in 1.6% of the cells surveyed (Figure 4). Therefore, 2008 presented a good case study of estimation of zone of influence at low abundances of caribou.

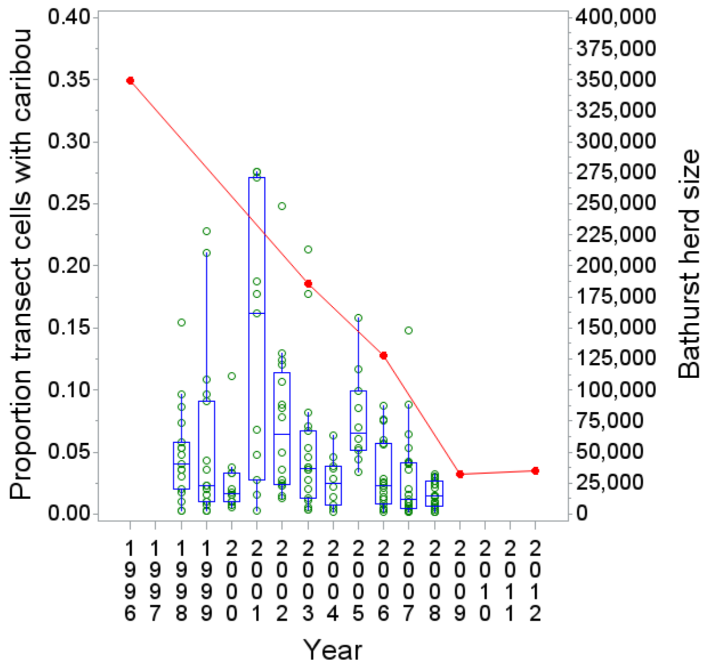

Figure 4: The relationship between proportion of cells that detected at least one caribou for Ekati and Diavik mine surveys in comparison with estimated Bathurst herd size (Boulanger et al. 2014).

Sample size summaries

Independent surveys for Ekati and Diavik were paired by closeness of date (Table 4) for this analysis. This ensured that each "survey" covered the full extent of the survey area. Data sets were then sequentially run with data from previous surveys pooled to increase cumulative sample sizes. The underlying habitat and zone of influence model did not converge adequately (as indicated by very large standard errors on slope estimates for all parameters) until 6 surveys (140 cells with caribou present out of 7865 cells surveyed; 1.8%). After 6 surveys the number of significant parameters in the underlying model increased up to 9 (out of 10 parameters total) indicating that power to detect habitat selection as well as zone of influence increased with sample size.

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Table 4: Summary of pair Ekati and Diavik surveys used in 2008 subsampling analysis. Ekati and Diavik surveys were paired by closeness of dates. Sample size as summarized by 1 km cells surveyed and the number of cells with caribou present, and the percent cells with caribou are given. Model outcome as summarized by whether the model converged or the number of significant parameters (10 parameters total) is given.

No. of	Survey dates		Sample size			Cumulative sample size			Model outcome
surveys	Ekati	Diavik	cells	caribou	%	cells	caribou	%	
1	7/21	7/27	1,423	6	0.4%	1,423	6	0.4%	No convergence
2	8/03	8/02	1,423	21	1.5%	2,846	27	0.9%	No convergence
3	8/18	8/09	1,087	30	2.8%	3,933	57	1.4%	No convergence
4	8/20	8/16	1,423	35	2.5%	5,356	92	1.7%	No convergence
5	8/24	8/23	1,423	18	1.3%	6,779	110	1.6%	No convergence
6	9/08	9/06	1,086	30	2.8%	7,865	140	1.8%	5 parameters
7	9/14	9/14	1,005	22	2.2%	8,870	162	1.8%	6 parameters
8	9/21	9/19	1,422	14	1.0%	10,292	176	1.7%	7 parameters
9	10/06	9/27	928	11	1.2%	11,220	187	1.7%	8 parameters
10	10/11	10/07	1,423	19	1.3%	12,643	206	1.6%	9 parameters

Plots of zone of influence distance and effect size (odds ratio) of zone of influence showed relatively stable zone of influence estimates for 6 or more surveys and a slightly increasing effect size of zone of influence. Coefficients of variation decreased slightly for zone of influence distance and were roughly stable for effect size. As discussed later, any change in zone of influence could be due to seasonality given that sessions were added temporally sequentially. However, the general results suggest that 6 surveys (140 cells (1.8%) with caribou present with 7,865 km of transects) were needed to detect the zone of influence for 2008. ROC scores for all of the session-specific estimates ranged from 0.78 to 0.80 indicating adequate model fit.

