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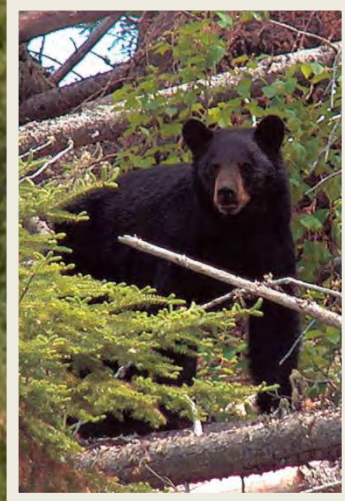
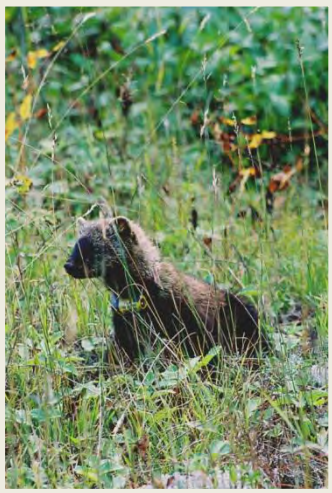
Science Package

Simulations, Rationale, Inputs and Results









Science and Information

in support of the

Forest Management Guide

for

Great Lakes - St. Lawrence Landscapes

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Simulations, Rationale, Inputs and Results

Electronic Document – Version 2019

This electronic document contains numerous linked embedded objects including journal articles, data summaries, government reports etc. The user of both this electronic document and the linked embedded documents should refer directly to the linked those documents and cite appropriately. Otherwise this Science and Information Package should be cited as;

Elkie, P., M. Gluck, J. Boos, J. Bowman, C. Daniel, J. Elliott, D. Etheridge, L. Frid, D. Heaman, G. Hooper, R. Kushneriuk, G. Lucking, S. Mills, B. Naylor, F. Pinto, B. Pond, R. Rempel, K. Ride, A. Smiegielski, G. Watt, M. Woods. 2019. **Science and Information in support of the Forest Management Guide for Great Lakes – St. Lawrence Landscape Guide: Science Package: Simulations, Rationale, Inputs and Results.** Version 2019. Ontario Ministry of Natural Resources and Forestry. Crown Lands and Forest Policy Branch, Forest Guides and Silviculture Section.

The various linked objects and embedded objects are highlighted in blue with context specific descriptions and underlined text.

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1 Overview

This document describes the science, rationale and methods used in the simulation modeling that was considered in preparing the background for the Forest Management Guide for Great Lakes–St. Lawrence Landscapes (GLSL LG) (Figure 1).

The GLSL LG was reviewed in **2015** and **2024**. The 2015 review concluded that a revision of the guide was not needed, while the 2024 review recommended minor short term revisions and longer term revisions. The 2015 review identified that the simulated ranges of natural variation (SRNV), estimated in 2005-2008, could be improved upon. This package includes revised estimated SRNVs based on simulations conducted in 2017-2018. The revised results were incorporated into Ontario's Landscape Tool in 2018.



Figure 1 Location of the Great Lakes – St. Lawrence Landscape Guide region.

1.1 List of supporting embedded documents

This package includes several embedded documents that are referenced throughout the text and will open when clicked:

1. **2015 GLLG review report** (link)
2. **Forest unit queries** (link)
3. **Silviculture system by forest unit listing** (link)
4. Forest unit summaries:
    i. **species composition** (link)
    ii. **ecosites**(link)
    iii. **age classes** (link)
    iv. **area**(link)
    v. **Provincial forest types** (link)
    vi. **development stage and codes** (link)
    vii. **descriptions** (link)
5. **Simulation methods and rationale report** (link)
6. **Habitat use relative to landscape classes** (link)
7. **Evaluative predicted responses** (link)
8. **Kirtland's warbler model description** (link)
9. **Simulation fire occurrence example maps** (link)
10. **Simulation example animation** (link)
11. **Predictive indicator simulation results portfolio** (link)
12. **Evaluative indicator model descriptions portfolio** (link)
13. **Evaluative indicator simulation results portfolio** (link)

2 Forest management guides for landscapes, adaptive management and science

The goal of the Forest Management Guides for Great Lakes – St. Lawrence Landscapes (GLLG) is to direct forest managers to meet the objective of conserving biodiversity in an effective and efficient manner, thereby, contributing to forest sustainability in an effective and efficient manner. The direction identifies and helps to set landscape level goals and desirable levels of forest composition, structure and pattern in forest management plans. Application of the guides recognizes the importance of the natural variability of landscapes and provides a parsimonious set of standards and guidelines designed to assist planners in conserving these characteristics within desirable ranges. The application of the GLLG will result in strategic landscape maps that forecast the future characteristics of landscape mosaics in the context of the long-term management direction of forest management plans. Additional guides (e.g. stand-site, silviculture guides) provide complementary direction at finer scales.

2.1 Science scope

Landscape simulations supported by historic surveys and expert opinion were used to estimate ranges of natural variation. The objective of the landscape simulations was to estimate a range of natural variation of landscape level composition, structure and pattern; where the natural level would be consistent with pre-European forest landscapes.

The original request to the GLLG science team was as follows:

1) What arrangement and composition of forest patches provides the best compliance with natural landscape pattern signatures?

2) What arrangement and composition of forest patches and strategic forest management options provides the best compliance with landscape habitat signatures?

3) How well do landscapes generated by simulation exercises inspired by natural landscape pattern signatures comply with landscape-level and stand-level direction of the natural disturbance pattern emulation guide?

This science and information package provide descriptions the various simulation inputs, rationale and results carried out by the GLLG science team.

The following is a list of members and the organization they represented in the original 2004 - 2010 science team (alphabetical order):

- John Boos, Regional Planning Biologist, Southern Region Planning, Peterborough.
- Jeff Bowman, Wildlife Research Scientist, Peterborough Main Office
- Rob Davis, Senior Parks Ecologist, Peterborough
- Colin Daniel, Modeling specialist – ESSA Technologies, Ottawa
- Phil Elkie, Co-ordinator GLSL Landscape Guide - Science Team, Forest Policy/Northwest Science and Information, Thunder Bay
- Leonardo Frid, Modeling Specialist – ESSA Technologies, Vancouver BC
- Michael Gluck, Ecology Forester, Forest Policy, Thunder Bay
- Dave Heaman, Fire Science Specialist, Southern Region, Peterborough
- Rob Kushneriuk, Forest Landscape Ecology Analyst, Centre for Northern Forest Ecosystem Research, Thunder Bay
- Margaret McLaren Wildlife Specialist, Southern Region, Science and Information, Bracebridge
- Stephen Mills Wildlife Biologist, Northeast Science and Information, South Porcupine
- Brian Naylor Forest Habitat Biologist, Southern Region Science and Information, North Bay
- Fred Pinto Conifer Program Leader, Southern Region, Science and Information, North Bay
- Bruce Pond Wildlife Research Scientist, Peterborough Main Office. Peterborough
- Murray Woods Senior Forest Landscape Specialist, Southern Region, Science and Information. North Bay

