Predicting Harvesting Impacts on Caribou Habitat

AN ANALYSIS USING FPS-ATLAS AND ARCGIS

TREVOR LUU • FRST 497 • APRIL 17, 2015

Table of Contents

List of Figures

List of Tables

List of Appendices

1. Introduction and Background

The northern woodland caribou is one of the three ecotypes of caribou that exist within British Columbia. In the recent year, decreases in herd populations of caribou have raised concerns about the species' survival. There are two prominent factors that seem to be the cause of the decline: the recent mountain pine beetle epidemic and timber harvest activities. This project is an analysis on how tools such as FPS-ATLAS and ArcGIS can be utilized to provide a broad understanding of how different harvest schedule will affect caribou habitat suitability.

Study Area

This project focuses on a study area located in the Lakes Timber Supply area of the Nadina Forest District. Located in west-central British Columbia, the area is bordered by Ootsa Lake to the northeast, Tetachuck Lake to the southeast, and Tweedsmuir North Provincial Part directly to the west. The Chelaslie study area, as it is named, totals 160,000 hectares.

There are two main biogeoclimatic (BEC) zones within the Chelaslie area: the Engelmann Spruce-Subalpine Fir (ESSF) and Sub-Boreal Spruce (SBS) zones, with the latter being the most prominent BEC zone. The ESSF zone is generally found in the higher elevations while the SBS is found in the lower elevation valleys. The landscape is primarily dominated by pine and spruce-leading stands with fir and aspen-leading stands occupying a very small portion of the total area.

Northern Caribou Habitat

The woodland caribou (Rangifer tarandus caribou) is the main subspecies of Caribou occurring within British Columbia and the species of focus in this project. They belong to the same family of even-toed ungulates such as moose, elk, and deer, the Cervidae family. In terms of size, the woodland caribou sits between the larger elk and the smaller deer.

There are three ecotypes of Woodland Caribou in BC: Mountain, Northern, and Boreal. Only the northern ecotype occurs within the study area. (Paquet, 2000) In contrast to subspecies, ecotypes are not differentiated by any genetic or physical traits, but rather by their differing patterns in behaviour and habitat selection.

Caribou are social animals that travel in herds requiring large landscapes that allow them to evade predators by dispersion. They primarily select mature to old-growth stands as there is suitable stand structure for snow interception as well as for predator evasion. Pine is their primary species of choice, mostly preferring pine-leading and pine-mixed stands for their winter range.

Issues

Northern caribou are currently listed as vulnerable by the Committee on the Status of Wildlife in Canada (COSEWIC). The winter range of the caribou has been a concern as it is the period when food source is limited and changes in supply can hinder survival. Timber harvesting is one of the leading factors in the reduction of available winter range for caribou. Forest cover acts to intercept snowfall and reduce the depth of accumulated snow which reduces the energy expended to traverse through the forest and allows the caribou to more easily evade predators. Trees, primarily pine species, are also tied to their food supply. The primary food source for caribou is lichen which is found within the canopy of the trees (arboreal) as well as the base (terrestrial). Therefore, the removal of tree cover only reduces available winter range.

The mountain pine beetle epidemic is also a concern regarding caribou winter range. Despite being native to western North America, the increase in the proficiency of fire suppression and warmer winters have broken the disturbance cycle that maintains beetle populations to endemic sizes. The epidemic that broke out in the recent decade has put much of the Central Interior region in the grey-attack stage. In this stage of the epidemic, attacked trees are no longer alive and starting to shed their needles. It is the next stage, falldown, which is of the most concern. Once standing dead snags begin to lose structural integrity due to decomposition, they start to fall over due to blowdown and snow press. Because the falldown stage removes tree cover and a critical lichen source, it is a source of concern for caribou winter range.

Objective

The aim of this project is to utilize readily available data provided by the BC provincial government to predict future habitat supply for northern caribou. By linking the harvest schedule scenarios produced by FPS-ATLAS to a habitat suitability model, we can predict the future supply of caribou habitat (Figure 1). Scenarios were created by imposing constraints on the harvest while the habitat model was created based on the ecology of northern caribou.

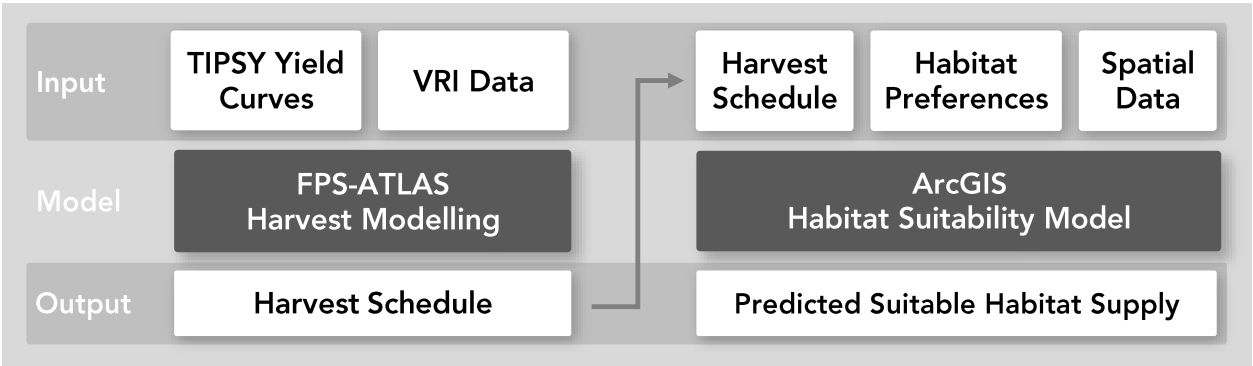

Figure 1 - Schematic of the project from modelling harvest schedules to habitat suitability modelling.

2. Tools and Software

TIPSY

The Table Interpolation for Stand Yields (TIPSY) software is a growth and yield program that interpolates the growth and yield for a specific user-defined site through inputs such as site productivity, management and species composition. TIPSY utilizes yield tables from a database built from data generated primarily by proprietary programs run by the Ministry of Forest, Lands, and Natural Resource Operations (FLNRO), TASS and SYLVER (Ministry of Forests, Lands and Natural Resource Operations, 2013a).

TASS (Tree and Stand Simulator) contributes growth data based on biologically-centric and spatially explicit simulations of individual tree growth. The program also takes into account the growth in response to silvicultural treatments. (Ministry of Forests, Lands and Natural Resource Operations, 2013b) SYLVER (Silviculture on Yield, Lumber Values, and Economic Return) focuses on the recovery of lumber at a stand level utilizing outputs from TASS among a multitude of other factors. (Ministry of Forests, Lands and Natural Resource Operations, 2013c) As the TASS and SYLVER software are not publically distributed, the generated data is only accessible through the use of TIPSY (2013a). TIPSY was used to generate stand yield curves used in FPS-ATLAS.

Vegetation Resources Inventory (VRI)

The Vegetation Resources Inventory (VRI) is an inventory database of resources within BC relating to vegetation. At its inception in 1995, VRI solely included timber resources as its original intention. Over the past two decades, the database has expanded to include all vegetation resources. Additional information including but not limited to soil type, terrain, biogeoclimatic zones, and health condition are also available through VRI (Sandvoss, et al., 2005). The information pertaining to the condition of the forest is a valuable resource in the production of derived data. In the case of this project, VRI data was crucial in the projection of future stand growth and the modelling of the impacts of harvesting on the study area. Forest attributes such as leading species, dead standing timber, site productivity, etc. were taken from the VRI database to use in the analysis (Ministry of Forest, Lands and Natural Resource Operations, 2015).

VRI data is distributed through DataBC, a service provided by the Government of British Columbia to allow access to public data (Government of B.C., n.d.).

FPS-ATLAS

ATLAS (A Tactical Landscape Analysis Software) was designed by Dr. John Nelson of the University of British Columbia. Used in the forestry sector, ATLAS allows the effective modeling of forest inventory through the simulation of a harvest schedule. The harvesting schedule is determined by a hierarchy of constraints (harvest flows, seral stage distributions, buffers, etc.) which are imposed upon stand polygons. The polygons, which have attributes such as rotation age, and growth and yield information attached, are then ranked based on all priorities and constraints set by the user to produce a harvest schedule. Each run (or simulation) within ATLAS will harvest the polygon with the highest priority. The entire prioritized list of polygons is then checked for any conflicts with the constraints (green up, adjacency, patches, etc.). Once conflicts are resolved and polygons are reordered (if necessary), the now highest priority polygon is harvest. This proceeds until the harvest flow set by the user is fulfilled or until no polygons are left to harvest. ATLAS proceeds to the next period and repeats the process until the user-defined planning horizon (Figure 2).

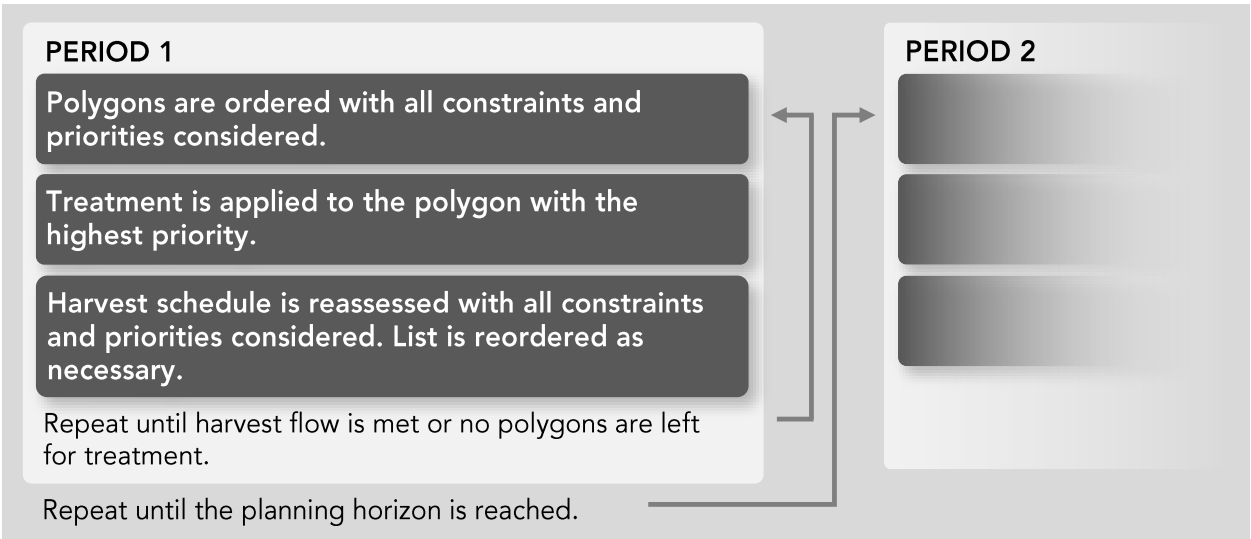

Figure 2 - The steps through which FPS-ATLAS determines a harvest schedule.

Spatial Units

In order to establish harvest priorities when determining the harvest schedule, a hierarchy of spatial units is established. The basic spatial unit is a polygon. Each polygon has a set of attributes (age, area, state, harvest system, distance to mill, stand group) assigned. Polygons cannot be divided as they are the smallest spatial unit. The next smallest spatial unit are zones, followed by access units, then ranges. The forest estate denotes all polygons available within the model and represents the largest spatial unit. There is only one forest estate to which all polygons belong. These are considered the essential spatial units as all polygons must belong to a single zone, a single access unit, and a single range.

Cliques

Cliques are an optional spatial unit allowing polygons to be grouped together. This differs from other spatial units and stand groups as polygons can belong to multiple cliques as well as no cliques at all. In addition, priority does not exist between cliques.

In the Chelaslie study area, cliques were used to identify the two BEC zones (SBS and ESSF), lake and river buffers, and wildlife tree retention (WTR) areas. The largest of these 5 cliques are the two BEC zones. Because multiple cliques can contain the same polygon, the buffer cliques and retention areas overlap with the BEC zone cliques.

Stand Groups

Stand groups allow the grouping of polygons into groups of similar treatment and condition. Each stand group is characterized by its assigned silvicultural treatment as well as its growth and yield projection.

There are five treatments that can be assigned to stand groups: thinning, clearcut, partial cut, rehabilitation, and succession. The minimum and maximum age that the treatment may be applied is user-determined. Stand groups will transition to a user-determined stand group once the treatment has been applied.

Each stand group is also described by a unique growth and yield curve. TIPSY output data is used to determine these curves. Stand groups within the study area were delineated through the use of 4 different polygon characteristics. These characteristics include: stand status, site productivity, BEC subzone, and leading-species. The combination of the four primary characteristics were used within TIPSY to determine unique growth and yield curves for each stand group.

Stand Status

The stand status of a polygon describes the state of management, or lack thereof. Stands that have not yet been harvest are denoted 'Natural' whereas stands that have been harvested are denoted 'Managed'. In FPS-ATLAS, 'Natural' stand groups that are subjected to harvesting are reassigned to 'Managed'. As logic would follow, harvested 'Managed' stands do not change status.

Site Productivity

Site productivity describes how well trees grow within a stand. This is generally quantified as site index which, as defined by the VRI Data Dictionary, describes the mean height of the dominant tree will reach at a standardized age of 50 years. The SI value of each polygon was reclassified from a continuous range of values to 4 simpler, discrete classes (Table 1).

Table 1 - Reclassification of site index to site productivity.

Reclassified Site Productivity Label	SI Range
1 Good	≥ 18
2 Medium	12 – 17.9
3 Poor	≤ 11.9
4 None	Null or Missing Data

BEC Subzone Adjustments

Certain BEC subzones required an adjustment within TIPSY to produce a slightly different growth and yield. Of the three BEC subzones, the SBSmc and SBSdk required an adjustment. These adjustments were only applied to the managed stands.

Leading Species

The leading species defines the dominant tree species within a polygon. This is defined as the tree species with the highest percent composition in gross volume. VRI provides two fields, 'species_cd_1' and 'species_pct_1', which are used to classify the leading species. The 'species_pct_1' field is used specifically to differentiate between pine-leading stands and pine-mixed stand. Stands with ≥ 80% pine in volume are denoted pine-leading whereas < 80% pine is denoted pine mixed (Table 2).

Table 2 - Reclassification of leading species and species percentage.

Leading Species	species_cd_1	species_pct_1
1 Spruce-Leading	SX	
2 Pine-Leading	PL	≥ 80%
3 Pine Mixed	PL	< 80%
4 Fir Leading	BL	
5 Aspen-Leading	AT	

Percent Dead

In addition, a fifth polygon characteristic, percent dead, was added for the purpose of simulating falldown. Each stand group was divided into 6 new classes representing the proportion of standing dead volume per hectare.