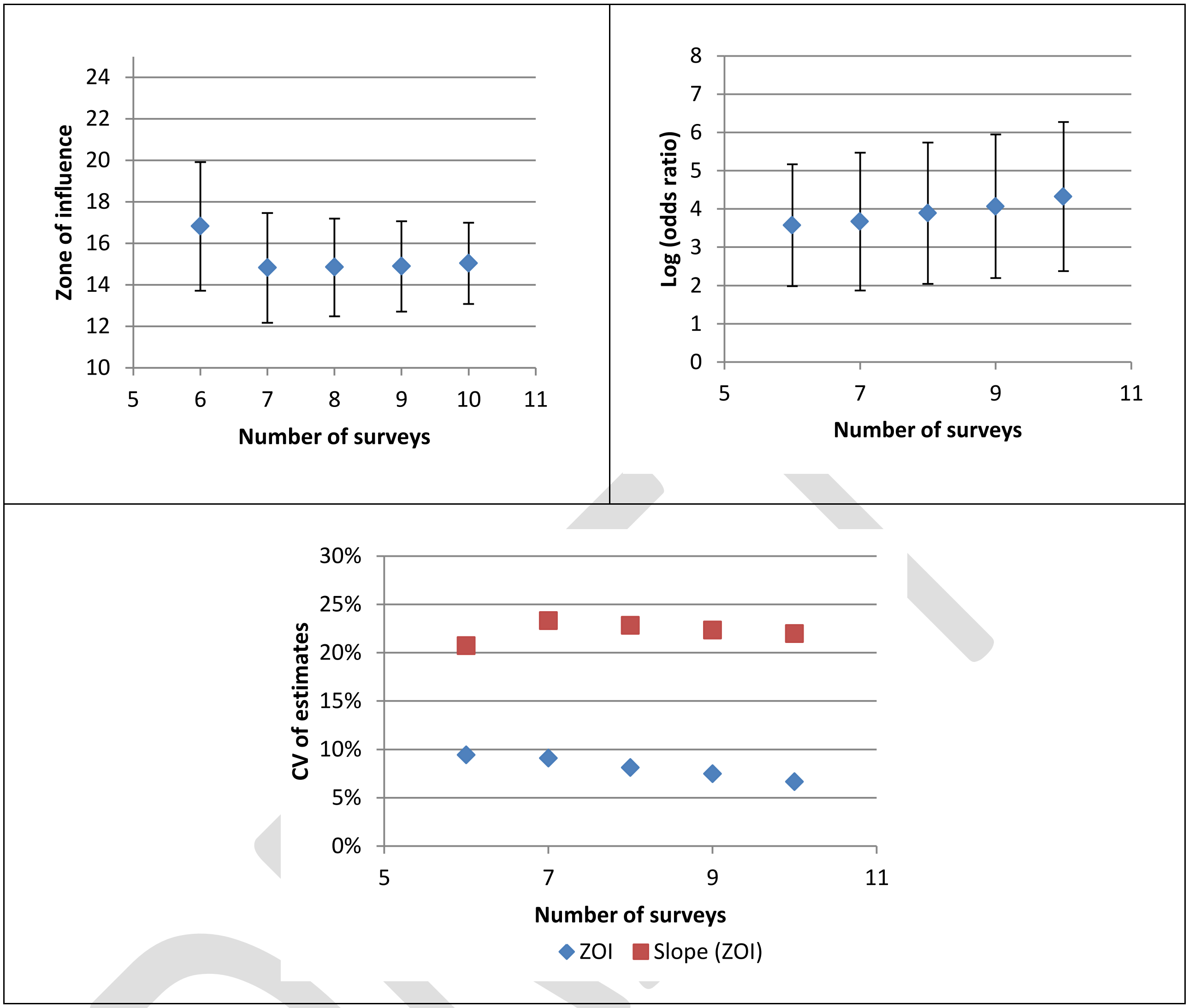

Figure 5: Estimates of zone of influence, effect size of zone of influence, and precision of estimates as a function of sequential increase in sample size for 6 or more surveys conducted in 2008 (Table 4)

