**Simulated Effects of Forest Harvest on Caribou Habitat Disturbance**

**in the Prince George Timber Supply Area**

28 November, 2016

Tyler Muhly, Ph.D.
Natural Resource Modeling Specialist
Forest Analysis and Inventory Branch
Ministry of Forest, Lands and Natural
Resource Operations

## Executive Summary

This report describes the application of an analytical approach to model the effects of forestry on caribou habitat in north-central British Columbia. The objectives were to statistically model current caribou habitat disturbance as a function of current and historic forestry disturbance, and use the model to simulate future caribou habitat disturbance as a function of simulated future forestry. The goal of the analysis was to develop an understanding of how current and future forestry development might influence caribou habitat and populations. There is a legal need for the government of British Columbia to adequately consider the effects of land use decisions, including annual allowable cut determinations, on Aboriginal rights to harvest wildlife, including caribou

Here I present an approach to model the effects of forestry on caribou critical habitat in British Columbia. The approach was applied within the context of Environment Canada's guidance to maintain less than 35% habitat disturbance in caribou herd ranges. I applied this approach to the Prince George timber supply review to assess both the effects of future simulated forestry on caribou and theoretical forest management scenarios on timber supply. I compared the outcomes of the various management scenarios, including current forest practices and scenarios designed to conserve biodiversity or minimize caribou habitat disturbance in the region. Results will be summarized to present to the Chief Forester as part of the 2017 Prince George timber supply review.

I fit a linear regression between current caribou habitat disturbance density (i.e., areas within 500 m of less than 40 year old cutblocks or roads, or within less than 40 year old burns) and less than 40 year old cutblock and road density at the landscape unit scale to model caribou habitat disturbance based on forestry development. The location and timing of future forest harvest (i.e., cutblocks) in the Prince George TSA was simulated using a timber supply model implemented in the program SELES. Seven timber harvest scenarios were simulated to assess the effects of different biodiversity and caribou management regimes on the amount of disturbed habitat in caribou ranges and to assess the effects of these management regimes on timber supply. The scenarios included a reference scenario, which represented a simulation of current timber harvest restrictions carried into the future, four natural range of variability (NRV) forest age scenarios, which included minimum, medium and maximum area thresholds for conserving old forest (greater than 120 years old) and a young forest (less than 40 year old) maximum area threshold, and two caribou critical habitat management scenarios, which included a scenario where a maximum area cut of 18.5% was permitted in landscape units defined as critical matrix or non-matrix habitat for caribou and a second scenario where the maximum cut was applied to non-matrix habitat only. Disturbed caribou habitat was calculated by landscape unit and caribou range at each time interval of the timber supply model for each scenario.

Currently, the proportion of disturbed habitat is high in the Narrow Lake and North Cariboo herds and the western portions of the Hart Ranges, and moderately-high in the southern portions of the Wolverine and Takla caribou ranges. In all future forestry simulation scenarios, disturbance levels increased the most in the Chase, Wolverine and Takla caribou ranges. Disturbance was always well above the 35% threshold in the Narrow Lake and North Cariboo herds in all scenarios. The Hart Ranges, Kennedy Siding, Narraway and Spatsizi herds always remained below the 35% habitat disturbance threshold in all scenarios. In the NRV scenarios, more old forest conservation generally resulted in decreased disturbed

caribou habitat in the future compared to the reference scenario. In the caribou habitat management scenarios where forestry was limited in caribou critical habitat, disturbance levels were less than in the reference scenario, except in the Hart Ranges. The majority of scenarios had a significant downward pressure on timber supply in the short-term (up to 65%), mid-term (up to 38%) and long-term (up to 44%) relative to the reference scenario.

Habitat disturbance increased in the Chase, Wolverine and Takla caribou herds in all forestry scenarios, suggesting these herds may be most vulnerable to future forestry in the Prince George TSA. These herds should likely be the focus of programs to mitigate future forestry disturbance. Managing the amount of old forest within its historic NRV in the region, or restricting forestry in caribou critical habitat areas are both options to limit habitat disturbance in caribou ranges. However, to achieve the maximum benefits to caribou will very likely have a significant downward pressure on timber supply. While no formal plan to address this threshold has been developed by the government of British Columbia, a reduction in timber supply is a likely outcome and could be considered as part of the current annual allowable cut decision.

## Table of Contents



## Figures

## 1. Introduction

This report describes the application of an approach to model the effects of forestry on woodland caribou (*Rangifer tarandus caribou*) in British Columbia. The objectives were to develop an analytical approach to statistically model current caribou habitat disturbance as a function of current and historic forestry disturbance, and use the statistical model to simulate future caribou habitat disturbance as a function of simulated future forestry. The goal was to develop an approach to support understanding of how current and future forestry development might influence caribou habitat and populations. Specifically, the approach could be used to inform allowable annual cut (AAC) determinations from timber supply reviews by providing an assessment of the potential effects of forest harvest on caribou and their habitats, and how caribou management could influence future timber supply.

Boreal caribou populations occur in northeastern British Columbia and southern mountain caribou populations occur throughout areas of eastern and north-central British Columbia.[1] Both types of populations are listed as *Threatened* under the Government of Canada's *Species at Risk Act* (SARA) and are provincially red-listed (i.e., species at risk of extinction or extirpation). Caribou critical habitat is legally defined as habitat within caribou population units (i.e., herd ranges) that have not been disturbed. Disturbed habitat is defined as areas burned within the last forty years, or areas that that are within 500 m of less than forty year old logged forest (i.e., cutblocks) or linear feature created by humans (i.e., roads, trails and pipelines; Environment Canada 2012; Environment Canada 2014). Environment Canada has set an objective of maintaining greater than 65% undisturbed habitat in boreal caribou ranges (Environment Canada 2012) and maintaining greater than 65% undisturbed habitat in low elevation winter range (and no disturbance in high elevation winter or summer range) in southern mountain caribou ranges (Environment Canada 2014). The 65% undisturbed habitat threshold was established based on a statistical relationship between the proportion of disturbed habitat in caribou herd ranges and the sustainability of those herds. Previous analyses showed that the probability that a boreal caribou population was self-sustaining (i.e., stable or growing) was negatively correlated with the amount of disturbance in caribou range (Sorenson et al. 2008; Environment Canada 2012). The 65% undisturbed habitat threshold was adopted because below this threshold, caribou herds were found to have less than a 60% probability of being self-sustaining (Environment Canada 2012).

There is a need to consider the effects of forestry on wildlife in AAC determinations. Forest harvest can have strong and complex effects on the distribution and abundance of many wildlife species. In general, forestry has been found to have a negative effect on caribou populations across Canada (Courtois et al. 2007; Vors et al. 2007; Wittmer et al. 2007). Biodiversity conservation is a goal under the *Forest and Range Practices Act* (FRPA), and specific management attention is given to conserving regionally important wildlife species (i.e., species that are important to a region that rely on habitats that are not otherwise protected under FRPA and may be adversely affected by forest practices) and wildlife species at risk (i.e., endangered, threatened or vulnerable species; BC MWLAP 2004). Most important is that there is a legal need for the government of British Columbia to adequately consider the effects of land

[1] http://www.env.gov.bc.ca/wld/speciesconservation/caribou_by_ecotype.html

use decisions, including forestry development via AAC determinations, on Aboriginal rights to harvest wildlife such as caribou.[2,3,4]

Here I present an approach to model the effects of forestry on caribou critical habitat in British Columbia, and the assumed effects on caribou population sustainability. I apply this approach to the Prince George timber supply review to assess both the effects of future simulated forestry on caribou and theoretical future caribou management options on timber supply. First, I test for a statistical relationship between less than 40 years old cutblock density, forestry road density and disturbed caribou habitat density using a linear regression model within landscape units in the Prince George timber supply area (TSA). Second, I apply this model to simulated forestry outputs from a timber supply model to assess how future forestry scenarios might affect habitat disturbance in caribou range within the Prince George TSA, specifically as it related to the 65% undisturbed habitat threshold. I compare the outcomes of various scenarios, including current management practices and scenarios designed to conserve biodiversity and minimize caribou habitat disturbance in the region. Results are then summarized to present to the Chief Forester as part of the 2017 Prince George timber supply review.

## 2. Methods

### 2.1. Study Area

Road density, cutblock density, and habitat disturbance density was measured within landscape units in the Prince George TSA and defined caribou herd areas[5], including areas where caribou were previously extirpated or with only trace occurrences. Landscape units are a relatively moderate-scale resolution (mean area = 805 km$^2$ for this study) planning unit in British Columbia that can be easily integrated into timber supply models.

### 2.2. Current Forestry Road Density

Spatial data on roads was obtained by merging digital road atlas[6] and forest tenure road[7] data. To remove duplicate roads, I converted the merged linear road data into a 20 m spatial resolution raster. I then vectorised the raster back into line data using the ArcScan extension in ArcGIS 10.2. Vectorization settings are provided in Appendix A.

