# Analyzing cumulative effects from human development on reindeer habitat in Sweden

*An approach from Canadian Caribou Recovery Planning*

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**Arbetsrapport 420 2014**
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**MSc. European Forestry Program**

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# Summary

*Rangifer* sp., also called reindeer or caribou, are characterized by their seasonal movements over the landscape, making them a good indicator for cumulative disturbance effects caused by human developments. This study integrates indigenous ecological knowledge from reindeer herders in northern Sweden to identify current proportions of developed reindeer range and to assess cumulative impacts of development on reindeer husbandry. Mapping revealed the study area as 16.3 % developed, within which 18.4 % of high-use areas were developed. Applying a minimum buffer distance from literature around all developments suggested impacts of 58.7 % on the winter range and 78.6 % on high-use areas. Without buffering forest harvest, impacts were 24.7 % and 24.2 % respectively. A resource selection function with herder-defined high-use area data highlighted the challenge and importance of integrating both social and ecological factors into future cumulative effects analysis.

Keywords: *Rangifer*, cumulative effects, indigenous ecological knowledge, northern development

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# 1 Introduction

## *1.1 Overview*

Arctic and northern regions are undergoing rapid change due to increased industrial exploration and exploitation. Northern development promises social and economic benefits, but also poses risk to delicate ecological and social systems. Sustainable development planning is now critical, and relies on a sound understanding of spatial and temporal systems, as well as continuous monitoring and recording of disturbance effects. Caribou or reindeer (*Rangifer tarandus* subsp.*)* are an important part of the northern environment. Caribou in North America may travel up to five thousand kilometres each year in the world’s largest terrestrial migration. Domesticated reindeer in northern Europe and Russia are part of complex socio-ecological systems supporting indigenous livelihoods (IUCN, Forbes 2013). The concept of disturbance management thresholds (DMTs) taken from the Canadian Caribou Recovery Plan (herby referred to as the Recovery Plan), offers a potential tool for balancing northern development effects on wild and herded reindeer and interconnected social systems (Environment Canada 2012).

The main aim of the study is to investigate and test DMT methodology from the Recovery Plan on reindeer husbandry systems in Sweden. As part of the DMT testing, I map and summarize disturbance and buffers in Gabna Reindeer Herding Community in northern Sweden. To support the application of DMTs I developed a buffer analysis using a resource selection function with indigenous ecological knowledge data to detect possible herded-reindeer avoidance of disturbance.

## *1.2 Background*

### 1.2.1 Northern Cumulative Effects

A warming climate and continued drive for energy and minerals is opening northern regions to new development activities. These include oil and gas, hydroelectric power, mines, forestry, transmission and transportation lines, tourism sites, population centers and windmills, among others. The relatively small physical imprint of development on the vast northern landscape becomes much larger when unseen disturbance and cumulative effects are considered. Fragmentation and wildlife avoidance zones currently affect 48 percent of areas globally, and are expected to increase 72 percent by year 2030 (UNEP 2002). The accumulated influence from development is referred to as cumulative effects, and is defined as "changes to the environment that are caused by an action in combination with other past, present, and future human actions" (UNEP 2002). Cumulative effects of northern development are difficult to assess and pose substantial risk to *Rangifer* systems. Recent studies address the need to mitigate cumulative effects at the regional level, across multiple land uses, and at different spatial and temporal scales (Holroyd 2008; Antonnen et al. 2011; Nellemann et al. 2003; Vistnes & Nellemann 2008).

### 1.2.2 *Rangifer* as an Indicator of Ecological Effects

*Rangifer* sp. are distributed across the circumpolar north, with various subspecies found in Fennoscandia, Greenland, Russia, and Canada. In North America, boreal woodland caribou (*Rangifer tarandus caribou*) populations are declining in most of their range and receding northward due to suspected habitat loss (Environment Canada 2012; Vors & Boyce 2009). Domesticated reindeer (*Rangifer tarandus tarandus*) in northern Europe face similar spatial constraints, with almost 1/3 of Sámi reindeer herding ranges severely affected or made partially inaccessible due to industrial development, infrastructures and other human activities (UNEP 2001).

While some *Rangifer* sp. are migratory and others more sedentary, all rely on spatial and temporal movement across the landscape for their survival. This movement is characterized in regional, intermediate and patch scales, called scales of selection (Senft et al.

1987; Skarin & Åhman 2014). The regional scale includes migration pathways between seasonal ranges and feeding areas. The intermediate scale refers to feeding areas that last for days, weeks and months, and the patch scale are those selected for hours or minutes. All scales of selection are affected by human-caused disturbances and can be indicated by reindeer avoidance from these disturbance sources. This movement across different spatial scales at different periods makes *Rangifer* an excellent indicator of cumulative disturbance effects. In literature, this avoidance is spatially represented by placing buffer distances around disturbance sources. Studies show avoidance at the regional scale studies to be most indicative of cumulative effects, and will be the scale of focus in this study (Vistnes & Nellemann 2008).

### 1.2.3 Sweden's Reindeer Husbandry System and Reindeer Husbandry Planning

Domesticated reindeer in Sweden (*Rangifer tarandus tarandus*) are herded within a pastoral system, but are mainly free ranging and less tolerant of humans in comparison with other domesticated animals (Skarin & Åhman 2014). Reindeer shape both the ecological and social landscape because of their economic and cultural significance to the Sámi indigenous minority of northern Sweden (Herder et al. 2003; UNESCO n.d.). The Reindeer Husbandry Act of 1971 grants the Sami exclusive rights to carry out reindeer husbandry on land in northern Sweden, regardless of land ownership. Fifty-one reindeer herding communities cover 55 % of Sweden's land base. Multiple-use of the land can result in competition and conflict among users. In year 2000, the Swedish Forest Agency, researchers, and reindeer herders, initiated the Reindeer Husbandry Planning process in attempt to facilitate communication and reduce conflict among users (Sandström et al. 2003). The goal of Reindeer Husbandry planning is to monitor, record and communicate information about habitat and reindeer movements across the landscape (Sandström et al. 2012).

### 1.2.4 The Caribou Recovery Plan and Disturbance Thresholds

The Canadian Recovery Plan (2012) attempts to address declining populations of caribou (*Rangifer tarandus caribou*), boreal woodland population, across Canada. The plan is built upon Environment Canada's Scientific Review for the Identification of Critical Habitat for Woodland Caribou (2009), and Scientific Assessment to Inform the Identification of Critical Habitat for Woodland Caribou (2011), which address natural and anthropogenic habitat loss across Canada's fifty-one boreal caribou ranges. The Recovery Plan bases its strategy on the use of disturbance management thresholds (DMTs).

The definition of thresholds in ecology has evolved over time. The early description was an abrupt system change induced relatively small changes (Holroyd, 2008). Today, thresholds encompass both social and ecological perspectives: social or technically-based standards that define the point where an indicator reaches an unacceptable state (Antoniuk & Ainslie 2003). The Recovery Plan defines DMTs as the point at which disturbance tips the standard of self-supporting populations from 'likely to be obtained' to 'unlikely or highly uncertain' and sets this value at 65 % of undisturbed habitat required to support self-sustaining populations (Canada 2011). DMTs can help to mitigate negative impacts of northern development on reindeer husbandry in northern Sweden by defining social and ecological indicators and standards and supplying a simple tool for development planning and disturbance mitigation.

