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Caribou Landscape Vulnerability Mapping

Bathurst Inlet Port and Road

Submitted by the Canadian Arctic Resources Committee

To the

Nunavut Impact Review Board

As Part of the CARC Technical Presentation

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Introduction 1
Methods 3
Figures 9
Acknowledgements 30
List of References 30
Web References 32

1. Introduction

The proposed Bathurst Inlet Port and Road (BIPAR) project crosses the seasonal ranges of two large herds of migratory tundra caribou: the Bathurst herd and the Ahiak herd. Given the importance of caribou to aboriginal people and their central ecological role, we have focused our review of the BIPAR environmental assessment on caribou.

Behavioral responses of caribou to human and specifically industrial activities (Wolfe et al. 2000, Stankowich 2008, Vistenes and Nellemann 2008) frequently reveal that caribou reduce their use of areas within 1–15 km of industrial developments such as roads, mines and oil fields (Boulager et al. submitted, Wolfe et al. 2000, Vistnes and Nellemann 2008, Stankowich 2008). Caribou response to human activity is probably similar to their responses to predation risk, which includes the trade-offs between countering predation risk without risking other behaviors, such as having enough to eat or not wasting energy by fleeing unnecessarily (Frid and Dill 2002). We expect then, that caribou are constantly evaluating the landscape features to balance the fear of predation (or human activities) with the need to forage efficiently (Hernandez and Laundre´ . 2005). It follows from this, then, that caribou will be assessing and selecting landscape features such as topography, and vegetation in the context of reducing predation risk and maximizing foraging efficiency.

Caribou's nutritional needs change seasonally and thus the pattern of balancing response to predation risk (or human activities) and foraging change seasonally. During the snowfree season, caribou forage selectively preferring plants as their buds unfold and new leaves and flowers emerge (Russell et al. 1993, Griffith et al. 2001). Caribou cows with newborn and young calves are more responsive to human activities and their vulnerability is increased during calving and early post-calving as most all the cows in the herd and concentrated together on the calving grounds. Their need for uninterrupted foraging is also much greater than at other times of year as energetic demands for lactating cows double within 10 days of the calf's birth (White and Luick 1984; Parker et al., 1990; Chan-McLeod et al., 1994),The first three weeks is important because it is then that calves are most sensitive to factors that influence growth rate (e.g., maternal and environmental conditions), and they are most vulnerable to predation.

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Our approach to assessing potential effects of BIPAR was a GIS-based analysis of caribou seasonal locations using satellite telemetry and habitat to assess caribou risk to disturbance from the proposed BIPAR road alignment. We mapped the relative potential probability of overlap between caribou seasonal distribution and the proposed BIPAR alignment, as well as the East of Kugluktuk (EOK) and Grays Bay Port and Road (GPAR). We then used expert opinion and experience from other caribou herds to rate vegetation habitat maps for the likelihood of their use relative to foraging and predation risk. The composite map of caribou seasonal distribution and habitat was then a measure of the relative seasonal vulnerability of caribou across the landscape.

The study area is the seasonal ranges of the Ahiak and Bathurst caribou herds within an area of the Slave geological province stretching from the western shores of the Bathurst Inlet, west to the border between the Northwest Territories, and south to the boreal forest tree line (see Figures 1 and 2). The methodology is intended to be a conceptually simple, yet data and research-driven approach that can be drawn upon for alternate development proposals, and replicated efficiently for other areas. We wanted a common basis to compare, for example, the relative vulnerability of caribou to alternative routes. A second objective was to examine at the landscape scale, seasonal vulnerability which could be used to refine monitoring and mitigation.

Four spatial terms describe calving grounds:

1. Annual Calving Ground = the calving ground for a particular year;
2. Extent of Calving = the outer perimeter of all known annual calving grounds;
3. Annual Concentrated Calving Area = the area of relatively high use within an annual calving ground; and
4. Extent of Concentrated Calving = the outer perimeter of all known annual concentrated calving areas (the probability statement in the second part of the definition was included because it helps control the tendency for continual expansion of the extent of calving area).

Terms relative to timing

The point of peak calving is:

- when 50% of cows in the herd have calved (i.e., at peak of calving) which varies both annually and from herd to herd.

Calves can be considered independent foragers:

- at about three weeks of age (based on expert opinion), but this varies by herd; agreed on the standard approach of using three weeks after peak of calving.

Bathurst herd

The earliest dates (3-6 June) and the latest dates (11-15 June) for peak of calving (Sutherland and Gunn 1996) reveal the annual variation and the extent of calving is 24 June to 13 July is three weeks after the peak.

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2. Methods

The analysis consists of mapping several spatial data sets, or layers, of caribou satellite collar telemetry and habitat which are normalized to a common index, weighted in terms of their relative importance in determining risk to caribou populations as a result of disturbance, and averaged together to produce a composite vulnerability index map.

Ecological variables that can serve as indicators to caribou herd health have been identified by Griffith et al. (2002) to include vegetation type and Normalized Difference Vegetation Index (NDVI). Based on this research, these are used to determine the suitability of habitat for caribou herds within the area surrounding the proposed BIPAR road alignment. The WKSS West Kitikmeot / Slave Study Society vegetation classes as classified by Mathews et al. (2001) and interpreted by Griffith et al., 2002, and Johnson et al., 2005 did not have sufficient spatial coverage of the study area. Other habitat data considered for analysis was the Circumpolar Arctic Vegetation Mapping (CAVM) data, however this was difficult to calibrate to existing studies for interpreting habitat class value to caribou populations, and is of more coarse resolution. Satellite-collar data for the Ahiak and Bathurst caribou herds throughout 1996 – 2008 is also used to spatialize the historical use of this habitat within the study area. Gunn et al. (2008) provide a comprehensive review of this telemetry data. This data set is used to determine the relative probability of occurrence of caribou herds in the study area. The following indicators layers will be used in this analysis:

a. **Indicator: NDVI**. Normalized Difference Vegetation Index data was collected over the summers (July 11th to August 31st) of 1993 and 1995, accessed from the University of Alaska, Fairbanks (see CAVM, last accessed 2009).

b. **Indicator: Caribou Telemetry.** Ahiak and Bathurst herd telemetry data is split into temporal (seasonal) ranges as defined by Gunn et al., 2008 (see Table 1) to allow for a seasonal analysis of caribou vulnerability. To reflect the variation in vulnerability associated with these seasonal distributions, and the differential impact these have on a final map of caribou vulnerability, weightings were assigned to the seasonally separated telemetry data (see Tables 2 and 3 respectively) for the subsequent analysis.

Table 1: Seasonal Break-down of caribou herd telemetry data (Gunn et al., 2008)

Season	Start date	End date
Calving	3-Jun	13-Jun
Extent of calving	14-Jun	5-Jul
Summer	6-Jul	22-Aug

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Fall - Winter	23-Aug	14-Apr
Spring	15-Apr	2-Jun

Table 2: Weightings and rationale for weightings of seasonal Ahiak telemetry data

Season	Weightings	Rationale
Calving	3	
Extent of calving	2.5	
Summer	2	
Fall – Winter	1	
Spring	1.5	

Table 3: Weightings and rationale for weightings of seasonal Bathurst telemetry data

Season	Weightings	Rationale
Calving	3	
Extent of calving	2.5	
Summer	2	
Fall – Winter	1	
Spring	1.5	

Maps for all of the above variables were produced which were rasterized to a 1 km^2 grid to provide cell values which could then be translated to a vulnerability index. Index values from 1 – 10 for are ascribed for all terrain in the study area, with 1 being areas where caribou would be the least sensitive to road development, and 10 being areas where caribou would be the most sensitive to road development.

a. **Indicator: NDVI.** Original NDVI values ranged on a scale from 1 to 8, with higher values indicating more productive vegetation cover (see Figure 3). Griffith et al., 2002,

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point out that caribou cows and calves rely on areas of high green plant biomass during the calving and extent of calving periods. These NDVI values were translated to a range from 1 to 10, to match the vulnerability indices for the other indicators.

b. **Indicator: Caribou Telemetry.** The attribute information in the telemetry data for several cows suggested some were incorrectly assigned to herds. Caribou are assigned to a herd based on where they spend the calving and extent-of-calving seasons. The incorrectly labeled cows points were manually corrected by changing which herd they were assigned to or by removing them from the analysis. Table 4 shows which cows these were and the corresponding action, and Figure 4 shows the location of the Bathurst calving ground (From Cizek, 2003). The complete Bathurst and Ahiak herd telemetry data sets are shown in Figures 5 and 6.

Table 4: Showing modifications to the Ahiak and Bathurst telemetry data due to incorrect herd assignment

PARM PTT	ID Number	Year	Issue	Action
75026	202	2008	Outside of Bathurst and Ahiak Calving and Extent of Calving ranges	Removed from Bathurst dataset
55200	192	2005	Outside of Bathurst and Ahiak Calving and Extent of Calving ranges	Removed from Bathurst dataset
45902	167	2006	Outside of Bathurst and Ahiak Calving and Extent of Calving ranges	Removed from Bathurst dataset
55209	194	2008	Spends Calving and Extent of Calving seasons in Ahiak range	Moved from Bathurst to Ahiak dataset
55188	180	2008	Spends Calving and Extent of Calving seasons in Ahiak range	Moved from Bathurst to Ahiak dataset
64387	308	2007, 2008	Spends Calving and Extent of Calving seasons in Bathurst range	Moved from Ahiak to Bathurst dataset

A translation of individual caribou collar telemetry points into continuous patches of use-area is necessary to more realistically represent caribou herd behavior. To achieve this, a Kernel Density Estimator was performed for the seasonal Ahiak and Bathurst herd telemetry datasets using ESRI ArcGIS extension Hawth's Tools. The datasets for these two herds were each filtered into seasonal subsets, generating 10 telemetry sub datasets in total. The parameters of this Kernel Density Estimator analysis were adjusted iteratively. Higher density cluster areas

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indicate the relative importance of particular habitat areas for caribou foraging as a result of the presence of larger caribou populations or durations of foraging occurring there. The percent volume contours were calculated which represent the boundaries of areas which contain 25%, 50%, 75% and 100% of the caribou herd GPS points. A 100% volume contour indicates the smallest area which would contain 100% of the caribou collar locations, or the least dense probability distribution. The 25% contour represents the smallest area to contain 25% of the caribou collar points, or the most dense calculated density distribution. These contour layers were converted to rasters with a consistent spatial extent which was equal to the minimum sized rectangle necessary to contain all caribou telemetry points (shown in Figures 5 and 6 as the "Greater Study Area"). Indexes were assigned by redistributing these percent contour values along a range of 1 – 10 (see Table 5 for vulnerability index assignment), and then mapped (see Figures 7 – 16) for incorporation with the other indicator layers to generate a final landscape vulnerability map (Figure 17).