Percent dead was determined using the fields 'live_stand_volume_125' and 'dead_stand_volume_125'. These fields represent the net volume per hectare for trees with a diameter (dbh) of 12.5 cm or higher for all tree species. Percent dead was calculated by taking the 'dead_stand_volume_125' field and dividing by the sum of 'live_stand_volume_125' and 'dead_stand_volume_125'. The standing dead percent is expressed as an integer rather than a decimal (Figure 3).

$$Percent\ Dead = \frac{Dead\ Standing\ Volume}{(Dead\ Standing\ Volume + Live\ Standing\ Volume)} \times 100\%$$

Figure 3 - Equation used in the calculation of percent dead.

Each polygon was then reclassified into 6 classes based on their calculated percentage. Polygons with less than 50% dead were not reclassified and was therefore not reassigned into a new stand group. Stands with 50% or greater were assigned to new stand groups.

To simulate falldown, 5-digit stand groups (50% or higher dead standing volume) were reduced from their total standing volume to just their live standing volume through the reduction of their age. In FPS-ATLAS, standing volume is calculated using the unique growth and yield curve assigned to each stand group. Using the age of a polygon as an input value, age is interpolated through the use of the yield curve. A certain volume per hectare value is outputted, multiplied by the total area of the polygon to produce the total standing volume within that polygon. By exploiting this relationship between volume and age, volume can be directly reduced through a change in polygon age. A simple approach was taken to determine the successional age of each stand group. The succession age is the age of the stand after falldown, and it is used in the "Succession" treatment within FPS-ATLAS. Assuming that on average, the stands were attacked when they carry their maximum amount of growing stock, we can decrease each stand group as a whole from their respective maximums.

Using the maximum value of each curve as the maximum (100% possible growing stock), the percent dead was subtracted from the volume. The reduced volume was used to interpolate the corresponding age through the vlookup function in excel (Figure 4).

Maximum value of the curve:	491 m^3/hectare
Reduce by 50% of the total volume:	491 m^3/ha × 50% live standing = 245.5
Index and Match Functions in Excel:	= INDEX (1111Curve, MATCH(ReducedVol, 1111Curve, 1)) The MATCH function is used to find the closest volume less than or equal to the reduced volume. The INDEX function then uses the closest volume to find the corresponding age.
Closest volume matched:	228 m^3/hectare
Corresponding age:	80 years (8th decade)

Figure 4 - An example calculating the age to which stand group 51111 should reduce during falldown.

The succession 'treatment' assigned to the 5-digit stand groups within ATLAS (Table 3). Within the first period, each of these stand groups will go through simulated succession and proceed to their new age while reverting back to their original stand groups that are not affected by mountain pine beetle attack (Figure 5). Because all of this is designed to occur within the first period of a run, all 5-digit stand groups disappear after period 1.

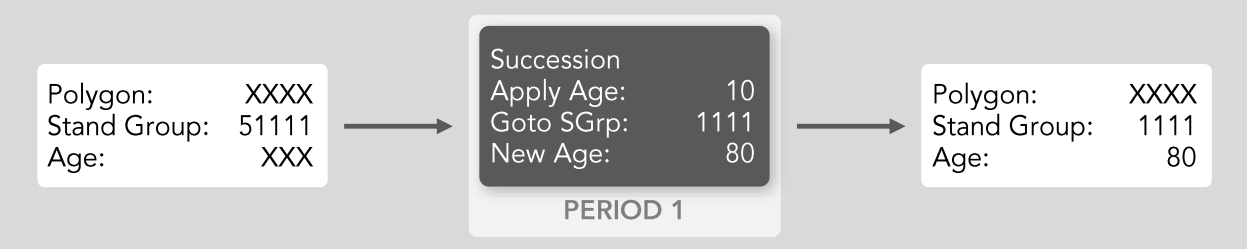

Figure 5 - An example of the simulation of falldown for stand group 51111 (1111 with 50% dead standing volume).

Table 3 - Description of each polygon characteristic determining stand group identification codes.

Percent Dead	Stand Status	Site Productivity	BEC Subzone Adjustments	Leading-Species
0-49%	1 Natural	1 Good	1 None	1 Spruce-Leading
5 50-59%	2 Managed	2 Medium	2 SBSmc	2 Pine-Leading
6 60-69%		3 Poor	3 SBSdk	3 Pine Mixed
7 70-79%		4 None		4 Fir-Leading
8 80-89%				5 Aspen-Leading
9 90-100%				

Note: Not all stand groups combinations exist within the Chelaslie landbase. In addition, there is a stand group labeled 888 which includes denotes the unknown nature of the stand. This is an artifact of the VRI data.

Constraints and Constraints Sets

Constraints of can be applied to any spatial unit within ATLAS. These constraints provide limitations that ATLAS uses to determine a harvest schedule. They can limit the maximum or minimum proportion specific seral stages that must exist, limit the total proportion of area to be harvested, or even completely disabling harvesting. These constraints are grouped together as constraints sets which can be applied to each spatial unit. Duration and timing of constraints can be defined by the user.

Ubiquitous Constraints

Several areas within the study area require special constraints which are permanently applied independent of the scenario. The first group of areas are the river buffer, lake buffer, and wildlife tree retention cliques. The second group is the unknown stand group. Harvesting is disabled in these areas.

ArcGIS

A geographic information system (GIS) is a system for processing and analysing data collected on the geographic properties of the earth for the purposes of information communication and decision making. While GIS is comprised of multiple components including hardware, software, people, and data, it is usually commonly used to refer to the software tools. These tools take raw spatial data (e.g. elevation models) from various sources and express the information with a relevant context (e.g. thematic maps) (Chrisman, 2002).

In this project, GIS is used as a tool to take the information from VRI Data and FPS-ATLAS to carry out a habitat analysis on the suitability of the study area as northern caribou winter range. The main

application used is the ModelBuilder within ArcGIS. ArcMap, another program within the suite, is used to produce and view maps created by the ModelBuilder. ArcGIS was developed by Environmental Systems Research Institute (Esri). ModelBuilder allows the user to produce workflows incorporating geoprocessing tools to analyse data. The workflows are expressed in a visual flowchart-type programming language (Esri, 2011a). Tools are simply dragged and dropped into ModelBuilder from the toolbox and arranged sequentially by the user as desired. A flowchart for the habitat model used in this study can be found in Appendix II.

There are three types of elements (Figure 6) that can exist in a model. Within those elements exist several sub-elements (Esri, 2011b).

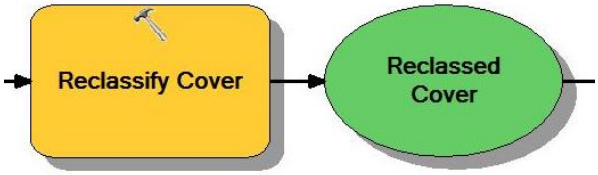

Figure 6 - Sample elements in ModelBuilder.

- Tools – These model elements are responsible for the geoprocessing and analysis of data. They are represented as orange rounded rectangles.
- Variables – These elements include input data, derived/output data, and value variables. These are represented as green ovals.
- Connectors – As the name suggests, these elements allow tools and variables to be connected. For example, this allows outputs data from one tool to be used as input data for another tool in the model.

Because the ArcGIS includes a vast array of tools and applications, this report will only cover the tools used for this project.

Raster Overlay Analysis

In order to assess the suitability of the study area for northern caribou winter range, a raster overlay analysis was used. A raster overlay analysis involves assigning new normalized values to different attributes of interest and overlaying those values to create an aggregated analysis. One of the simplest methods to carry out an overlay analysis is to use raster layers. Converting spatial data from multiple sources into a simple array (grid of values) simplifies the concept for the user as well as provides simpler data for processing. Each attribute of interest is converted (rasterized) into a single layer consisting of only values of that attribute. The values in each layer are then reassigned (reclassified) new values based on their importance to the goal of the analysis. This allows certain values of an attribute to be weighed more or less depending on their significance. Once all layers have been reclassified and normalized into the same range of values, the layers are overlain to produce the final analysis (Esri, 2012).

In this analysis, the attributes used were leading species, site productivity, stand status, and stand age. Stand age is the only attribute that changes through time as modeled by FPS-ATLAS. These attributes were reclassed into values ranging from 1 to 4, with 4 being the most preferred. The layers were then summed to produce the final suitability value; suitability ranges from 6 (least suitable) to a maximum of 16 (most suitable).

Leading Species

Northern caribou have been observed to choose pine leading stands as their primary winter range habitat from December to March. This is followed by pine-mixed stands then spruce-leading stands with all other species least preferred (Table 4).

Table 4 - Reclassification of leading species during raster analysis.

Leading Species (Original Value)	Reclassed Value	
Pine-Leading (Stand Groups XXX2)	4	(Most Suitable)
Pine-Mixed (Stand Groups XXX3)	3	
Spruce-Leading (Stand Groups XXX1)	2	
Other (All other Stand Groups)	1	(Least Suitable)

Site Productivity

Site productivity also plays a role in habitat quality. Caribou mainly chose lower productivity sites regardless of the leading species of the stand (Table 5). This corresponds to the ecology of the arboreal and terrestrial lichen that make up a large proportion of the caribou's winter diet.

Table 5 - Reclassification of site productivity during raster analysis.

Site Index (Original Value)	Reclassed Value	
0 – 11.9	4	(Most Suitable)
12 – 17.9	3	
18 – 27	2	(Least Suitable)

Stand Status

The status of a stand also plays a large role in the selection of habitat. Caribou are prefer natural stands much more than stands that have been disturbed by humans, especially harvested stands (Table 6).

Table 6 - Reclassification of stand status during raster analysis.

Stand Status (Original Values)	Reclassed Value	
Natural (Stand Groups 1XXX or X1XXX)	4	(Most Suitable)
Managed (Stand Groups 2XXX or X2XXX)	2	(Least Suitable)

Age

Age plays the most crucial role in this analysis as it is a strong factor for habitat preference. In addition, it is the only attribute that changes over time. This allows the analysis to show changes in

available habitat over time. In studies by Cichowski (2010), it was found that northern caribou tend to favor mature stands for their structure and density. Stands of 80 – 120 year were preferred most (Table 7). Older mature stands are less preferred but preferable to young stands. Young seral stands are of the lowest interest to the caribou.

Table 7 - Reclassification of age during raster analysis.

Age (Original Value)	Reclassed Value
80 – 120	4 (Most Suitable)
120 – 300	3
40 – 80	2
0 – 40	1 (Least Suitable)

The stand age was exported from FPS-ATLAS using the Schedule Module outputs. The ASCII files for each time step were then imported into ArcGIS as tables. The age and standgroup fields were then joined to the main layer used in the habitat model (Figure 7).

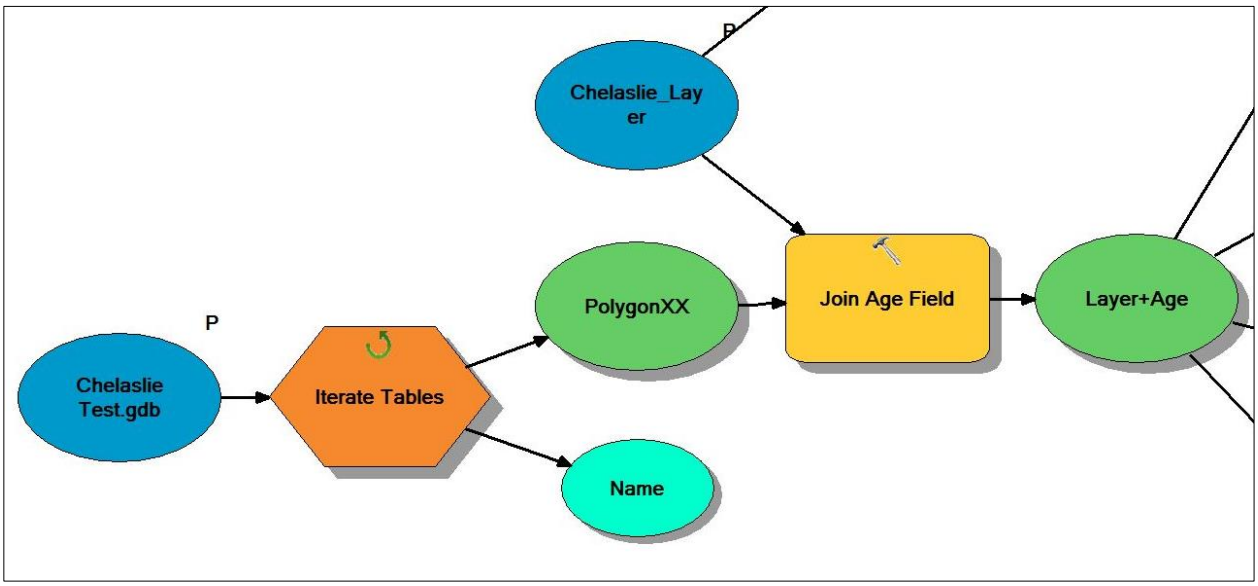

Figure 7 - Importing age and standgroup into the habitat model in ArcGIS. (See Appendix II for the full model.)

3. Scenarios

Two sets of scenarios were developed to assess how harvest flows change with variation in both remaining growing stock and constraints (Table 8). In order to concentrate on the effect of changing a specific constraint, each scenario was altered by single factor. The goal of each scenario was to achieve long term sustained yield (LTSY). This is the state where the harvest flow and growing stock remain at a steadied level over the long term. To ensure that LTSY is maintained, each scenario was run to 500 years, despite the assessment period being only 300 years.

Table 8 - Two sets of scenarios were produced with the first varying growing stock and the second varying constraints.

	100% Growing Stock	75% Growing Stock	50% Growing Stock	25% Growing Stock
No Constraints	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Prioritized Zoning			Scenario 5	
Min/Max Seral			Scenario 6	

Growing Stock Variation

The first set of scenarios where developed by varying the total long term growing stock within the forest estate. First, a scenario (Scenario 1) was run without harvesting to simulate forest growth and to determine the maximum growing stock of which the forest estate is capable. It was determined that the long term growing stock (denoted 100%) of the forest estate is approximately 40,000,000 m^3. From there, 3 additional scenarios were developed by increasing harvest flow to reduce growing stock to different levels: 75%, 50%, and 25%. Scenario 2 reduced total growing stock to 75% (30,000,000 m^3) of Scenario 1. Scenario 3 reduced total growing stock to 50% (20,000,000 m^3) and Scenario 4 to 25% (10,000,000 m^3). Growing stock was kept as close as possible to the goal of each scenario.