I measured the total length of the vectorised road data in each landscape unit by TSA[8]. I estimated the length of road attributed to forestry in each landscape unit using the Forest Practices Board (2015) heuristic, which estimated that 75% of roads in British Columbia are “resource roads” (i.e., roads developed for resource extraction) and 75% of resource roads were developed for forest harvest. Therefore, I multiplied the road length in each landscape unit by 0.56 (i.e., 0.75 x 0.75) to estimate the

[2] https://www.crownpub.bc.ca/Content/documents/williams_decision.pdf
[3] http://www.courts.gov.bc.ca/jdb-txt/CA/11/02/2011BCCA0247.htm
[4] http://www.courts.gov.bc.ca/jdb-txt/CA/13/00/2013BCCA0001.htm
[5] https://catalogue.data.gov.bc.ca/dataset/caribou-herd-locations-for-bc
[6] https://catalogue.data.gov.bc.ca/dataset/digital-road-atlas-dra-demographic-partially-attributed-roads
[7] https://catalogue.data.gov.bc.ca/dataset/forest-tenure-road-section-lines
[8] https://catalogue.data.gov.bc.ca/dataset/fadm-timber-supply-area-tsa

length of forestry roads. I divided forestry road length by the total area of the landscape unit to calculate forestry road density ($km/km^2$).

### 2.3. Current Cutblock Density

Spatial data on cutblocks less than 40 years old (harvest year from 1976 to 2015) was obtained from the 2015 consolidated cutblocks dataset[9]. The total area of less than 40 year old cutblocks was calculated within each landscape unit and divided by the total area of the unit to calculate cutblock density ($km^2/km^2$).

### 2.4. Fire Density

Spatial data on the location of the outer perimeter of fires less than 40 years old[10] was used to define areas disturbed by fire. The total area of less than 40 year old burns was calculated within each landscape unit and divided by the unit area to calculate less than 40 year old burn density ($km^2/km^2$).

### 2.5. Current Caribou Habitat Disturbance Density

Roads and cutblocks less than 40 years old were buffered by 500 m and merged with areas of less than 40 year old burns to calculate the area of disturbed caribou habitat in each landscape unit. Disturbed area in each landscape unit was divided by the total area of the landscape unit to obtain an estimate of disturbed habitat density ($km^2/km^2$). All spatial data processing was completed using ArcGIS 10.2.

### 2.6. Statistical Model of Caribou Habitat Disturbance

I fit linear regression models between habitat disturbance density (dependent variable) and cutblock, road and fire density (independent variables) at the landscape unit scale. I fit different models with linear and quadratic terms for roads and cutblocks and with and without fire density. I visually evaluated the fits of the different models by comparing actual to predicted amount of caribou habitat disturbance and by assessing how the model predicted caribou habitat disturbance across a range of road and cutblock density values and selected the model that appeared to best fit the data. Models were fit using the program R version 3.3.0 (R Core Team 2016).

### 2.7. Simulated Future Cutblock Density

The location and timing of future cutblocks in the Prince George TSA was simulated using a timber supply model implemented in the program SELES. Cutblocks were simulated at annual intervals for the first ten years of the model and then over five year intervals thereafter. The area of less than 40 year old cutblocks was summarized at each interval in each landscape unit. Previously documented cutblocks were removed from the total area of less than 40 year old cutblocks in the landscape unit when they became greater than 40 years old.

Key drivers in the timber supply model were the spatial forest inventory data[11], the timber harvest land base (THLB) definition and the accessibility of the THLB (i.e., distance to mills). Detailed assumptions and

[9] https://catalogue.data.gov.bc.ca/dataset/harvested-areas-of-bc-consolidated-cutblocks-
[10] https://catalogue.data.gov.bc.ca/dataset/fire-perimeters-historical
[11] https://catalogue.data.gov.bc.ca/dataset/vegetation-cover-polygons

details on the timber supply model, including how the THLB was defined, were provided in the Prince George TSA data package[12] and public discussion paper.[13]

Seven timber harvest scenarios were simulated to assess the effects of different biodiversity and caribou habitat management regimes on the amount of disturbed habitat in caribou ranges and to assess the effects of these management regimes on timber supply. The scenarios included:

1. a reference scenario, which represented a simulation of current legal timber harvest restrictions carried into the future, including existing legally-defined restrictions for caribou such as ungulate winter ranges[12] (note that these restrictions were included in all scenarios),
2. four natural range of variability (NRV) scenarios, which included minimum, medium and maximum area thresholds for conserving old forest (greater than 120 years old) and a young forest (less than 40 year old) maximum area threshold as defined for natural disturbance units in the Prince George TSA area by Delong (2003), and;
3. two caribou critical habitat management scenarios, which included a scenario where a maximum 35% habitat disturbance was permitted in areas defined as critical matrix and non-matrix habitat for caribou by Environment Canada (2014) and second scenario where the maximum disturbance was applied to non-matrix habitat areas only.

## 2.8. Simulating Future Road Density

Future road density in landscape units was estimated for each timber supply scenario using a statistical model of the relationship between road density and cutblock density at the landscape unit scale (Muhly 2016), where:

$$RD = (CD *\ 3.36) + (CD^2 * -1.91)\ \text{- 0.04}$$

*RD* is estimated road density (km/km$^2$) and *CD* is cutblock density simulated in each landscape unit at each time interval from the timber supply model.

I assumed that roads that were previously developed to harvest cutblocks would be re-used, i.e., no new roads were created to cutblocks that were previously cut. Thus, before I calculated future road density from simulated future cutblock density, I removed the area of simulated new cutblocks from the timber supply model that overlapped with areas of past known cutblocks to avoid creating new roads into previously harvested areas. In addition, sixty years into the future were summarized, as this was the period of the timber supply model where any new simulated cutblocks would only be cut once. After sixty years, simulated cutblocks could be cut a second time, and thus counting these cutblocks would result in double-counting of newly developed roads.

## 2.9. Simulating Future Caribou Habitat Disturbance

Disturbed caribou habitat was calculated by landscape unit at each time interval of the timber supply model using the statistical model described in Section 3.6, where:

---

[12] https://www.for.gov.bc.ca/hts/tsa/tsa24/current2015/24tsdp_2015.pdf
[13] https://www.for.gov.bc.ca/hts/tsa/tsa24/current2015/24tspdp16_final.pdf

$$DH = (RD * 0.680) + (RD^2 * -0.137) + (CD * 0.175)$$

*DH* is the estimated density of disturbed caribou habitat ($km^2/km^2$) in each landscape unit. *CD* is the density of less than 40 year old cutblocks and *RD* is the density of roads in each landscape unit.

Disturbance density was summarized by caribou range by calculating the sum of the disturbance estimates of landscape units that overlapped each herd range, adjusted for the area of the caribou range that overlapped with the landscape unit (i.e., area-weighted). Disturbance density was summarized within southern mountain caribou herd ranges[14] that occurred in the Prince George TSA, including the Chase, Hart Ranges, Kennedy Siding, Narraway, Narrow Lake, North Cariboo, Spatsizi, Takla, Tweedsmuir and Wolverine herds.

The 35% habitat disturbance density threshold within Environment Canada critical habitat areas that I used in the caribou management simulation scenarios (Section 3.7) was established by setting a THLB threshold in landscape units that overlapped those areas. The THLB threshold was set at 18.5% in those landscape units, as this was equivalent to 35% habitat disturbance using the equations described above and in section 3.8.

## 3. Results

### 3.1. Statistical Relationship between Disturbed Caribou Habitat, Cutblocks and Roads

A linear regression of caribou habitat disturbance as a function of road density and cutblock density had a good fit to the data ($R^2$ = 0.955) and was therefore used to predict future caribou habitat disturbance density based on future cutblock density in landscape units. I found a quadratic relationship between road density and caribou habitat disturbance density and a linear relationship between cutblock density and caribou habitat disturbance density (Fig. 1).

### 3.2. Timber Supply Volume under Different Forestry Scenarios

Most old forest and caribou management scenarios resulted in a reduction in the annual modeled timber supply volume compared to the reference scenario in the Prince George TSA (Fig. 2). The NRV minimum scenario had the least effect on timber supply in the short-term (one to ten years), resulting in a 19% reduction. The NRV maximum scenario had the greatest effect on timber supply in the short-term, resulting in a 62% reduction. Limiting habitat disturbance to 35% in all caribou critical habitat areas resulted in a 48% short-term reduction in timber supply. Limiting timber harvest in non-matrix caribou habitat types only resulted in a 35% short-term reduction in timber supply. The NRV maximum scenario had the greatest effect on timber supply in the mid-term (15 to 60 years), resulting in a 38% reduction compared to the reference scenario. Limiting timber harvest in non-matrix caribou critical habitat resulted in a 2% increase in mid-term timber supply compared to the reference scenario. In the long-term (60 to 70 years) the scenario where timber harvest was restricted in all caribou critical habitat areas resulted in a 44% reduction in timber supply compared to the reference scenario. The NRV minimum scenario had the least effect in the long-term, resulting in a 12% reduction in timber supply.