The 2019 team that re-estimated the simulated ranges of natural variation included (alphabetical order):

- Colin Daniel, Systems Ecologist – Apex Resource Management Solutions
- Phil Elkie (project lead), Ecology Forester – Ministry of Natural Resources and Forestry - Crown Forests and Lands Policy Branch
- Julie Elliott, Landscape Analysis - Private
- Leonardo Frid – Systems Ecologist – Apex Apex Resource Management Solutions
- Bronwyn Rayfield, Landscape Ecologist - Apex Resource Management Solutions
- Glen Watt, Regional Analyst – Ministry of Natural Resources and Forestry - Southern Region

3 Landscape Simulations

3.1 Simulation and management currency: forest units

For the purposes of the many analyses that support the development and implementation of the GLLG, modeling surfaces were created by classifying forest resource inventories (FRI) representing various biodiversity values (i.e., composition, habitat, age, development stages, etc.). The starting point for each classification was forest unit based. Forest unit classifications are aggregations of common or associated forest cover types as described by various attributes in the FRI. Forest units were developed considering a balance between ecological function and management practices. The forest unit framework that was developed provides enough detail to represent the level of information that is valid in the science interpretations including the information to be reported that serves as quantifiable targets and milestones.

From an analytical perspective, many different terms are used across the many models and tools used to define or describe the forest aggregation classes. Even within the tools used for analysis, the technical language for forest units is more commonly referred to as vegetative state classes or cover types. The terminology of forest units was chosen primarily because they are the currency used in forest management planning in Ontario.

For the 2019 SRNV estimates the most recent enhanced forest resource inventories (eFRIs), where available, were used. The only exception was the Ottawa Valley forest management unit where an older inventory was used.

In the 2019 simulations we used the same regional forest unit classification that was used in the initial 2004 simulations. The 2004 regional standard forest units were used as a starting point when the landscape guide forest units were developed. The GLLG guide forest units are an aggregation of the 2004 - 30 approved standard forest units. The initial forest units were assessed and summarized by age class in each ecoregion (5E and 4E)

to assist in understanding dominant and rare occurrences.

These summaries assisted in developing a standard set of 25 landscape guide forest units. Initially, 20 unique forest units for both ecoregion 4E and 5E were used in the landscape simulations. However, to provide consistency for forest management planning, 25 forest units were selected and a simulation model for each ecoregion was developed based on the expected succession and post disturbance transition responses.

The **queries** (link) for the GLLG forest units provide forest managers with a repeatable methodology for FRI forest unit classification. These queries are the standard for the GLSL forest and are used in Ontario's Landscape Tool.

The FRI has forest stand attributes including tree species composition, age, stocking and site class. We developed the GLSL landscape guide forest units considering tree species compositions and abiotic (fire, soil moisture, topography, silviculture treatments etc.) relationships and responses. Recognizing these relationships was part of a conscious effort to adopt expert opinion in the development of **silviculture treatments** (link).

Several summaries are available that illustrate the differences found among forest units within ecoregions 5E and 4E. Summary tables including tree **species composition** (link), **ecosite proportions** (link), **age-class distribution** (link) and **area by forest unit** (link) were used when developing forest units.

When developing the GLLG forest units, the importance of aggregating for higher level **provincial reporting** (link) was considered. The 25 GLLG forest units can be aggregated into the typical set of 12-15 forest units that are often used in plans and aggregated into both the eight Provincial forest types and the 7 GLLG landscape classes.

In the **summary analysis** (link), a dominant ecosite and numeric code was assigned to each landscape guide forest unit which allowed us to assign a **development stage** (link) to each forest unit. Forest unit **descriptions** (link) provide relative summaries of each forest unit including strategic direction and development information.

The following is a list of GLLG forest units and acronyms:

1. Red Pine: PR
2. White Pine 4–cut Shelterwood: PWUS4
3. White Pine–Red Oak: PWOR
4. White Pine-Conifer Shelterwood: PWUSC
5. White Pine-Hardwood Selection: PWUSH
6. White Pine-Seed Tree: PWST
7. Jack Pine-Pure: PJ1
8. Jack Pine-Conifer: PJ2
9. Hemlock: HE1
10. Cedar: CE1
11. Black Spruce: SB1
12. Lowland Conifer Mix: LC1
13. Upland Spruce: SP1
14. Spruce-Fir: SF1
15. Yellow Birch: BY1
16. Red Oak: Oak
17. Hardwood Selection-South: HDSL2
18. Hardwood Selection-North: HDSL1
19. Lowland Mixedwood: LWMW
20. Hardwood Shelterwood: HDUS
21. Poplar: PO1
22. White Birch: BW1
23. Mixedwood Shelterwood: MWUS
24. Mixedwood Dry: MWD
25. Mixedwood Rich: MWR

Refer to **descriptions** (link) for more complete definitions.

3.2 Great Lakes - St. Lawrence Landscape Guide Region simulations

3.2.1 Overview

The following models/tools were used in the initial GLLG simulations.

i) Vegetation Dynamics Development Tool (VDDT) – non-spatial tool designed for probabilistic succession models, probabilistic fire occurrence models, probabilistic insect outbreaks and probabilistic wind events (ESSA Technologies Ltd, 2005).
ii) Tool for Exploratory Landscape Scenario Analysis (TELSA) – spatial tool used to simulate landscape dynamics etc. (see literature cited for a list of TELSA reports and publications.
iii) Modeling Ontario's Stand Succession and Yield (MOSSY) – non-spatial tool used for summarizing FRI, providing forest unit specific species break-downs and providing support to development of probabilistic succession rules.
iv) Landscape Scripting Language (LSL) – spatial engine used to summarize results of landscape simulations.

TELSA was the main spatial landscape simulation model used in the original simulations. The revised 2019 SRNV estimates used a model called ST-Sim. ST-Sim software uses a state-and-transition simulation model (STSM) approach to simulate landscape dynamics, including projecting changes in both vegetation and land use. Because the STSM method is inherently stochastic, it is well suited for characterizing uncertainty in model projections. The revised 2019 methods and rationale including coarse summary results can be found in a **report** (link) provided by Apex Resource Management Solutions.

3.2.2 Types of landscape dynamics simulated in the GLLG

The GLLG landscape simulations include five types of forest cover transitions and disturbances;

i) surface fire,
ii) stand initiating crown fire,
iii) spruce budworm outbreaks,
iv) stand initiating wind events and
v) succession.

3.2.2.1 Surface fire

Surface fire – low intensity fires with no crown damage, no overstorey mortality on mature trees, up to approximately 2 metres flame height including some pre-sapling and sapling girdling. Surface fires are consistent with fires in intensity classes 2 and 3 from the Canadian forest fire behaviour prediction system (FBP):

Intensity 2: Creeping or gentle surface fire.

Intensity 3: Low vigour to moderately or highly vigorous surface fire (Taylor *et al.*, 1997).