Harvest flow was the key factor in reducing growing stock. The conversion period was limited to approximately 100 years. By the year 100, the harvest flows should have reached the LTSY level. By year 150, growing stock begins to stabilize along with harvest flow.

Constraint Variation

The second set of scenarios focused on the effect of variations in constraints that did not involve the change in growing stock levels. Growing stock was kept at a constant level of 20,000,000 m^3 (50% of maximum total growing stock). A single constraint was applied to each scenario to focus on the specific effects of each. The base case scenario used in this set of scenarios is Scenario 3, where 50% of the maximum growing stock is maintain over the long term.

Scenario 5 adds three zones as well as a harvest priority between the zones. Based on the study done by Cichowski (2010) 3 zones were delineated based on the data collected on northern caribou occurrence (Figure 8). The highest occurrence of caribou was concentrated on a triangular area in the southwest corner of the study area. This was designated the 'High' use zone. The subsequent 'Medium' use zone occurs in the middle portion of the study area stretching in a diagonal strip from the northwest to the southeast. The 'Low' use zone was a diagonal strip from the northwest to the southeast in the northeaster-most portion of the study area. Because prioritizing zones occurs universally regardless of the scenario (or 'ruleset' within ATLAS), a separate database was used solely for this scenario.

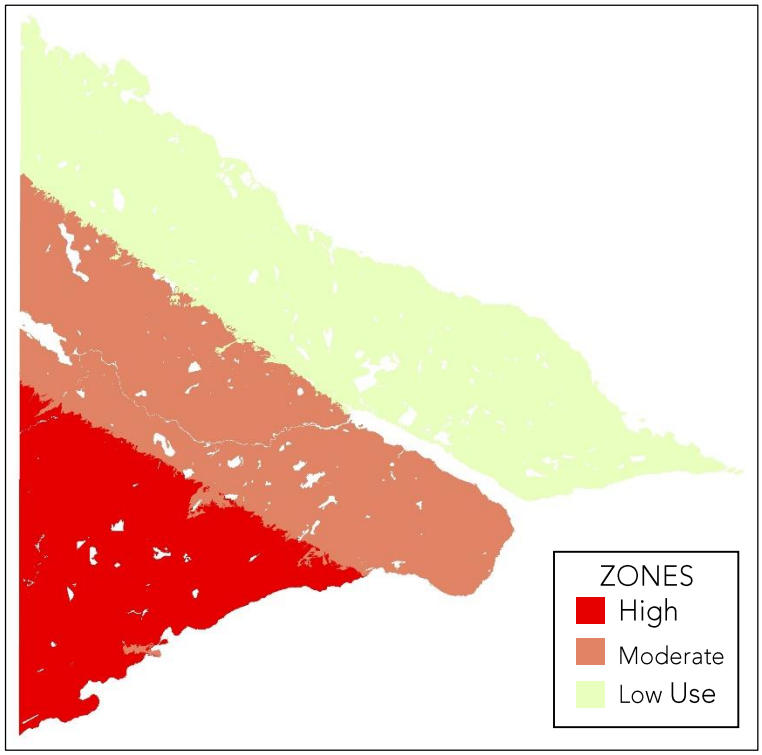

Figure 8 - Zoning of the study area.

Scenario 6 focuses on the constraint on the seral stage constraints. Three seral stages are constrained within scenario. The 'Early Seral' constraint ensures that no more than 50% of the study area is below the age of 40 years. The 'Mature Seral' and 'Late Seral' constraints ensure that at least 30% of the study area is above the age of 80 years and 120 years, respectively. An 'Old Seral' constraint was not applied.

4. Results

Scenarios 1 to 4 (Varying Growing Stock)

Growing Stock

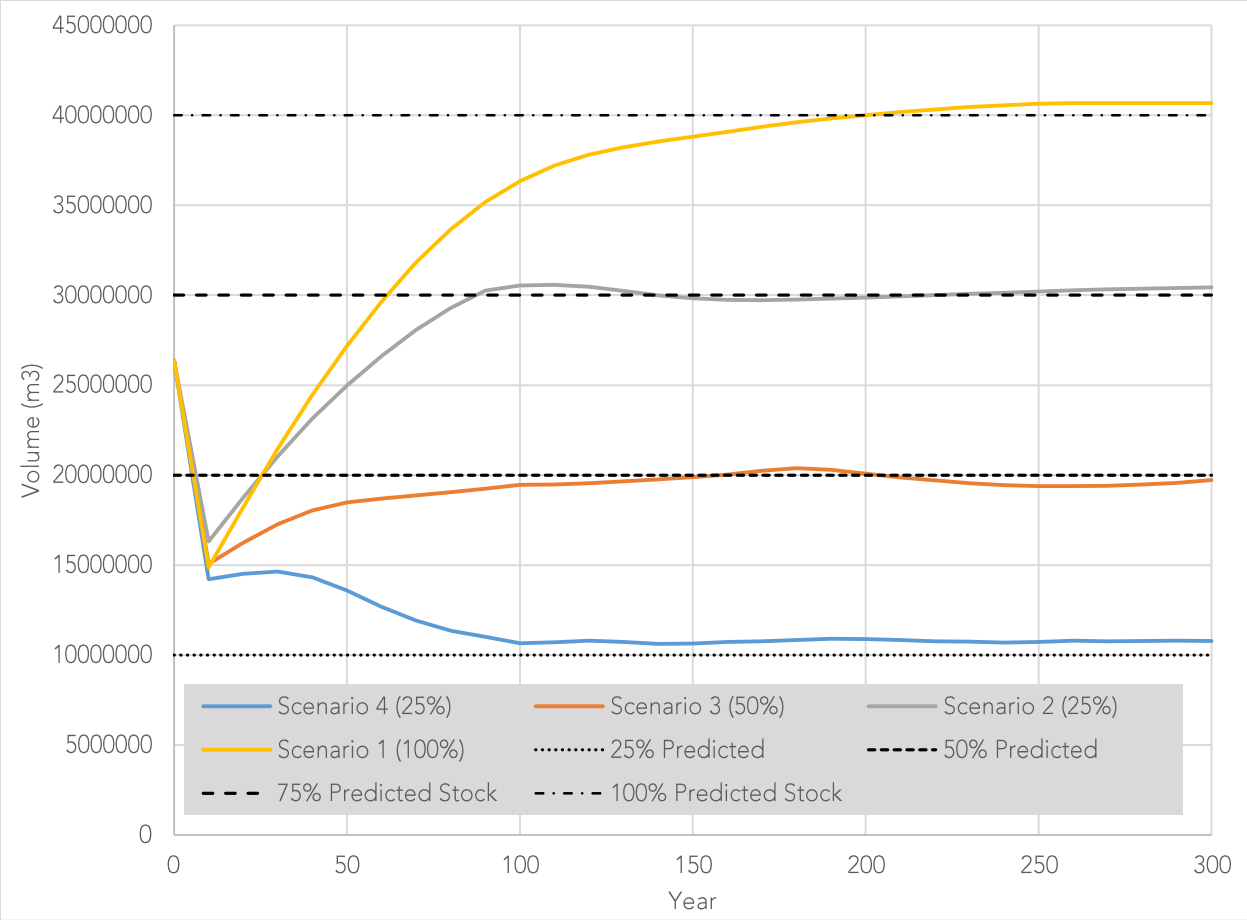

Figure 9 - The growing stock for each scenario as well as the intended levels of growing stock in the long term.

Long term harvest flow was kept very close to the intended levels set by each scenario as shown in Figure 9. The t-statistics were calculated for each scenario where values below 2.18 are considered significantly similar to their respective intended growing stock (with a significant level of $\alpha = 0.05$) (Table 9). Scenario 4 shows the largest t-value

Table 9 - A comparison of the average long term growing stock between Scenarios 1 to 4.

	Scenario 1 (100%)	Scenario 2 (75%)	Scenario 3 (50%)	Scenario 4 (25%)
Average Long Term Growing Stock	40,559,228 m^3	30,122,696 m^3	19,549,546 m^3	10,766,180 m^3
t-statistic	3.75	1.92	-2.98	48.88

Harvest Flows

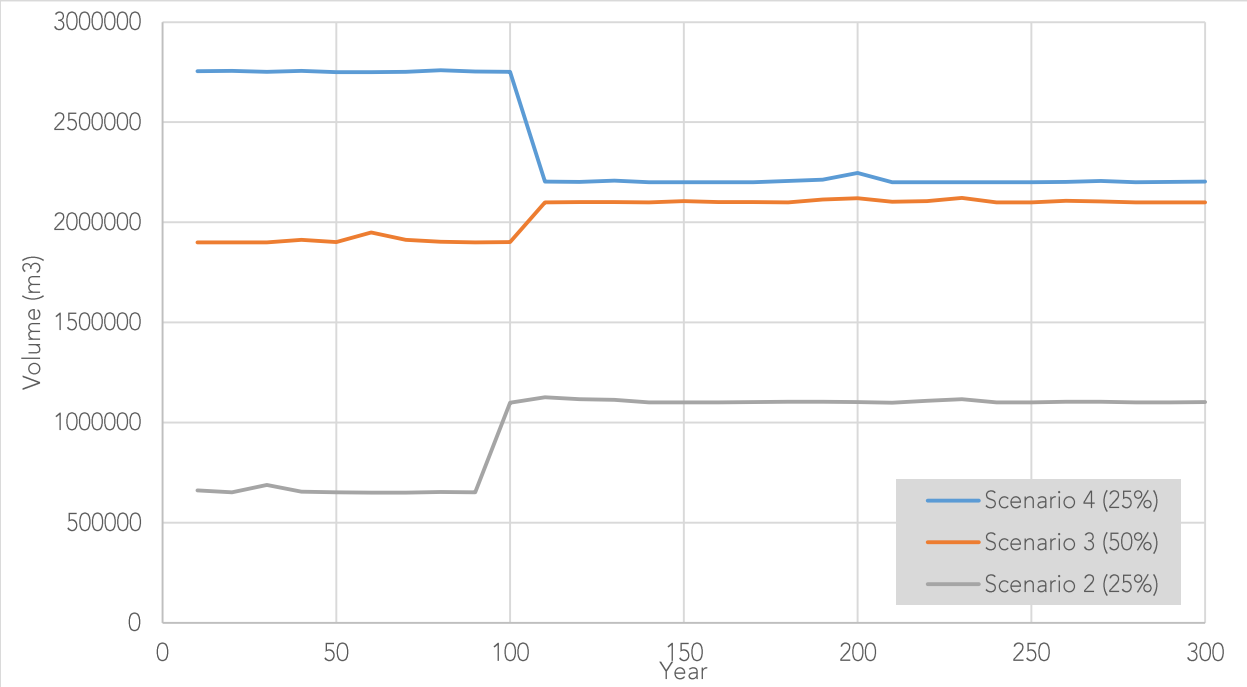

Figure 10 - The harvest flows each scenario within the first set.

Harvest flow of Scenario 1 is not shown as there is no harvest occurring. Scenario 2 (75%) shows the lowest harvest flow compared to Scenario 3 and 4, as expected. Scenarios 3 and 4 show a very similar volume of flow with Scenario 4 (25%) slightly higher, also as expected (Figure 10 and Table 10).

Table 10 - A comparison of the average long term harvest flow between Scenarios 1 to 4.

	Scenario 1 (100%)	Scenario 2 (75%)	Scenario 3 (50%)	Scenario 4 (25%)
Average Long Term Harvest Flow	0 m^3	2,205,189 m^3	2,105,633 m^3	1,103,706 m^3

Habitat Suitability

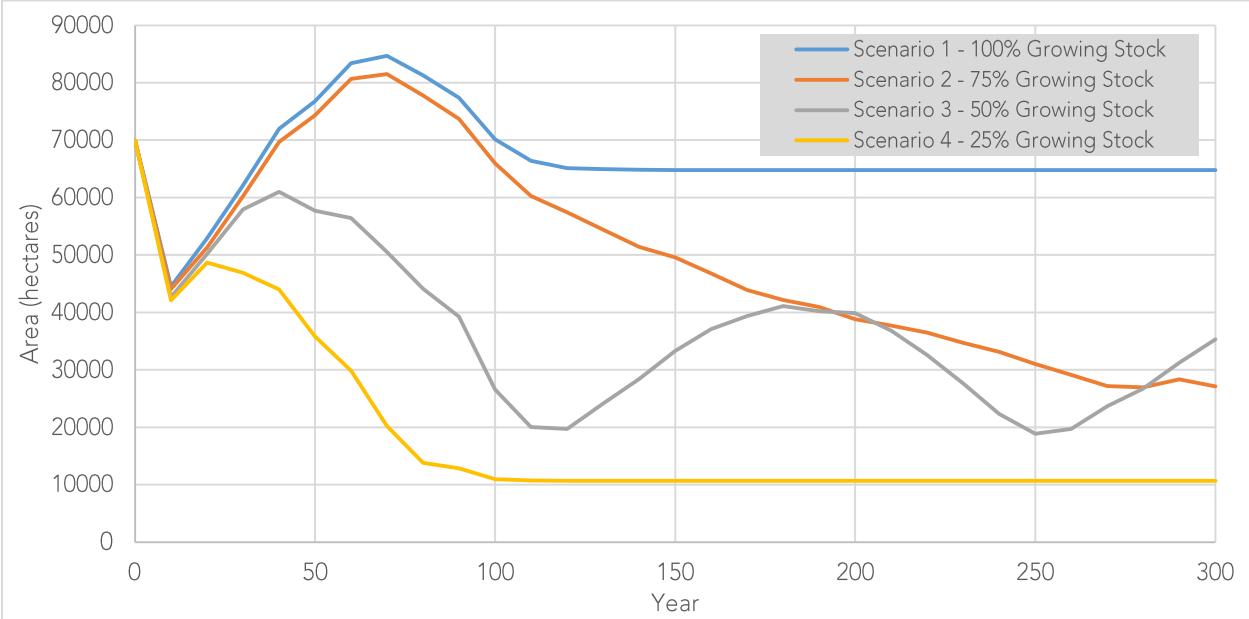

Figure 11 - A comparison of high suitability areas between the growing stock scenarios.

Scenario 1 shows the highest amount of area of high suitability whereas Scenario 4 shows the lowest amount of area of high suitability (Figures 11 and 12). This is expected as the increased harvesting activity will reduce the amount of highly suitable caribou winter range area. Despite Scenarios 3 and 4 showing very similar harvest flows, Scenario 3 seems to produce more highly suitable caribou winter range in area.