4. Discussion

The analysis in this document provides further inference on zone of influence as well as sampling effort needed to estimate zone of influence. Program *segmented* provided similar estimates to previous methods with substantial less effort. One of the most notable advancements is that the zone of influence can be estimated through a set of statistical tests rather than interpretation of the shape of likelihood curves. While the general approach is similar, the segmented method is more computationally efficient and provides a more robust estimate of standard error (and confidence limit for the zone of influence). Because program/package *segmented* is available in program R (a free statistical package) it should be possible for researchers to easily estimate zone of influence once base habitat models are developed.

APPENDIX C – Further Analyses

Estimation of yearly zone of influence revealed that zone of influence did change with phase of mine development with a defined distance at approximately 15 km after 2002 when both mines became operational. This change was assumed in Boulanger et al. (2012) but had not been tested using yearly zone of influence estimates. The zone of influence was relatively stable for most years after 2003 (with the exception of 2007 when it was 7 km). Interestingly, the magnitude of zone of influence, as estimated by the log of the odds ratio, increased suggesting a trend of greater avoidance of the zone of influence from 2005 to 2008.

This analysis used consistent base habitat model terms but allowed the actual values of the parameters to be estimated for each data set. This approach ensured that the zone of influence estimates were comparable across years under the assumption that factors affecting habitat selection was relatively similar (but allowed to vary in terms of seasonality using NDVI terms). This assumption seemed reasonable as indicated by reasonable fit of models based on ROC scores. Using this approach has merit in that it means that a new habitat model may not need to be derived each year as long as the goodness of fit of the model to the data is tested for each analysis (using ROC scores).

A general conclusion of this analysis is that is possible to estimate zone of influence on a yearly basis if within year sample sizes are adequate. Analysis of the 2008 data suggest that at least 6 surveys (7,865 km of transect with caribou present in 140 of the 1 km cells) are needed to estimate the parameters of the underlying habitat model and the zone of influence terms. After this sample size is achieved the main effect of increasing sample size is an improvement of precision of the zone of influence estimates. This result is similar to the “rule of 10’s” (Hosmer and Lemeshow 2000) which indicates that at least 100 cells with caribou are needed to support the 10 parameter base habitat/zone of influence model. When sample size was below 140 the GEE model did not converge. The GEE model also estimates correlation between observation and therefore will have higher sample size requirements than a simpler logistic regression model. A simpler logistic regression model will overestimate precision by erroneously assuming that repeated observations are not correlated and therefore the GEE model is essential for robust estimates (Boulanger et al. 2012).

Further research

This analysis provides a base assessment of minimal sample size needed to estimate a zone of influence. Further research could apply the same case study to other years of data to determine if this result applies across multiple years. Of particular interest would be to examine the 2009 data, the last year of aerial surveys by both mines but not included in the Boulanger et al. (2012) analyses. Examination of 2009 would provide an additional data point at low caribou abundance.

The present 2008 analysis only considered sequential addition of surveys and therefore may be susceptible to seasonality or other factors influence zone of influence estimates. A randomized approach which considered different combinations of sessions would be more robust to this potential issue.

The segmented analysis for each period of mine activity (Table 2) was conducted “stand-alone” for each period whereas the analysis of Boulanger et al. (2012) used an overall base habitat model and the estimated each period zone of influence as a factor in the analysis. The rationale behind the Boulanger et al. (2012) design was that the factor approach would maximize sample size for the base habitat model and therefore increase overall precision of estimates. Therefore, it is likely that the lower precision of the segmented analysis was caused by this difference in analysis strategies. The difference in analysis strategies may also explain slight differences in estimated odds ratios from segmented and historic analyses. An analysis using program/package *segmented* that treats each phase as a factor would increase sample size and subsequent precision of segmented estimates.

The lower zone of influence in 2007 was potentially due to a different distribution of caribou within the study area for this year. Further exploration of session-specific data sets, as well as determination of any differences in mine activities would assist in determining the reason for this lower estimate.