### 1.2.5 Study Aims and Limitations

This study regards the Canadian caribou system and reindeer husbandry system in Sweden as parallel: both supporting intricate social-ecological networks and facing common pressures from human developments. The indigenous knowledge used in the analysis represents current areas of high-use by reindeer during a representative year, and while spatially extensive does not show changes to reindeer use over time or increasing pressure from human development. The final aim of the analysis is to test the possibility of using this herder-defined data to indicate disturbance impacts on herded reindeer systems in Sweden.

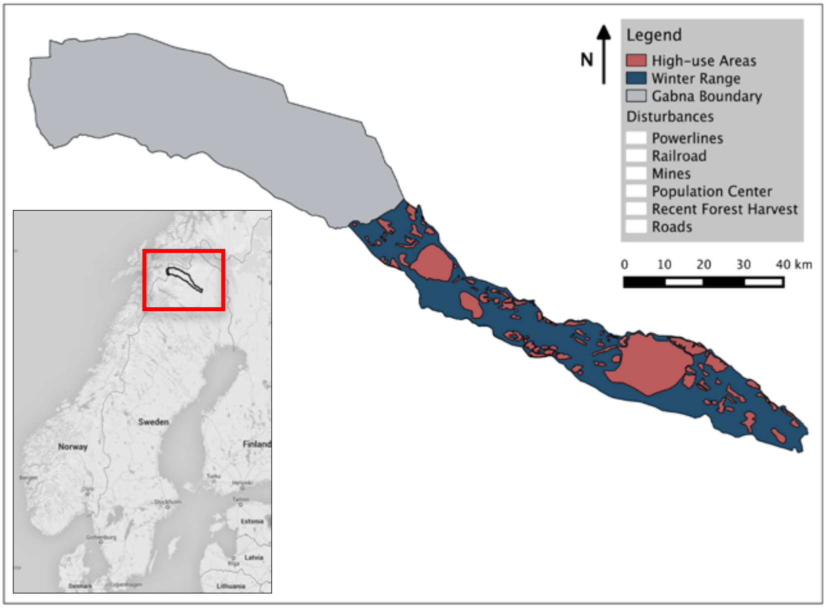
# 2 Methods

The exploratory nature of this study led to a series of methods for testing DMTs. I first compared the Recovery Plan DMT methods with the available data and methods in reindeer husbandry in Sweden. This comparison led to a review and summary of the regional buffer literature and mapping to demonstrate possible avoidance on the landscape. Finally, I developed a buffer analysis to establish my own buffer distances in Sweden by fitting a resource selection function on herder-defined data.

## *2.1 Study Area*

The study focuses on Gabna Reindeer Herding Community as a pilot area for future study. Gabna reindeer Herding Community is located in Swedish Lapland directly north of the city of Kiruna (67.85° N, 20.21° E), and has an area of 3557 $km^2$ (Figure 1a,b). Each year reindeer herders and reindeer migrate from the winter grazing area in lowland forests in the south, to the mountainous summer grazing areas. This study analyzes use at the seasonal winter range scale as it represents the most critical time of year for reindeer survival and management (Roturier 2009; Kumpula et al. 1998). At the northern part of the winter range the E10 highway cuts towards the city of Kiruna and the world's largest underground iron-ore mine operated by Luossavaara-Kiirunavaara AB, (LKAB). The southern portion of the range contains active forestry operations and proposed windmill development. Plans to relocate the city of Kiruna due to mining activities will shift human development into the center of the Gabna Reindeer Herding Community, making this study particularly relevant for assessment of disturbance effects.

*a*




*b*

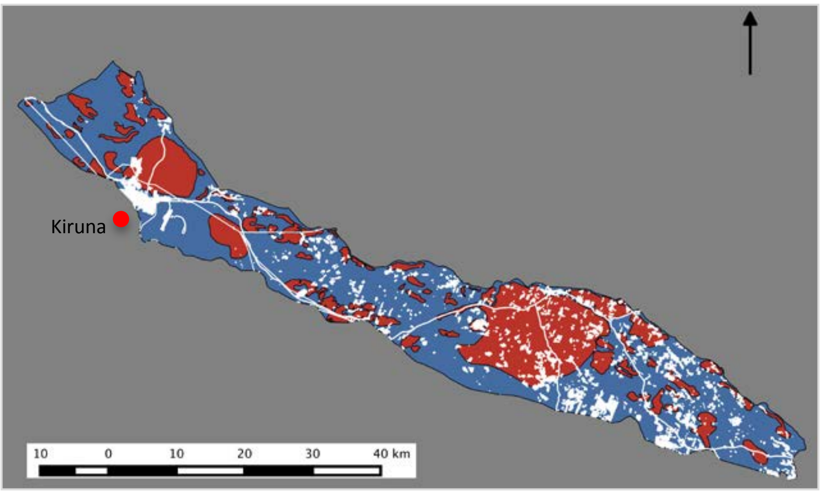



Figure 1. *a) Study area map of Gabna Reindeer Herding Community in northern Sweden b) Gabna winter range (blue), with herder-defined high-use areas (red) and all disturbances included in the analysis (white)*

## *2.2 Investigating Disturbance Threshold Methods in Canada and Sweden*

I first reviewed the Recovery Plan (Environment Canada 2012) and Scientific Assessment (Environment Canada 2011) for DMT methods, and became familiar with the reindeer husbandry planning data and methods through literature and discussion with researchers. I then summarized key aspects of the DMT methodology, compared available data and highlighted similarities and differences between the caribou and reindeer systems. The following terminology was used to compare methods across systems: **equivalent** indicates that similar processes or equivalent data already exists in Sweden, **not equivalent**, suggests method or data is incompatible due to insufficient data or system differences requiring major adjustments to methods, **redefinition required** indicates a similar process with minor adjustments to methods required to be applicable in Sweden. Here, I identified the importance of quantifying disturbance avoidance by herded reindeer for the development of DMTs in Sweden. Avoidance is quantified in literature by using disturbance buffers around development. The subsequent “buffer analysis” makes an attempt to define new buffers distances to represent avoidance in the Gabna Reindeer Herding Community.

## *2.3 Data Acquisition for the Buffer Analysis*

Spatial data is required to inform the buffer analysis. The chosen spatial data is preexisting, having been recorded by reindeer herders into a participatory GIS program called RenGIS through Reindeer Husbandry Planning in Sweden (Sandström et al., 2003, RenGIS 2011). This data is accessible as part of an ongoing project with Gabna and Laevas Reindeer Herding Communities funded by LKAB.

Reindeer Husbandry Planning divides reindeer grazing data spatially and temporally according to the eight traditional Sami seasons of the reindeer year. Within the participatory RenGIS program, herders identify and delineate seasonal ranges into three levels of importance for reindeer husbandry: general seasonal grazing units, core areas and interior core areas. The analysis uses interior core areas as input data, hereafter termed high-use areas (Figure 1b).

Reindeer Husbandry Planning has collected human development data from government and private databases and compiled it into RenGIS database. The available data is categorized into mining, hydro and wind power, forestry, agriculture, recreation, consideration for conservation and heritage, and climate. Each of these human developments have unseen spatial impacts on *Rangifer*, perhaps a result of noise, light, or air pollution around the development area. The following section reviews buffer distances from literature to help define potential impacts of such disturbances on reindeer in Gabna.

## *2.4 Buffer Literature Review*

I reviewed studies of regional avoidance of *Rangifer* from Canada and Fennoscandia to summarize and observe trends in disturbances from development. Much of the literature was found in the buffer sensitivity analysis conducted by the Scientific Assessment to Inform the Identification of Critical Habitat for Woodland Caribou (Environment Canada 2011), from a review by Skarin & Åhman (2014), and by a Google Scholar search for additional studies.