[14] https://catalogue.data.gov.bc.ca/dataset/caribou-herd-locations-for-bc

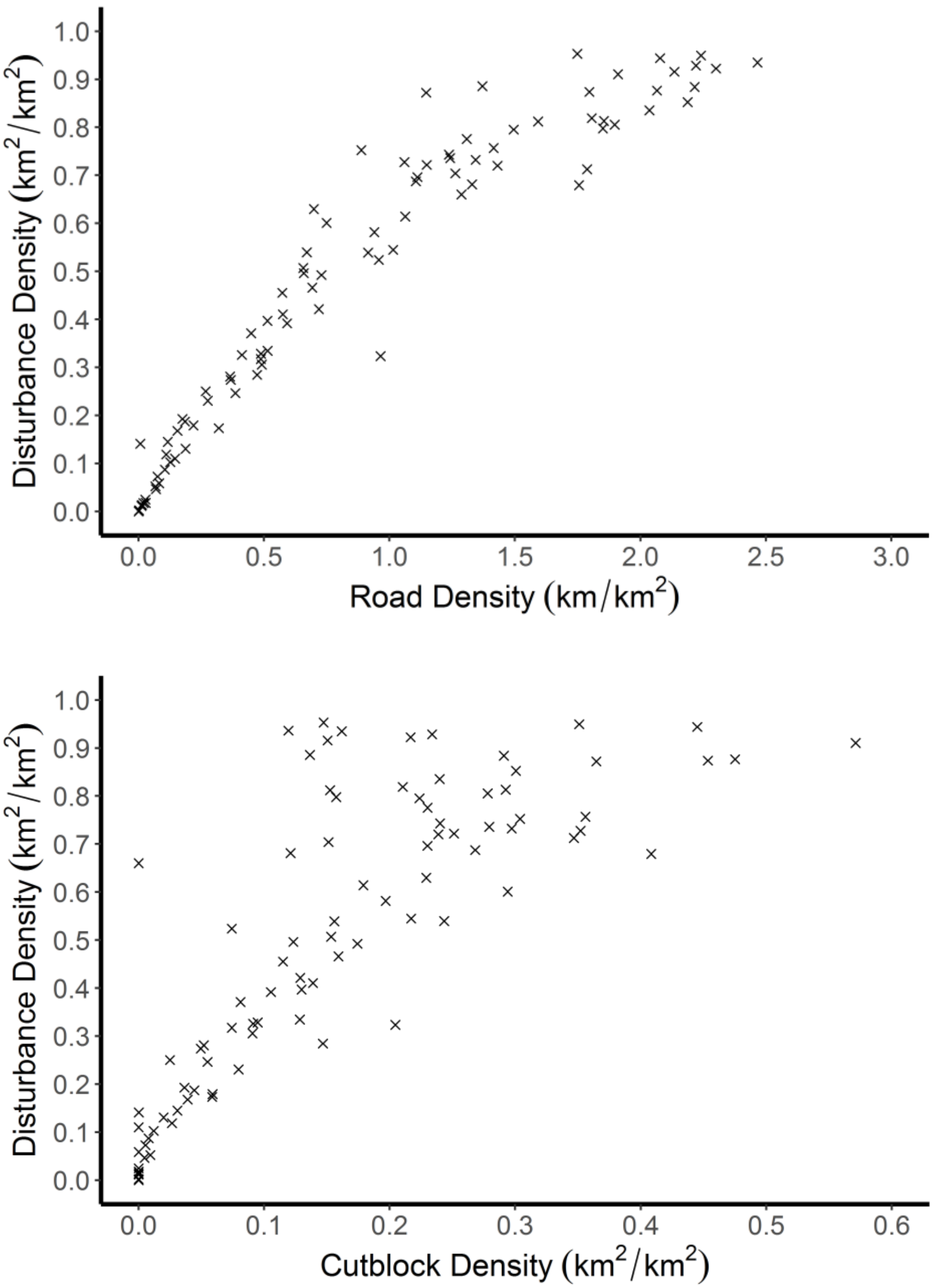



Figure 1. Relationship between road density and caribou habitat disturbance density (top) and cutblock density and caribou habitat disturbance density (bottom) within landscape units in the Prince George timber supply area (TSA).

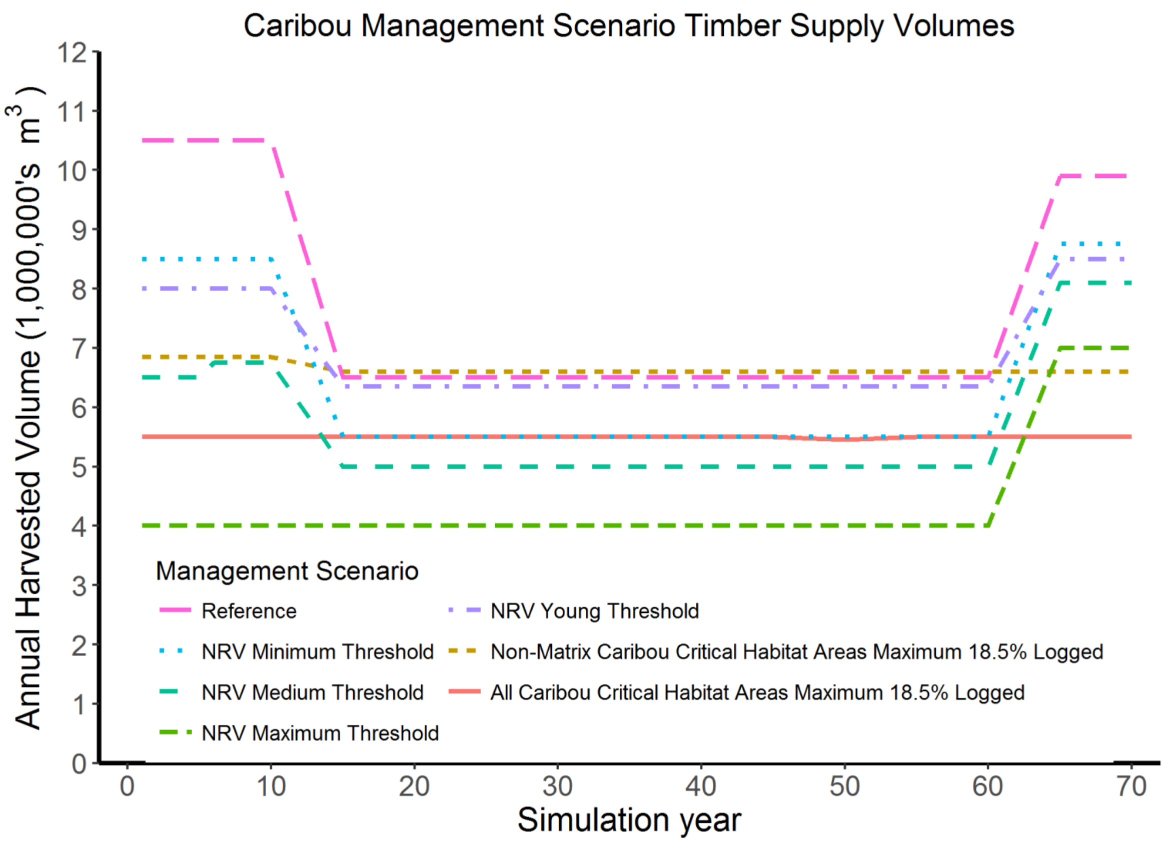



Figure 2. Annual volume of timber harvested under different caribou management scenarios as simulated in a timber supply model for the Prince George timber supply area.

### 3.3. Habitat Disturbance in Caribou Range under Different Forestry Scenarios

Currently, the density of disturbed caribou habitat in landscape units is high in the Narrow Lake, North Cariboo and western portions of the Hart Ranges caribou herd ranges, and moderately-high in the southern portions of the Wolverine and Takla caribou herd ranges (Fig. 3). In the reference scenario, the density of disturbed habitat increased throughout the Takla herd range and the western edge of the Wolverine herd range by 2045 (Fig. 3). The density of disturbed habitat further increased throughout the majority of the Wolverine herd and southern portions of the Chase herd by 2065. Disturbance estimates remained relatively stable over time in landscape units in the Hart Ranges, Kennedy Siding, Narroway, Narrow Lake, North Cariboo, Saptsizi and Tweedsmuir herds.

In the NRV minimum old forest area scenario (Fig. 4), the density of disturbed habitat in landscape units followed a similar pattern as the reference scenario. In the NRV medium old forest area scenario (Fig. 5), the density of disturbed habitat in landscape units in the Wolverine and Takla caribou herd ranges was less than compared to the reference scenario after 30 years, and in general landscape units in the Chase, Wolverine and Takla herd ranges were less disturbed than in the reference scenario. Similarly, in the NRV maximum old forest area scenario the density of disturbed habitat in landscape units in the Chase, Wolverine and Takla herd ranges was less than in the reference scenario (Fig. 6). In the NRV maximum young forest area scenario, landscape units in the Chase, Wolverine and Takla herd ranges were in general less disturbed after 30 years and slightly less disturbed after 60 years than in the reference scenario (Fig. 7).

In the caribou critical habitat management scenario where disturbance was limited to 35% of all identified caribou critical habitat areas, disturbance levels were maintained similar to initial (2015) disturbance levels after 30 years (Fig. 8). Disturbance levels were also less in this scenario than in the reference scenario after 60 years. In the caribou critical habitat management scenario where disturbance was limited to 35% of the non-matrix types of caribou critical habitat, habitat disturbance levels were also similar to initial (2015) disturbance levels after 30 years (Fig. 9). However, after 60 years, disturbance levels were greater in the Hart Ranges, Chase, Wolverine and Takla herd ranges. Nevertheless, these disturbance levels were less than in the reference scenario, except in the Hart Ranges.