Table 5: Kernel density estimator percent volume contours, and associated vulnerability indexes

Percent volume contour	Vulnerability Index
25	10
50	7.5
75	5
100	2.5
Greater Study Area Boundary	0

The vulnerability indexes of all indicator map layers are averaged, with each layer having unique weights or impact on the final composite vulnerability score for all terrain within the study area (Table 6).

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Table 6: All indicator layers and corresponding weightings used to generate scores for the vulnerability landscape map

Vulnerability Indicator Layer	Weightings
Ahiak telemetry - Calving	3
Ahiak telemetry - Extent of calving	2.5
Ahiak telemetry - Summer	2
Ahiak telemetry - Fall–Winter	1
Ahiak telemetry - Spring	1.5
Bathurst telemetry - Calving	3
Bathurst telemetry - Extent of calving	2.5
Bathurst telemetry - Summer	2
Bathurst telemetry - Fall–Winter	1
Bathurst telemetry - Spring	1.5
NDVI	1

All indicator layers are inputs for a weighted average calculation, culminating in a cumulative "vulnerability landscape" map which identifies the areas where disturbance would pose the greatest risk to caribou herds (Figures 17). Index values between 0.95 and 5.62 were observed

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throughout the landscape from this weighted average calculation. This indexed map was reclassed to 10 equal interval classes, providing a range from 1 – 10 in the final map (Figure 18).

Proposed road alignments for the BIPAR, East of Kugluktuk (EOK) and Grays Bay Port and Road (GPAR) were received from MMG Minerals and Metals Group. The vulnerability landscape map area within a 20km zone-of-influence buffer around these proposed road alignments is examined (Figure 19). Profiles and summary statistics for the vulnerability scores of habitat within these 20km BIPAR, EOK and GPAR zone-of-influence areas is shown in Figures 20 and 21.

This vulnerability landscape map may be seen as a map which expands or contracts the ecological footprint of the proposed road depending on its crossing over terrain which received higher or lower vulnerability scores respectively. In effect, it gives an indication on relative road corridor widths and corresponding habitat loss from the perspective of the Ahiak and Bathurst caribou herds. This map could be used in subsequent studies to assess:

1. Alternate indicators (input map layers for the vulnerability landscape map)
2. Alternate weightings (to assign different importance to indicators map layers)
3. Alternate road alignments (to overlay onto the existing vulnerability landscape map, and compare to vulnerability profile for the alignments shown in Figure 20)
4. Subsequent development which would spawn as a result of BIPAR or other proposed roads
5. The targeting of mitigation efforts to areas with higher vulnerability scores for caribou populations.

This assessment could also be used as an input driver for ongoing modeling by Johnson (in progress) that explores the cascading impacts of development on environmental change and caribou population demographics.

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3. Figures

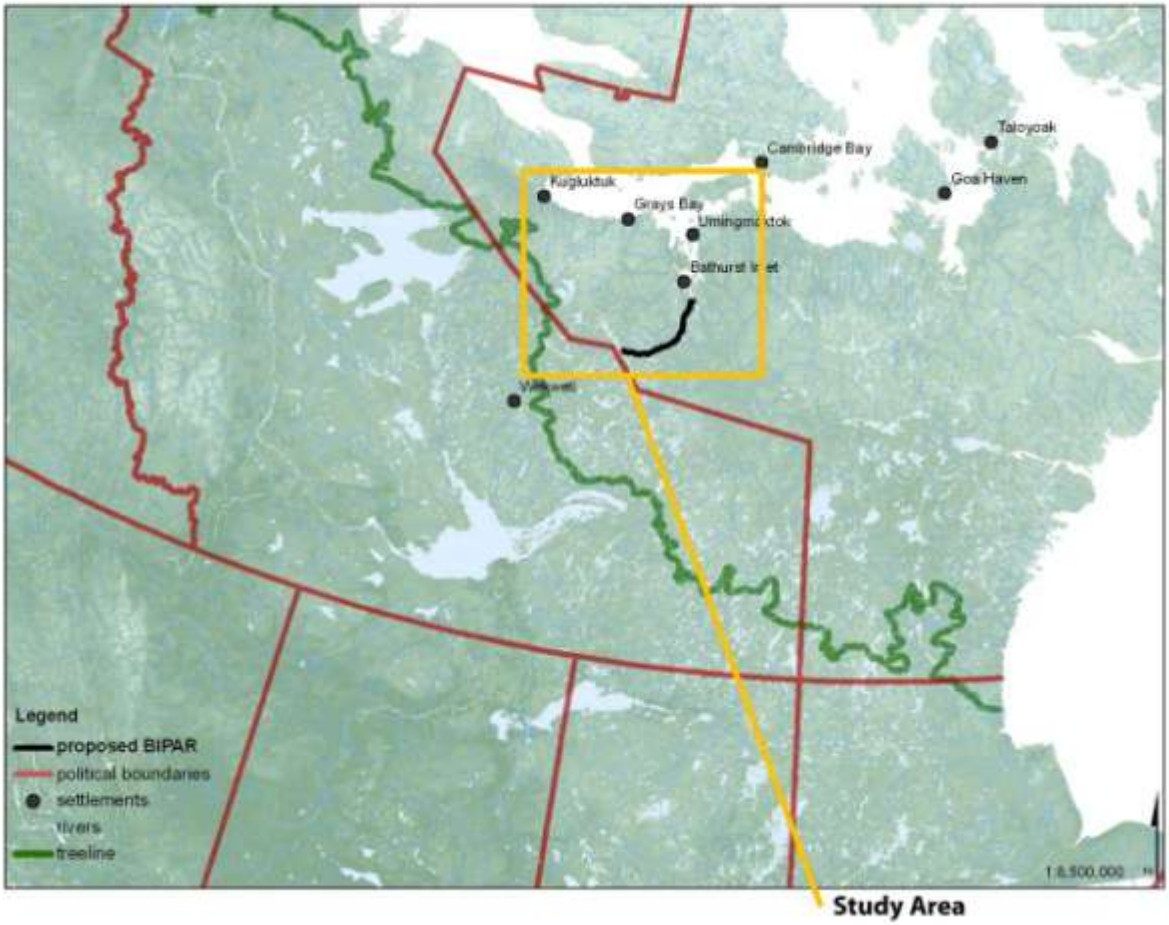

Figure 1: Proposed Bathurst Inlet Port and Road (BIPAR) and northern extent of treeline within Northwestern Canada

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Figure 2: Project study area, which resides within the area bounded by the treeline, northern coastline and western coast of Bathurst Inlet

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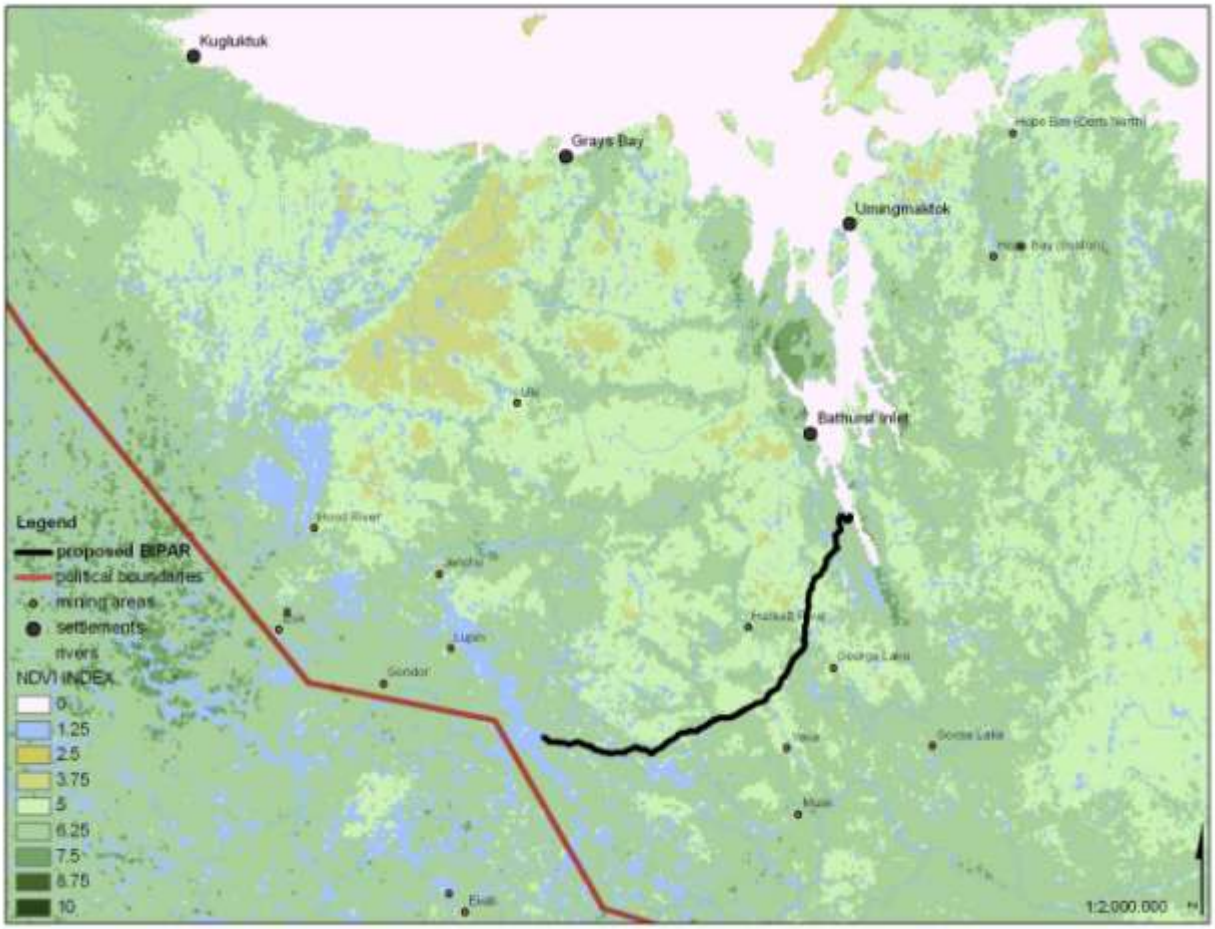

Figure 3: NDVI mapping translated to Vulnerability Index (772m x 772m)

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Figure 4: Extent of Bathurst herd calving ground from 1996 - 2002 (source: Cizek, 2003)

