PROJECT REPORT
1999-3

sustainable forest management network

réseau sur la gestion durable des forêts

Natural Disturbance Analysis and Planning Tools

A Network of Centres of Excellence
Un réseau de centres d'excellence

Robert S. Rempel

For copies of this or other SFM publications contact:

Sustainable Forest Management Network
G208 Biological Sciences Building
University of Alberta
Edmonton, Alberta, T6G 2E9
Ph: (780) 492 6659
Fax: (780) 492 8160
http://www.biology.ualberta.ca/sfm/

ISBN 1-55261-017-9

Natural Disturbance
Analysis & Planning Tools

SFM Network Project: Planning and analysis tools for sustainable forest management

by

Robert S. Rempel

Lakehead University and
Ontario Ministry of Natural Resources
955 Oliver Road,
Thunder Bay, Ontario
P7B 5E1

June 1999

ABSTRACT

Emulating patterns of natural disturbance through the practices of forest management is becoming an important component of the ecosystem-based approach to sustainable forest management (SFM). Our work has focused on developing decision support tools to aid forest management analysis and planning, with the specific objective of assisting planners as they develop harvest cutblock layouts with defined spatial objectives. In this report I will describe the following major components of our work in developing the knowledge and the computer software necessary to create and evaluate our decision support tools: mapping landscape patterns of forest residual following historical natural wildfires in boreal Ontario; GIS-based tools to characterize and assign habitat values to landscape patterns; hierarchical (multiscale) analysis of landscape patterns in boreal Ontario; applying decision support tools to analyze economic versus ecological trade-offs of spatial objectives in SFM planning; and applying decision support tools to support Criteria & Indicator analysis of National Parks ecological-integrity objectives.

ACKNOWLEDGEMENTS

SFMN supported the research reported here by providing funding to the following graduate students and summer student research assistants (SSRA), and in so doing contributed to the development of highly qualified staff. Many of these have now moved on to permanent employment directly related to their training under this project.

- Phil Elkie (Graduate Student - completed) - now Landscape Specialist for MNR
- Andrew Promaine (Graduate Student - completed) - now Park Ecologist for Parks Canada
- Cynthia Kaufmann (Graduate Student - in progress)
- Mark Petrick (SSRA - programmer for NDAPT) - now doing PhD in computer science
- Angus Carr (SSRA - programmer for Patch Analyst) - now Regional Landscape Specialist for MNR
- Michael Gluck (SSRA - landscape analyst for fire mapping) - now Regional Landscape Analyst for MNR (on leave with IASSA in Vienna.)

SFMN also provided funding for networking travel, both through my grant and through direct travel grants. This permitted myself, my students, and other associates to present the results of this work, and to learn from others.

OMNR provided most of the base-funding, including the GIS hardware and software, remote sensing data, and my salary. Parks Canada (Pukaskwa Park) provided additional funding to support Andrew Promaine's thesis on applying criteria and indicators to national parks ecosystem objectives.

John McNicol, a major non-SFMN funded partner, funded the contracted work to map historical patterns of natural disturbance through the Forest Management Branch, Ontario Ministry of Natural Resources.

INTRODUCTION

Emulating patterns of natural disturbance through the practices of forest management is becoming an important component of the ecosystem-based approach to sustainable forest management (SFM). The natural disturbance approach requires knowledge of natural patterns of disturbance, including bounds of natural variability, and it also requires computer-based decision support tools to assist planners in applying principles of natural disturbance to operational aspects of SFM. Our work has focused on developing decision support tools to aid forest management analysis and planning, with the specific objective of assisting planners as they develop harvest cutblock layouts with defined spatial objectives. A forest management plan's spatial objectives are based in part on an ecoregion-specific understanding of natural disturbance effects, and in part on socio-economic considerations, legal policy issues, and other ecological and silvicultural drivers.

In this report I will describe the following major components of our work in developing the knowledge and the computer software necessary to create and evaluate our decision support tools:

-Mapping landscape patterns of forest residual following historical natural wildfires in boreal Ontario

-GIS-based tools to characterize and assign habitat values to landscape patterns

-Hierarchical (multiscale) analysis of landscape patterns in boreal Ontario

-Applying decision support tools to analyze economic versus ecological trade-offs of spatial objectives in SFM planning.

-Applying decision support tools to support Criteria & Indicator analysis of National Parks ecological-integrity objectives.

SUMMARY OF DATA ANALYSIS

Mapping landscape patterns of forest residual following historical natural wildfires in boreal Ontario

Mapping landscape patterns created by historical fires is an important first step in providing decision support and direction to forestry planners who need to know how they can layout harvest cutblocks to emulate patterns of natural disturbance. Two scales of pattern are immediately relevant: the regional scale and the landscape scale (Fig. 1). The regional scale deals with how much area to log annually, how large the cuts should be, and how far apart they should be spaced. The landscape, or multi-stand scale deals with the shape of cuts, amount of uncut residual, and dispersion of residual within cuts.