Disturbance density estimates summarized by caribou herd range was compared across the different timber supply scenarios and against Environment Canada's target for less than 35% (a proportion of 0.35) of disturbed habitat in caribou range (Fig. 10). In all scenarios, disturbance levels were above the 35% threshold in the Narrow Lake and North Cariboo herds (but see Discussion, Section 4.1, below). In addition, in all scenarios, the Hart Ranges, Kennedy Siding, Narraway and Spatsizi herds remained relatively stable and below the 35% habitat disturbance threshold. The Chase herd also remained below the 35% threshold in all scenarios, although it increased over time in all scenarios from less than 10% to approximately 10% to 20% habitat disturbance within 40 years. In the reference scenario, habitat disturbance surpassed the 35% threshold in the Takla and Wolverine caribou herds, within approximately 10 years and 35 years, respectively. A similar trend of increased habitat disturbance in the Takla and Wolverine caribou herds occurred in all scenarios. However, habitat disturbance was maintained at relatively low levels in some of the scenarios. In particular, in the scenario where

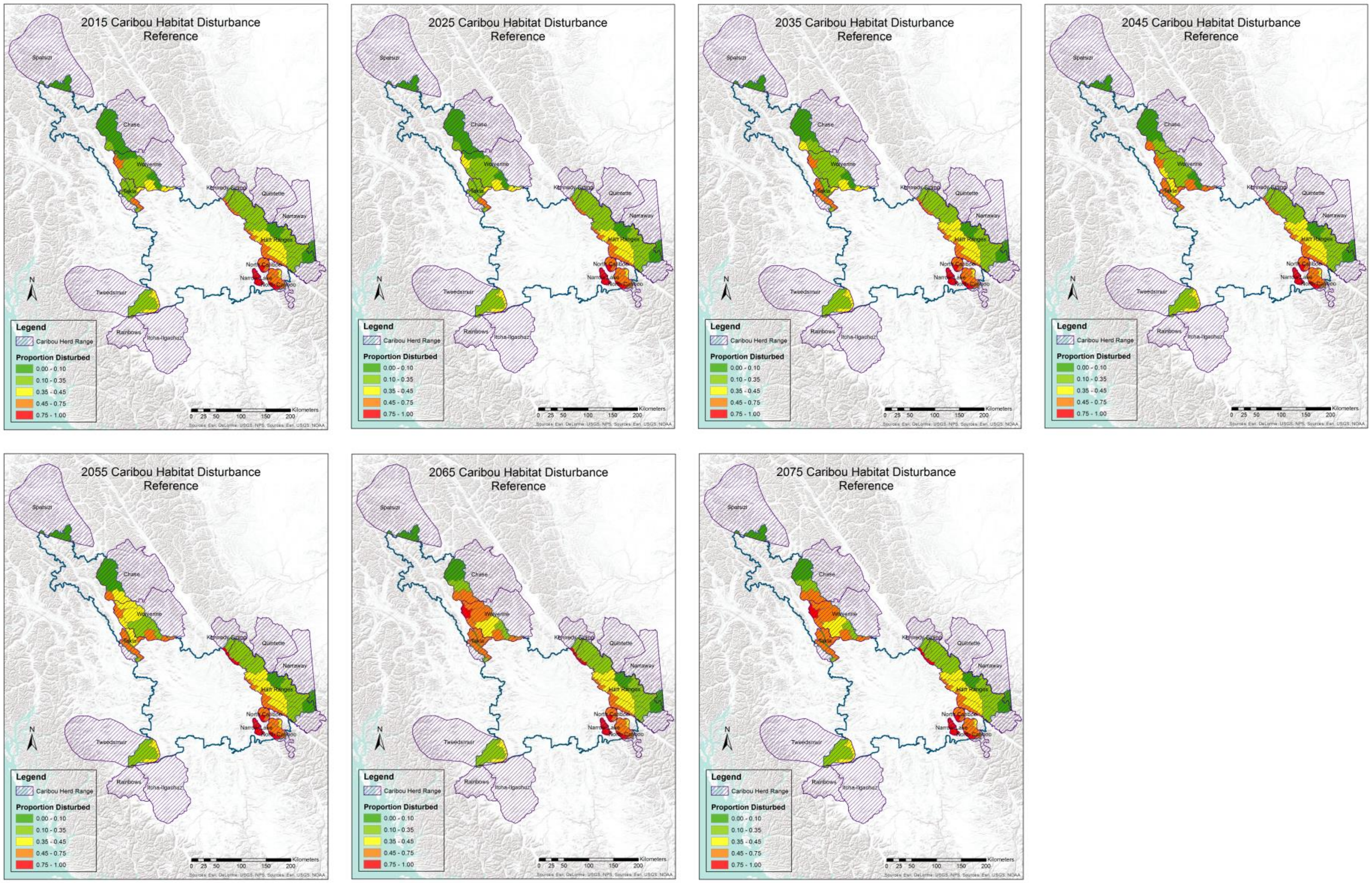



Figure 3. Proportion of disturbed habitat in landscape units in caribou range as simulated by the reference forest harvest scenario.

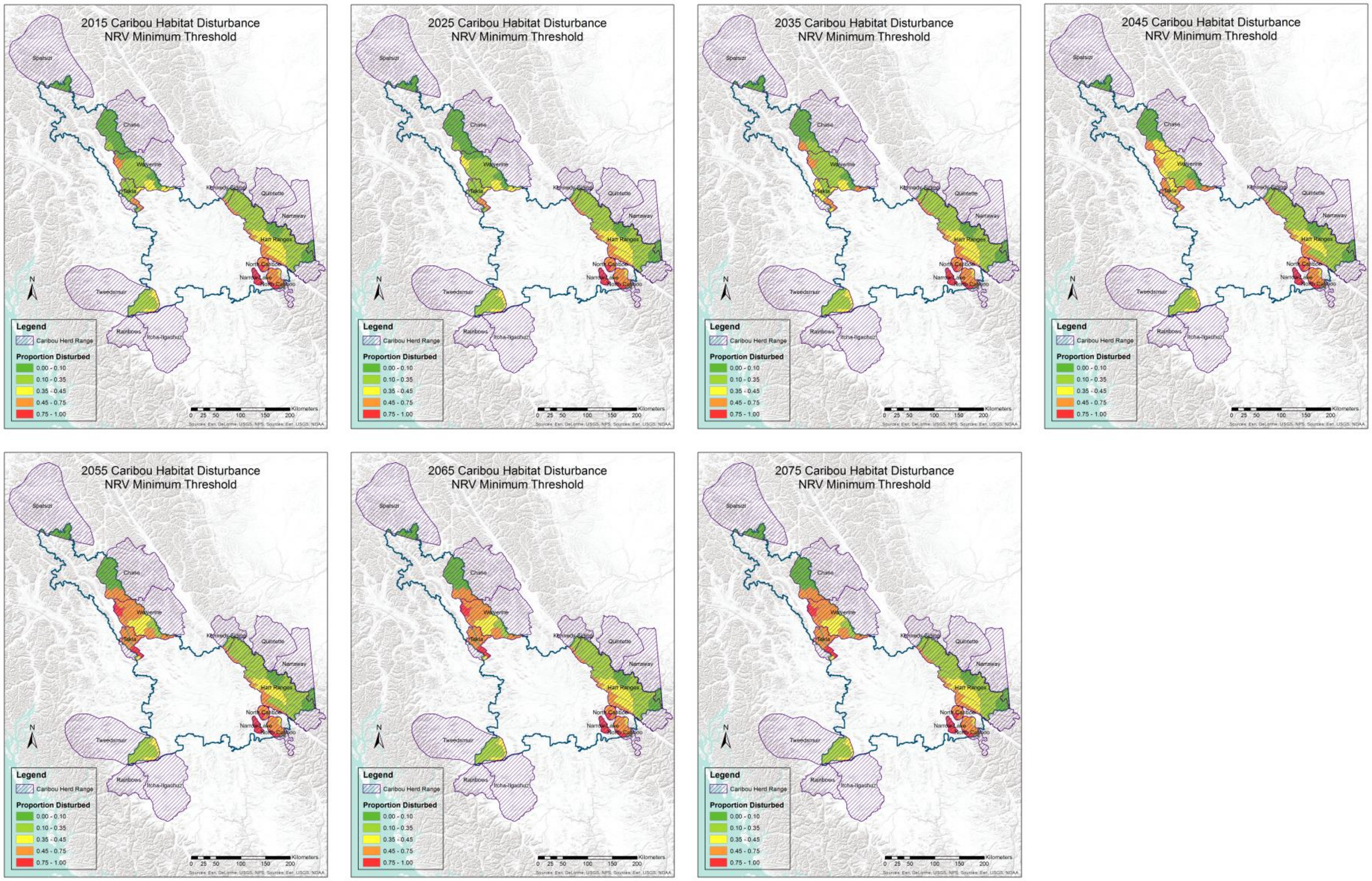



Figure 4. Proportion of disturbed habitat in landscape units in caribou range as simulated by the minimum natural range of variability (NRV) management threshold forest harvest scenario.