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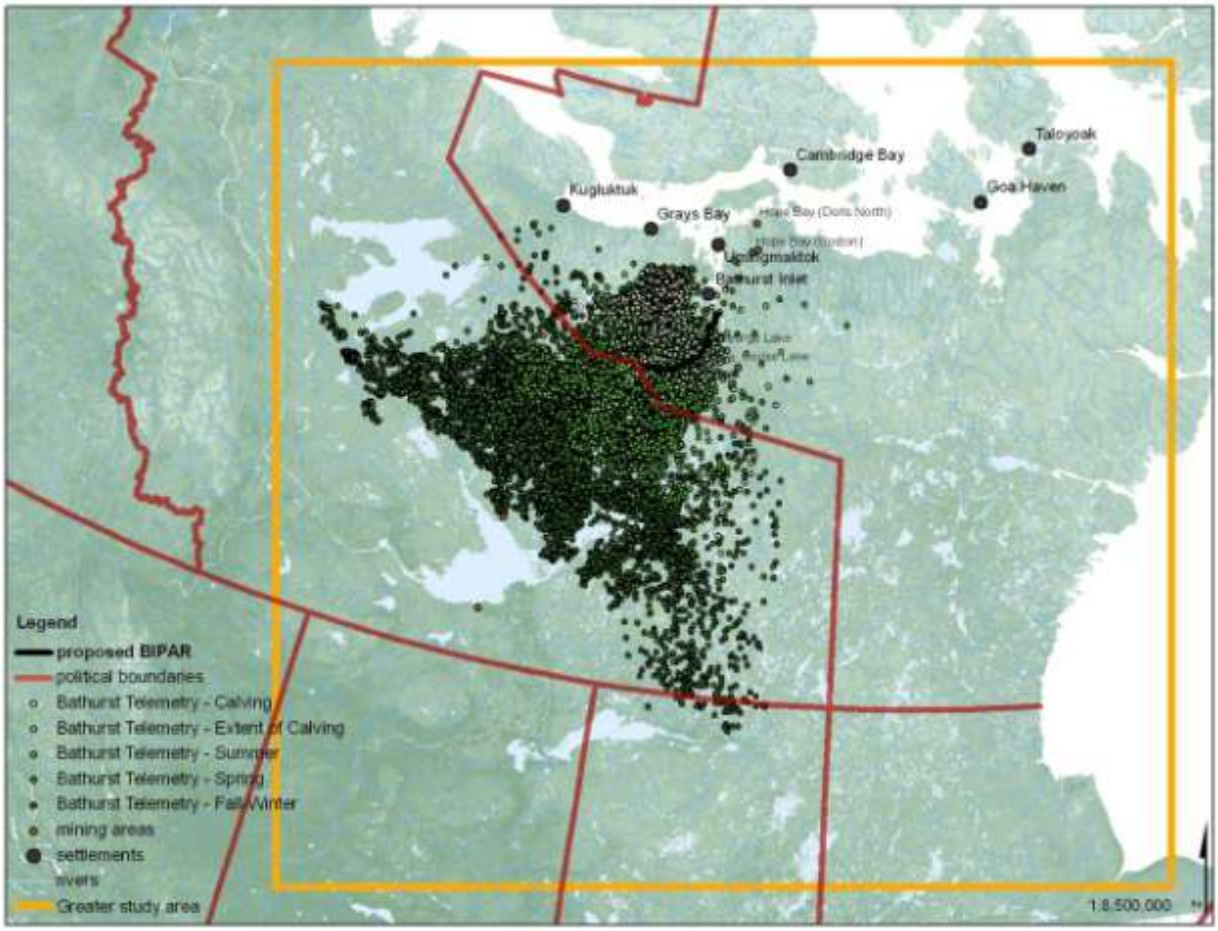

Figure 5: Bathurst herd telemetry data set from 1996 - 2008, organized by season

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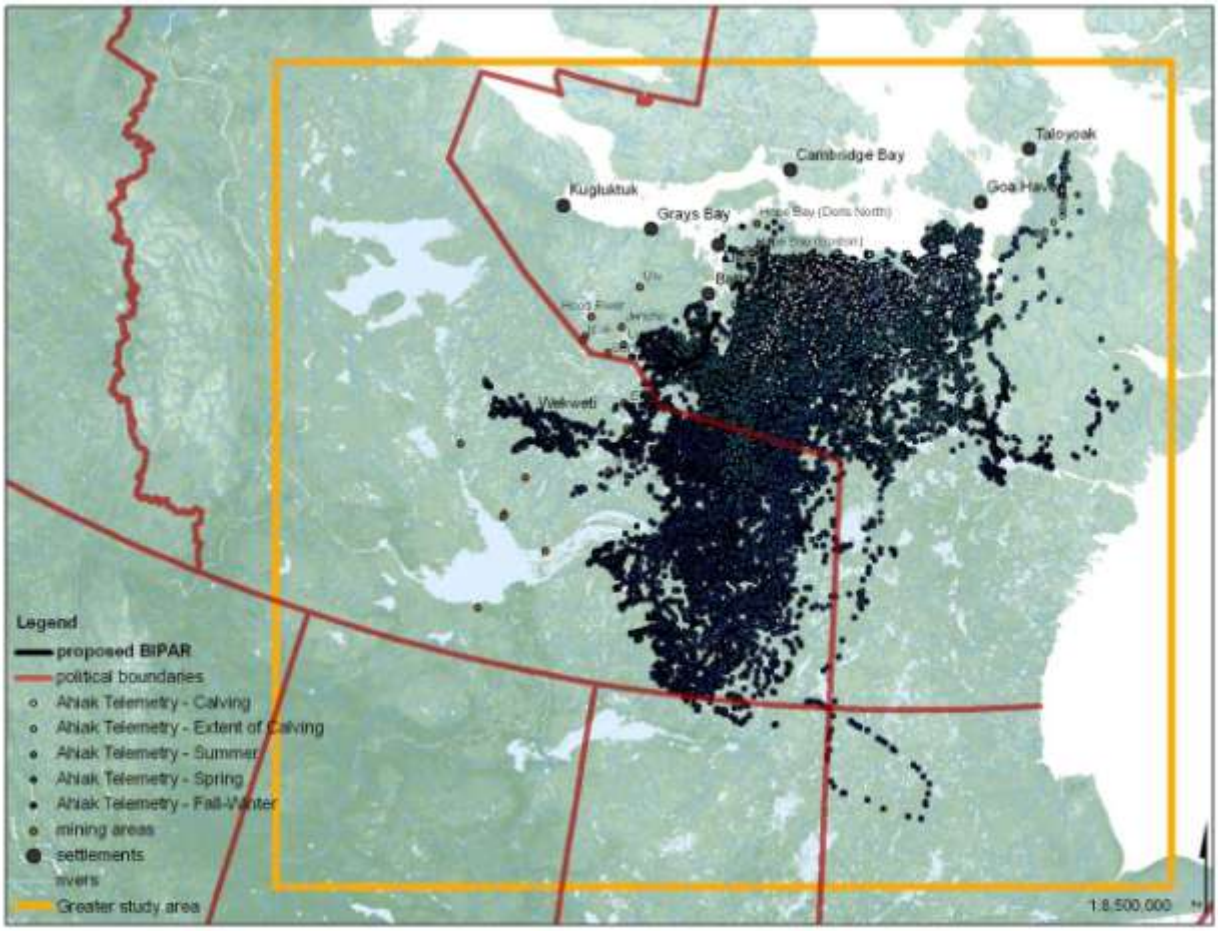

Figure 6: Ahiak herd telemetry data set from 1996 - 2008, organized by season

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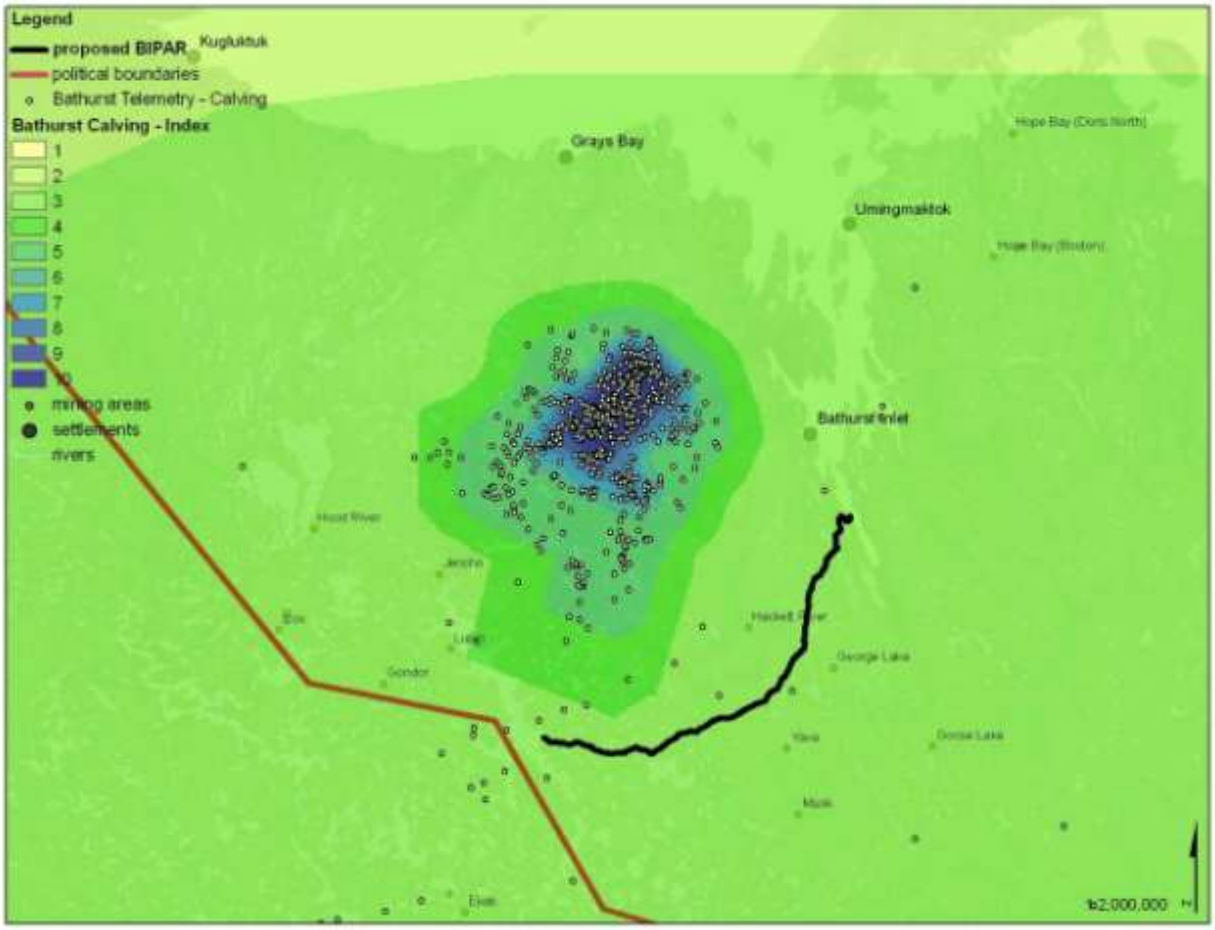