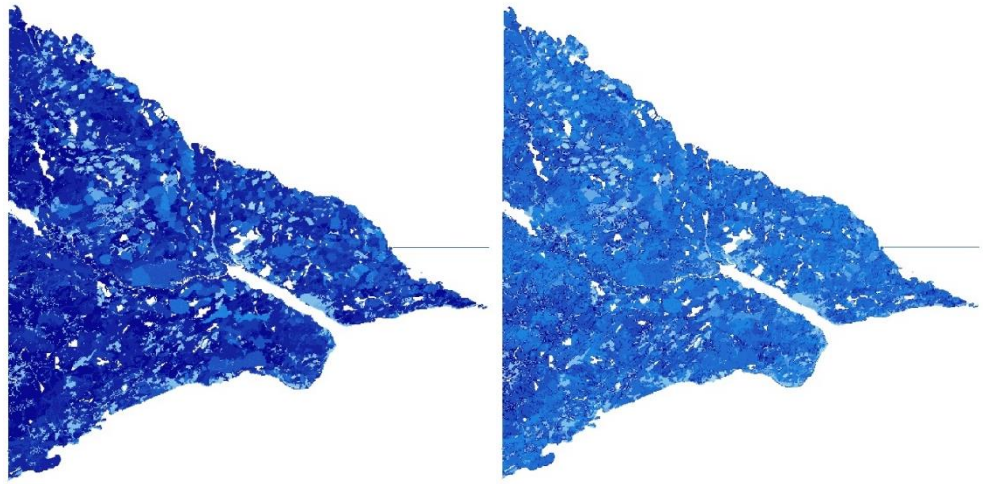

Figure 12 - A comparison of the habitat suitability of Year 300 between Scenario 1 (left) and Scenario 4 (right).

Scenario 3 seems to fluctuate about 30,000 hectares of highly suitable habitat at a frequency of 125 years. This is reflected in the harvest schedule. The area harvested fluctuates in synchrony with the high suitability area (Figure 13).

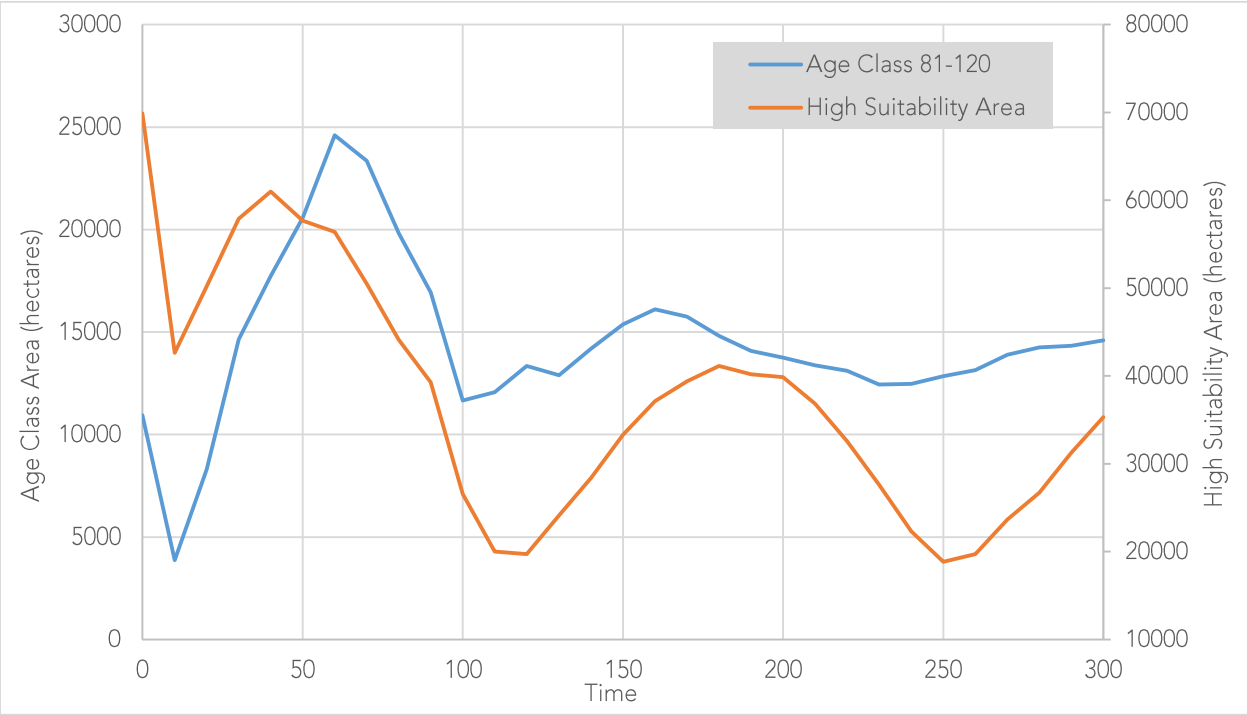

Figure 13 - A comparison of the fluctuation of area harvested and high suitability area for Scenario 3.

Scenarios 3, 5, and 6 (Varying Constraints)

Growing Stock

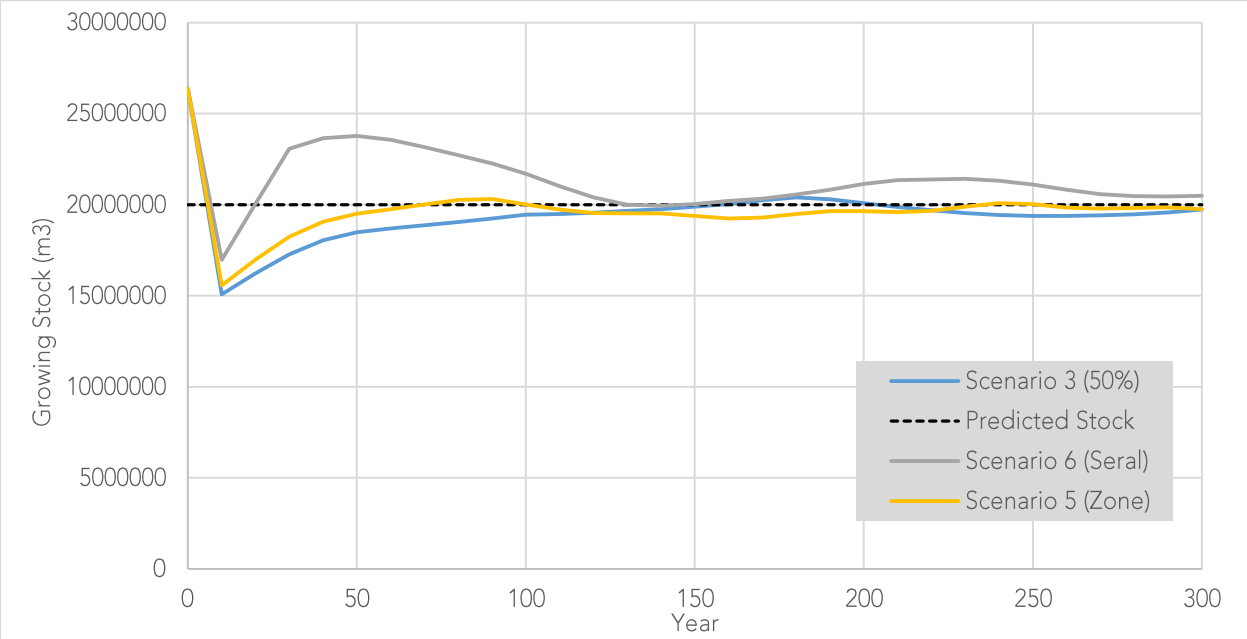

Figure 14 - The growing stock levels of the second set of scenarios as well as the intended level of growing stock.

The long term growing stock was kept as close to 20,000,000 m^3 as possible as Scenario 3 (50%) was used as the base case with no constraints applied (Figure 14 and Table 11).

Table 11 - A comparison of the long term growing stock between Scenarios 3, 5, and 6.

	Scenario 3 (50%)	Scenario 5 (Zoning)	Scenario 6 (Seral)
Average Long Term Growing Stock	19,776,572 m^3	19,685,146 m^3	20,775,954 m^3

Harvest Flows

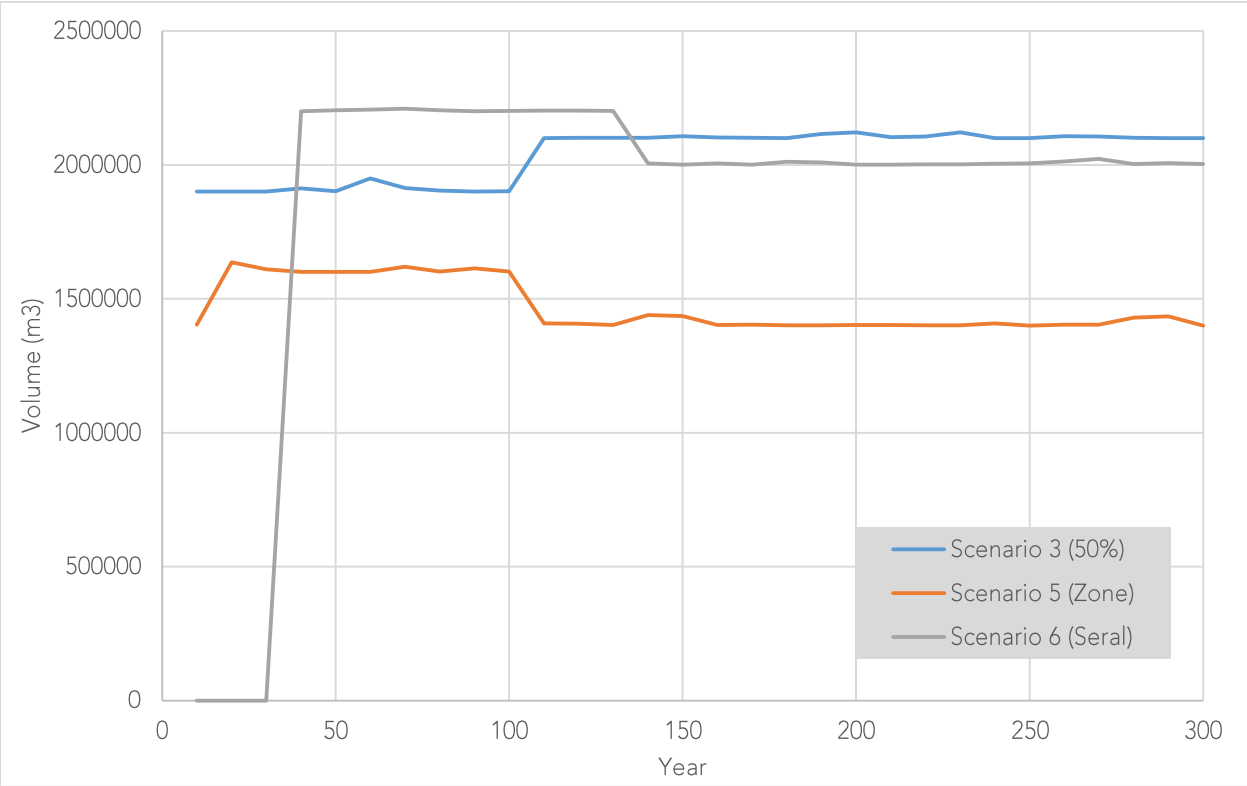

Figure 15 - The harvest flows of each scenario within the second set.

As expected, the harvest flow of Scenario 3 is the highest, although only slightly higher than Scenario 6. The harvest flow for Scenario 5 is much lower than Scenarios 3 and 6 (Figure 15 and Table 12).

Table 12 - A comparison of the average long term harvest flows between Scenarios 3, 5, and 6.

	Scenario 3 (50%)	Scenario 5 (Zoning)	Scenario 6 (Seral)
Average Long Term Harvest Flow	2,105,633 m^3	1,407,885 m^3	2,005,495 m^3

Habitat Suitability

Figure 16 - Comparisons of the habitat suitability, high (top), medium (bottom left), low (bottom right), between Scenarios 3, 5, and 6.

Scenarios 3, 5, and 6, do not seem to differ significantly in any level of habitat suitability, be it high, medium, or low. The scenarios do, however, seem to differ in their fluctuation (Figure 16). Both Scenarios 3 and 6 seem to fluctuate greatly (± 10,000 ha) about its long term average every 100-125 years whereas Scenario 5 seems to fluctuate less (± 5000 ha) about its long term average every 150-200 years.

By comparing the high suitability area with the age class 81-120 years in area (Figure 17), it becomes apparent that the fluctuations are caused by the rise and fall in area of the crucial age class. Both fall in year 10 when falldown occurs and begins to recover through to year 70. Once more area reaches that age class (81-120), harvest begins to reduce that total area. This cycle of recovery and harvest explains the fluctuations.

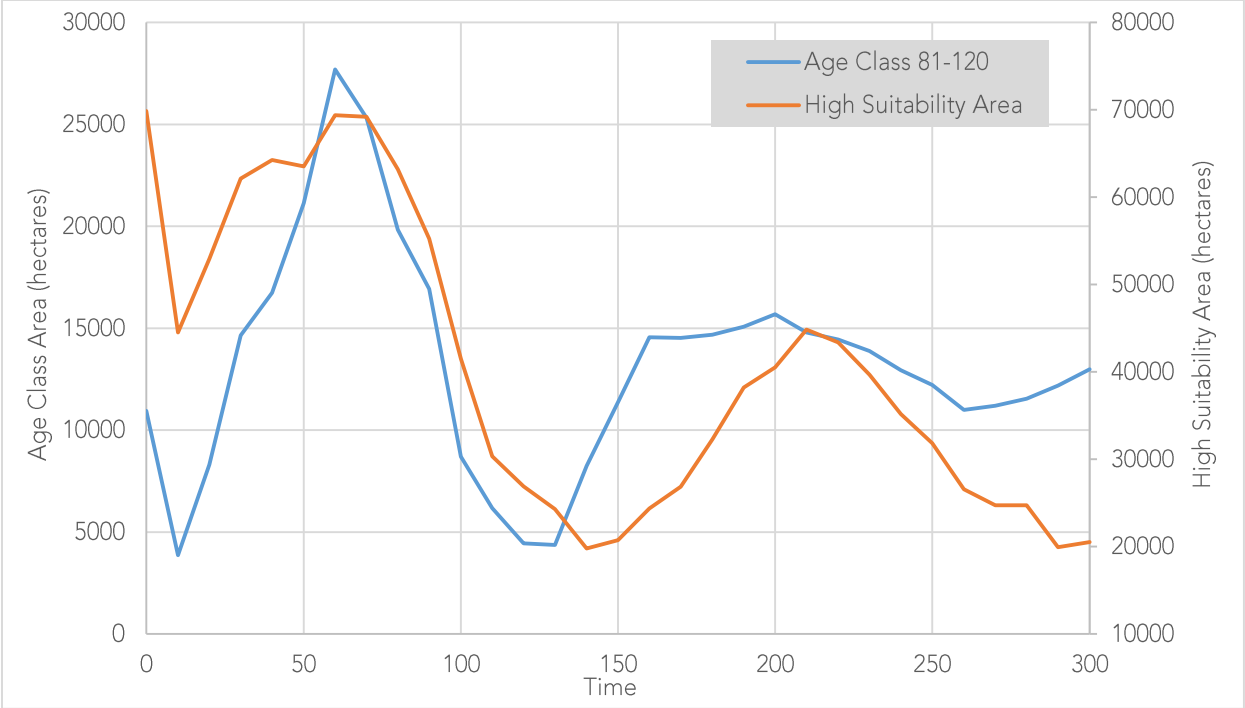

Figure 17 - A comparison of the fluctuation of the area harvested and the highly suitable areas in Scenario 6.