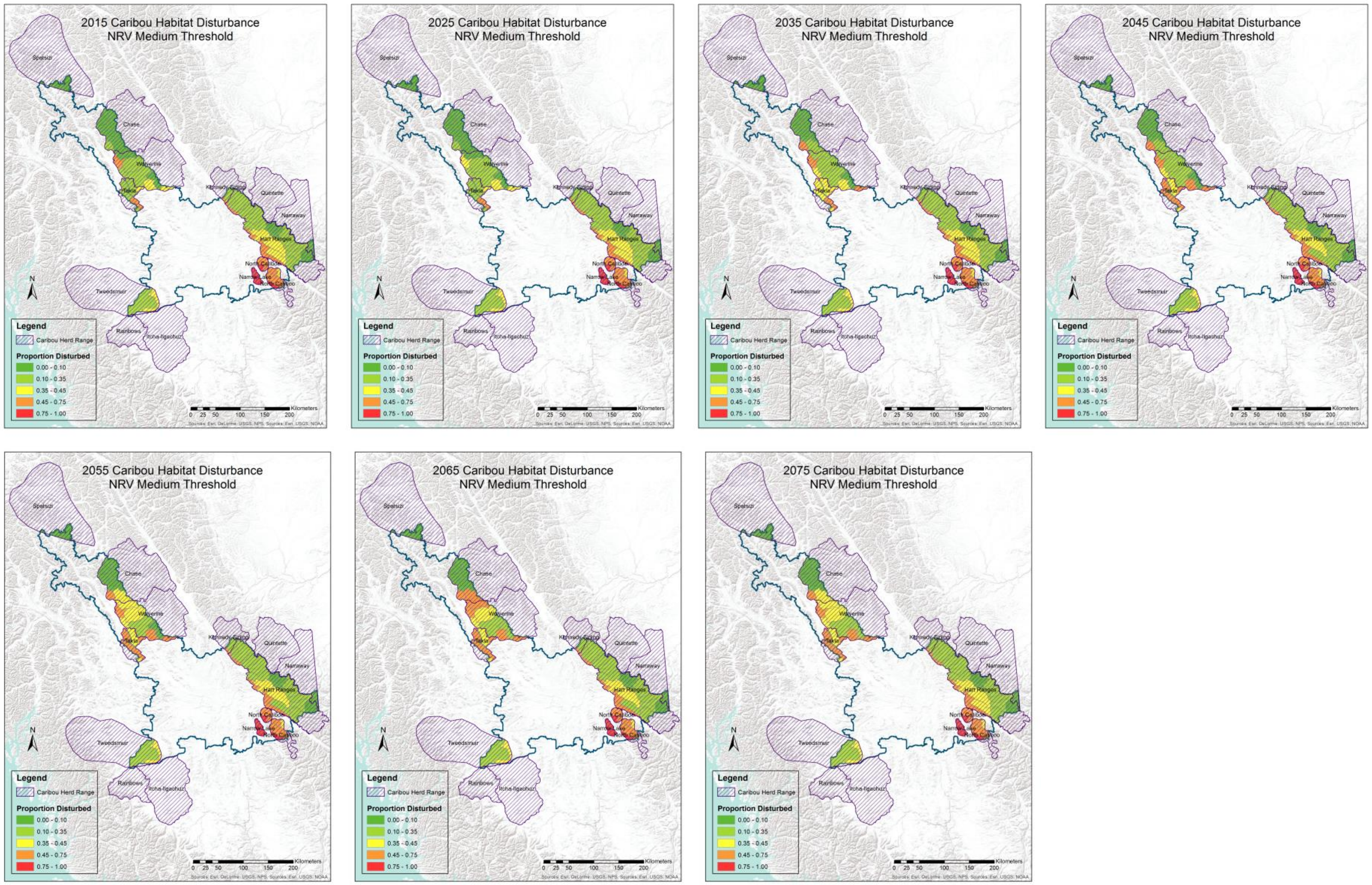



Figure 5. Proportion of disturbed habitat in landscape units in caribou range as simulated by the medium natural range of variability (NRV) management threshold forest harvest scenario.

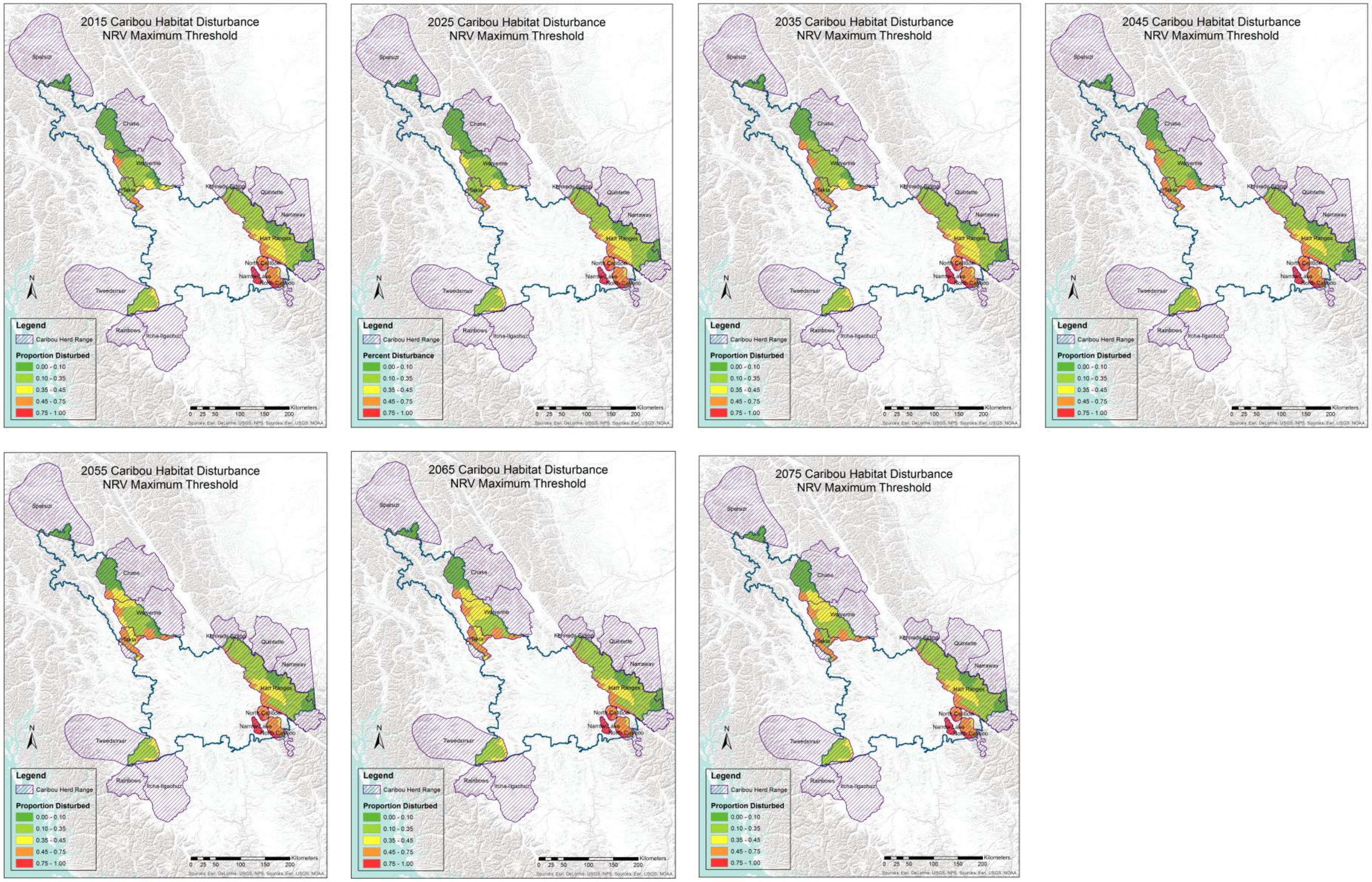



Figure 6. Proportion of disturbed habitat in landscape units in caribou range as simulated by the maximum natural range of variability (NRV) management threshold forest harvest scenario.