Figure 7: Results of the Kernel Density Estimator for the Bathurst caribou herd calving range (shades of blue), along with individual caribou collar telemetry GPS points during the calving season (points)

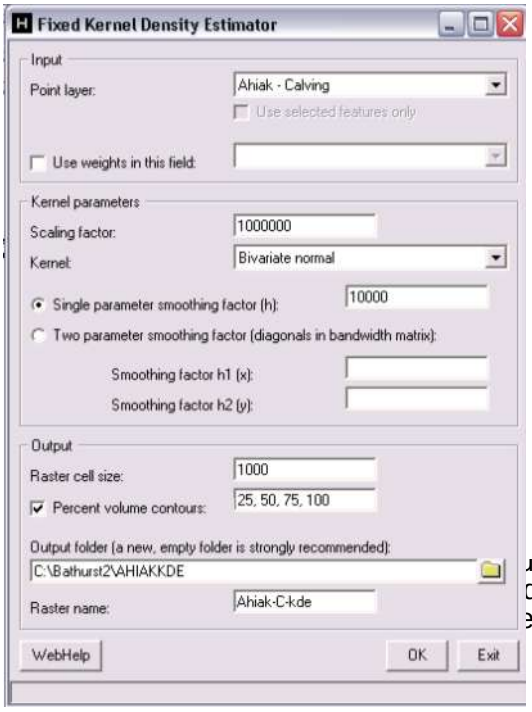

Image inset: Parameters for Hawth's Tools Fixed Kernel Density Estimator (Figures 5 – 9), cell size: 1000m x 1000m

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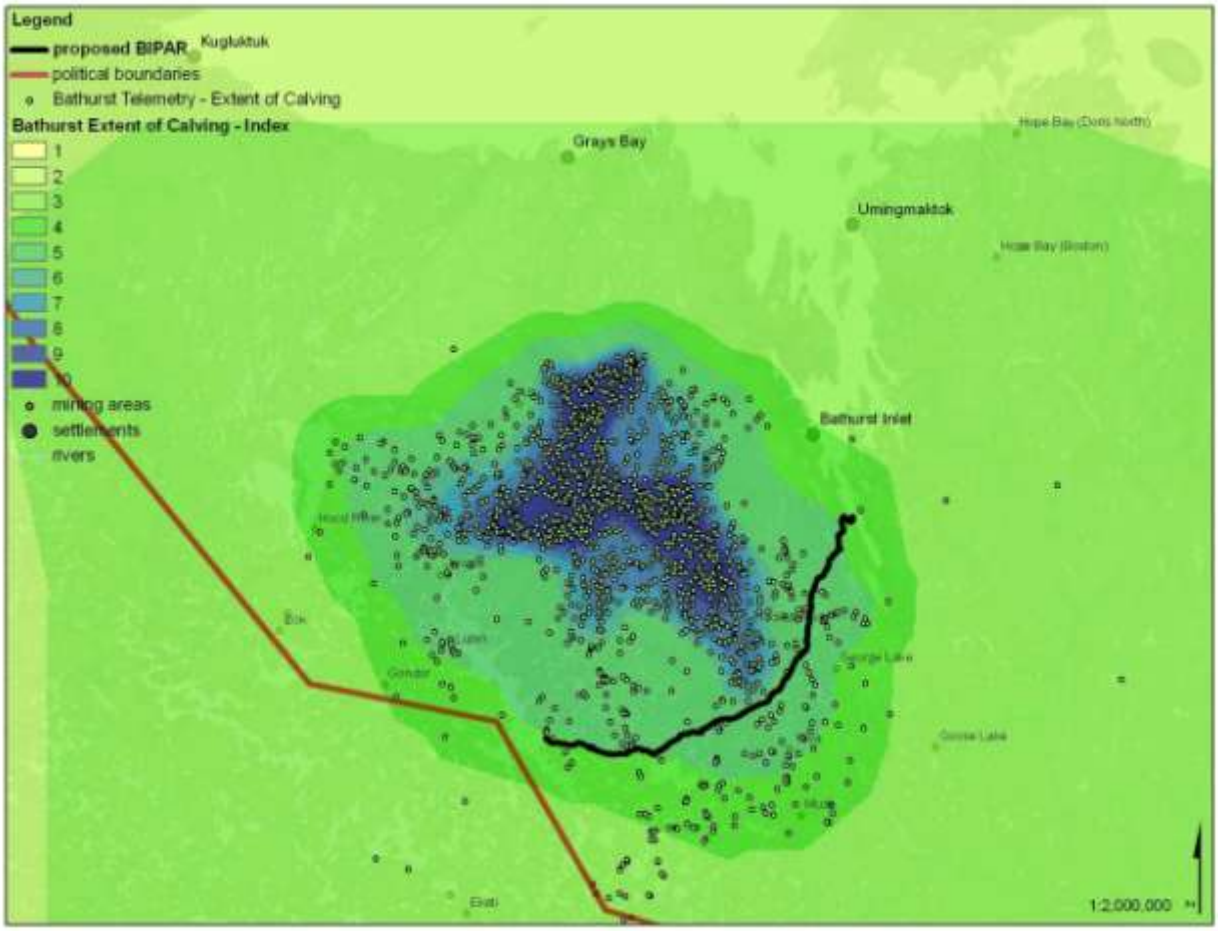

Figure 8: Results of the Kernel Density Estimator for the Bathurst caribou herd extent of calving range (shades of blue), along with individual caribou collar telemetry GPS points during the extent of calving season (points)

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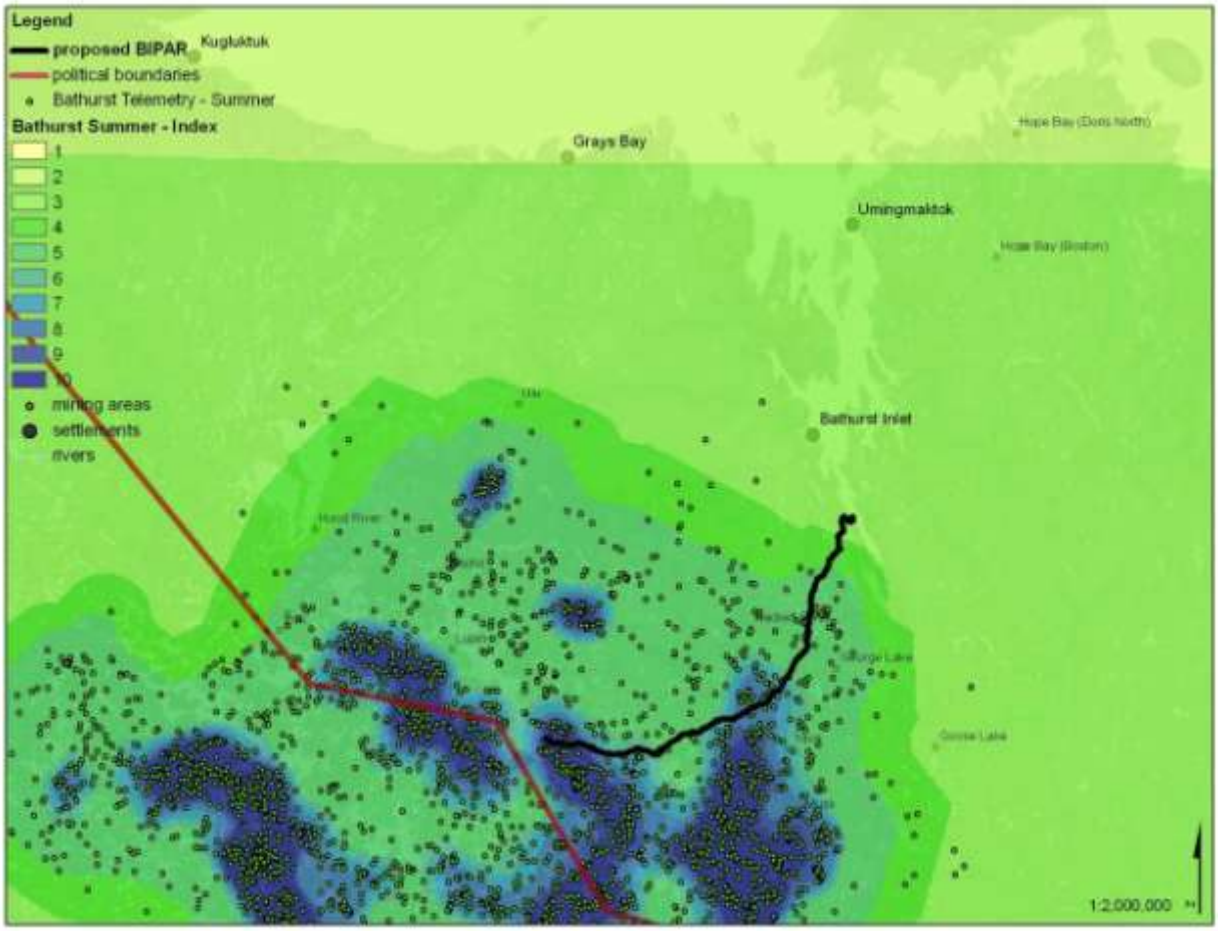

Figure 9: Results of the Kernel Density Estimator for the Bathurst caribou herd summer range (shades of blue), along with individual caribou collar telemetry GPS points during the summer season (points)