## *2.5 Disturbance and Buffer Mapping and Summary Statistics*

Disturbance mapping quantified the current extent of human developments on the Gabna landscape. Disturbance and high/use area shape files from the RenGIS dataset were manipulated and analyzed in the open-source GIS program, QGIS (QGIS 2014). The output was a series of maps showing different disturbance imprints, along with summary tables of the proportion of disturbance in the district. The buffer mapping assigned each disturbance source a buffer distance to represent possible avoidances by reindeer, based on values from the literature review. I applied a 500-meter buffer from the Recovery Plan, as well as the largest buffer distance found in literature on all disturbnaces to demonstrate what spatial effects of disturbance on reindeer could look like on the landscape. I repeated this step but without placing buffers on forest harvest areas to demonstrate difference in impacts based on whether reindeer use harvested areas or not.

## *2.6 Model Development and Identification of Buffer Distances*

Resource selection functions (RSFs) have been used in literature to predict habitat use by fitting linear regressions on habitat characteristics and disturbance sources variables (Manly et al. 2002). I used reindeer herder-defined “high-use” areas as a proxy for habitat characteristics and distance from disturbance as the disturbance source variable.

### 2.6.1 Experimental Design

I fitted a logistical regression based on a use-availability design that compares distances to disturbance sources at randomly placed locations within use and available use areas (Manly et al. 2002). I adjusted the study design to compare distances at random points within high-use areas to those outside of high-use areas, or “other-use” areas and eliminate other habitat variables based on the assumption that high-use areas provide adequate information on high quality habitat.

I drew a random sample of 400 points, 200 within high-use areas and 200 in other-use areas. The binomial response variable represented high use (1) or other use (0) for each random point based on distance from disturbance. Disturbance sources included were those a) found commonly in literature, b) suspected to be influential by Sami herders and in literature, and c) found within the Gabna Reindeer Herding Community. To detect possible avoidance within reasonable range of each disturbance, I limited distance values to a maximum of 20,000 meters. Initially the variables included in the model were distances from powerlines, railroads, public highways, mining sites, population centers and forestry. I divided forestry areas into three categories, recently harvested, young forest and lichen areas.

Using Spearman’s correlation, I removed disturbances variables that were strongly inter-correlated (greater than r=0.5) and with Kendall Tau correlation I removed those variables weakly correlated with occurrence (p-value of greater than 0.10). I fit models with remaining variables and used Akaike’s Information Criterion (AIC) (Akaike 1973) and to retain the model that yielded the lowest AIC value.

### 2.6.2 Assumptions and Potential Sources of Error

In support the study design I made assumptions about avoidance based on herder-defined areas. I assume (1) that high use areas are used in entirety by reindeer, (2) delineations are consistent across the range, (3) that herders consider disturbance impacts when delineating high-use areas and (4) that reindeer choose to maximize grazing opportunities and to avoid sources of disturbance.

### 2.6.3 Note on Data Transformation and Manipulations

I attempted to reduce effects of large distances between the disturbance and high-use areas by transforming the distance from disturbances variables using both log(10) and 1/x. I also tried to improve the model fit by removing two large high-use areas from the analysis. Finally, I decided to input raw data in the model because collinearity between occurrence and disturbance distances was low using transformed data and models had no greater predictive power.

### 2.6.4 Model Prediction and Validation

The model's predictive ability was tested by inputing a different set of random points and predicting high-use (1) or other-use (0) for each point. I compared the model predictions statistically by running Pearson's Correlation.

### 2.6.5 Identification of Buffers

To define a buffer distance around a disturbance type, I first identified a range of distances that included all suggested buffers distances from literature (Table 2). For each disturbance variable in question, I fixed the other model variables using a mean buffer value from literature. I graphed at what distance the model predicted a shift from high-use to other-use (Figure 3).

# 3 Results

## *3.1 Investigating Disturbance Threshold Methods in Canada and Sweden and Buffer Literature Review*

The first two steps of DMT method acknowledged better availability of disturbance, habitat selection and *Rangifer* demography data in Sweden than in Canada (Table 1). Despite the availability of data, and wide recognition by herders and managers of industrial disturbance to domesticated reindeer, results of the investigation showed that quantifying disturbance effects on domesticated reindeer is difficult and literature scarce, thus I determined the need for a buffer analysis specific to the Gabna Reindeer Herding Community.

A review of regional scale studies indicated that the buffer distance used to represent avoidance varies substantially according to study area and study design. Table 2 summarizes this variation among common disturbance types found in literature and Table 3 summarizes the literature found. Of all regional scale studies estimating disturbance buffers, I found eleven on wild caribou in North America, five on wild reindeer in Norway, two on semi-domesticated reindeer in Sweden and one of semi-domesticated reindeer in Finland.

Table 1. *Investigating the applicability of methods from the Recovery Plan disturbance threshold development, to the Swedish Reindeer Husbandry Planning System* (Environment Canada 2012)

| Caribou Recovery Plan | Swedish Reindeer Husbandry Planning |
|---|---|
| 1 Enhanced Disturbance Mapping: attempt to improved limited information on timing and location of disturbances in caribou ranges | 1 *Equivalent*, Cumulative Effects Mapping: Government and other land users contribute digital data, present for entire reindeer husbandry area |
| 2 Habitat Selection Analysis: highlighted bio-physical attributes of caribou habitat using available caribou location data | 2 *Equivalent*, Categorization, Identification and Delineation of important grazing lands: field visits and satellite interpretation combined with local knowledge |
| 3 Buffer Analysis: examined the effects of buffering configuration of disturbance and on caribou demography | 3 *Not equivalent*, analysis of areas of avoidance within herding areas needed: test key areas for evidence of disturbance avoidance? Advantage of having good indigenous knowledge to use in testing? |
| 4 Meta-analysis of population and habitat condition: modeled calf recruitment in different populations as functions of disturbance type, configuration, influence of undisturbed habitat and high quality caribou habitat | 4 *Not equivalent*, to run a meta-analysis across reindeer herding communities, the demographic response (calf recruitment for caribou) needs to consider additional feeding and predator protection levels across reindeer herds |
| 5 Assessing current conditions: used indicators to assess probability of self-supporting ranges, based on stable and positive growth and long term persistence of caribou populations | 5 *Redefinition required*, what is considered a self-supporting reindeer herd? Need indicator for healthy populations, consider economic inputs of herders, losses from of road kill or predation, calf recruitment |
| 6 Future conditions: developed a habitat dynamics model to observe how future changes in habitat could affect future populations | 6 *Not equivalent*, could develop a similar model using forest growth predictions and including increases in new infrastructures, windmills, railroads, mines etc., requires definition of “self-supporting populations” |
| 7 Range-specific disturbance thresholds: “a probabilistic assessment of potential outcomes relative to desired state” | 7 *Not equivalent*, Next steps: defining a desirable state for reindeer husbandry, further development of steps 3-6 |