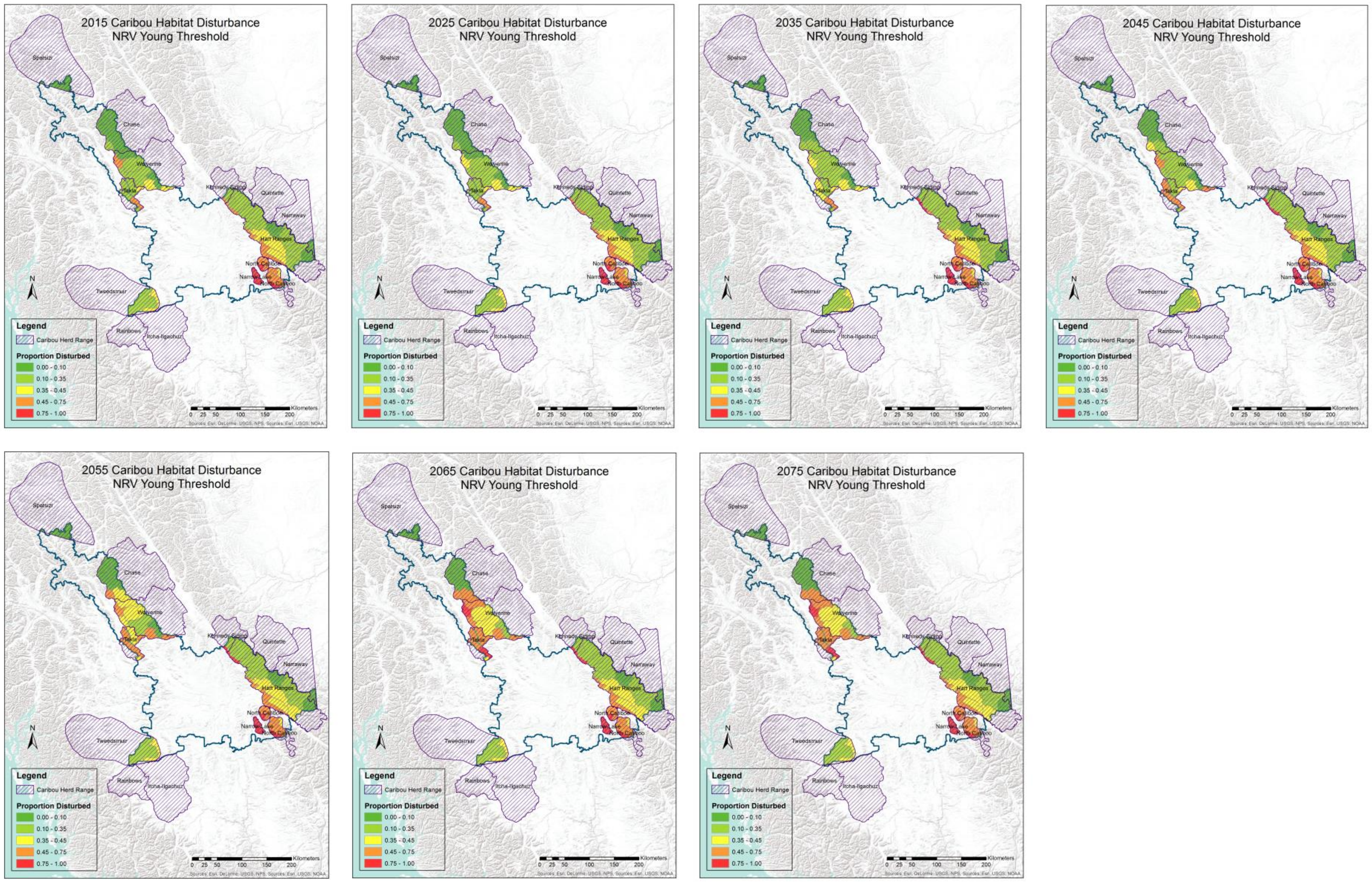



Figure 7. Proportion of disturbed habitat in landscape units in caribou range as simulated by the young natural range of variability (NRV) management threshold forest harvest scenario.

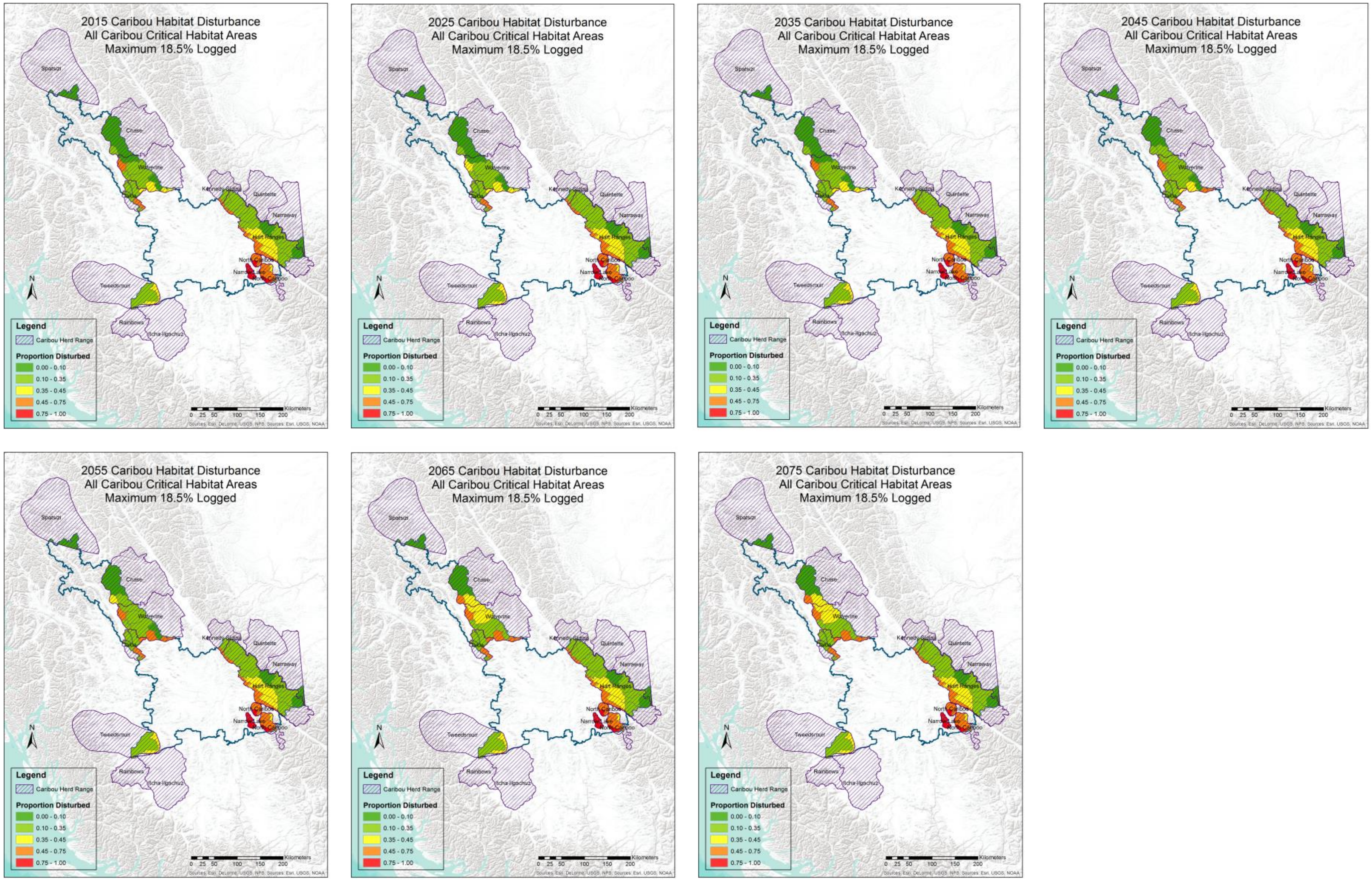



Figure 8. Proportion of disturbed habitat in landscape units in caribou range as simulated by the maximum 35% disturbance of all caribou critical habitat forest harvest scenario.