3.2.2.2 Crown (stand initiating) fire

Crown (stand initiating) fire – medium intensity fire with some scorching of mature trees, flame 3 – 5 metres in height, that girdle polewood and smaller trees, and cause some overstorey mortality. These fires often are associated with a severe fire storm resulting in stand mortality. Crown fires are consistent with fires in intensity classes 4 and 5 from the Canadian forest fire behaviour prediction system (FBP):

Intensity 4: Very vigorous to extremely intense surface fire (torching common).
Intensity 5: Intermittent crown fire to active fire development at (>10,000) kW/m (Taylor *et al.*, 1997).

3.2.2.3 Spruce budworm outbreaks

Spruce budworm outbreaks – areas on the simulated landscape where an outbreak of spruce budworm occurs. Stands with a high component of white spruce and/or balsam fir become vulnerable to annual defoliation eventually resulting in stand mortality (Williams and Birdsey, 2003, Fleming et al. 2002, Williams and Liebhold, 2000, Candau *et al.*, 1998,).

3.2.2.4 Stand initiating wind events definition

Stand initiating wind events – change in forest stand structure due to large and catastrophic wind events.

3.2.2.5 Succession

Succession – natural changes in forest stand structure and species composition consistent with a number of conceptual succession models including the initial establishment of a variety of tree species and their change in abundance due to growth and reproductive adaptations and disturbances of varying intensity and frequency.

3.2.3 Fire cycles

In ST-Sim the user sets annual probabilities of burn for each forest unit and development stage combination (e.g. state class). During a model run ST-Sim sums the probabilistic outcomes and the result is an annual area burned. We used a historic survey line analysis and considered peer reviewed literature to estimate fire cycles for each forest unit. Collectively these provided the base ST-Sim inputs for estimating burn probabilities.

Historic survey lines in eco-regions 4E and 5E were digitized and geo-referenced from paper survey notes and an attribute database was built. The survey note attributes included both tree species and recent burns which were used to calibrate the models. It is generally accepted that when a surveyor characterized the landscape immediately adjacent to a control line that was being established, tree species were recorded in order of occurrence the same way FRI lists tree species (Leadbitter *et al.*, 2002, Jackson *et al.,*

2000). Assignments to a working group (WG – dominant tree species) to each line was segment based on the first species recorded on the line. Similarly, it is generally accepted that when a surveyor recorded a line segment as burn, it represents a burn that happened between 1-30 years prior to time of the survey and fifteen years is the value most frequently used in peer-reviewed literature (Lorimer, 1977, Canham & Loucks 1984, Whitney, 1987, Zhang et al. 1999, Cleland et al. 2004).

Using the combination of assigned working group and proportion of line burned, an estimate of fire cycle for each forest unit was made (Equation 1).

Equation 1 Fire cycle calculation from historic survey lines.

CycleFUx =100 / (proportion of line burned in WGx/15)

where;

CycleFUx = fire cycle for forest unit x

and

WGx = the working group equivalent of CycleFUx.

Due to the small sample sizes the results from ecodistricts 4E and 5E were pooled. For each landscape guide forest unit, the working group composition based on FRI summaries were determined for the entire ecoregion. For each forest unit a fire cycle (weighted) based on the working group specific cycle and the proportion of the landscape guide forest unit comprised by each working group was calculated. These were compared fire cycle values to peer-reviewed literature results and adjusted based on an understanding of the landscapes being modelled. Each calculated fire cycle was divided by 100 to estimate an annual probability.

3.2.4 Fire sizes

In St-Sim the user provides a histogram representing expected fire size. The following size classes were used;

i) 0-1 hectares,
ii) 1-10 hectares,
iii) 11-100 hectares,
iv) 101-1000 hectares and
v) 1001-10000 hectares.

ST-Sim will attempt to burn the landscape using the user-defined distribution as a target distribution. After some exploration and sensitivity analyses, a decision was made to use the five size classes with an understanding that they were wide enough to allow for stochastic fire spread which was consistent with the desire to capture inherent landscape variability.

Fires burn and spread in ST-Sim depending on the flammability of adjacent raster cells and the calculated landscape area to burn (based on summed probabilities). The historical survey line network was used to estimate a fire size frequency distribution. It is difficult to estimate fire size using historic transect data that intersects a fire. However, in estimating fire sizes assumptions were made: i) burns are circular and ii) that when a survey line recorded as burn intersected a fire, it intersected at a point halfway between a 0 tangent length (i.e., edge of the hypothetical circular burn) and the centre point of the circle, the ½ way secant (Figure 2).

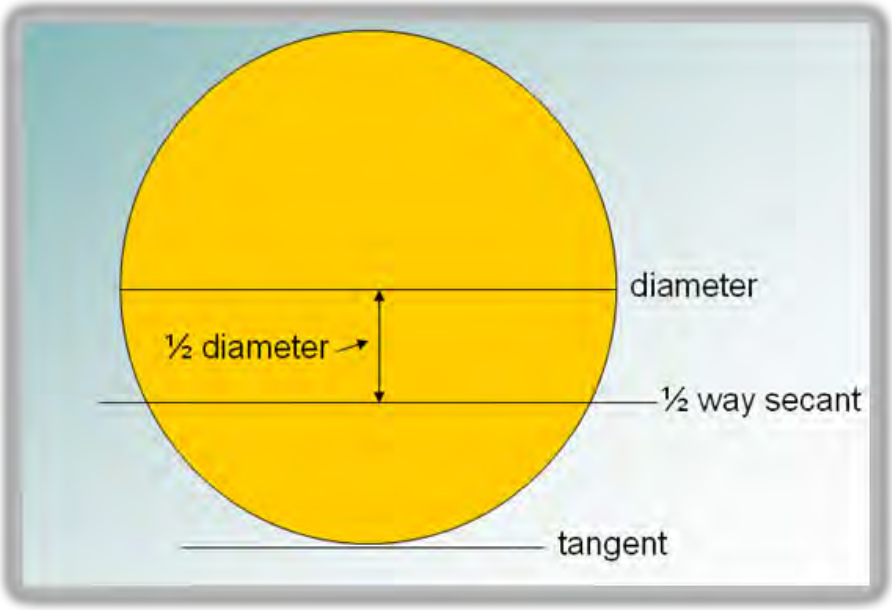

Figure 2 A hypothetical burn showing the ½ half way secant between the diameter and the ~ 0 length tangent.

Equation 2. Fire size calculation from historic survey lines.

$$A = 3.14 * (0.577 * s)^2,$$

where,

A = area of fire and s = secant line length (length of survey line recorded as burned.

Using this technique, estimates of the number and proportions of burns from the survey notes in ecoregions 4E and 5E were made (Table 1).

Table 1 Number and proportion of burns by size class in ecoregions 4E and 5E from historic survey lines. Burn size estimated using two assumptions i) burns are circular and ii) line transect, on average, intersects circular burn at ½ way secant (Figure 2).

Size class (ha)	Number of fires 4E	Proportion of fires 4E	Number of fires 5E	Proportion of fires 5E
0-10	76	14.18	99	18.79
11-100	227	42.35	194	36.81
101-1000	190	35.44	157	29.79
1001-10000	43	8.02	70	13.28
10000+	0	0.00	7	1.33

When reviewing the more recent survey notes it was apparent larger burns in ecoregion 5E were human caused and perhaps influenced by landscape condition (i.e., private-land, agriculture etc.). Therefore, the burn size class distribution of 4E was used for both ecoregion models (Figure 3).