This analysis provides sample sizes required to estimate a zone of influence assuming that the abundance is similar to 2008 levels and zone of influence is of similar levels to Ekati/Diavik in 2008 (i.e. zone of influence of approximately 14 kilometer with Log(OR_{zoi}) of 4) and the study design is also similar to Ekati/Diavik. Sample size requirements will vary if abundance or zone of influence is different than these levels. A simulation approach that varies abundance and level of zone of influence would provide sample size requirements and power estimates for different abundance and zone of influence levels. This approach is feasible now that a more efficient method of zone of influence has been developed.

This analysis used aerial survey data, however, program *segmented* could also be applied to collar data given that any generalized linear model can be used as a base model for program *segmented*. It would be expected that the same advantages of program *segmented* with aerial survey data would also apply to collar data.

Methods to confront the challenge of sample size

I suggest the following general strategies to confront low sample sizes of caribou:

1. The analyses conducted in this paper used terms from a pre-existing habitat model (Table 1) but allowed estimates of the parameters to vary for each subset analysis. The assumption in this case was that the same underlying habitat model will describe habitat selection for any year or portion of a year considered. Results from the ROC analyses suggest that habitat models were adequate as indicated by ROC scores of greater than 0.7 in model runs (Figures 3 and 5). Using this approach avoids formulating a habitat model for each year or survey which may be problematic given low sample sizes for any given year or sample within a year. I suggest that formulation of a base habitat model that is used for all surveys be utilized to avoid issues with obtaining adequate sample sizes for base model formulation. The base habitat model can be tested for goodness of fit and refined as more data is collected.
2. A design that has tighter line spacing in the proximity of mines may help offset lower sample sizes of cells in likely zone of influence areas. This approach may improve power to detect zone of influence by allowing a higher sample size of observations in the proximity of mine areas.
3. The results of this analysis suggest that if survey design and abundance is similar to 2008 and a base habitat model is formulated, then at least 140 cells in which caribou are detected is needed

to estimate a zone of influence. For the Ekati/Diavik sampling design it took 7,865 kilometers of transect flying across 6 surveys to achieve this sample size requirement (Table 4). As a starting point in evaluation of survey design, the number of surveys required to meet this sample size could be estimated as 7,865 divided by the kilometers flown per survey. This general statistic could then be used to determine the feasibility of estimating zone of influence of similar magnitude to Ekati and Diavik. From this exercise, a target proportion of cells with caribou needed per survey could be set and used in an adaptive design as described next.

4. An adaptive survey design for aerial surveys could be employed where an initial survey of 100-200 km is flown at a wider reconnaissance level transect spacing. During the survey, the proportion of cells that detected caribou would be tallied. I note that there are a variety of tablet computers with GPS interfaces that would allow on-the-fly calculation of the proportion of cells with caribou. Therefore this calculation could be done without having to land the plane. The proportion cells could then be used to estimate the number of cells expected to have caribou. If this proportion was equal to or higher than the target proportion in survey planning (step 3) then the full survey would be flown.
5. Further monitoring of mechanisms that cause the zone of influence, such as dustfall, could potentially be a more powerful predictor of the zone of influence than the assumed symmetrical shape of the piecewise zone of influence model. However, more analyses and development are required before any potential causal mechanism can be used with confidence.

5. Acknowledgements

Dr. Vito Muggeo (Institute of Social Statistics, University of Palermo, Palermo, Italy) provided assistance in the use of program segmented including adaption of the R code for GEE models. Kim Poole (Aurora Wildlife Research, Nelson, BC) provided helpful comments on an earlier draft of this report. As acknowledged in Boulanger et al. (2012) the mine aerial survey data sets were supplied by BHP Billiton Diamonds Inc. (D. Abernethy & A. Nichols) and Diavik Diamonds Mines Inc. (S. Bohnet & C. English). D. Panayi, C. Wood and J. Virgl (all Golder Associates Ltd.) and M. Wen (Rescan Environmental Services Ltd.) provided additional data. This analysis was funded by Environment and Natural Resources, Government of Northwest Territories, Yellowknife, NWT.

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