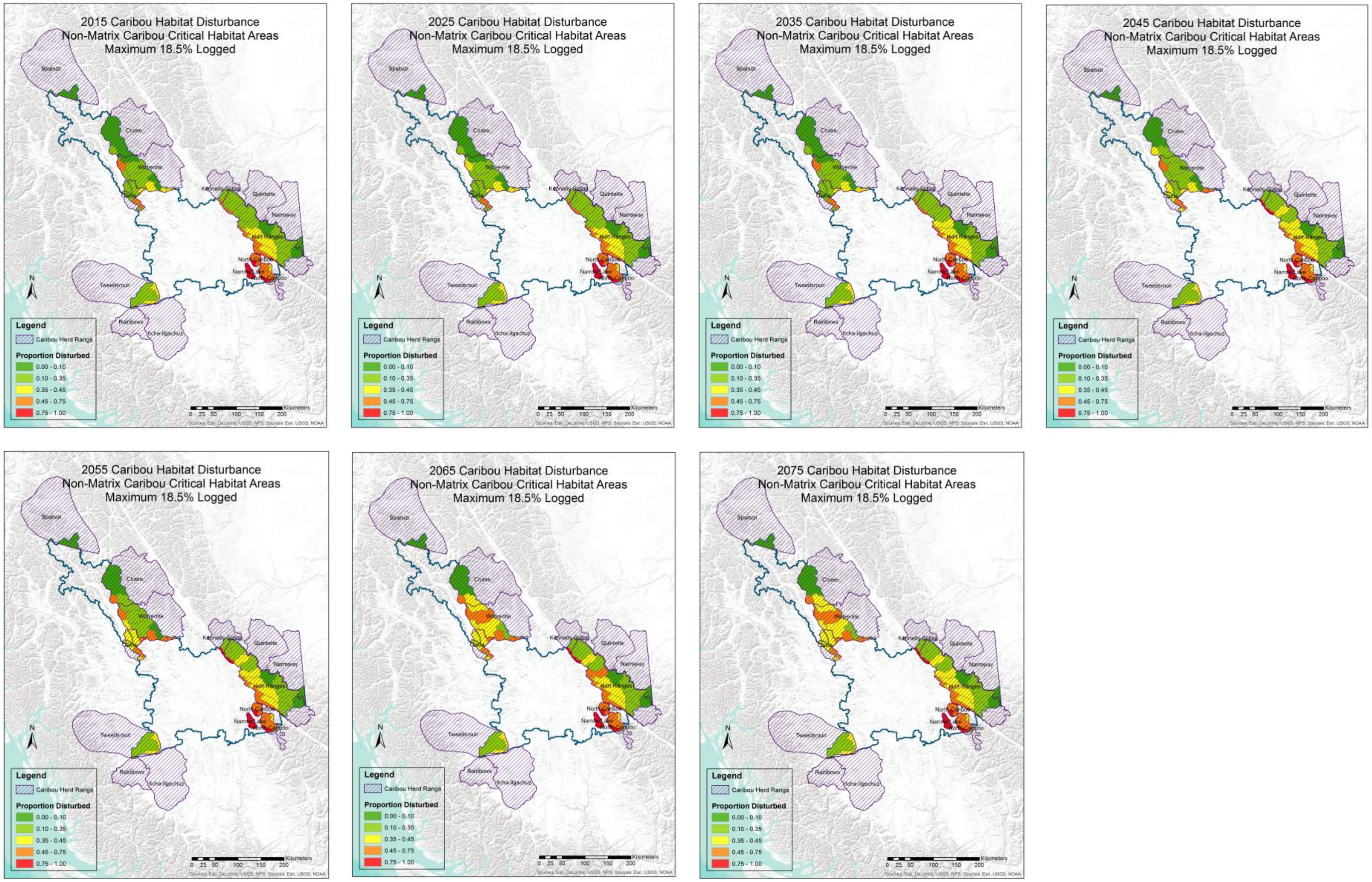
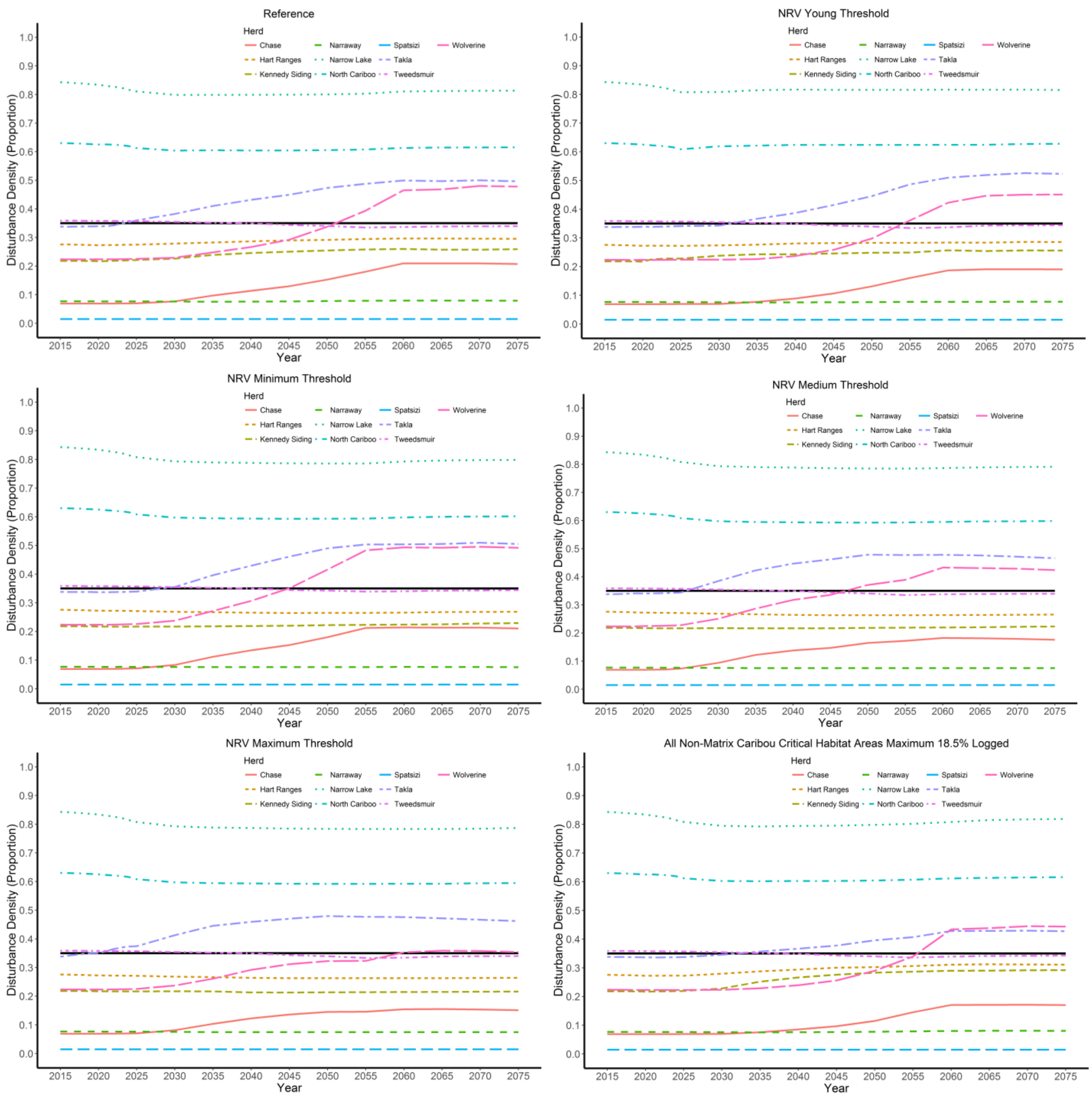



Figure 9. Proportion of disturbed habitat in landscape units in caribou range as simulated by the maximum 35% disturbance of non-matrix caribou critical habitat logged forest harvest scenario.


Reference
NRV Young Threshold
NRV Minimum Threshold
NRV Medium Threshold
NRV Maximum Threshold
All Non-Matrix Caribou Critical Habitat Areas Maximum 18.5% Logged
Herd
Chase
Narraway
Spatsizi
Wolverine
Hart Ranges
Narrow Lake
Takla
Kennedy Siding
North Cariboo
Tweedsmuir
Disturbance Density (Proportion)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Year
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075

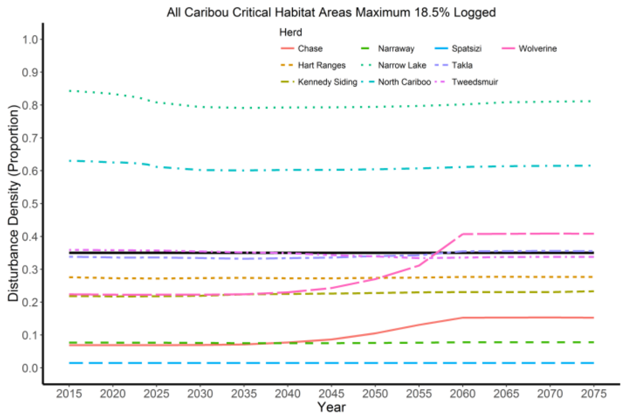



Figure 10. Habitat disturbance density in caribou ranges in the Prince George timber supply area (TSA) under different forest harvest and caribou management scenarios. Natural range of variability (NRV) scenarios include minimum, medium and maximum thresholds for old (greater than 120 years old) forest that reflect historic patterns in forest age as defined for natural disturbance units in the Prince George TSA area by Delong (2003) and a young (less than 40 year old) forest maximum threshold. Critical habitat management scenarios include a scenario where a maximum of 35% disturbance was permitted in critical matrix and non-matrix habitat for caribou, and a scenario where the maximum was applied to non-matrix habitat only.

habitat disturbance was restricted to less than 35% in all caribou critical habitat, habitat disturbance barely surpassed 35% in the Takla herd within 60 years and only surpassed 35% in the Wolverine herd after approximately 40 years.

## 4. Discussion

### 4.1. Forestry, Caribou Habitat Disturbance and Model Limitations

Forestry cutblock and road density was found to be highly correlated with caribou habitat disturbance. Thus, I could produce a statistical model of future caribou habitat disturbance based on simulated future forestry cutblocks. This model provides a linkage between forestry development and caribou population sustainability, as habitat disturbance has been correlated with self-sustaining caribou populations, which has been used to established habitat disturbance thresholds by Environment Canada (Environment Canada 2012; Environment Canada 2014).