The scenarios do show differences when comparing between 3 (or 6), and 5. Because of the zoning priorities added to Scenario 5, most of the highly suitable area is concentrated in the high use zone in the southwest corner (Figure 18).

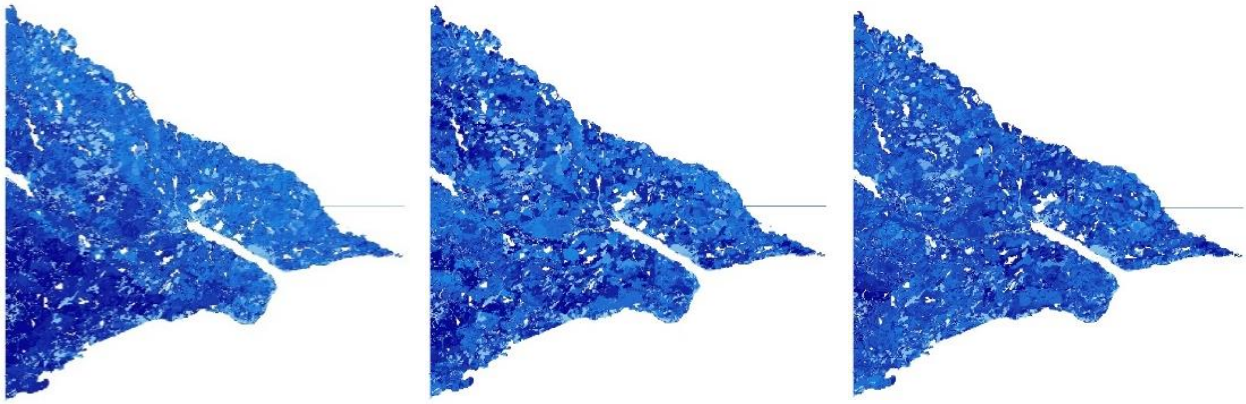

Figure 18 - A comparison between Scenario 5 (left) to Scenarios 3 (middle) and 6 (right) showing the concentration of highly suitable area in the southwest of the study area in Scenario 5.

5. Discussion

The goal of this report was to give an example of how FPS-ATLAS and ArcGIS can be used to carry out a coarse analysis of the future conditions of a forest landscape with an emphasis on caribou winter range. By using FPS-ATLAS, a harvest schedule of the study area can be established into a defined planning horizon, in this case 300 years. Using outputs from FPS-ATLAS, an assessment of winter habitat for caribou can be done through a raster analysis in ArcGIS (Figure 19).

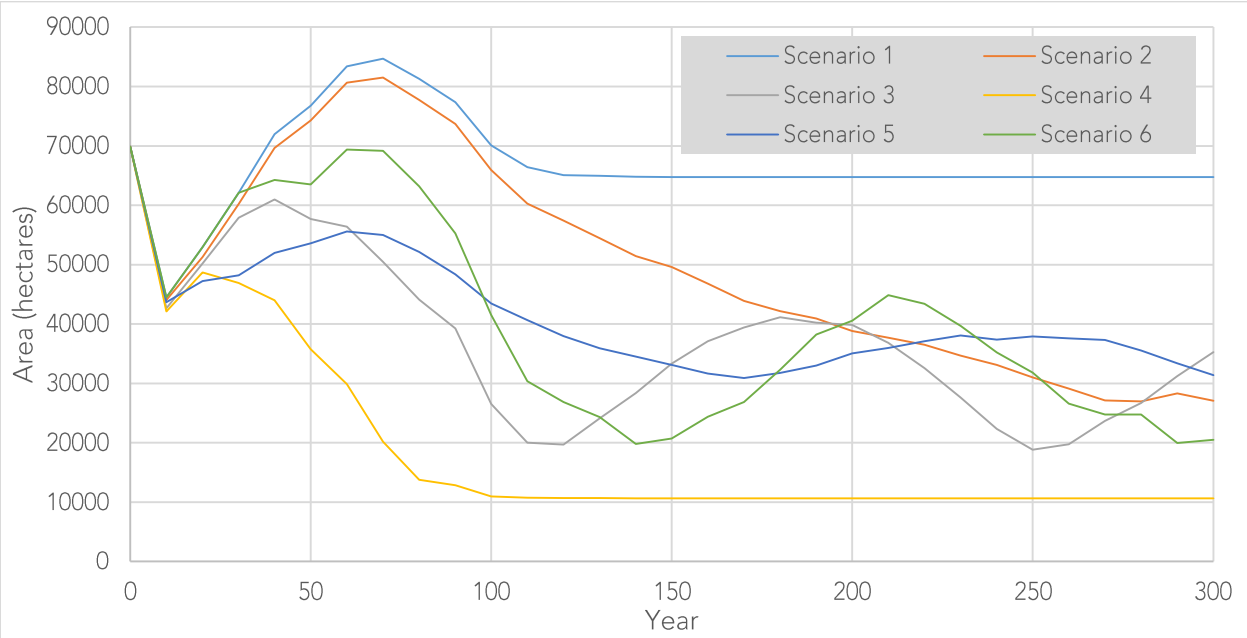

Figure 19 - A comparison of the high suitability area for all scenarios over time.

As expected, there are many limitations to the method proposed in this report. The first limitation comes from the temporal resolution that was chosen. In terms of tree growth, 10-year time steps may seem sufficient. However, the same 10-year time steps seem too coarse for habitat assessment as caribou have a much shorter generational period compared to trees. The temporal resolution was limited due to the scope and depth of this project. This project was also limited by the software used. There are many other software programs that could add more depth to the project and its results. Software such as FORECASE and SIMFOR could have provided many more variables and attributes to add into the harvest model or the suitability analysis. Again, the scope and depth of this project, as well as my lack of knowledge, has omitted the use of these programs.

All in all, this project was to provide a simple use case for the combined use of these software programs. The process of decision-making and problem solving while building the models and establishing the scenarios was much more the focus of this report rather than the results.

Appendix I – FPS-ATLAS Outputs

Harvested Area (FPS-ATLAS)

Varying Growing Stock

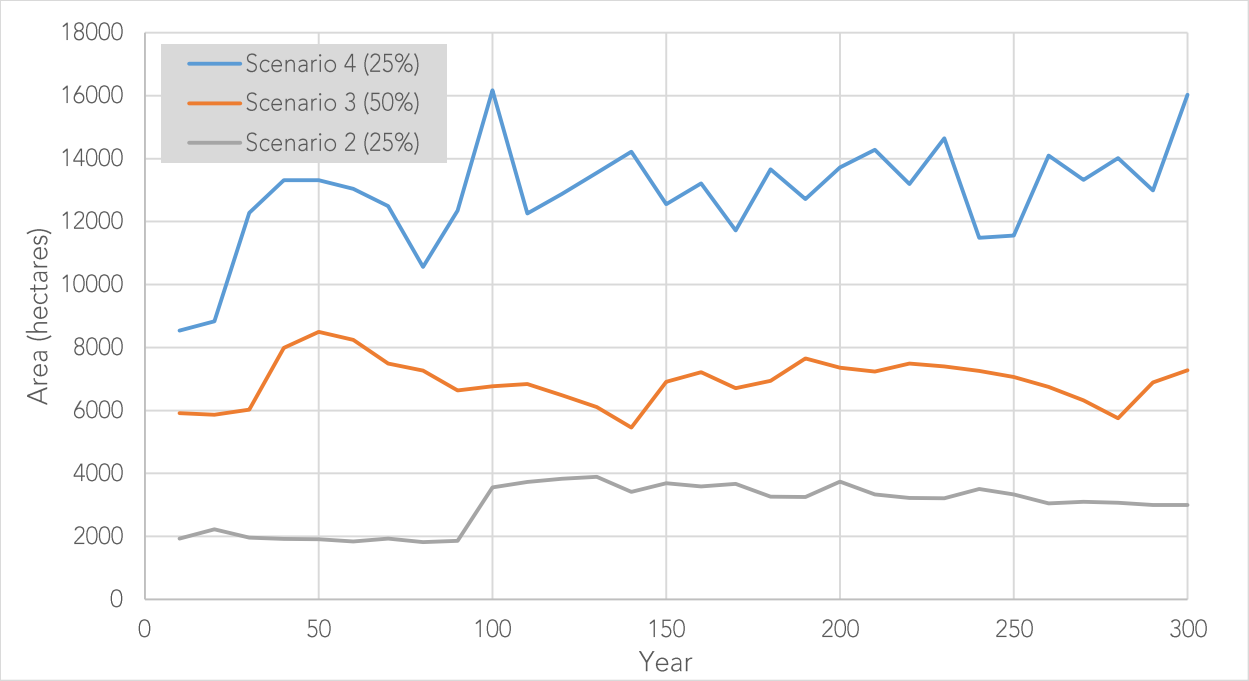

Figure 20 - The total area harvested in hectares for each scenario in the first set.

Varying Constraints

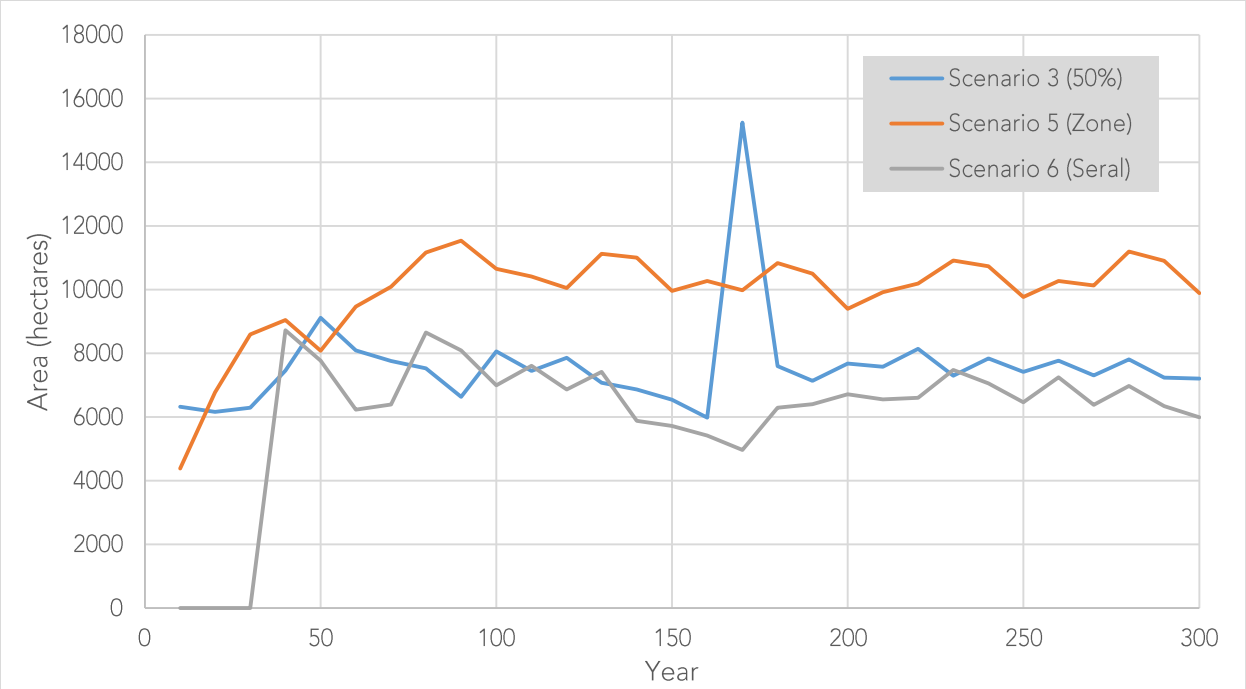

Figure 21 - The total area harvested in hectares for each scenario in the second set.

Appendix II – Raster Analysis Model

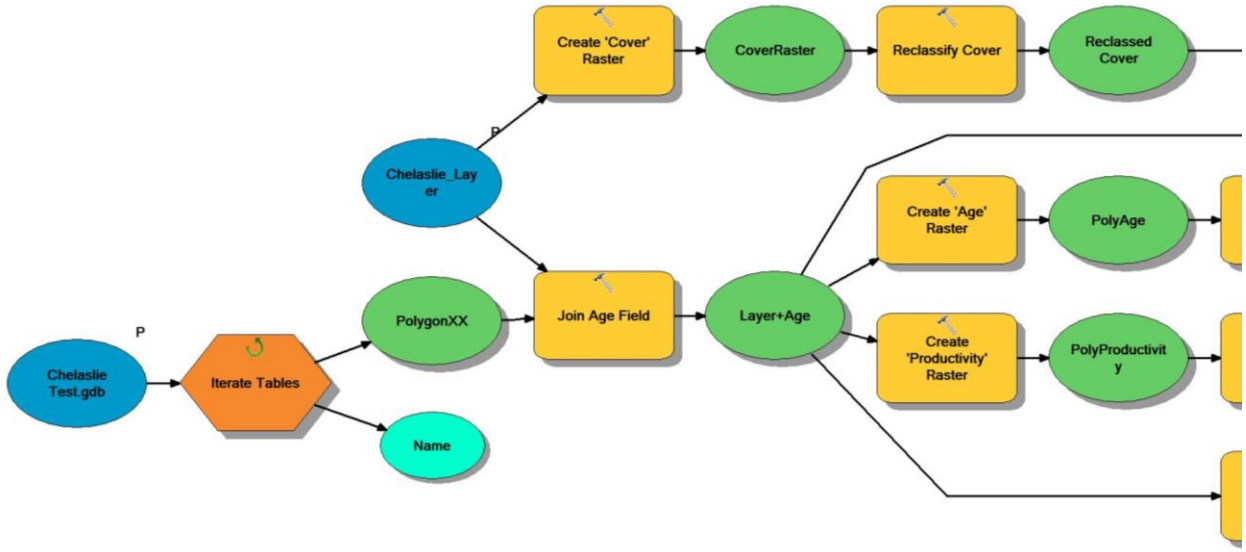

Figure 22 - The first third of the habitat suitability model.