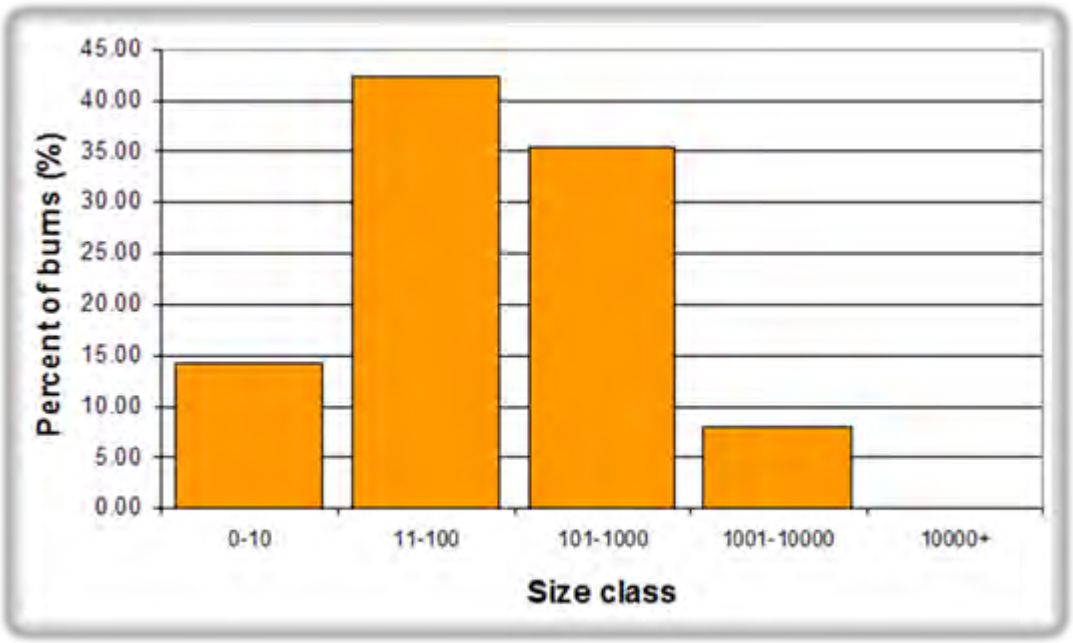

Figure 3 Burn size class distribution used as target burn size distribution in ST-Sim for ecoregions 4E and 5E. Size class distribution derived from historic survey line analysis in ecoregion 4E.

The burn size class distribution acts as a target and is not necessarily the distribution that will be achieved. The distribution achieved will be based on landscape condition/flammability at any given time in a simulation.

3.2.5 Post fire transitions

Once a raster cell is burned in a simulation it usually transitions, depending on assigned probabilities, into another state class. When developing post fire transition inputs,

relevant literature was reviewed resulting in summarized forest units by development stages for each eco-region and summarized average forest unit compositions from transition pathways were developed.

3.2.6 Spruce budworm outbreaks

Spruce budworm (*Choristoneura fumiferana* (Clemens)) outbreaks occur, on average, every 35 years in eastern North America. Candau *et al*., 1998 show two outbreaks in northeastern Ontario, one occurring from 1940-1950 and the other from 1970–1985. Generally, after 5 years of heavy defoliation, stand mortality occurs (Flemming *et al*. 2002, Williams and Liebhold 2000, Williams and Birdsey 1999).

The GLLG St-Sim simulations run in 5-year time intervals. Therefore, assignments of probability were made of 1 (100%) of a spruce budworm attack every 7 modeling steps (i.e., 5 years X 7 modeling steps = 35-year outbreak). The first outbreak was randomly set for each simulation in years 1, 5,10,15, 20, 25, 30 or 35.

ST-Sim requires the user to assign a range of disturbance sizes for all disturbances including spruce budworm. The sizes of budworm outbreaks that would occur every 35 years were estimated based on historic data.

Stand mortality usually occurs after 5 consecutive years of defoliation (Flemming *et al*. 2002). Spatial defoliations layers from forest insect and disease surveys were provided from the Canadian Forest Service. These layers represent relative defoliation for several periods from 1941 to 2004 and represent broad areas where defoliation has occurred. The intent for modeling was to capture general landscape dynamics across ecodistricts within ecoregions 4E and 5E. Specifically, to capture where and how often mortality of stands occurred due to spruce budworm disturbance.

All defoliation polygons were isolated and classed as severe for each period (1941 - 2004). Water polygons were intersected and removed from each layer. When there was spatial coincidence among the defoliation layers of at least five years, the layers were intersected, and spatially isolated polygons were termed potential mortality areas.

Outbreaks of spruce budworm in the eastern region of Ontario occurred between 1940 and 1946 and between 1970 and 1981 (Figure 8.8 in Fleming *et al*. 2002). Therefore, because the objective was to estimate the results of spruce budworm dynamics on the

landscape, all areas that did not fit into the outbreak time periods were dropped. However, because surveys from the 1940's only captured partial outbreaks they were removed. Figure 4 illustrates the total amount of the landscape with five consecutive years of spruce budworm outbreak for the outbreak period 1970-1981. The total area was estimated with five years of severe defoliation ensuring that no area was counted twice (5,936,865 hectares).

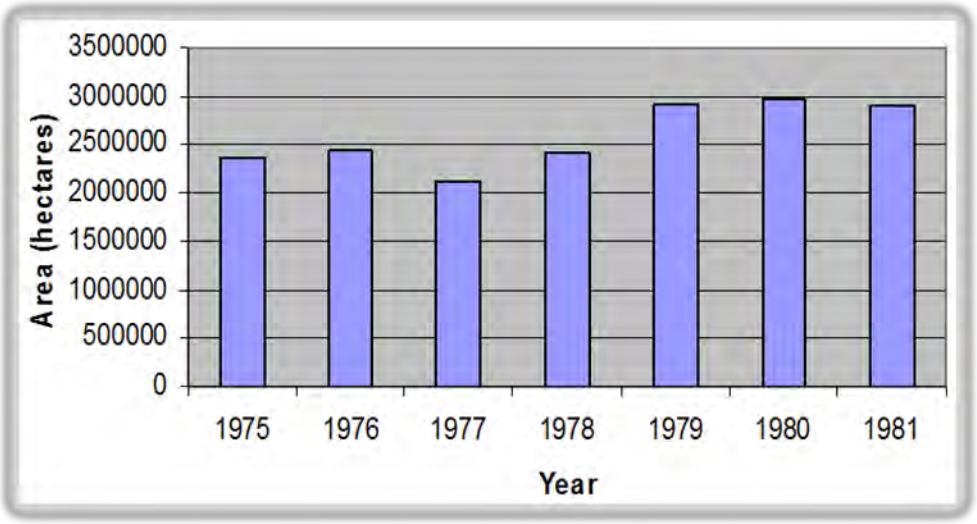

Figure 4 Area in ecoregions 4E and 5E with five consecutive years of severe spruce budworm defoliation for the outbreak periods 1970-1981. Note: 1970 plus five years of defoliation=1975.