Table 2. *Summary of disturbance buffers found in regional studies in Canada and Fennoscandia* (Skarin & Åhman 2014; Environment Canada 2012)

| Disturbance Type | Minimum Buffer (km) | Maximum Buffer (km) | Mean (km) |
|---|---|---|---|
| Public Roads* | 1<br>Leblond et al. 2011, Lundqvist 2007, Panzacchi et al. 2012 | 5<br>(Vistnes and Nelleman 2001, Polfus et al. 2011) | **3** |
| Seismic Lines | 0.1<br>Dyer et al. 2001 | 0.1<br>Dyer et al. 2001 | **0.1** |
| Forest Harvest Areas | 1.2<br>Smith et al. 2000 | 1.2<br>Smith et al. 2000 | **1.2** |
| Mines* | 2<br>Polfus et al. 2011 | 14<br>Boulanger et al. 2012 | **8** |
| Hydroelectric Dams | 3<br>Mahoney & Schaefer 2002 | 4<br>Nellemann et al. 2003 | **3.5** |
| Powerlines | 2.5<br>Nelleman et al. 2001 | 4<br>Vistnes and Nelleman 2001 | **3.25** |
| Windmill | 3.5<br>Skarin et al. 2013 | 3.5<br>Skarin et al. 2013 | **3.5** |
| Population Center* | 4<br>Helle et al. 2012 | 12<br>Helle and Särkelä 1993 | **8** |

*roads = public roads, excluding small private roads and forest roads, mines = both active mine and mine infrastructure areas, hydroelectric dams = reservoir and dam infrastructures, population center = areas of concentrated inhabitation including tourist resorts

Table 3. *A compilation of buffers for regional-scale avoidance of human infrastructure by Rangifer sp., from Canada, Norway, Sweden and Finland* (Skarin & Åhman 2014; Environment Canada 2012)

| Activity | Buffer Distance (km) | Study Reference | Short Description (location, tools, scale) |
|---|---|---|---|
| Roads | 0.3-0.9 | (Nellemann & Cameron 1998) | Alaska, aerial surveys, density within road distances |
| | >0.25 | (Dyer et al. 2001) | North-eastern Alberta, GPS radio collar on 36, across 5 seasons late winter, calving, summer, rut, and early winter |
| | 5 | (Nellemann et al. 2001) | Norway, densities of calving reindeer within 0-4 km buffers |
| | >4 | (Vistnes & Nellemann 2001) | Central Norway, aerial surveys, lichen abundance surveys |
| | 2 | (Cameron et al. 2005) | Alaska, radio collared females, presence and movement through oil field |
| | 5 | (Polfus et al. 2011) | British Columbia, mountains, 10 GPS collars on high use roads |
| | 1 | (Leblond et al. 2011) | Quebec, Resource Selection Functions |
| | 1.25 | (Leblond et al. 2013) | Quebec, GPS collars before during and after construction with habitat analysis |
| | 1 | (Lundqvist 2007) | Sweden, Reachability study |
| | 1 | (Panzacchi et al. 2012) | Norway, comparing traditional routes to current, temporal scale: centuries and spatial: across migration |
| Seismic Line and Wellsite | >0.10 | (Dyer et al. 2001) | above |
| Forest Harvest Areas | 1.2 | (Smith et al. 2000) | West central Alberta, radio-collared caribou to see home-range size and daily movement rates. Average distance of GPS collars to disturbance compared with random points |
| Mines | >13 | (Vors et al. 2007) | Ontario, modeling extirpation using thresholds, range-wide over |

| | | | |
|---|---|---|---|
| | | | decades |
| | 4 | (Weir et al. 2007) | Newfoundland, helicopter surveys in rings around mine, prior to, during and after construction |
| | 2 | (Polfus et al. 2011) | Above |
| | 11-14 | (Boulanger et al. 2012) | NWT Canada, aerial survey and satellite-collars with method for spatial impact of stressors, summer range around mines |
| Hydroelectric Dams | 3 | (Mahoney & Schaefer 2002) | Newfoundland Canada, radio-collars around hydroelectric power plant before during and after construction |
| | 4 | (Nellemann et al. 2003) | South-western Norway, visual-surveys pre and post development, piecemeal development |
| Powerlines | 2.5 | (Nellemann et al. 2001) | Central Norway, aerial surveys, lichen-abundance surveys |
| | >4 | (Vistnes & Nellemann 2001) | Norway, densities of calving reindeer within 0-4 km buffers |
| Windmills (future study, in construction) | 3.5 | (Skarin et al. 2013) | - |

## *3.2 Mapping and Summary Statistics*

The disturbance mapping and summary statistics demonstrate the physical and predicted disturbances within the Gabna winter range (Figure 2, Table 4). The proportion of winter range developed, not including buffer distances, was 16.3 %, and the proportion of high-use areas developed was 18.4 %. Using a conservative buffer distance of 500-meters from the Recovery Plan, 58.7 % of the Gabna winter range was disturbed, and 78.6% of high-use areas were disturbed and 24.7 % and 24.2 % respectively if forest harvest areas are not buffered. If maximum buffers from literature are applied to the Gabna situation, 97.1 % of the winter range is considered disturbed, and 97.3 % of high-use areas are disturbed.