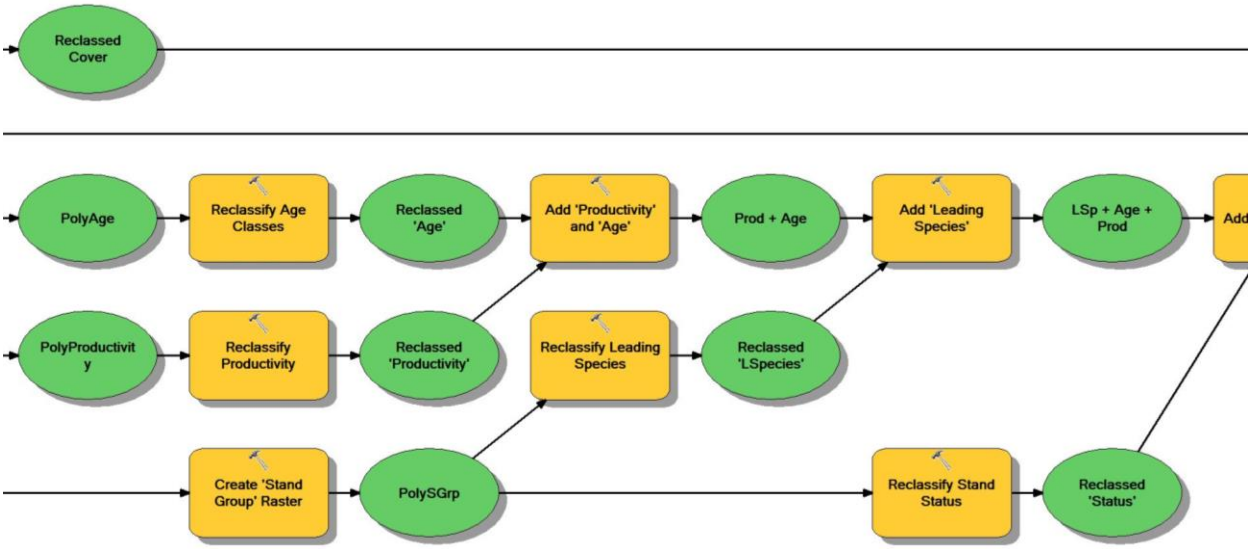

Figure 23 - The second third of the habitat suitability model.

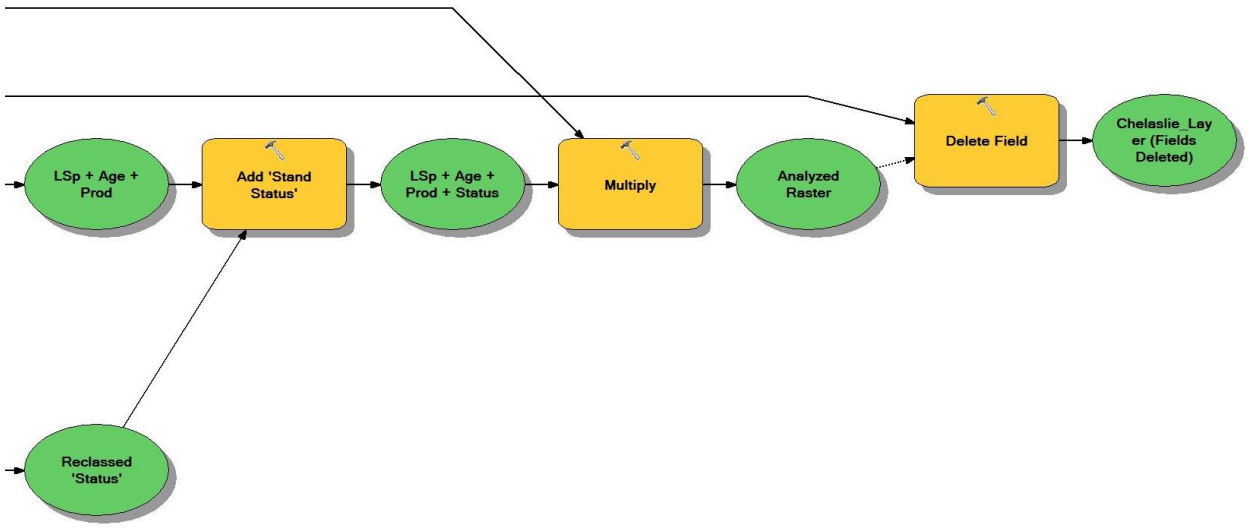

Figure 24 - The final third of the habitat suitability model.

Appendix III - Raster Analysis Outputs

Raster Analysis Maps

This section includes the caribou winter range suitability maps produced by the raster analysis. High suitability is indicated by dark blue whereas low suitability is indicated by light blue. Maps were produced for 4 of the 30 time steps analyzed:

- Year 50 – the approximate midpoint of the conversion period.
- Year 100 – the approximate end of the conversion period.
- Year 200 – the midpoint between the beginning of the LTSY period and the end of the planning horizon.
- Year 300 – the end of the planning horizon.

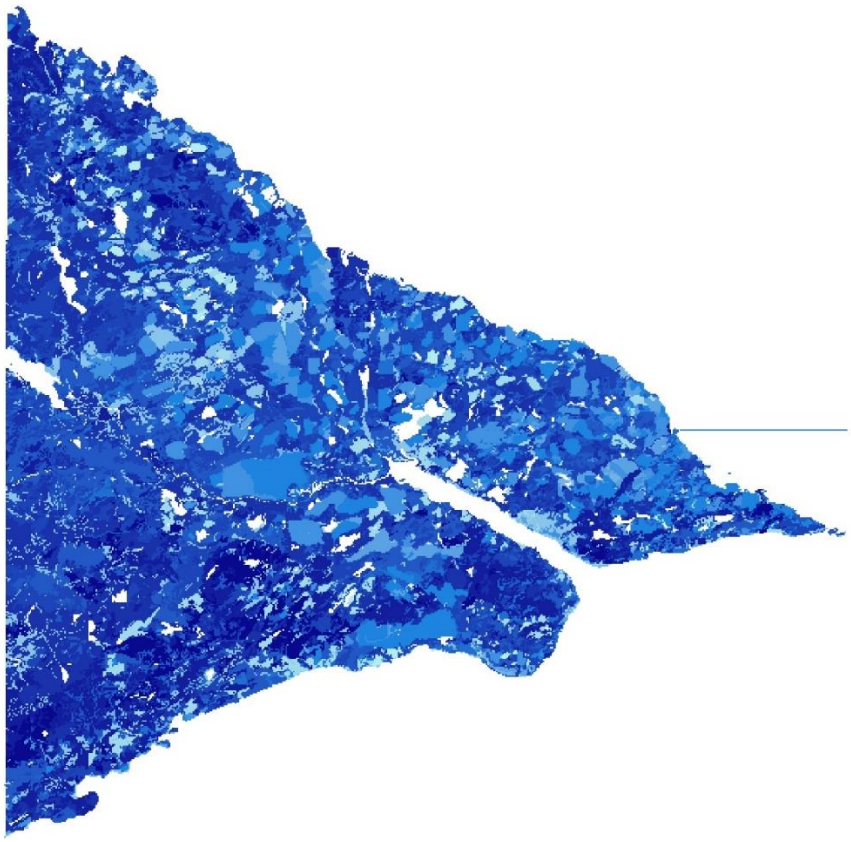

Figure 25 - Year 0, the starting state of the study area in all scenarios.

Scenario 1 – 100% Growing Stock

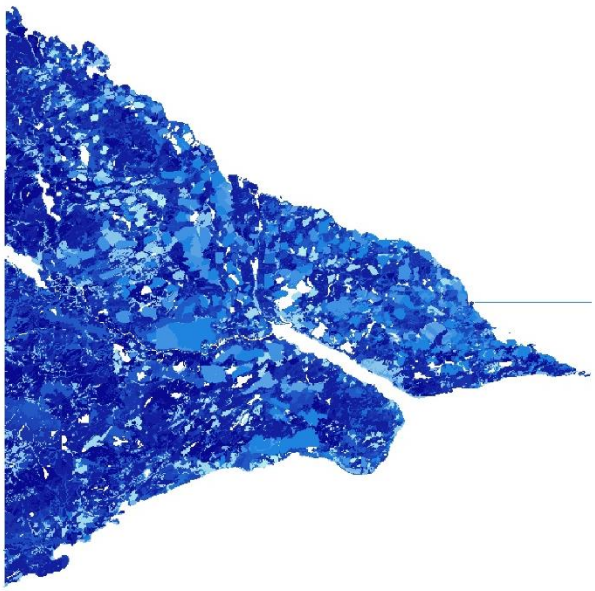

Figure 26 - Year 50 of Scenario 1.

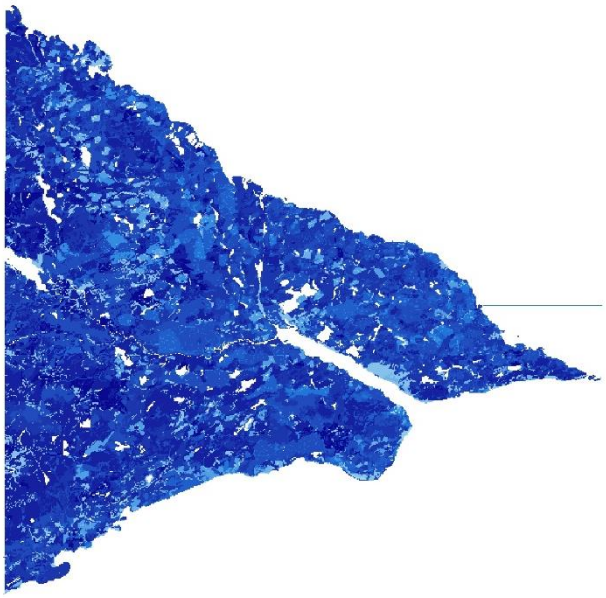

Figure 27 - Year 100 of Scenario 1.

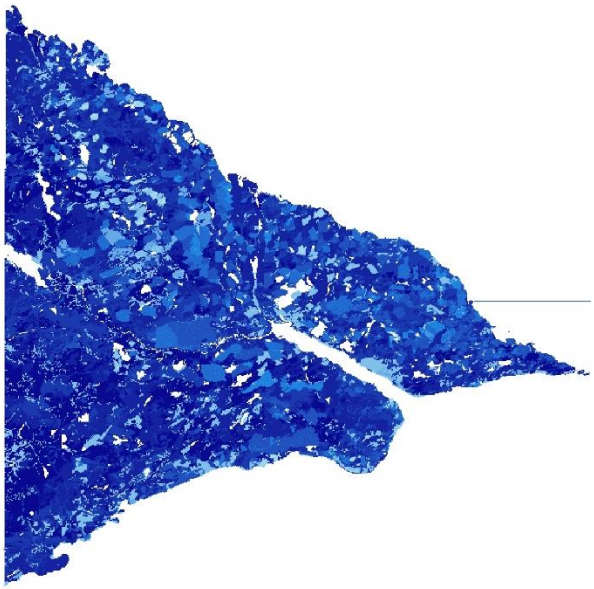

Figure 28 - Year 200 of Scenario 1.

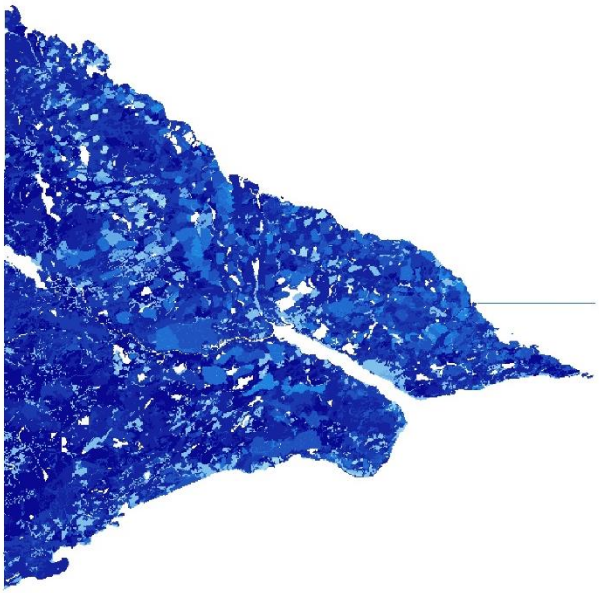

Figure 29 - Year 300 of Scenario 1.

Scenario 2 – 75% Growing Stock

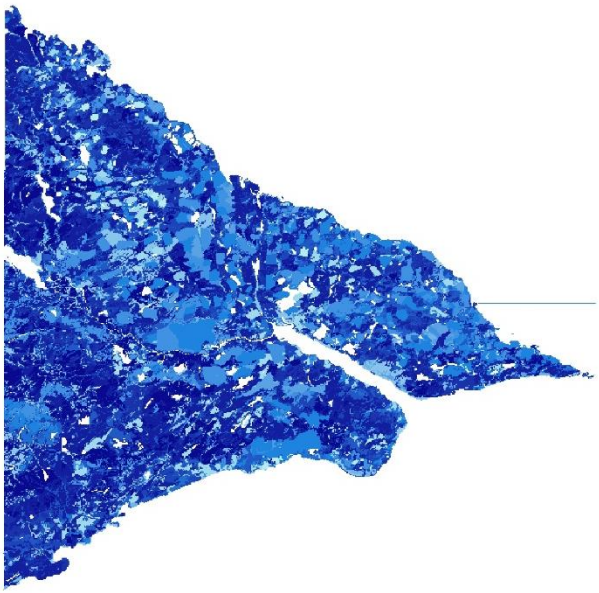

Figure 30 - Year 50 of Scenario 2.