Each polygon was classified into one of the five size classes and summaries of both the proportion and area of disturbance within each size class were made.Figure 5 and Figure 6). The 1-100 size class was dropped due to the coarseness of the underlying data.

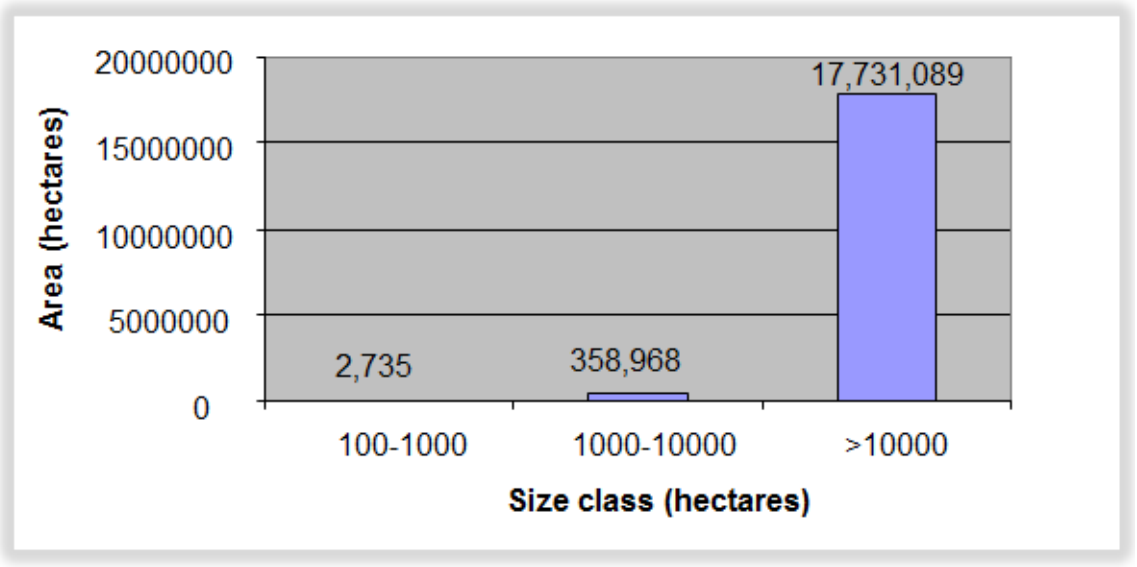

Figure 5 Mean area of spruce budworm outbreak with at least five consecutive years of severe defoliation. After five years of severe defoliation stand mortality takes place.

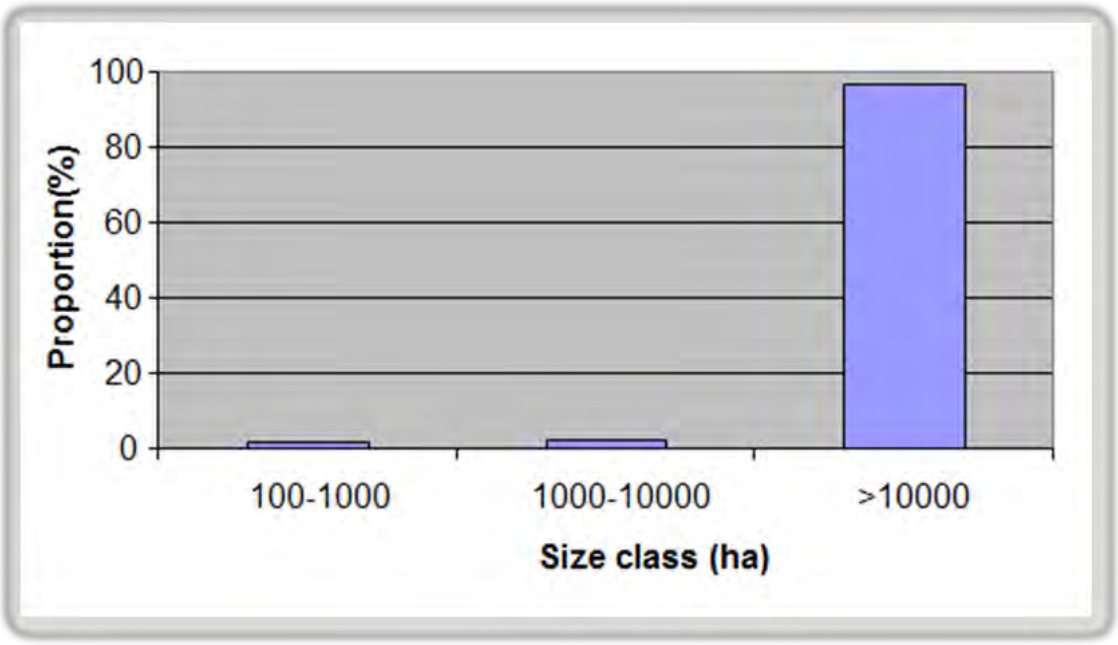

Figure 6 Proportion of spruce budworm outbreak areas with at least five consecutive years of severe defoliation. After five years of severe defoliation stand mortality takes place depending on stand composition.

Next the probability of a "5-year spruce budworm defoliation" (pSBW) event in an outbreak was calculated (Equation 3).

Equation 3 Probability of a five year spruce budworm defoliation event.

pSBW= [Area of 5-year spruce budworm defoliation] / [Total Analysis Area]

Result: pSBW=5,936,865/(11494400-1083912) =0.57

Once an outbreak occurs we set the model to a disturbance size of up to 2,588,216 hectares in size within the various size classes (Figure 16).

3.2.7 Post spruce budworm mortality transitions

A post mortality transition model for stands affected by spruce budworm was developed. Firstly, only stands with greater than or equal to 30% white spruce and/or balsam fir are affected. Although these numbers do not come from published empirical data, based on discussions with local experts, it was felt that stands with less than 30% white spruce and/or balsam fir would likely not build up high budworm numbers and thus experience high mortality (but still show some growth loss). The models only consider stands that are in the immature and older development stages as eligible.

A post spruce budworm mortality transitions model was developed by summarizing each stand in the inventories. Balsam fir, white spruce and black spruce were removed using following rules:

i) in immature stands, mortality was 25% for black spruce, 30% for white spruce, and 75% for balsam fir, and

ii) in mature or old growth stands, mortality was 50% for black spruce, 60% for white spruce, and 95% for balsam fir (Johnson *et al*. 1988).

Once these rules were applied, the species composition was recalculated, adjusting for losses of black spruce, white spruce, and balsam fir so that species composition summed to 100 (i.e., % sppx = %sppx/ (1-loss of Sb+Sw+Bf)). Next a new forest unit was assigned based on the adjusted species composition and calculated a new development stage based on the following rules;

i) if loss of black spruce + white spruce + balsam fir represented <= 33% of the total species composition, then no change to development stage,

ii) if loss > 33% but <= 67% then development stage changed to two-stage and

iii) if loss > 67% then development stage set to pre-sapling.