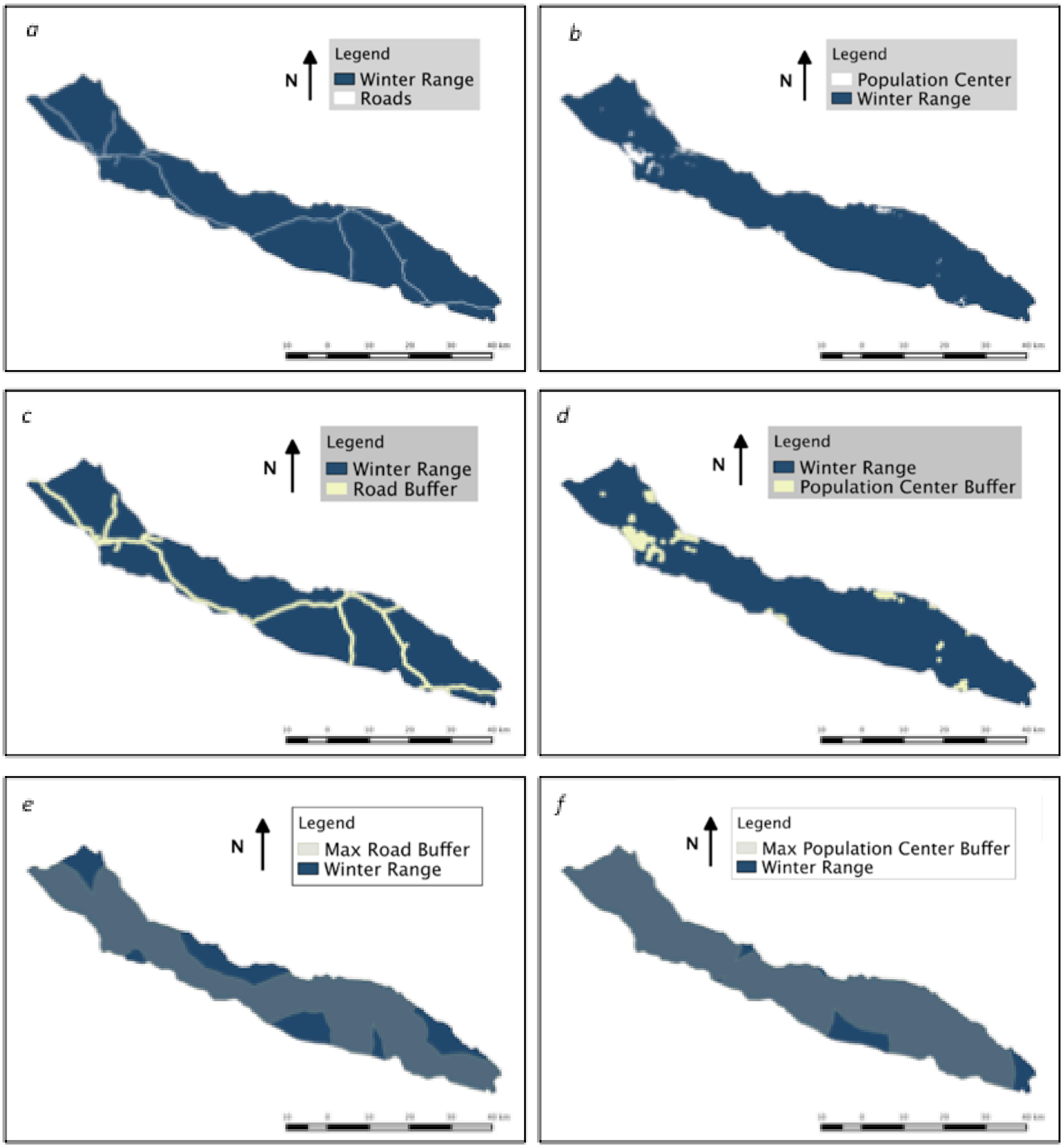



*Figure 2.* a) *Gabna winter range public roads with no buffer b) Gabna winter range population centers with no buffer c) Gabna winter range public roads with a 500 meter buffer d) Gabna winter range population centers with a 500 meter buffer e) Gabna winter range roads with 5 km buffer from literature f) Gabna winter range population centers with 12 km buffer from literature.*

Table 4. *Summary Statistics of Disturbed Areas within Gabna, physical imprint of disturbance, 500 meter buffer, and maximum buffer from literature*

| Disturbance type and buffer | Area ($km^2$) in winter range | % winter range disturbed | % high-use disturbed |
|---|---|---|---|
| Total area of winter range = 1574.2 $km^2$ | | | |
| Total area of high-use = 507.2 | | | |
| **Disturbance, no buffer** | | | |
| Public roads | 1.5 | 0.1 | 0.1 |
| Railroads | 0.2 | 0 | 0 |
| Mines | 6.5 | 0.4 | 0.7 |
| Population centers | 21.7 | 1.4 | 0.2 |
| Recent forest harvest[1] | 100.0 | 6.3 | 6.3 |
| All disturbances, excl. forestry[2] | 33.0 | 2.1 | 1.2 |
| All disturbances[3] | 256.7 | 16.3 | 18.4 |
| **Disturbance, 500-meter buffer** | | | |
| Public roads | 188.0 | 11.9 | 11.2 |
| Railroads | 30.5 | 1.9 | 0.3 |
| Mines | 23.5 | 1.5 | 2.1 |
| Population centers | 94.3 | 6.0 | 3.2 |
| Recent forest harvest | 724.4 | 46.0 | 50.9 |
| All disturbances, excl. forestry | 298.9 | 19.0 | 18.7 |
| All disturbances, no forest buffer[4] | 389.0 | 24.7 | 24.2 |
| All disturbances | 923.6 | 58.7 | 78.6 |
| **Disturbance, maximum buffer** | | | |
| Public roads, 5 km | 1226.4 | 77.9 | 84.9 |
| Mines, 14 km | 789.7 | 50.2 | 39.1 |
| Population centers, 12 km | 1457.0 | 92.6 | 95.4 |
| All disturbances, excl. forestry | 1524.8 | 96.9 | 97.3 |
| All disturbances, no forest buffer | 1526.6 | 97.0 | 97.6 |
| All disturbances | 1527.9 | 97.1 | 97.3 |

1 Recent forest harvest is those areas classified as under 2 meters in 2005 combined with areas changed detected areas from 2003 to 2013.

2 All disturbances excl. forest, considers recent forest harvest areas to be used by reindeer are excluded from analysis.

3 All disturbances include areas and buffers on public roads, railroads, powerlines, mines, population centers. Recent forest harvest areas are considered disturbances here.

4 All disturbances, no forest buffer, considers recent forest harvest areas to be avoided by reindeer, however, are left un-buffered.

## 3.3 Model Development and Identification of Buffer Distances

### 3.3.1 Model Fit

I retained public roads, railroads and population centers using Kendall Tau and AIC values to fit the best model (Table 5).

Table 5. *Kendal Tau analysis of correlation among distance to disturbance and Use Occurrence*

| Disturbance (explanatory variable) | Distance | Kendal Tau | P value |
|---|---|---|---|
| Railroads | | 0.092 | 0.034 |
| Population centers | | 0.070 | 0.087 |
| Roads | | 0.112 | 0.006 |

### 3.3.2 Model Predictions

The resource selection function indicated a slight positive relationship between occurrence of high-use areas and distance from railroads; suggesting these areas are located at a distance from railways. Public roads and population centers showed slightly negative relationships with high-use area occurrence, suggesting high-use areas are located in close proximity to population centers and public roads. The model was fit with newly sampled random points and predictions correlated with actual occurrence values, but had a very low predictive ability when tested statistically (r=0.13).

### 3.3.3 Identification of Buffer Distances

The model predicts high-use areas are found within 500 meters of major roads and 2000 meters of population centers, and predicts high-use areas at a distance of 8000 meters from railroads (Figure 3).