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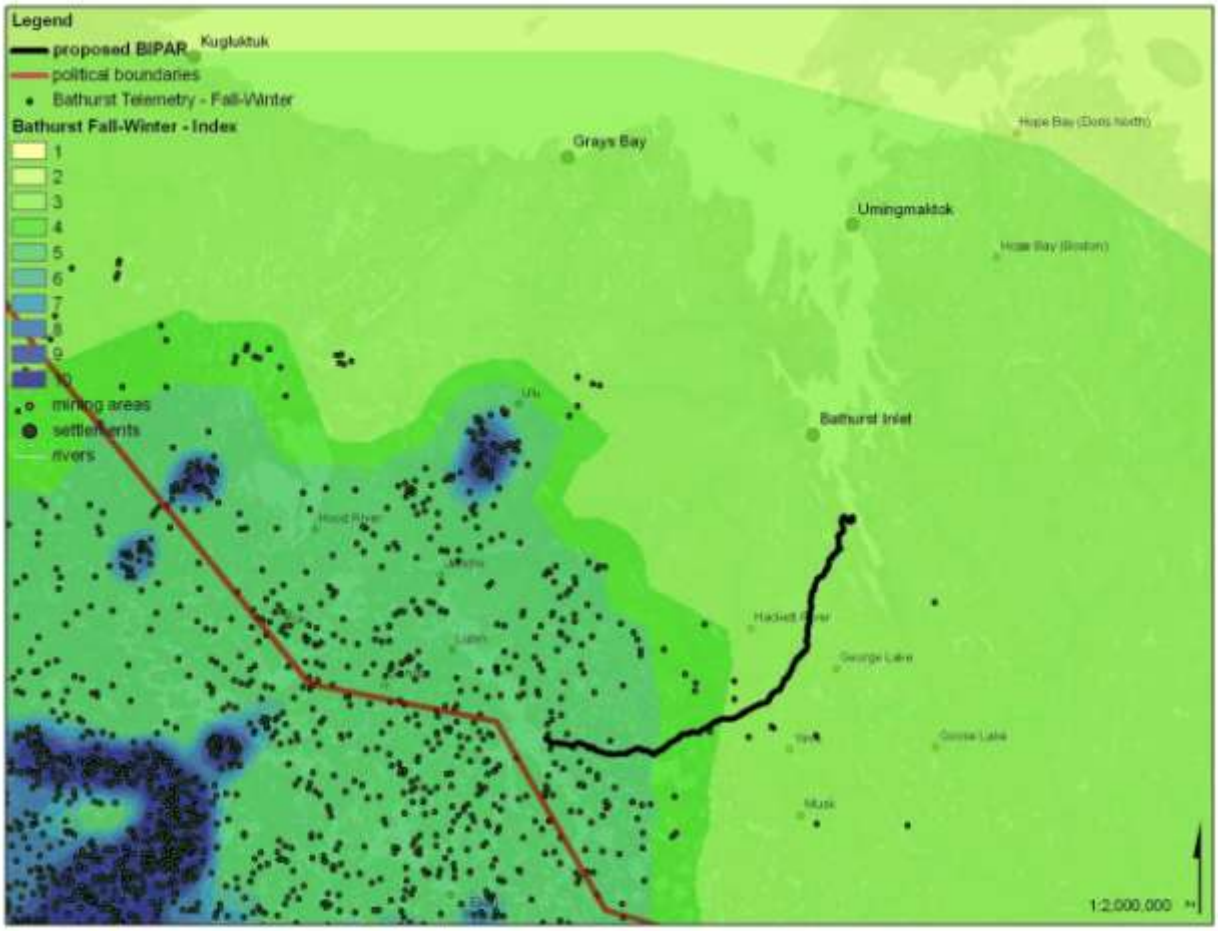

Figure 10: Results of the Kernel Density Estimator for the Bathurst caribou herd fall-winter range (shades of blue), along with individual caribou collar telemetry GPS points during the extent of fall-winter season (points)

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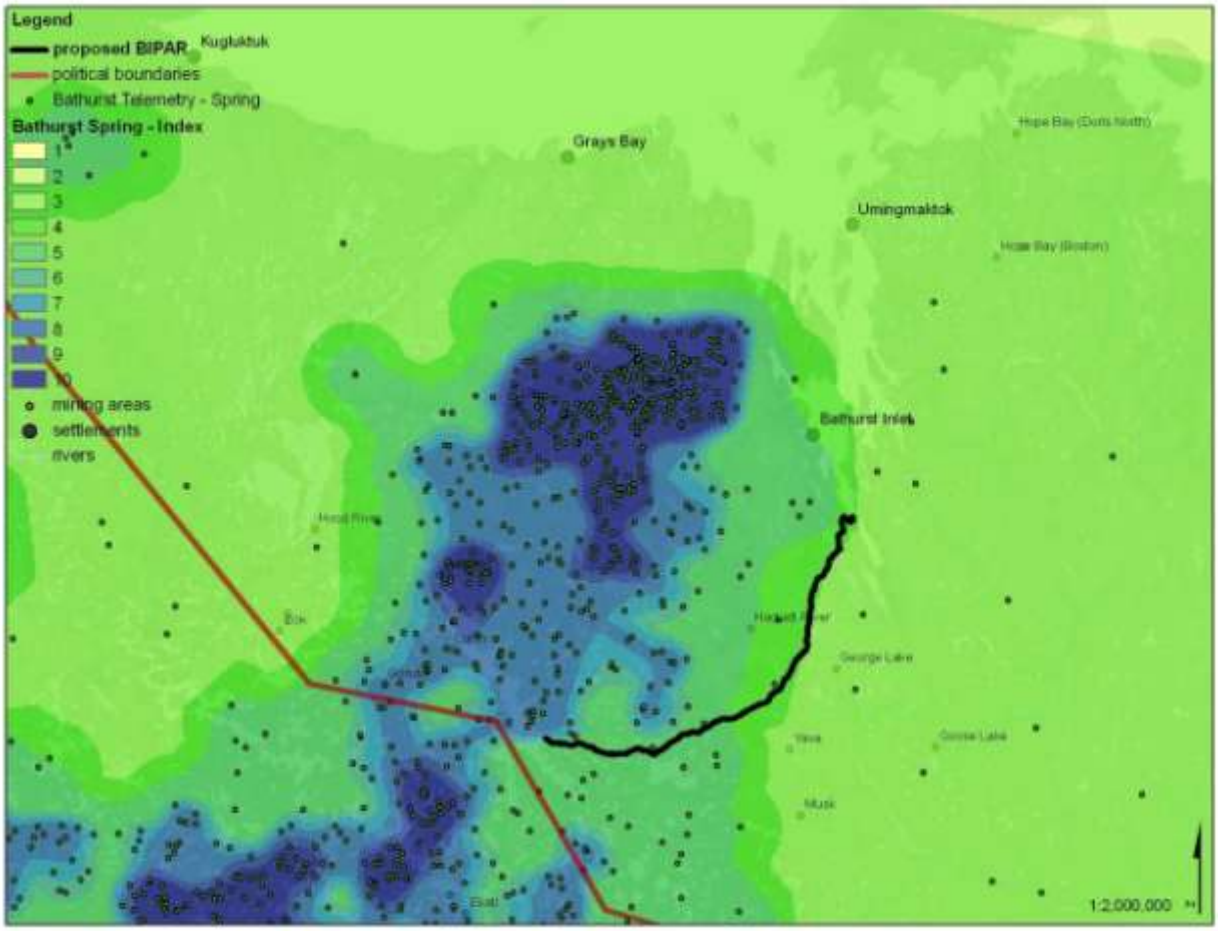

Figure 11: Results of the Kernel Density Estimator for the Bathurst caribou herd spring range (shades of blue), along with individual caribou collar telemetry GPS points during the spring season (points)

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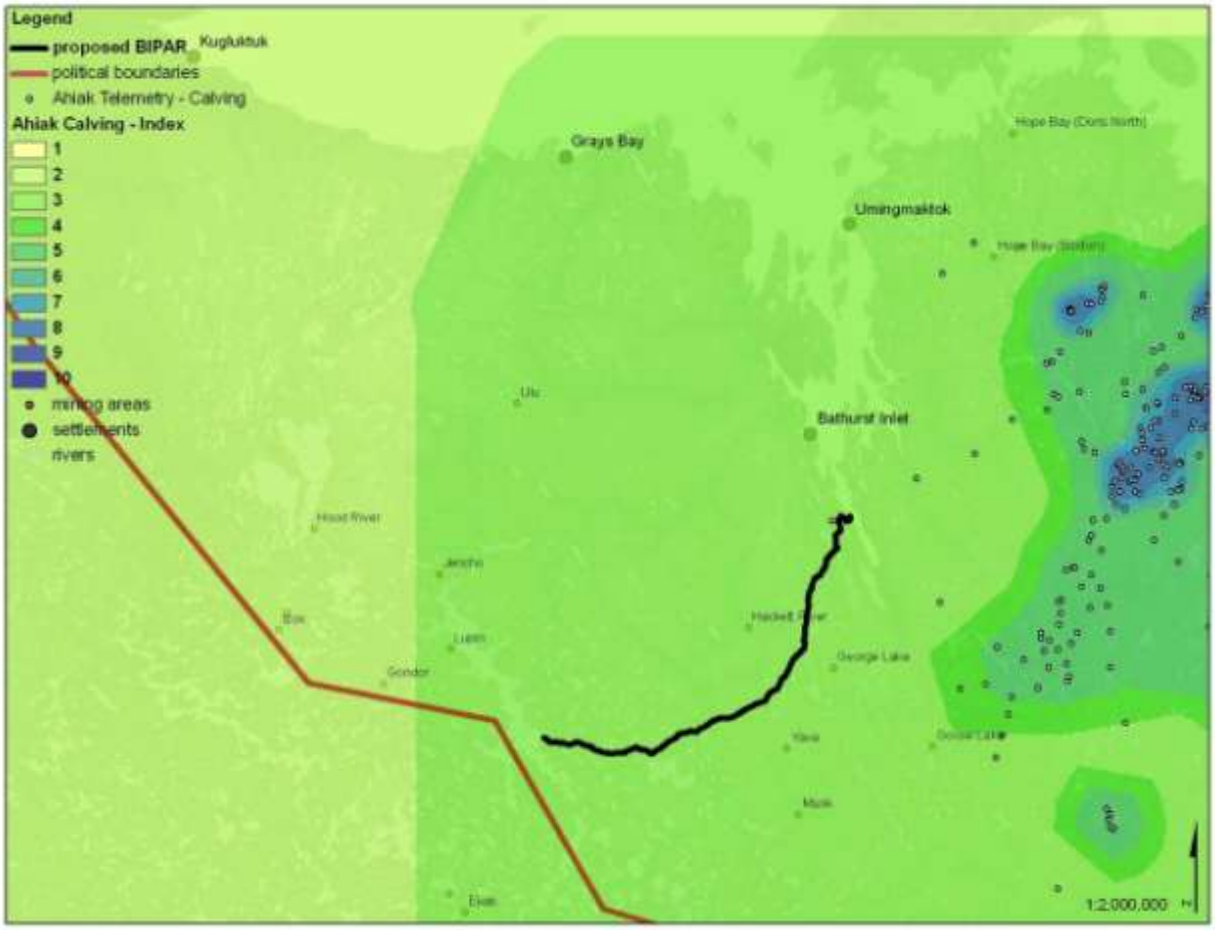

Figure 12: Results of the Kernel Density Estimator for the Ahiak caribou herd calving range (shades of blue), along with individual caribou collar telemetry GPS points during the calving season (points)

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Figure 13: Results of the Kernel Density Estimator for the Ahiak caribou herd extent of calving range (shades of blue), along with individual caribou collar telemetry GPS points during the extent of calving season (points)