3.2.8 Wind events – sizes and probabilities

Similar to fire, we used the historic survey work to approximate the size of wind events. We also used peer-reviewed science literature to calculate sizes of wind events in the Great Lakes St. Lawrence Forest Region (Lorimer, 1977, Canham & Loucks 1984, Whitney, 1987, Zhang *et al.* 1999, Cleland *et al.* 2004).

4 Landscape classes

4.1 Landscape class definitions

The forest mosaic across a landscape provides habitat for many wildlife species, each with its own preferences for combinations of vegetation types, development stages, arrangement and configuration. It would be difficult to assess landscapes for each species within the context of a forest management plan. To reduce the complexity of this problem and as a coarse filter approach, the landscape development team and science teams developed landscape classes according to a collective understanding of how forests function as habitat. A landscape class classification scheme of between 5-10 classes for easy visual and analytical interpretation was the objective where the landscape classes represent the fundamental coarse filter assessment units.

Landscape classes were developed based on clustering analyses of preferred and used habitat types depicted in MNRF's habitat matrices (Holloway *et al*. 2004). The habitat matrices summarize habitat affinities of selected vertebrate species based on forest type and development stage. The matrices contain up to 150 habitat classes and the objective of the clustering analysis was to find smaller subsets that generally reflect how vertebrates use habitat. Cluster analysis, also called segmentation analysis or taxonomy analysis, seeks to identify homogeneous subgroups. More specifically, cluster analysis seeks to identify a set of groups which both minimize within-group variation and maximize between-group variation. SPSS hierarchical cluster analysis (average linkage technique) was used to group forest type by development stage combinations for each region based on the similarities in suitability ratings.

The objective was to identify between five and ten classes in each region. It was decided that five to ten classes were appropriate for analysis and interpretation within the context of coarse filter application of the landscape guide. Further, it was felt that between five and ten classes provided in-class flexibility for forest unit desired level and target achievement while

providing a level of resolution while still maintaining the coarse-filter landscape guide direction for each region.

Based on the clustering analysis landscape classes were developed for the GLSL (Table 2) regions. Relationships between species from the **habitat matrices and landscape classes** (link) were generated for each region. Validation of wildlife habitat affinities for landscape classes is ongoing. Methods and initial results from the Great Lakes-St. Lawrence Landscape Guide Regions are detailed in Martin et al 2025.

Table 2 GLLG landscape classes.

Landscape Class	GLLG Forest Units	Development stages
1 - Presapling and Sapling	All	Pre-sapling, Sapling
2 - Immature	All	Immature
3 - Tolerant Hardwood	HDSL1, HDSL2, HDUS, BY, Oak	Mature and Old
4 - Intolerant Hardwood	PO, BW	Mature and Old
5 – Pine Mixedwood	PWOR, PWUSH, PWUS4, PWST	Mature and Old
6 - Mixedwood	HE, LWMW, MWD, MWR, MWUS	Mature and Old
7 - Mixed Pines	PR, PJ1, PJ2, PWUSC	Mature and Old

5 Simulated ranges of natural variation – SRNV

5.1 Area based SRNV

The 2019 St-Sim simulation models were used to estimate the "natural" range of conditions (i.e., composition and pattern) in a landscape without anthropogenic influences. The simulations included crown fires, surface fires, spruce budworm outbreaks, wind disturbances, succession and post disturbance transitions.

ST-Sim is stochastic where the model samples from input distributions when simulating natural landscape dynamics resulting in a different result for each simulation.

Multiple simulations provide a range of landscape conditions. Area results for various indicators are expressed using box and whisker diagrams. These box and whisker diagrams include the maximum, minimum, 25th percentile, 75th percentile and median for a given indicator. Collectively these make up the simulated range of natural variation (SRNV)

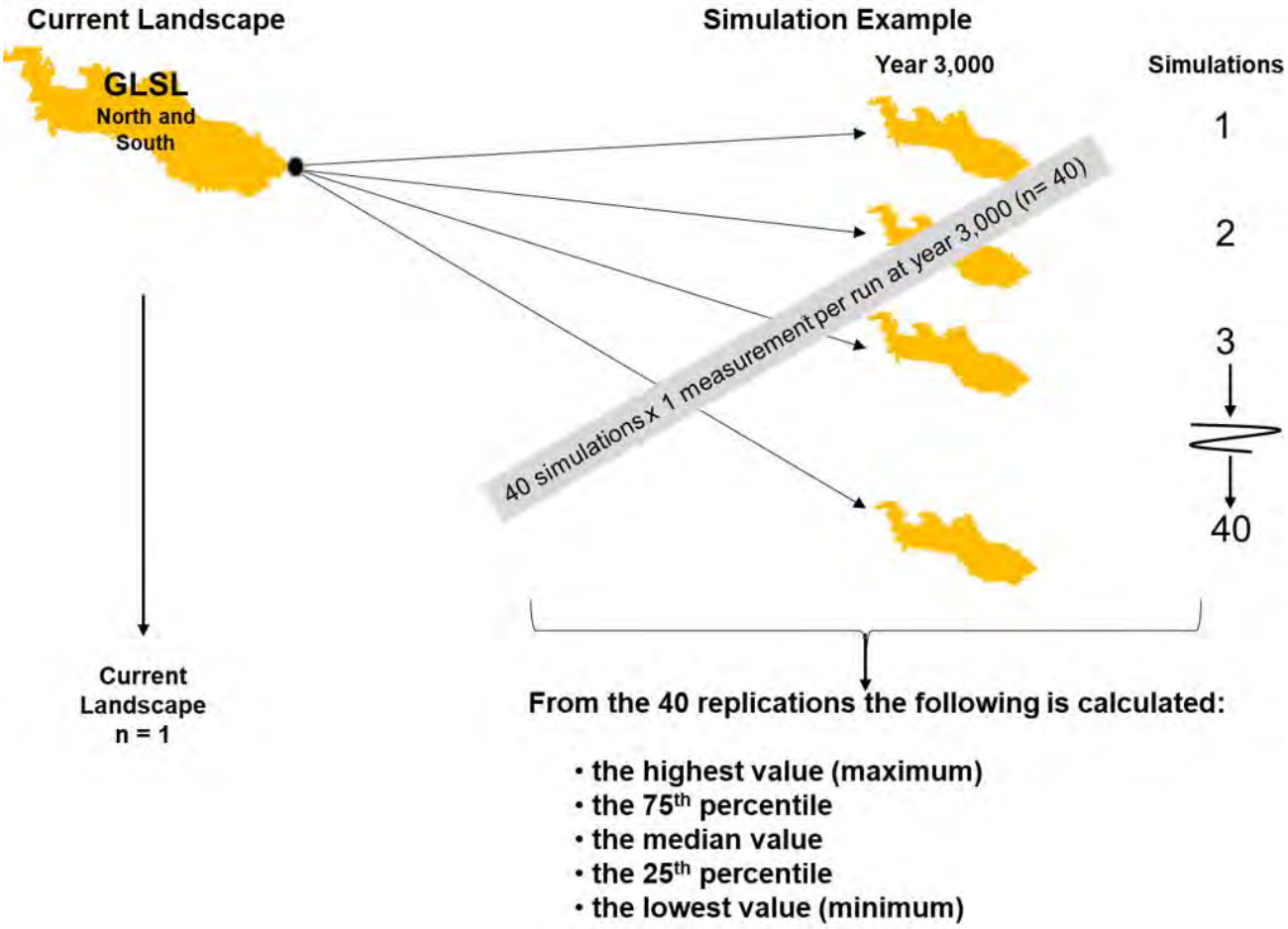

Figure 7 Example showing stylized GLLG region simulations and results used for the SRNV. In the 2019 GLLG SRNV – 40, 3,000-year simulation runs were used with one measurement take for each simulation – at year 3,000.