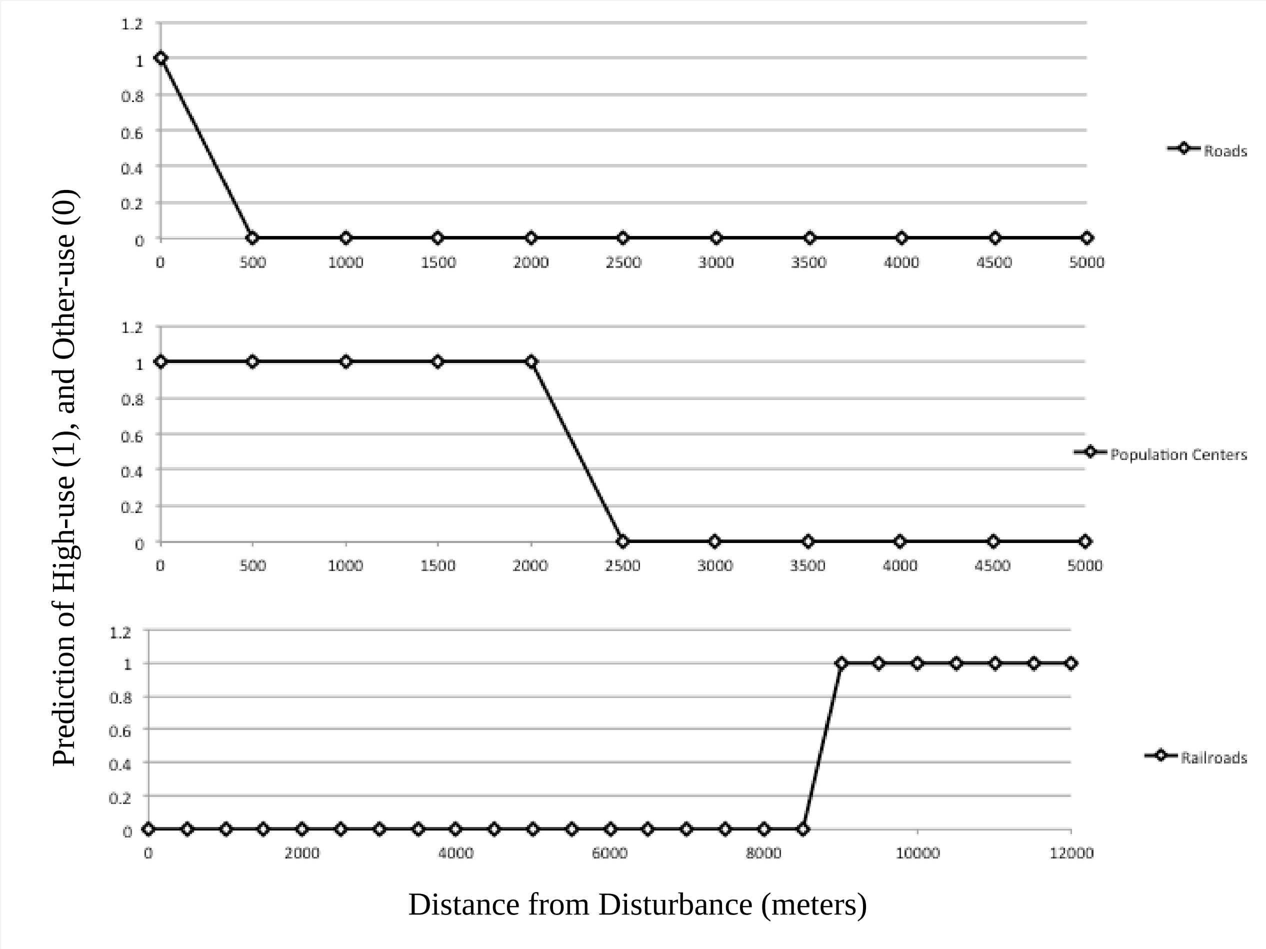



Figure 3. *Resource Selection Function Predictions of Reindeer Use (high-use (1) or other-use (0)) according to distance from disturbances: roads, population centers and railroads*

# 4 Discussion

## *4.1 Overview*

This study is among the first to use indigenous ecological knowledge to quantify avoidance of human disturbance sources by domesticated reindeer. Detecting avoidance and other effects of rapid development on reindeer in Sweden's north requires long-term and large-scale landscape information but can be costly and time intensive (Skarin & Åhman 2014; Vistnes & Nellemann 2008). Long-standing indigenous ecological knowledge from reindeer herders offers an alternative source of in-depth and long-term data that has recently been made accessible in Sweden through Reindeer Husbandry Planning (Sandström et al. 2003; Sandström et al. 2012).

This study makes use of this valuable herder-defined data by presenting landscape information and fitting a resource selection function to explore avoidance. By adapting the Canadian DMT methods for Sweden, the study summarizes similarities and shortcomings across the two systems and brings to surface the challenges of integrating indigenous ecological knowledge into scientific analysis. This comparative approach highlights mutual benefits of knowledge exchange across systems: where Sweden can adopt wildlife management and spatial disturbance analysis from the Recovery Plan, and caribou recovery in Canada can develop similar methods for compiling and presenting indigenous ecological knowledge. Overall, the study reinforces the need to incorporate socio-ecological indicators in the development of disturbance thresholds for reindeer systems in Sweden and presents an opportunity to integrate indigenous and scientific data to improve understanding of disturbance effects on *Rangifer* systems.

## *4.2 Adapting Threshold Methods from Canada to Sweden*

Adapting DMT methods from the Recovery Plan for the Swedish system benefits Sweden in the transfer of well-established disturbance analysis methods. However, differences in data and system functions require some methods to be redefined (Table 1).

The quality and quantity of information for disturbance mapping differed across the systems (Table 1, point 1). In Canada, lack of detailed spatial information on disturbances prompted the Recovery Plan's in-depth disturbance mapping process to estimate area of anthropogenic and fire-caused habitat loss. Meanwhile in Sweden, landscape disturbance was already available in RenGIS through Reindeer Husbandry Planning efforts (Sandström et al. 2003).

System differences such as productivity indictors limit direct application of methods, as shown in the comparison of population and assessment of current conditions in the DMT methods (Table 1, points 4,5). For example, population number and growth indicate self-sustaining populations in caribou systems. But in herded reindeer system population numbers are fixed according to needs of the herders and society. This is a result of support by the Swedish government for the slaughter of calves to increase the number of productive females, thus maintaining productivity while avoiding landscape impacts of large herds (SOU 2001). Therefore, instead of using population size and growth as indicators for effects of human developments, recent studies have observed individual carcass weights, herd production, animal fatness, and animal body shape (Olofsson 2011; Lundqvist 2007).

The applicability of buffer distances from wild reindeer to herded systems requires redefinition of responses across systems (Table 1, point 3). Studies have found that regional avoidance patterns are similar for wild and domesticated *Rangifer*, but can differ at the local scale (Skarin & Åhman 2014; Vistnes & Nellemann 2008). Local scale differences may result from differing herd composition, for example, adult females are shown to be more sensitive to disturbance during calving, and prefer undisturbed areas to high forage quality during summer calving (Helle et al. 2012; Maier et al. 2014). Herded reindeer are made up mostly of reproductive females, making the entire herd more sensitive to disturbance than wild reindeer herds within short time-frames (Skarin & Åhman 2014).

*Rangifer* responses to disturbance and effects on productivity are also dependent on landscape characteristics, and should be investigated before applying methods across systems. For example, wildfire occurrences in Sweden are infrequent, and effects on reindeer minimal, while in Canada wildfire is an important factor in caribou habitat loss (Environment Canada 2012). The density of human developments on the landscape also has an effect on *Rangifer* response to disturbance. Disturbance maps (Figure 1b) show a highly fragmented landscape: dense networks of linear features, mines and population centers, and intensive forestry production. In such highly disturbed landscapes avoidance may be impossible, however it is still unclear if *Rangifer* habituate or become tolerant as a result (Bejder et al. 2009). Skarin and Åhman (2014) discuss the possibility of habituation and caution that individual animal behavior should not be used to represent the responses of the entire herd, as some individuals can behave in a manner that is unrepresentative of the rest of the herd. Herding could also make avoidance detection difficult in domesticated reindeer systems, as regional scale responses are restricted to within the Reindeer Herding Community boundaries. Wild reindeer, in comparison, have more freedom to move across the landscape, as demonstrated by long-term shifts in range in response to landscape disturbance (Schaefer 2003).

Based on spatial constraints in Sweden, I infer that using the smaller buffer distances found in literature would more effectively estimate the impact of disturbance on domesticated reindeer. When placing a minimum buffer of 500-meters from the Recovery Plan on disturbances in Gabna winter range, disturbed area amounted to 58.7%, leaving 41.3 % of the winter range theoretically available for reindeer to use freely. This value is still far below the suggested 67 % of undisturbed habitat from the Recovery Plan (Figure 3, Table 4). However, if forest harvest areas are left un-buffered (see Table 4, note 4), these winter range disturbance becomes 24.7 % and high-use areas 24.2 %. Depending on the season and conditions, reindeer can use forest harvest areas for forage. However the Canadian Recovery Plan buffers forestry harvest areas with a 500-meter buffer, and studies show avoidance of recently harvest areas by reindeer due to reliance on arboreal lichens and during winter periods (Environment Canada 2012, Kumpula et al. 2007, Kivinen et al. 2010). An opportunity for further study is to assess avoidance of such forest harvest areas to determine if they should be included in buffer analyses.