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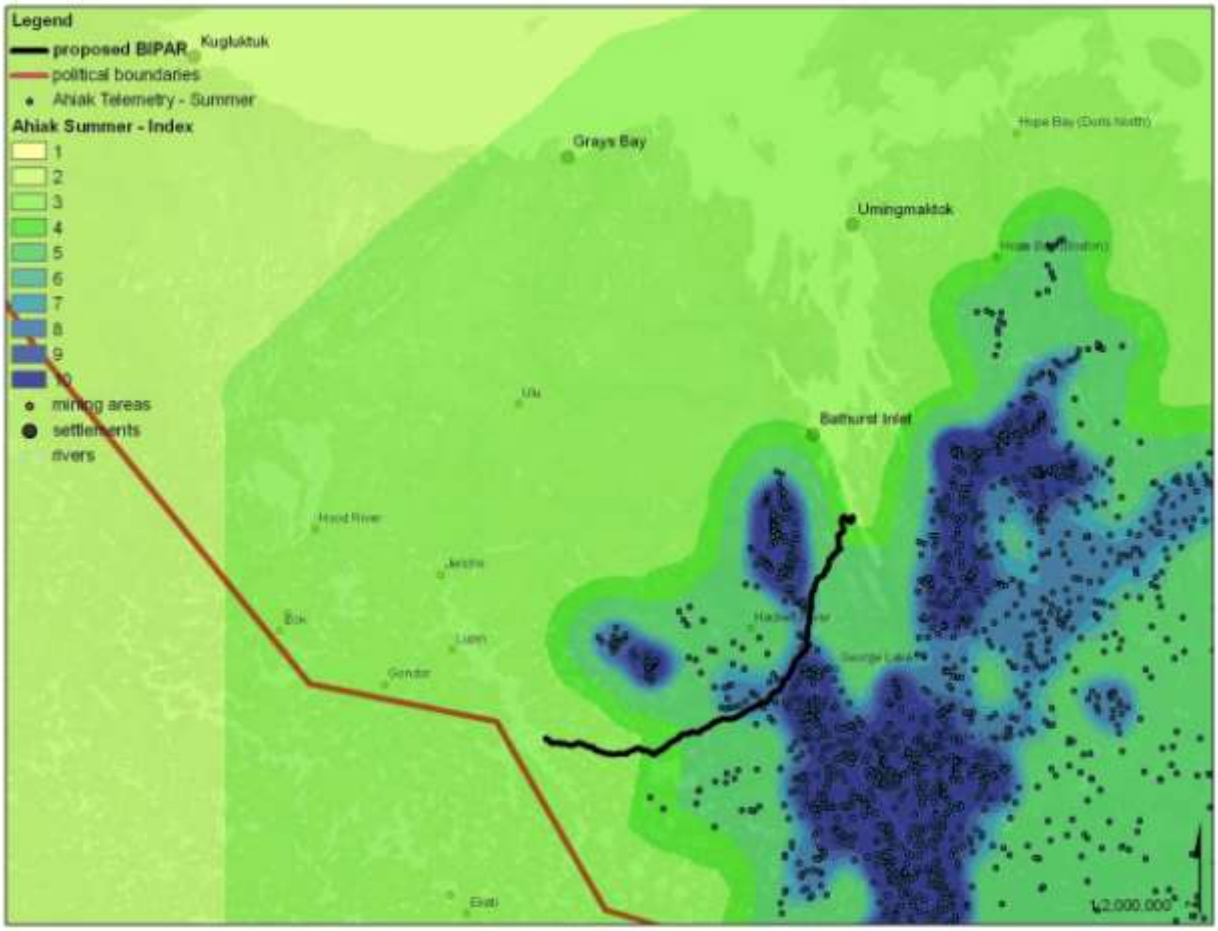

Figure 14: Results of the Kernel Density Estimator for the Ahiak caribou herd summer range (shades of blue), along with individual caribou collar telemetry GPS points during the summer season (points)

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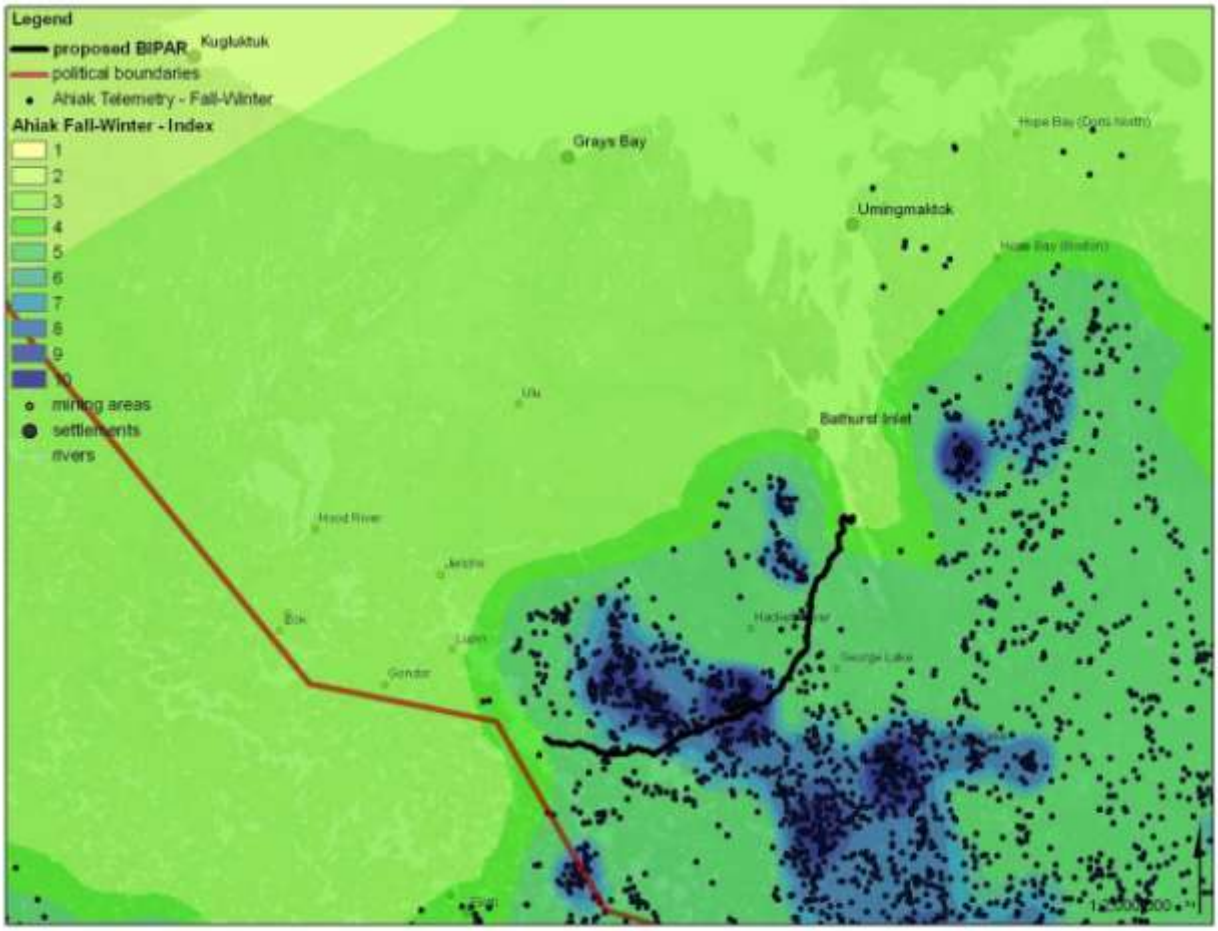

Figure 15: Results of the Kernel Density Estimator for the Ahiak caribou herd fall-winter range (shades of blue), along with individual caribou collar telemetry GPS points during the fall-winter season (points)

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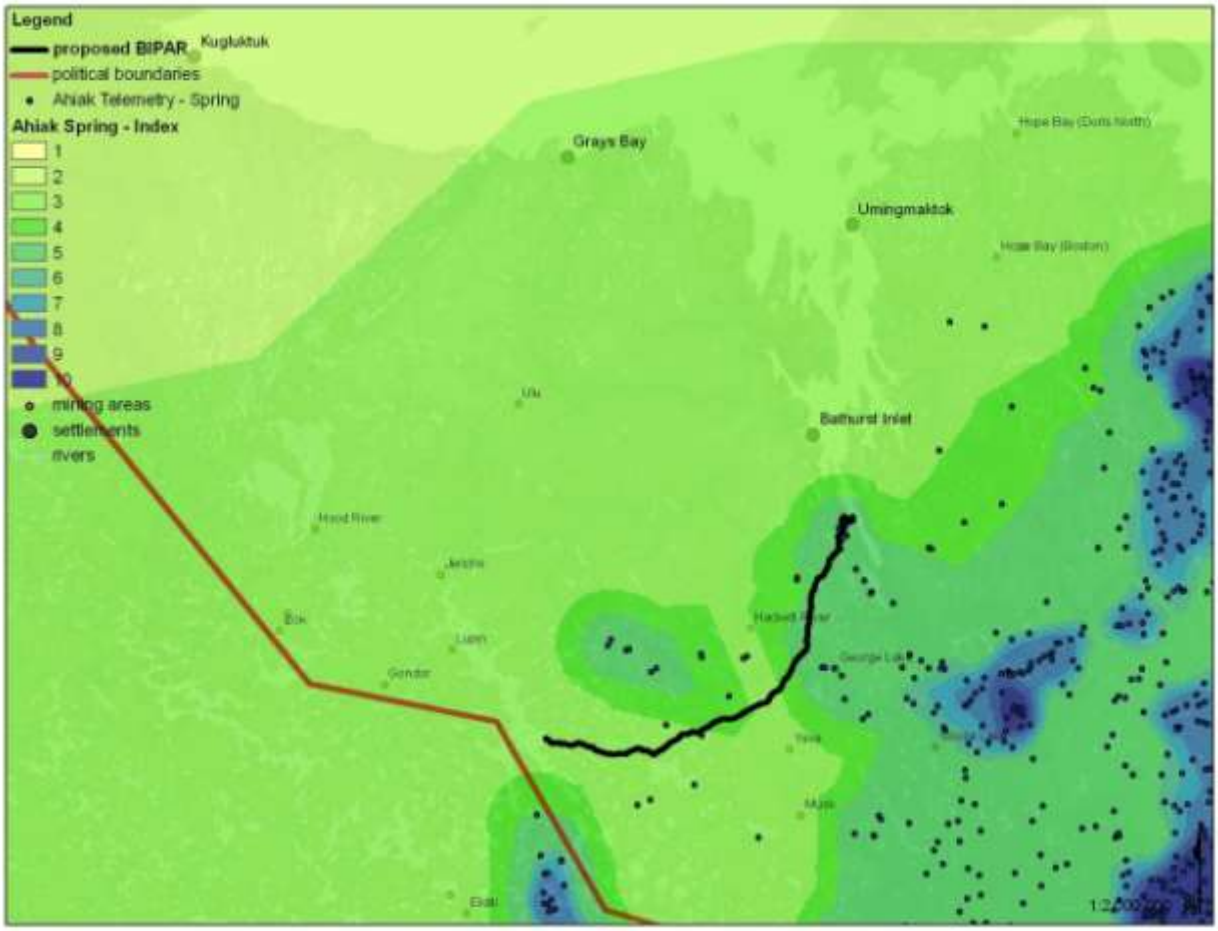