5.2 Texture based SRNV

For some indicators, characterizing the spatial landscape pattern using traditional measures such as patch size and patch frequency is not valid. For instance, using the patch size frequency technique for mature and old forest on landscapes that are several hundred thousand hectares in size and reporting a mean or median patch size for several thousand patches is difficult to interpret and consequently use for management targets. The mature and old forest is often distributed across the landscape with some areas made up of high concentrations and other areas with relatively low concentrations.

The Landscape Scripting Language (LSL) is a tool that is used to that is used to assess landscapes including generating texture analysis results. LSL was used in the summarizing simulation results and is the spatial assessment tool embedded in Ontario's Landscape Tool.

Using a texture analysis is a more meaningful method because it reduces the problems associated with the traditional patch measurement methods. For instance, at the 500-hectare level, LSL creates a 500-hectare hexagon fabric which is overlaid on a landscape classified into mature and old forest at the FRI polygon level. Within each hexagon, the amount of mature and old forest is summed, and the proportion is calculated based on the amount of forest in the hexagon. Hexagons with 50% or less forest are not used. LSL then creates a frequency distribution (Figure 8) and map (Figure 10).

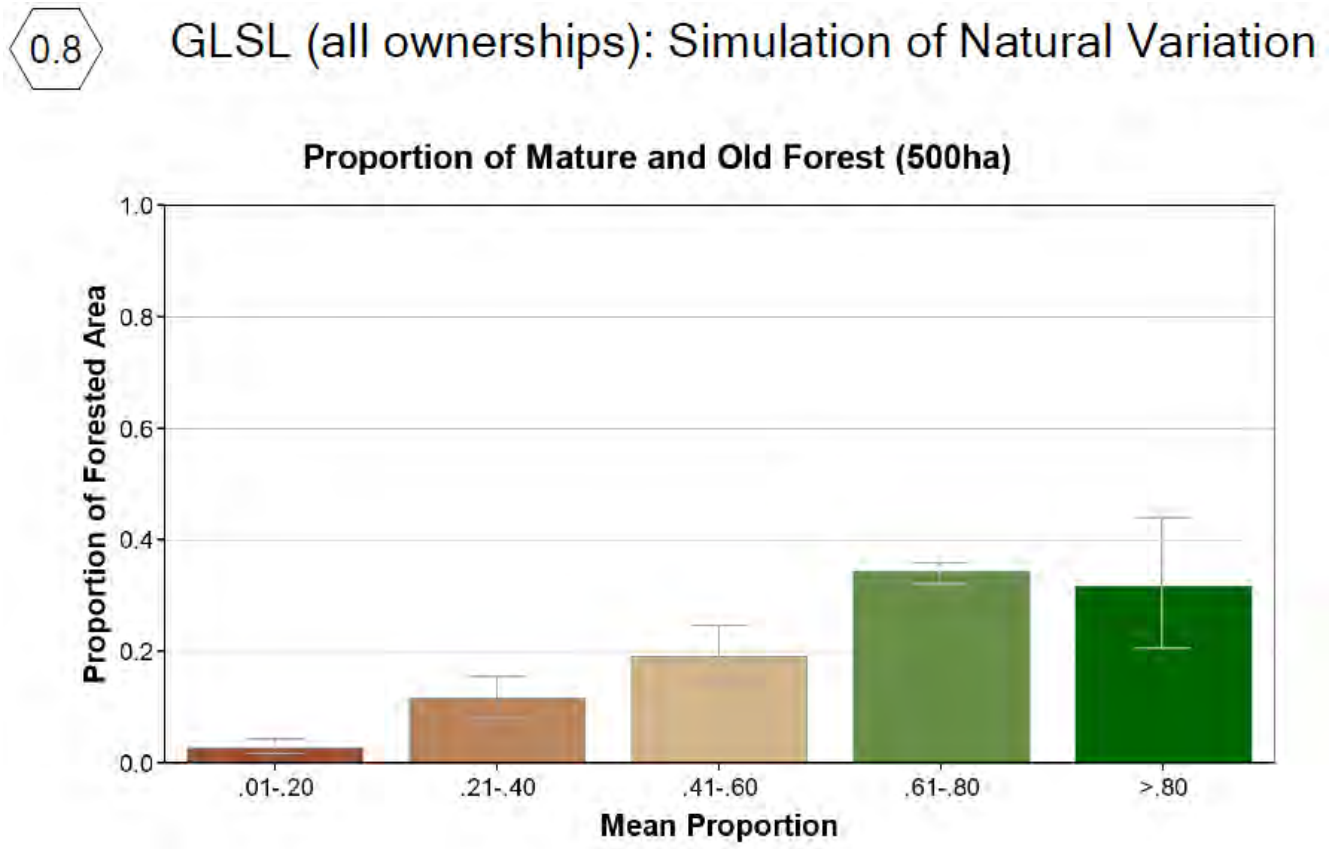

Figure 8 Frequency distribution histogram from the Landscape Scripting Language tool representing the relative distribution of 500-hectare hexagons with 0-20, 21-40, 41-60, 61-80 and 81-100 % of forested area in the mature and old class based on Figure 9. Error bars represent the range from multiple 3,000-year simulation runs (n=40) and hexagon layer offsets.