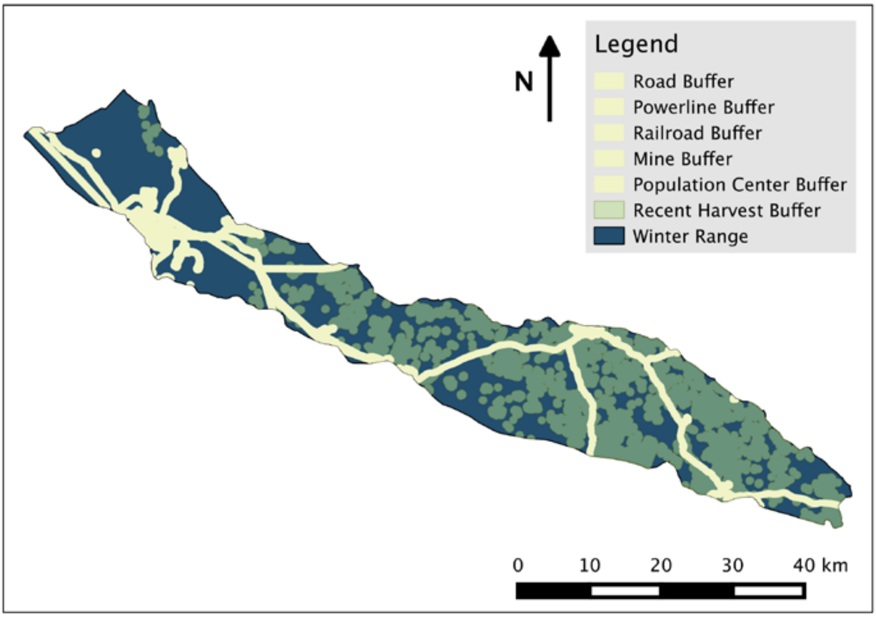



Figure 4. *500-meter buffer applied to disturbances within the Gabna winter range, showing 58.7% of the winter range as disturbed* (Environment Canada 2012)

## *4.3 Model Development and Identification of Buffer Distances*

Avoidance patterns are observed to be similar across wild and herded reindeer, but buffer distances for herded reindeer will reflect differences in strength and scale of avoidance (Skarin & Åhman 2014). Mapping buffers taken from literature demonstrated limitations of applying buffers directly from one system to another. For example, a 14 km buffer around mines (Boulanger et al. 2012) indicated that only 3 % of the Gabna winter range was available for reindeer use, and 0 % of high use areas were available (Table 4, Appendix). The development of effective disturbance management thresholds for reindeer husbandry requires a better understanding of appropriate buffer distances around disturbances. I used a resource selection function and herder-defined data in attempt to develop new buffer distances for Gabna Reindeer Herding Community.

### 4.3.1 Results of the Resource Selection Function

The resource selection function (RSF) borrowed methods from *Rangifer* studies with GPS based reindeer or caribou locations, and replaced these data inputs with herder delineated reindeer use data (Polfus et al. 2011; Leblond et al. 2013; Boulanger et al. 2012). In my adjustment of these methods to suit herder-defined data I had to make a number of assumptions about the herder-defined data, which included:

1. High-use areas are used in entirety by reindeer
2. All high-use areas are delineated according to consistent herder values
3. Herders consider disturbance impacts when delineating high-use areas, and that
4. Reindeer choose to maximize grazing opportunities and to avoid sources of disturbance

If herder-defined data did not meet all assumptions required by the study design, the RSF was likely to have a low predictive ability or to give inaccurate predictions. The RSF fit in the study showed low predictive ability and provided results differing from literature, showing high-use areas to be closely located to both public roads and population centers. Using the above assumptions I discuss possible factors influencing these results.

Firstly, RSF design of using random points may have violated assumptions 1 and 2. The placement of random points to represent reindeer locations assumes reindeer use high-use areas in entirety. In reality, the distribution of reindeer across the landscape will depend on animal sex, season and ground conditions and level of disturbance, among other factors (Skarin & Åhman 2014; Schaefer & Mahoney 2007; Roturier & Roué 2009). Most importantly, it is possible that within high-use areas reindeer are exhibiting avoidance of disturbance, which the study design is unable to detect.

The presence of two large high-use areas much larger than other high-use areas indicates a problem with the assumption that delineation is consistent across the range. Because individual herders delineate different parts of the winter range, differences in delineation methods arise from how herders define high-use and how they perceive the benefits of delineating large versus small areas in terms of negotiating land use. The design of placing random points over-represented large high-use areas, which may have resulted in the RSF showing that high-use areas favor disturbances.

Regional scale most effectively indicates the large-range and long-term effects human development on both wild and herded reindeer (Skarin & Åhman 2014; Vistnes & Nellemann 2008). However, herder-defined data proved to be too coarse to detect possible avoidance within high-use areas. Assumption 3 implies that herders are able to shift high-use areas to consider impact of disturbance on reindeer. In reality, herders may be unable to delineate high-use areas to avoid disturbance, reflecting that reindeer may also be unable to avoid disturbance to high density of disturbance or barriers to movement. The scale of the data cannot display smaller-scale responses by reindeer within high-use areas, nor can it show small features that result in unexpected use patterns, such as protective features. Protective features, such as fencing along a rail track, allow reindeer to graze in close proximity to some disturbances, while other disturbances without such features may require herders to vigilantly herd reindeer away from disturbance. These distances between certain disturbances and the high-use areas are known by herders, but remain unexplained to those working with the data and undetected as differences by the model, possibly reducing predictive power.

Including fine scale data in the buffer analysis could provide additional information on avoidance *within* high-use areas, and on impacts of protective features on high-use area locations. Integrating regional-scale indigenous ecological knowledge with more local-scale data such as GPS reindeer location and pellet count data could provide the necessary scale to detect avoidance in herded reindeer systems (Polfus et al. 2014; Antoniuk et al. 2009).

Finally, despite research showing similar avoidance effects by wild and herded-reindeer (Skarin and Åhman 2014), it is possible that our results indicate that disturbances, such as roads, are often located in similar conditions as reindeer high-use areas, and that reindeer do not exhibit high levels of avoidance of these disturbances, violating Assumption 4. As discussed previously, both spatial constraints and habituation towards humans may reduce reindeer response to disturbance. Therefore in herded reindeer systems, avoidance may be too weak an indicator of negative effects. It is possible that herded reindeer do in fact experience effects of disturbance, through grazing interruptions and more vulnerability to predators, despite inability or unwillingness to exhibit avoidance of disturbance. If this is the case, results of buffer mapping exercise can be used to represent these unseen influences on reindeer. For example, applying the minimum buffer of 500-meters on all disturbances other than forestry demonstrates negative impacts on nearly 20 % of high-use areas (Table 4). This 20 % impacted area could indicate negative impacts on reindeer grazing, and reproductive ability thus reducing overall productivity.

These results can contribute to existing research that tests the relationship between amount of disturbed area and reindeer productivity across multiple reindeer herding communities in Sweden (Lundqvist 2007). In place of percentage of disturbed area used by Lundqvist, percentage of high-use areas impacted with various buffer distances can be applied to compare effects across districts. Using high-use areas impacted can help to narrow-down factors affecting reindeer productivity by focusing on a smaller, more intensively used landscape area. Such a study could also be used as a buffer sensitivity analysis where buffer levels are adjusted, and effect on reindeer productivity is observed.

In Reindeer Herding Communities where reindeer productivity data is unavailable, economic input by herders could be used as an indicator of negative impacts on reindeer husbandry system as a whole. This type of economic and ecological analysis can contribute to a disturbance management threshold value for Reindeer Herding Communities in Sweden as discussed in the next section.