Figure 16: Results of the Kernel Density Estimator for the Ahiak caribou herd spring range (shades of blue), along with individual caribou collar telemetry GPS points during the spring season (points)

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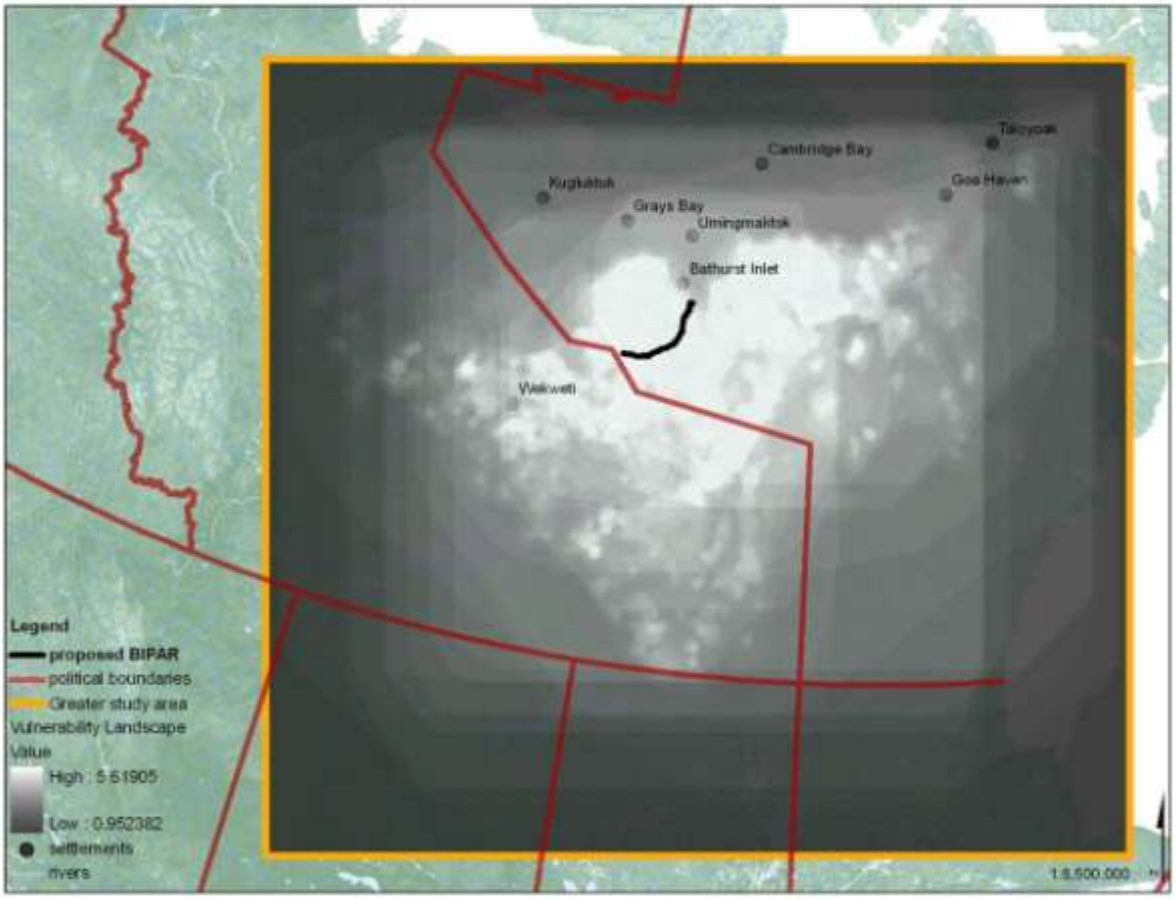
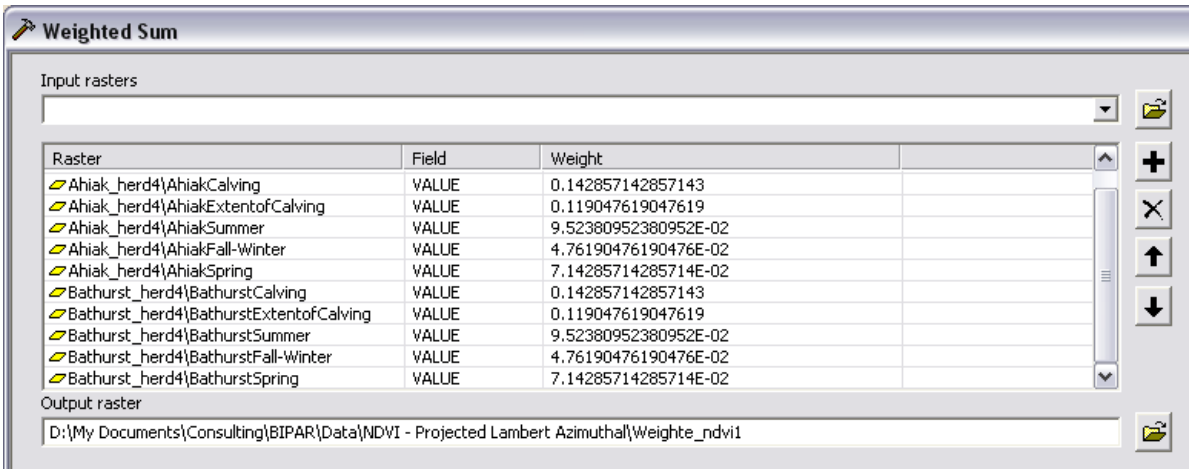


Figure 3: The caribou landscape vulnerability map, with values representing the average vulnerability indexes for the NDVI, WKSS, and seasonal Ahiak and Bathurst telemetry Kernel Density Estimators



Weighted Sum

Input rasters

Raster	Field	Weight
Ahiak_herd4\AhiakCalving	VALUE	0.142857142857143
Ahiak_herd4\AhiakExtentofCalving	VALUE	0.119047619047619
Ahiak_herd4\AhiakSummer	VALUE	9.52380952380952E-02
Ahiak_herd4\AhiakFall-Winter	VALUE	4.76190476190476E-02
Ahiak_herd4\AhiakSpring	VALUE	7.14285714285714E-02
Bathurst_herd4\BathurstCalving	VALUE	0.142857142857143
Bathurst_herd4\BathurstExtentofCalving	VALUE	0.119047619047619
Bathurst_herd4\BathurstSummer	VALUE	9.52380952380952E-02
Bathurst_herd4\BathurstFall-Winter	VALUE	4.76190476190476E-02
Bathurst_herd4\BathurstSpring	VALUE	7.14285714285714E-02

Output raster

D:\My Documents\Consulting\BIPAR\Data\NDVI - Projected Lambert Azimuthal\Weighte_ndvi1

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Image inset: Parameters for ESRI ArcGIS Spatial Analyst's Weighted Sum Overlay (Figures 26 - 28). Cell size: 1000m x 1000m. Assigned "Weight" values are from weightings shown in Tables 2 and 3, scaled to match the weighted sum algebraic formula.

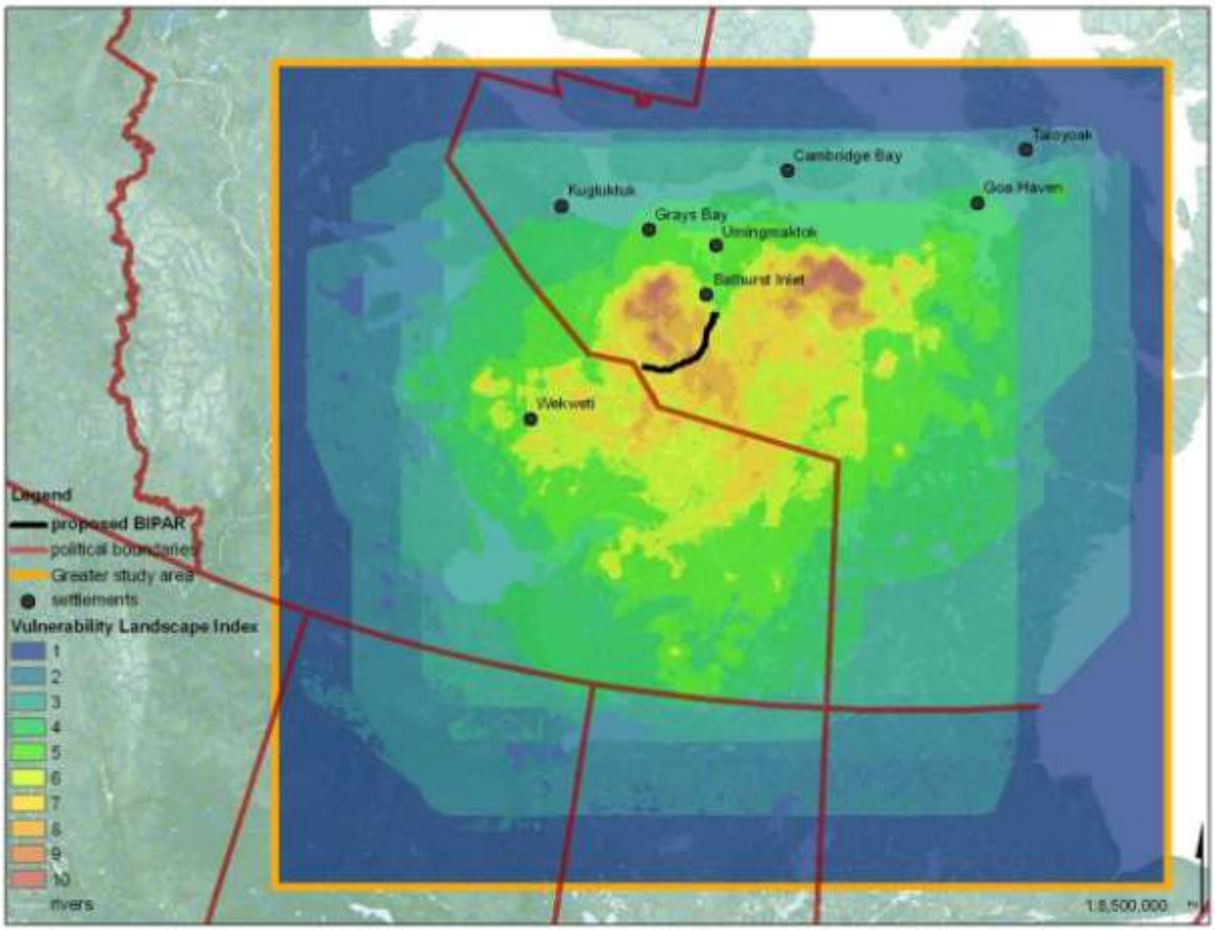

Figure 18: The caribou landscape vulnerability index map, with values representing the average vulnerability indexes for the NDVI, WKSS, and seasonal Ahiak and Bathurst telemetry Kernel Density Estimators, re-distributed along a range from 1 – 10.