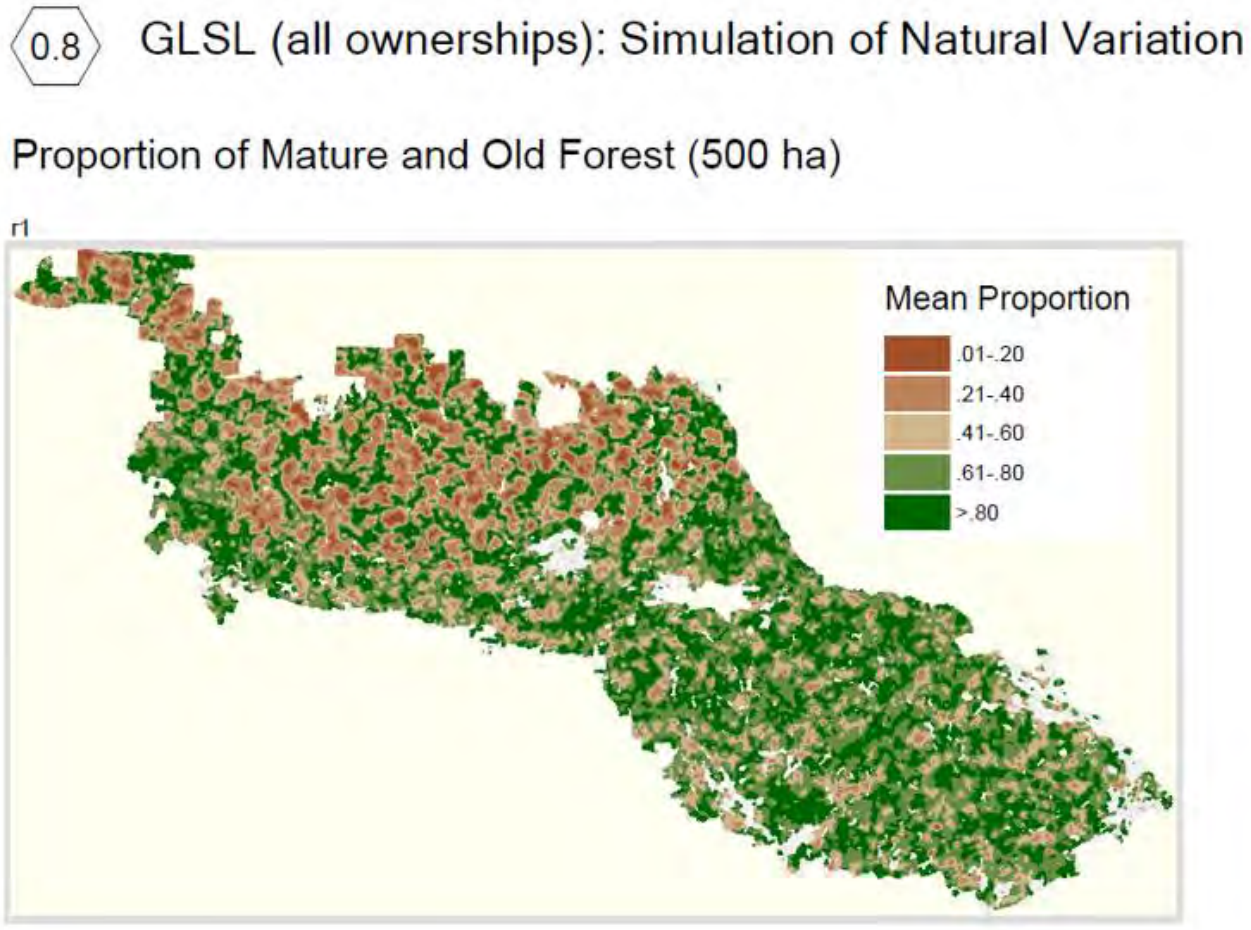

Figure 10 Example map from the Landscape Scripting Language (LSL) of one simulation result of mature and old forest at the 500-hectare hexagon level.

6 Indicators

6.1 Prescriptive

Ontario's forest landscape is designed through application of the coarse filter by addressing three key prescriptive indicators: pattern, composition and structure. Prescriptive indicators were defined by the landscape guide development team. Refer to the landscape guides for a listing and definition of each prescriptive indicator used in each Landscape Guide Region. Ontario's Landscape Tool contains techniques for estimating each of these indicators.

Prescriptive indicators used in the GLLG include:

i. landscape classes,
ii. mature and old forest,
iii. old growth,
iv. red and white pine and
v. young forest.

Refer to the GLLG for prescriptive indicator definitions.

6.2 Evaluative

Evaluative indicators are generally habitats for various wildlife species and are used in the GLLG as indicators that are subject to the evaluation of the effectiveness of the guides through monitoring.

The evaluative indicators team developed a list of species that could be used for evaluating the effectiveness of the landscape guide within an adaptive management framework. This list is intended to be inclusive and may change over time.

In developing the evaluative indicators list the following were considered;

i) the range and similarity of ecosite in the Great Lakes St. Lawrence forest region (ecosite and development stages),
ii) the range of habitats used by species that were currently (2004) being modeled in forest management planning,
iii) socially desirable species (i.e., moose-hunting),
iv) rare, threatened and endangered species (i.e., woodland caribou in boreal),
v) species that we expected a population response at a coarse level – landscape,
vi) the ability to measure population response and
vii) the ability to model and predict response.

The following is a list of evaluative indicators that may be used in the GLLG forest region.

i) White-tailed deer (*Odocoileus virginianus*),

ii) Black Bear (*Ursus americanus*),

iii) Lynx (*Lynx canadensis*),

iv) Snowshoe Hare (*Lepus americanus*),

v) Marten (*Martes Americana*),

vi) Fisher (*Martes pennanti*),

vii) Northern Flying Squirrel (*Glaucomys sabrinus*),

viii) Southern Flying Squirrel (*Glaucomys volans*),

ix) Spruce Grouse (*Falcipennis Canadensis*),

x) Beaver (*Castor candensis*),

xi) Wood duck (*Aix sponsa*),

xii) Red-shouldered Hawk (*Buteo lineatus*),

xiii) Northern Goshawk (*Accipter gentiles*),

xiv) Barred Owl (*Strix varia*),

xv) Ruffed Grouse (*Bonasa umbellus*),

xvi) Pileated woodpecker (*Dryocopus pileatus*) and

xvii) Pine Warbler

When developing the evaluative indicator list, the range of unique habitat/cover types across the GLSL forest region were considered and expert opinion **predictions** (link) of population response based on potential changes in forest cover were made. Each of these models is included in Ontario's Landscape Tool. Many of the GLLG models were built based existing models from Ontario Wildlife Habitat Analysis Models (OWHAM) and from "*Habitat Relationships of Wildlife in Ontario*" (Holloway *et al.* 2004).

An additional evaluative indicator and model was developed– **Kirtland's Warbler** (link). However due to the seral stages that the warbler uses SRNV for habitat was not able to be generated. Ontario's Landscape Tool estimates current habitat but does not provide a habitat SRNV.

7 Simulation results

7.1 Simulation example

The attached is an example **500-year simulation** (link) provided here to illustrate the behaviour of the simulation model.

7.2 Fire disturbance example maps and fire return interval

The attached includes examples of **simulation fire disturbance maps** (link) for 10 of the 40 simulations. Due to the complexity of crown and surface fire in GLLG simulation models maps of all pre-sapling and sapling were produced as opposed to fire maps. The maps are intended to illustrate where young forest (pre-sapling and sapling) including the general size/extent –providing a visual of fire disturbance behavior. The attached also includes a map illustrating relative occurrence of all fire (e.g. crown and surface) over 40 - 3,000-year simulations and a box and whisker graph illustrating the median fire return interval for each fire type.

Ontario's Landscape Tool includes simulated ranges of natural variation fire return intervals for each forest management unit.

7.3 Prescriptive indicators

Area-based and pattern simulated ranges of natural variation (SRNV) for prescriptive indicators are found here:

Forest units by development stages (link)
Landscape classes (link)
Old growth (link)
Mature and old forest (link)
Red and white pine (link)
Young forest (link)

7.4 Evaluative indicators

Area-based and pattern simulated ranges of natural variation (SRNV) for evaluative indicators are found here.

Evaluative indicator model descriptions (link)

Evaluative indicator simulation results (link)

8 Literature cited

8.1 Main body text literature cited

Note – refer to the various embedded objects for specific component literature citations.

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