The caribou habitat disturbance model described and applied here is useful to assess the general type and strength of relationships between forest development and caribou habitat and populations, but it should not be viewed as an absolute representation of caribou-forestry relationships. The model is purely correlative, thus the mechanistic relationship between caribou populations and forestry is oversimplified. There are several mechanisms for how human land use influences caribou populations, but the two predominant mechanisms are likely numerical and functional responses of caribou predators to human-caused habitat change. Numerical responses are increases in caribou predator densities that are the result of habitat change. Specifically, habitat change from land use activities can create early seral vegetation habitats (including cutblocks) that create more forage for ungulates (i.e., moose and deer) and thus support higher ungulate and predator densities (Wittmer et al. 2007; Wittmer et al. 2010). More caribou may be killed as a consequence of more predators in their range. Land use activities can concurrently cause a functional response in predator use of caribou ranges. In particular, land use activities that create habitats which facilitate the movement of predators in caribou range (i.e., roads, pipelines and trails; Latham et al. 2011; Dickie et al. 2016) may increase encounters with caribou (Whittington et al. 2011) and ultimately predation rate on caribou (James and Stuart-Smith 2000). Caribou may also respond to land use development by avoiding disturbed areas because they have more human activity (Dyer et al. 2001; Vistnes and Nellemann 2008; Wasser et al. 2011). The simplified relationship between forestry and caribou habitat disturbance that I used here does not attempt to disentangle the effect of these various mechanisms that may cause caribou populations to decline. Indeed, there is a lack of research studies that disentangle these effects because of the cost and complexity of such research. However, regardless of the mechanism, the negative relationship between habitat disturbance and caribou that I used here is appropriate because it has generally been found to be consistent across Canada (Festa-Bianchet at al. 2011) and is likely conceptually applicable for the caribou populations within the Prince George TSA. Nevertheless, a consequence of using this simplified model is that it may over- or under-estimate the influence of forestry activities on caribou, depending on which mechanism is driving caribou decline in the region.

The model may overestimate the effect of forestry on caribou if the mechanism for decline is primarily due to a numerical response by predators to habitat change. While forestry cutblocks are removed from disturbed habitat in the model once they are greater than 40 years old, forestry roads are never removed, and thus disturbance from roads may maintain high habitat disturbance levels in the model, despite low less than 40 year old cutblock densities in an area. If caribou decline is primarily caused by a numerical response of predators to cutblocks than caribou populations may perform better than predicted by the habitat disturbance model. However, the model also does not currently consider the effects of non-forestry linear features (i.e., trails and pipelines) on caribou, so it may also underestimate the functional response of predators to habitat disturbance.

Scale is another important consideration when assessing model results. I modeled habitat disturbance at a landscape unit scale. In most cases, habitat disturbance could reasonably be summarized at a landscape unit scale because whole landscape units were completely encompassed within caribou herd ranges where caribou management policies would be implemented. However, in the case of smaller caribou herd ranges (i.e., Narrow Lake and North Cariboo), landscape units extended to large areas outside of the ranges, and thus forestry development in those areas outside of caribou range could influence the amount of disturbance modeled in caribou range. The model quantifies habitat disturbance as if it was equally distributed across a landscape unit. However, in practice, landscape disturbance could be distributed within landscape units (i.e., at finer scales) more effectively to avoid disturbing habitat in caribou herd ranges. In sum, habitat disturbance in caribou range may be overestimated in the smaller herd ranges, or in landscape units along the edges of some of the larger herd ranges.

The model did not consider the effect of landscape disturbance outside of the Prince George TSA on caribou populations that partially overlapped with the TSA. For example, forestry development in the Wolverine and Chase herds outside of the Prince George TSA was not accounted for, but could also influence the amount of habitat disturbance in each range. In addition, the model did not consider the effects of other types of current and future land use developments on caribou habitat disturbance. For example, agricultural or oil and gas developments were not quantified in current or future disturbance levels. Thus, the model may underestimate total habitat disturbance.

Finally, the model did not consider the effects of programs such as predator control or caribou maternal penning that have been implemented in some areas to conserve caribou. Predator control and caribou maternal penning could mitigate predation of caribou and caribou population declines, regardless of habitat disturbance levels caused by land use activities. Nevertheless, the 35% habitat disturbance threshold target has been set in non-matrix critical habitat by Environment Canada (2014) despite these programs in recognition of the need to manage habitat for long-term sustainability of caribou populations.

## 4.2. Effects of Future Forestry on Caribou Habitat Disturbance

Habitat disturbance levels increased in the Chase, Wolverine and Takla caribou herds in all forest harvest scenarios, suggesting these herds may be most vulnerable to future forestry. In the short-term (approximately 10 years), the Takla herd may be at most risk from future forestry disturbance and in the mid-term (approximately 35 years), the Wolverine herd may be at most risk. These herds should likely be the focus of programs to mitigate future habitat disturbance from forestry in the region. The

Tweedsmuir herd in the southwest and the Hart Ranges and Kennedy Siding herds in the east were relatively well protected from habitat disturbance from forestry, even in the reference scenario, suggesting current management is effectively limiting habitat disturbance from forestry there. Disturbance did not change substantially in the North Cariboo and Narrow Lake herds either, however, habitat disturbance in those herds was very high to begin with, and disturbance estimates may be inflated.

Managing for old forest within its historic natural range of variability in the Prince George TSA, or restricting forestry in caribou critical habitat areas are both options to reduce disturbance levels in the Chase, Wolverine and Takla caribou ranges. These options either delayed the increase in disturbance, or maintained disturbance at relatively low levels in the long-term. However, to achieve these benefits to caribou required significant reductions in timber supply in the short-term (up to 65%), mid-term (up to 38%) and long-term (up to 44%). Restricting forestry in caribou critical habitat areas may in general have less downward pressure on timber supply than managing for old forest in the entire Prince George TSA, with more benefits to caribou.

Fundamentally, the results from the majority of the model scenarios demonstrate that as the THLB becomes modified over the next 60 years, many caribou populations in the central portion of the Prince George TSA will become increasingly unlikely to be self-sustaining. Conversely, maintaining habitat disturbance levels below the 35% threshold established by Environment Canada to increase the probability of sustaining caribou in the region will very likely have a significant and unacceptable downward pressure on timber supply. While no formal plan to address this trade-off has been developed by the government of British Columbia, a reduction in timber supply is a likely outcome and could be considered as part of the current annual allowable cut decision.

## 5. Literature Cited


Courtois, R., Ouellet, J. P., Breton, L., Gingras, A., & Dussault, C. (2007). Effects of forest disturbance on density, space use, and mortality of woodland caribou. Ecoscience, 14(4), 491-498.

DeLong, C., 2003. Land Units and Benchmarks for Developing Natural Disturbance-based Forest Management Guidance for Northeastern British Columbia. B.C. Min. For., Res. Br., Victoria, B.C. Technical Report. No. 59

Dickie, M., Serrouya, R., McNay, R. S., & Boutin, S. (2016). Faster and farther: wolf movement on linear features and implications for hunting behaviour. Journal of Applied Ecology.

Environment Canada. 2012. Recovery Strategy for the Woodland Caribou (*Rangifer tarandus caribou*), Boreal population, in Canada. Species at Risk Act Recovery Strategy Series. Environment Canada, Ottawa. xi + 138pp.

Environment Canada. 2014. Recovery Strategy for the Woodland Caribou, Southern Mountain population (*Rangifer tarandus caribou*) in Canada [Proposed]. Species at Risk Act Recovery Strategy Series. Environment Canada, Ottawa. viii + 68 pp.

Festa-Bianchet, M., Ray, J. C., Boutin, S., Côté, S. D., & Gunn, A. (2011). Conservation of caribou (*Rangifer tarandus*) in Canada: an uncertain future. Canadian Journal of Zoology, 89(5), 419-434.

James, A. R., & Stuart-Smith, A. K. (2000). Distribution of caribou and wolves in relation to linear corridors. The Journal of Wildlife Management, 64, 154-159.

Latham, A. D. M., Latham, M. C., Boyce, M. S., & Boutin, S. (2011). Movement responses by wolves to industrial linear features and their effect on woodland caribou in northeastern Alberta. Ecological Applications, 21(8), 2854-2865.

R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Sorensen, T., McLoughlin, P. D., Hervieux, D., Dzus, E., Nolan, J., Wynes, B., & Boutin, S. (2008). Determining sustainable levels of cumulative effects for boreal caribou. The Journal of Wildlife Management, 72(4), 900-905.

Vistnes, I., & Nellemann, C. (2008). The matter of spatial and temporal scales: a review of reindeer and caribou response to human activity. Polar Biology, 31(4), 399-407.

Vors, L. S., Schaefer, J. A., Pond, B. A., Rodgers, A. R., & Patterson, B. R. (2007). Woodland caribou extirpation and anthropogenic landscape disturbance in Ontario. The Journal of wildlife management, 71(4), 1249-1256.

Wasser, S. K., Keim, J. L., Taper, M. L., & Lele, S. R. (2011). The influences of wolf predation, habitat loss, and human activity on caribou and moose in the Alberta oil sands. Frontiers in Ecology and the Environment, 9(10), 546-551.

Whittington, J., Hebblewhite, M., DeCesare, N. J., Neufeld, L., Bradley, M., Wilmshurst, J., & Musiani, M. (2011). Caribou encounters with wolves increase near roads and trails: a time-to-event approach. Journal of Applied Ecology, 48(6), 1535-1542.

Wittmer, H. U., McLellan, B. N., Serrouya, R., & Apps, C. D. (2007). Changes in landscape composition influence the decline of a threatened woodland caribou population. Journal of animal ecology, 76(3), 568-579.

Wittmer, H. U., Ahrens, R. N. M., & McLellan, B. N. (2010). Viability of mountain caribou in British Columbia, Canada: Effects of habitat change and population density. Biological Conservation, 143(1), 86–93.

**Appendix A. ArcScan settings for converting rasterized road data to vector format.**

Vectorization settings:

- Geometrical intersection
- Max line width = 20
- Noise level = 20
- Compression tolerance = 0.025
- Smoothing weight = 3
- Hole size = 3