## *4.4 Socio-economic Factors in Threshold Development*

Threshold values in the Recovery Plan can be explained using the definition of socially or technically based standards to indicate a point where an indicator reaches an unacceptable state (Salmo Consulting Inc. 2006). The Recovery Plan sets the standard of "self-supporting populations", and indicators of stable and positive population growth. To place the reindeer/ caribou system in context, Figure 5 displays number of factors that affect the indicators, such as weather, predation, food availability, and compounding effects of human development. These standards, indicators and factors can be adapted for the reindeer husbandry system to accommodate differences in population dynamics and herder influences (Table 1).

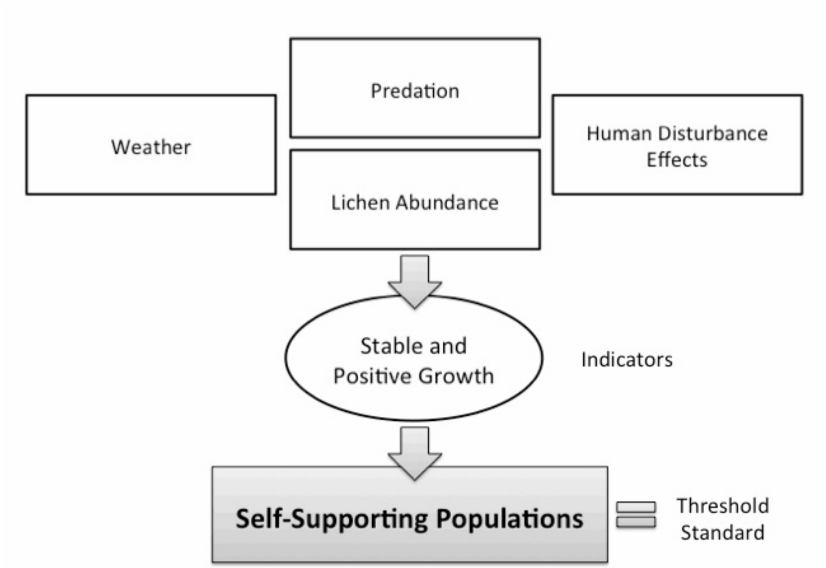



Figure 5. *A representation of the caribou system based on the Recovery Plan disturbance management threshold definition* (Environment Canada 2012)

For the Swedish husbandry system, indicators of stable and positive population growth can be replaced by another productivity measure, such as sustained calf production across years (Olofsson 2011). Factors affecting “sustained calf production” are the same as in wild systems, with the addition of herder inputs such as supplementary feeding, protection from predators and assisted transportation across fragmented areas. These additional inputs are born by reindeer herders as added costs, and are likely to decrease with high natural food availability, and to increase as a result of higher disturbance levels, fragmentation, and predation. The sustainability of reindeer husbandry as a livelihood activity depends on reliable outputs of animals for slaughter while keeping added herder costs at reasonable levels. That is to say that social and economic factors are critical for maintaining reindeer husbandry systems, and should be included in the framework by adding a socio-economic indicator, for example, “livelihood security” (Figure 6).

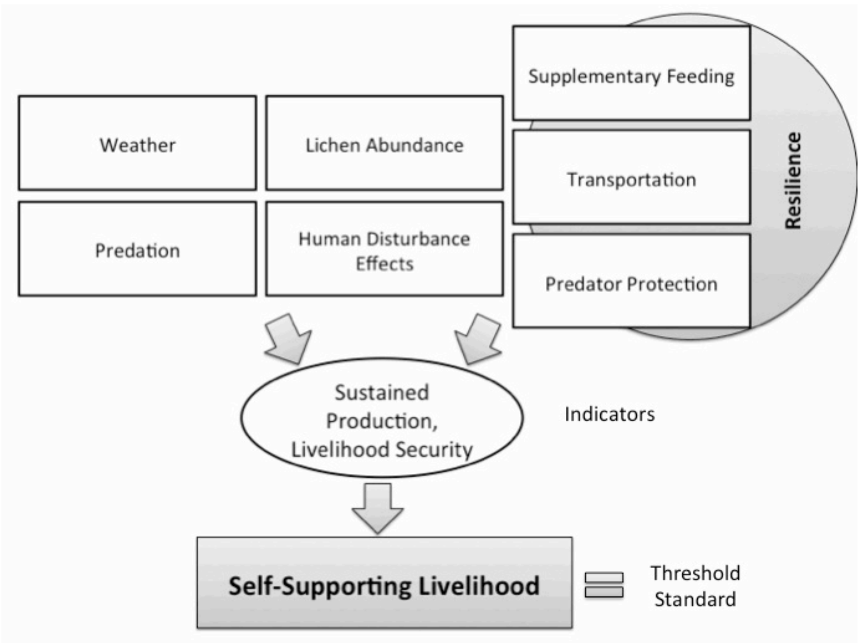



Figure 6. *A translation of the Recovery Plan's disturbance management threshold definition for reindeer husbandry in Sweden*

A study on the Yamal Nenets reindeer herding systems of the Russian tundra highlights the importance of acknowledging of socio-economic and ecological factors to maintain the sustainability of reindeer husbandry systems through resilience to changing environment and social conditions (Forbes et al. 2009). Their resilience is attributed to environmental abundance, open attitudes to outside drivers such as climate change and encroaching human developments and consciousness as stewards of the land, with resilience in other reindeer husbandry systems as a result of adaptive management by individuals and governing systems (Forbes 2013; Löf 2014; Olofsson 2011). Socio-ecological resilience is therefore an important factor in supporting sustained calf production and livelihood security (Figure 6). In the face of reduced environmental abundance due to development pressures, support from governing institutions stands out as an important factor in reaching a newly defined standard of “self-supporting livelihoods”.

This study has focused largely on the adaptation of methods from Canada to Sweden, yet Sweden’s Reindeer Husbandry Planning program offers valuable methods to assist in caribou recovery in Canada. The Recovery Plan (2012) has conducted an independent process to gather traditional ecological knowledge used to inform the recovery strategies, but the plan does cover the methods used to integrate this knowledge with scientific knowledge, nor does it explain to what extent traditional knowledge was used to inform strategies (Preface: Canada 2011). In contrast, Reindeer Husbandry Planning in Sweden places greater importance on indigenous knowledge by integrating it into geographic information systems and making this information available to Sami herders and other natural resource decision-makers. The integration of local and indigenous and scientific knowledge is an emerging field in Canada and around the world. A study on caribou in northern British Columbia found that using traditional ecological knowledge to construct habitat suitability index models can identify critical habitat identification and inform recovery planning (Polfus et al. 2014). The Recovery Plan could benefit from the adoption of a similar indigenous knowledge data-recording and sharing program.

# 5 Conclusion

Application of disturbance buffers from the Canadian Recovery Plan and from *Rangier* literature can offer insight into potential impacts of disturbance on herded reindeer in Sweden. A 500-meter buffer around all disturbances, including forestry, indicates 58.7 % of disturbed area within Gabna Reindeer Herding Community and infers high developmental pressures on the reindeer husbandry system. This is compared to the suggested maximum 35 % disturbed area threshold set by the Canadian Recovery Plan. However, differences between the *Rangifer* systems call for new buffer distances to be developed for herded reindeer systems. These should address human influences and high disturbance density effects on reindeer responses to disturbance. Similarly, the integration of socio-economic factors into a future disturbance management threshold values are important for herded reindeer systems. Overall, the exchange of methods between Sweden and Canada, along with the integration of indigenous ecological knowledge into scientific analysis, will help to inform development planning and mitigate effects of northern development on *Rangifer* systems.

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