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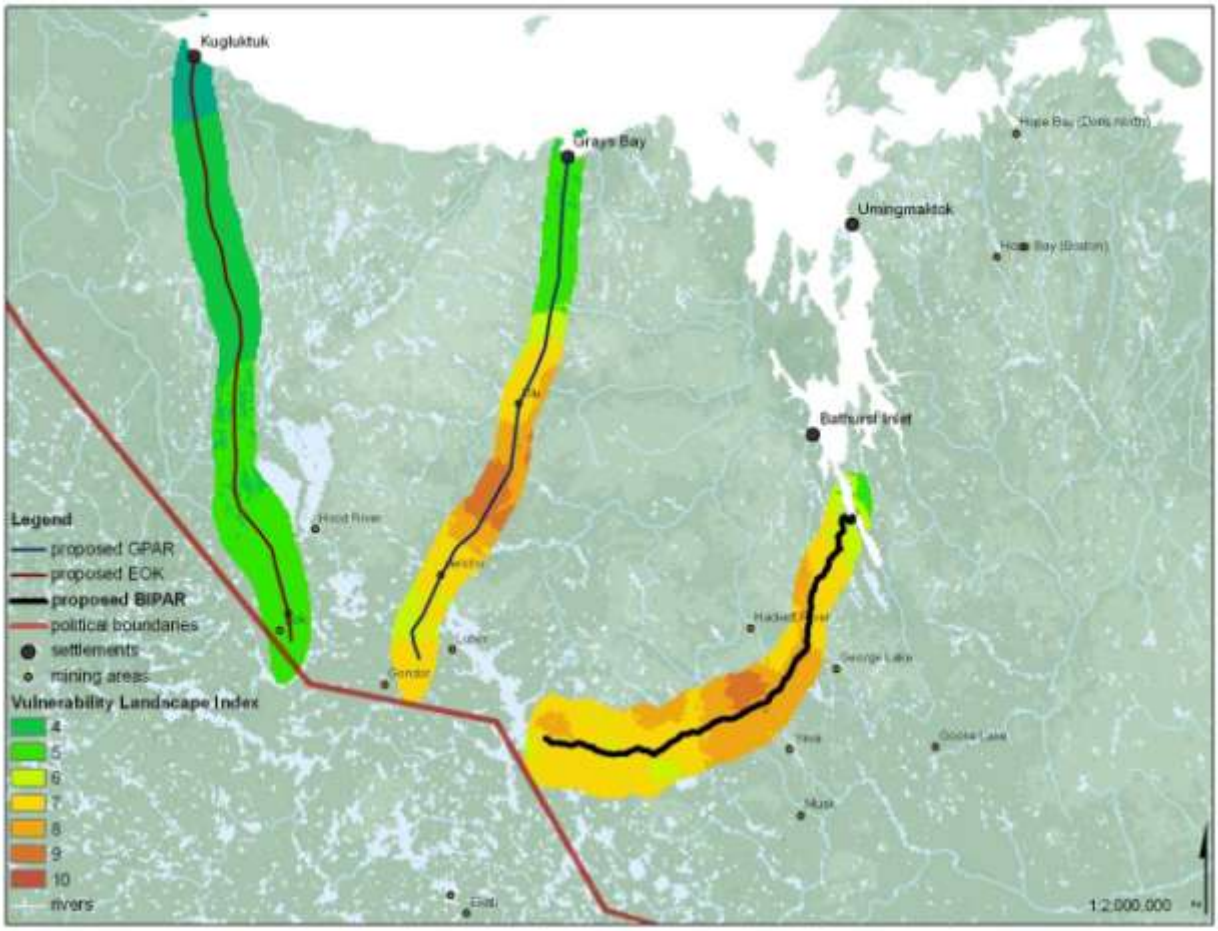

Figure 19: Areas of the caribou landscape vulnerability map within 20 km of the BIPAR, Grays Bay Port and Road (GPAR), and East of Kugluktuk (EOK) proposed road alignments.

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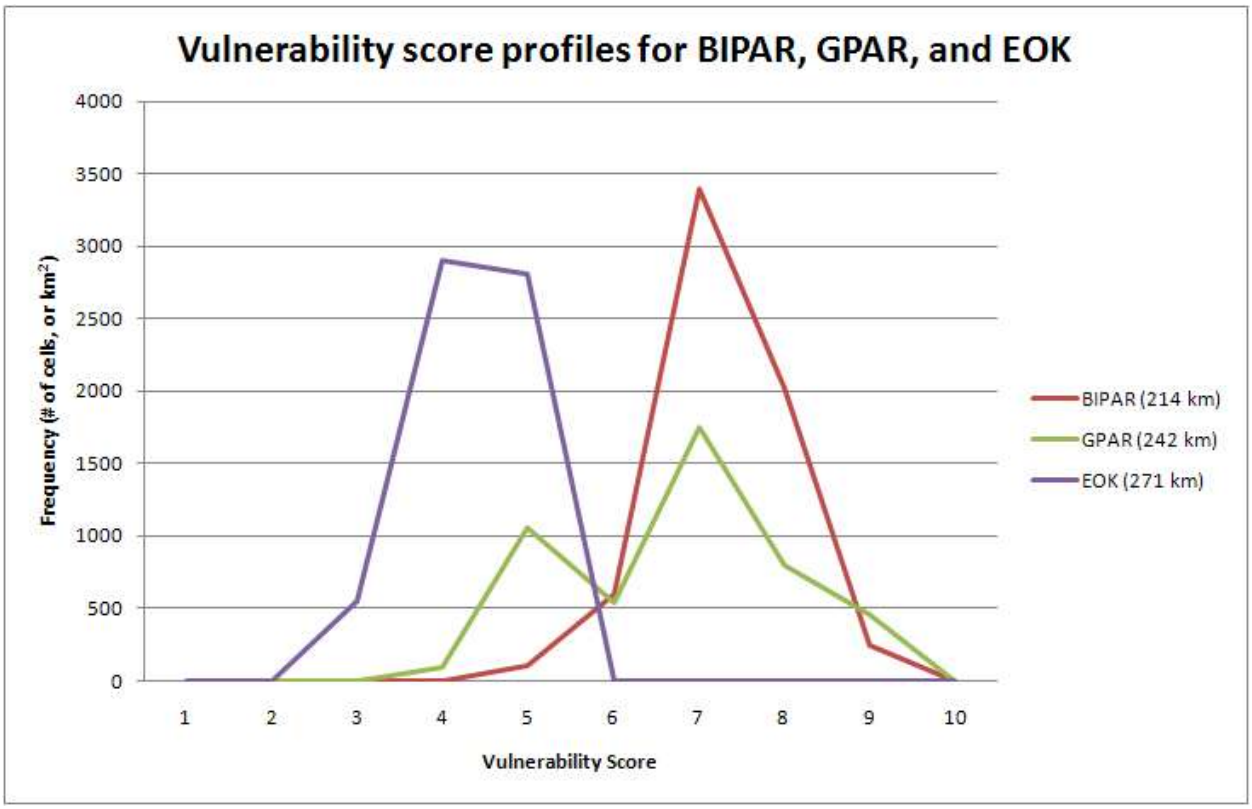

Figure 20: Profile of vulnerability scores for habitat within 20km zone-of-influence of proposed BIPAR, GPAR and EOK road alignments

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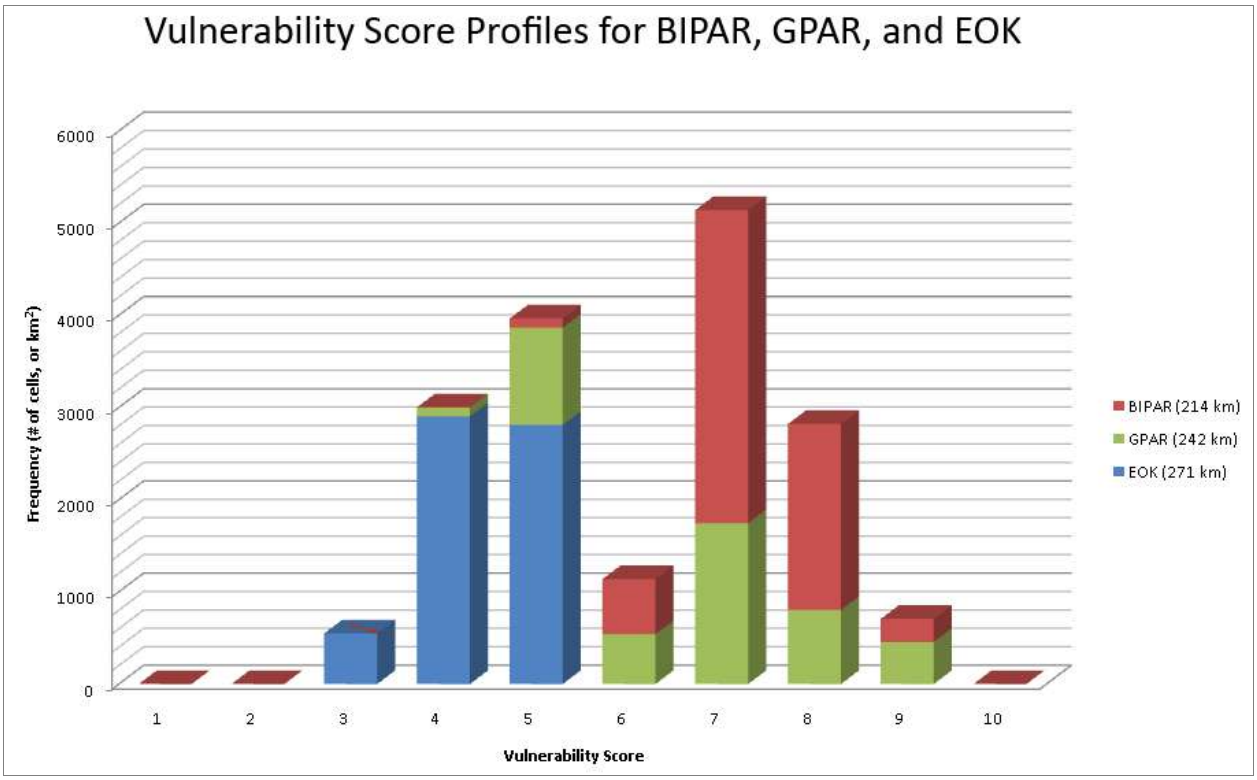

Figure 21: Profile of vulnerability scores for habitat within 20km zone-of-influence of proposed BIPAR, GPAR and EOK road alignments

	BIPAR	GPAR	EOK
Sum of Vulnerability Scores	46,264	31,649	27,313
Median Vulnerability Score	7	6.5	4
Modal Vulnerability Score	7	7	4
Average Vulnerability Score per grid cell (1 km2):	7.3	6.7	4.4
Sum of Vulnerability Scores per km of road:	216.2	130.8	100.8

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