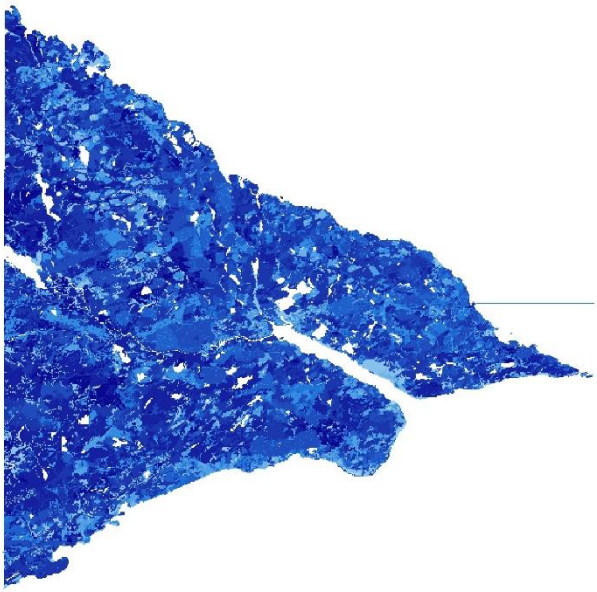

Figure 31 - Year 100 of Scenario 2.

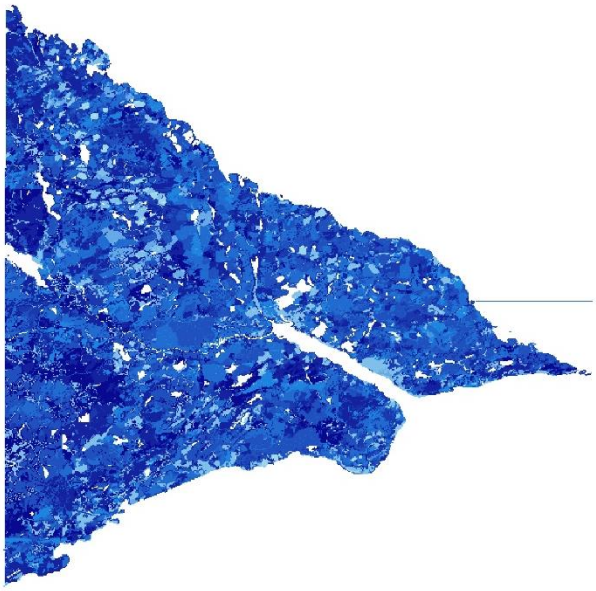

Figure 32 - Year 200 of Scenario 2.

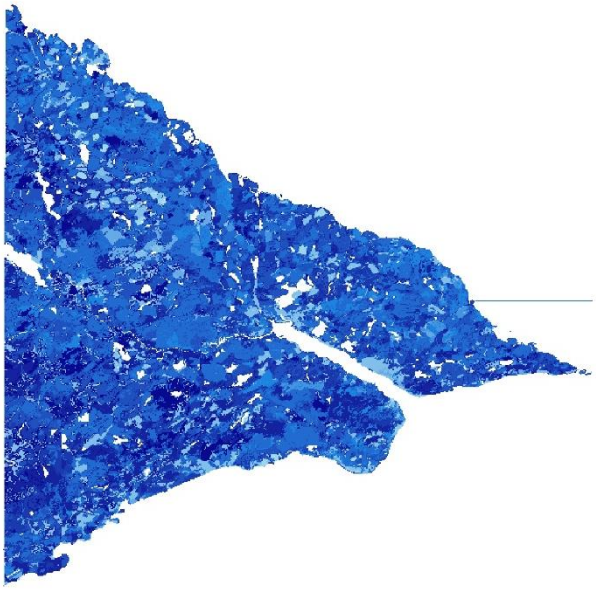

Figure 33 - Year 300 of Scenario 2.

Scenario 3 – 50% Growing Stock

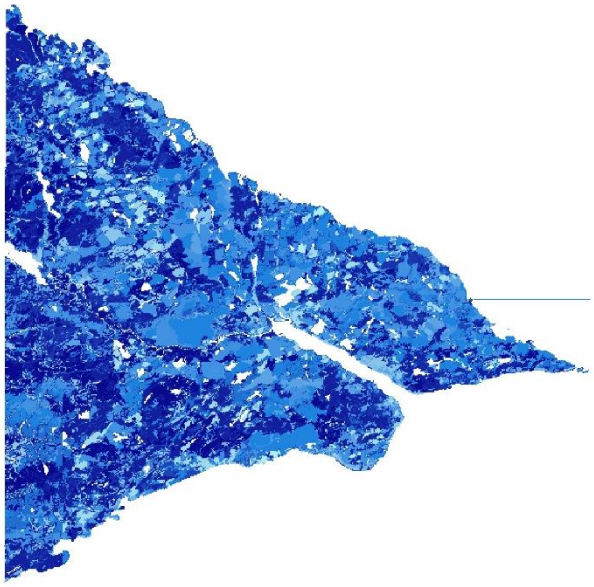

Figure 34 - Year 50 of Scenario 3.

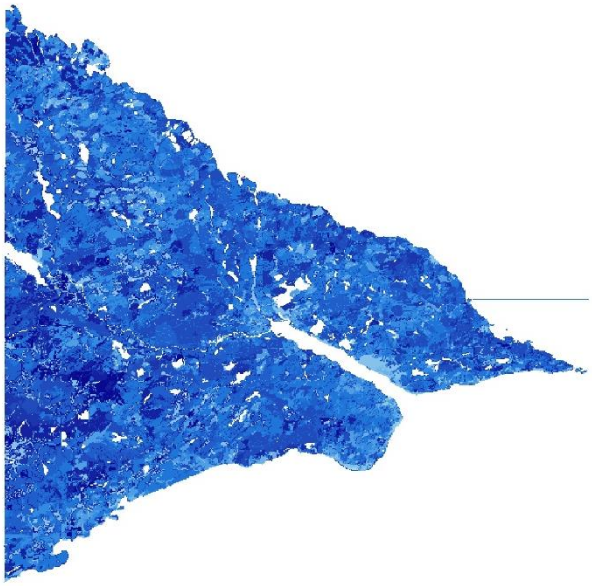

Figure 35 - Year 100 of Scenario 3.

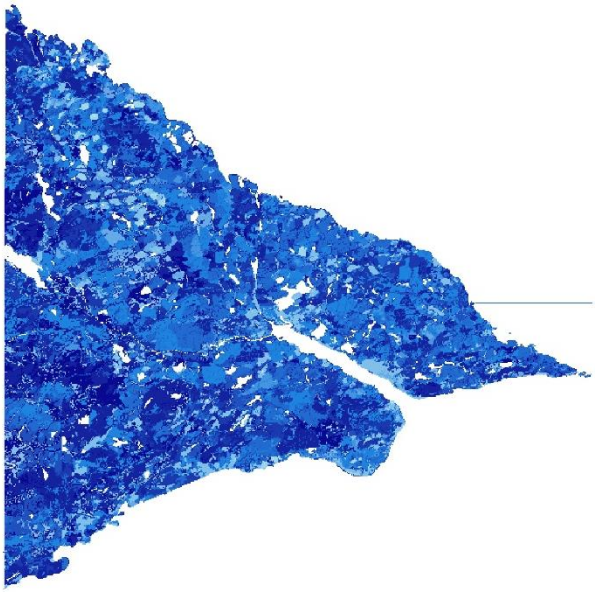

Figure 36 - Year 200 of Scenario 3.

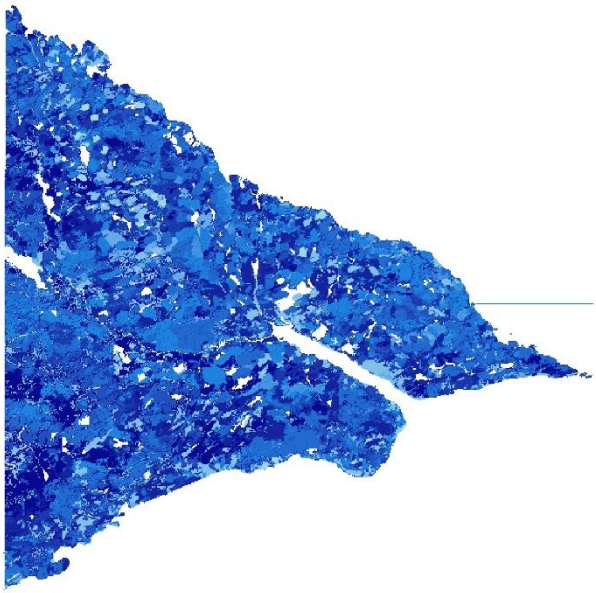

Figure 37 - Year 300 of Scenario 3.

Scenario 4 – 25% Growing Stock

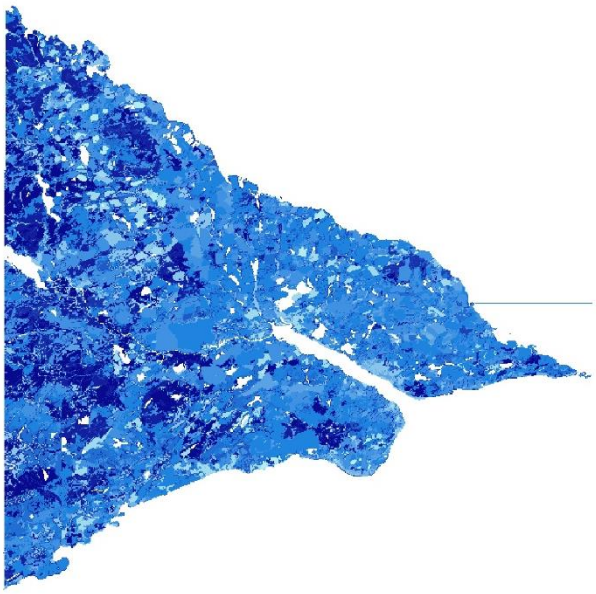

Figure 38 - Year 50 of Scenario 4.

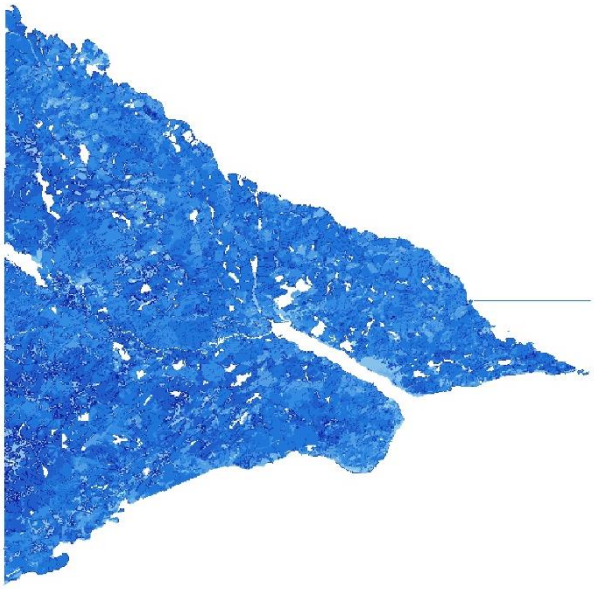

Figure 39 - Year 100 of Scenario 4.

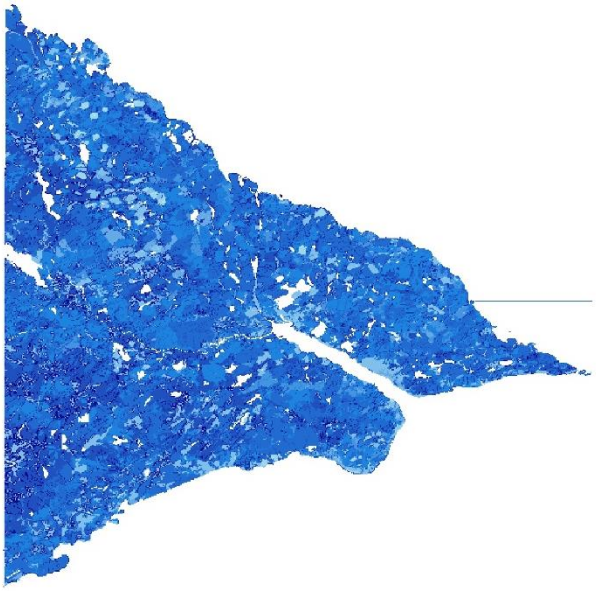

Figure 40 - Year 200 of Scenario 4.

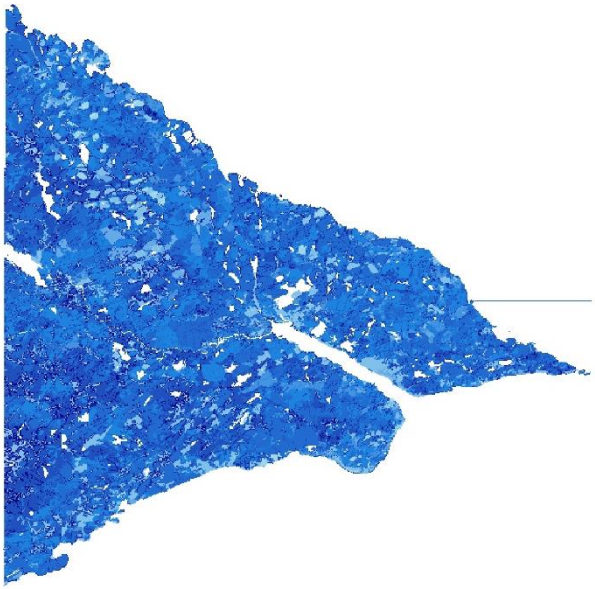

Figure 41 - Year 300 of Scenario 4.

Scenario 5 – Zoning Priority

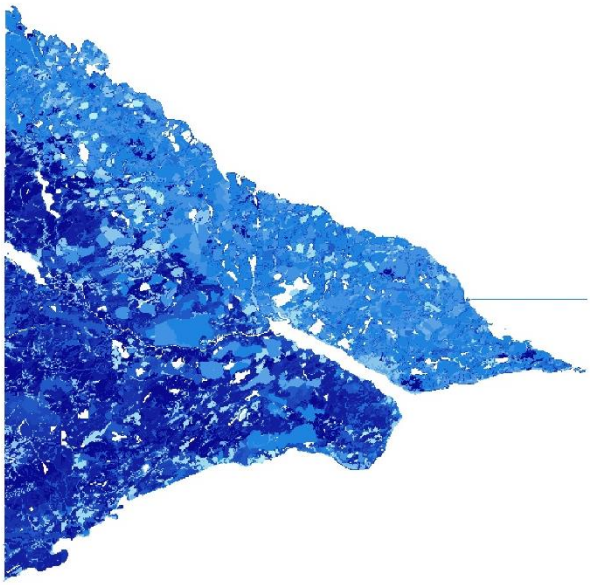

Figure 42 - Year 50 - of Scenario 5.

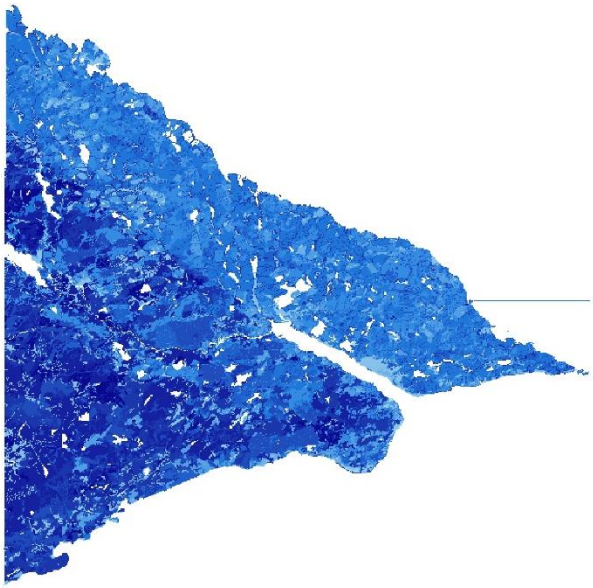

Figure 43 - Year 100 of Scenario 5.

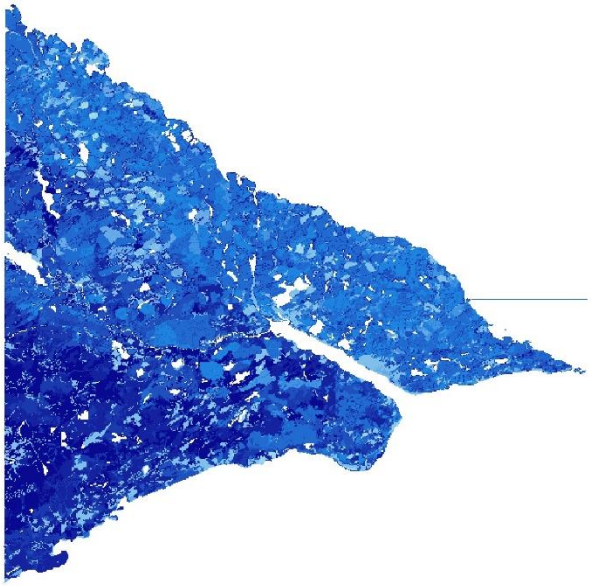

Figure 44 - Year 200 of Scenario 5.

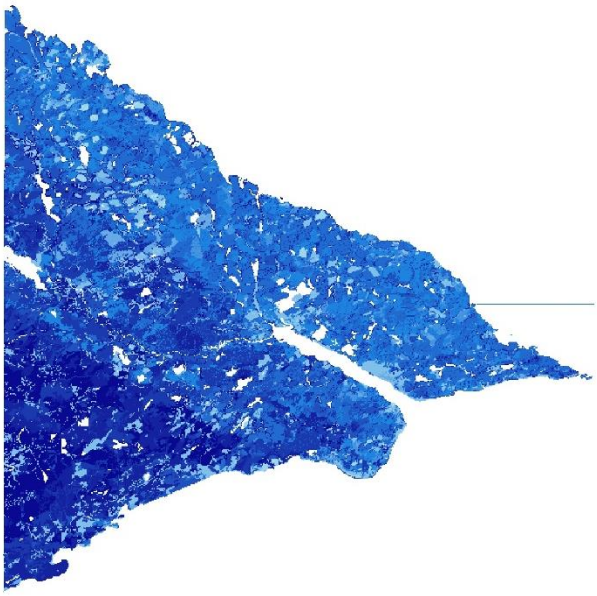

Figure 45 - Year 300 of Scenario 5.

Scenario 6 – Seral Stage Constraints

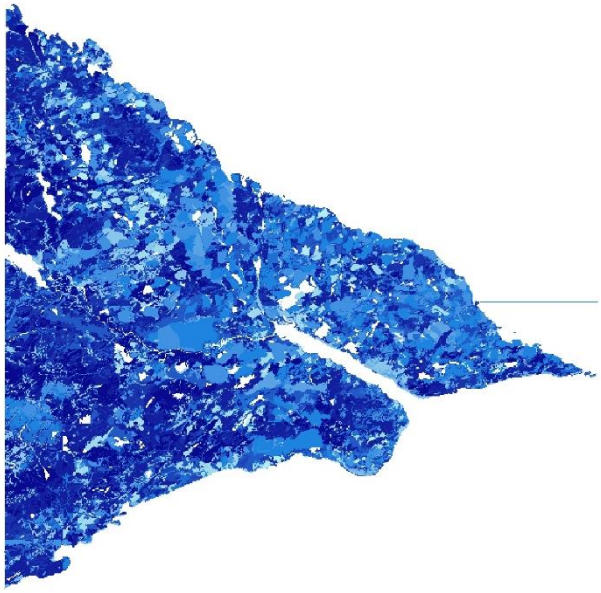

Figure 46 - Year 50 of Scenario 6.

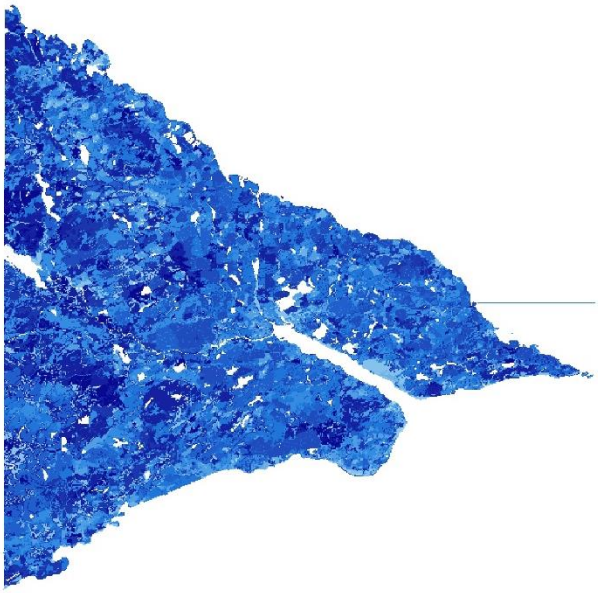

Figure 47 - Year 100 of Scenario 6.

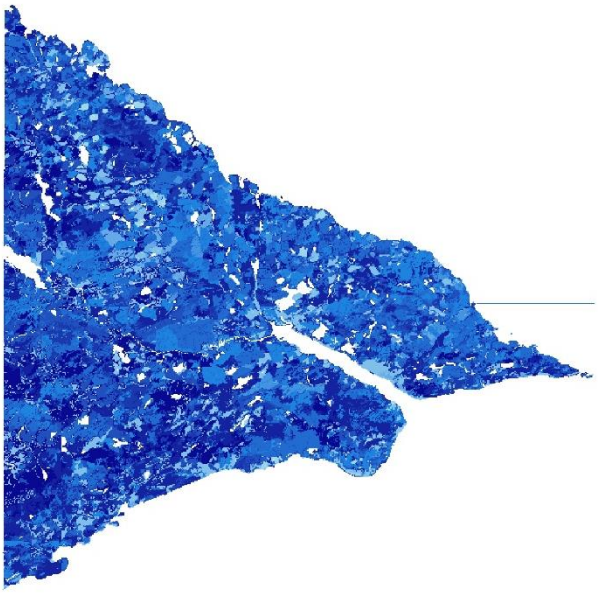

Figure 48 - Year 200 of Scenario 6.

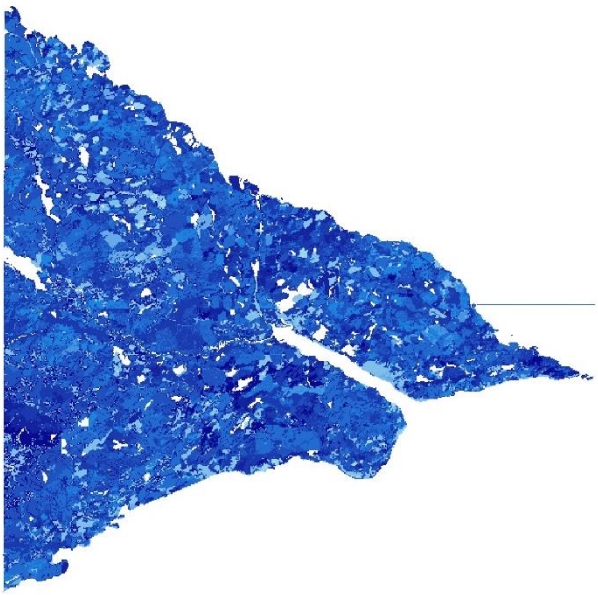

Figure 49 - Year 300 of Scenario 6.

Raster Analysis Graphs

Varying Growing Stock

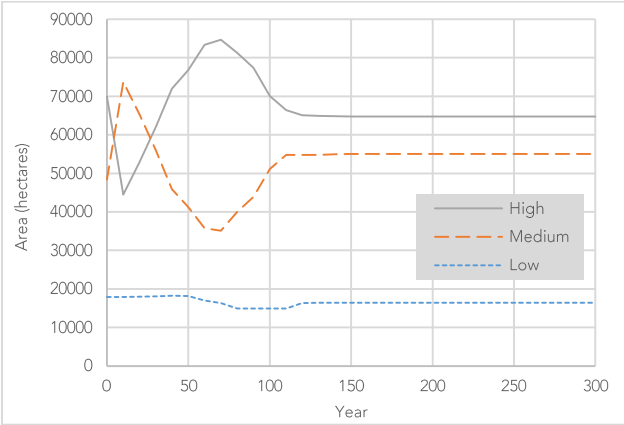

Figure 50 - The habitat suitability of Scenario 1 over time.

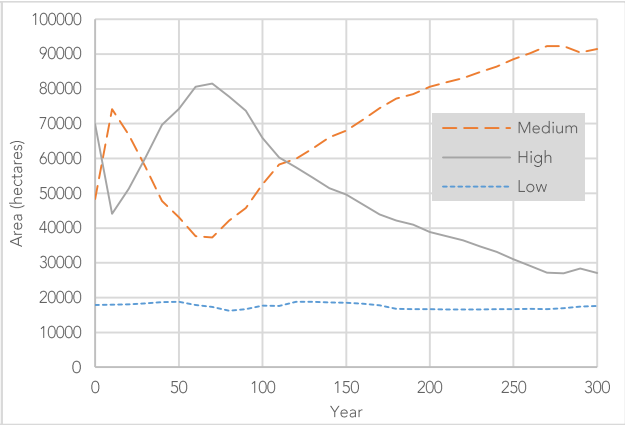

Figure 51 - The habitat suitability of Scenario 2 over time.

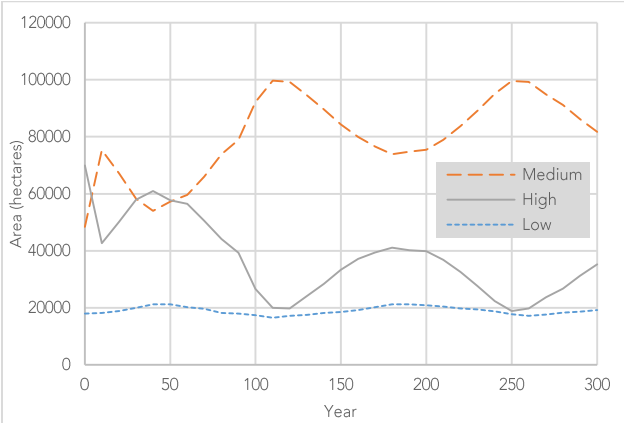

Figure 52 - The habitat suitability of Scenario 3 over time.

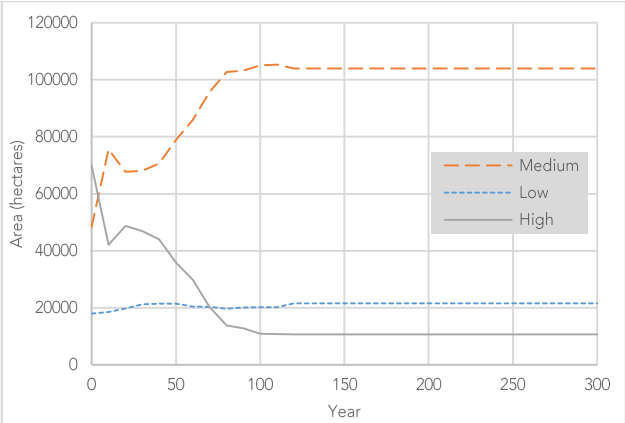

Figure 53 - The habitat suitability of Scenario 4 over time.

Varying Constraints

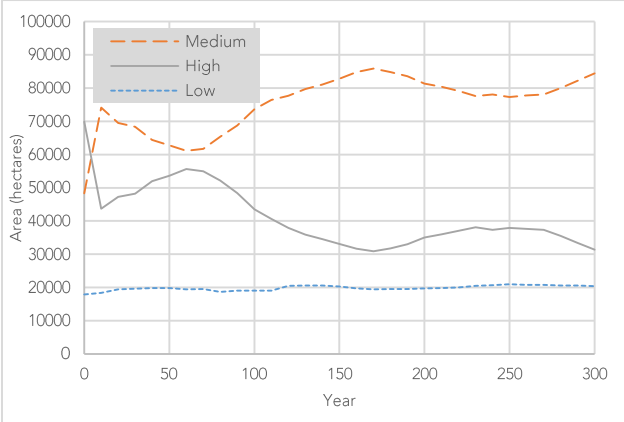

Figure 54 - The habitat suitability of Scenario 5 over time.

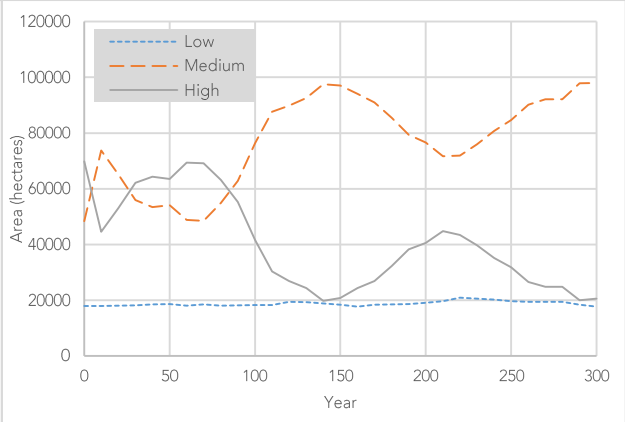

Figure 55 - The habitat suitability of Scenario 6 over time.

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