This study deals with the landscape scale, where we have mapped landscape patterns created by natural, unsuppressed wildfires in the boreal forest. From our analysis, we indicate how much residual uncut forest should be left for a cutblock of any given size (Fig. 2), and we provide baseline statistics concerning patch shape, size diversity, etc. for natural fires (Table 1). We also introduce a new approach to describing the dispersion of residual within a cutblock to help define specific spatial objectives for emulating natural disturbance.

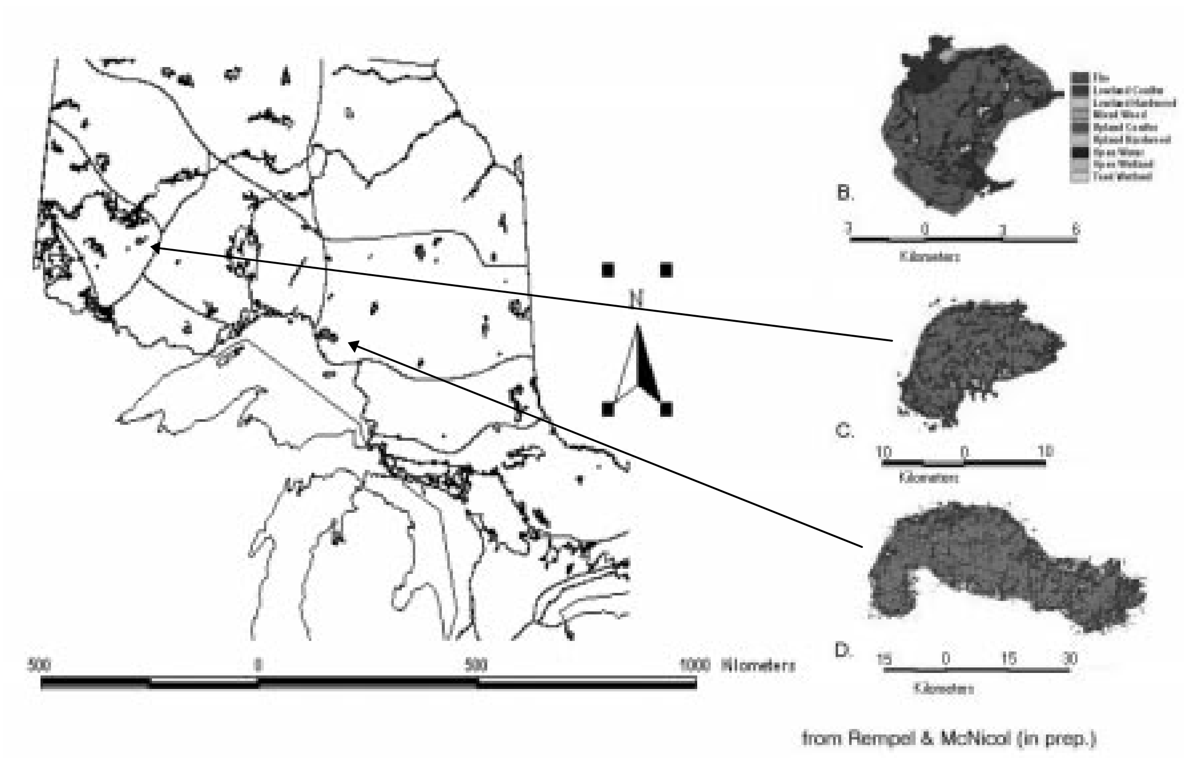

Fig. 1. Three examples of 42 fires digitized from 1930s to 1940s aerial photography, ranging in size from ca. 100 – 50,000 ha. Eight landcover classes were photo interpreted, and then digitized, with a minimum polygon size of 0.25 ha. Large polygons are Hill's Site Regions

To characterize natural fires, we obtained 1:15,840 scale black and white aerial photography (from the 1930s and 1940s) of 42 wildfires that either had very little or no fire suppression (Rempel et al.b 1999). Most photographs were taken within 15 years of the burn. We visually interpreted the photographs to create 8 landcover classes: burn, upland and lowland conifer, upland and lowland hardwood, mixedwood, open wetland, treed wetland, and open water (Fig. 1). The minimum digitized polygon size for photo interpretation was 0.25 ha, which represents a ground observation of 50 m by 50 m. This is a similar size to a Landsat TM (satellite) pixel (30 m by 30 m), and therefore facilitates application of these results to modern and cost effective monitoring technology. Fires for the full data set ranged from 54 – 54,722 ha, and occurred in both eastern ecoregions (Hills' site regions 2E, 3E, 4E, and 5E), western ecoregions (Hills' site regions 2W, 3S, 3W, 4S, 4W, and 5S) of the Province.

Table 1. Summary statistics for landscape analysis of digitized historical aerial photography (1920s - 1940s)

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Burned Area (ha)	42	36	43168	3387.52	7629.74	4.190	19.442
Event Area (ha)	42	54	52772	4664.52	9320.07	3.971	18.183
Event edge-area ratio (m/ha)	42	26	200	83.83	41.21	.692	.168
Number of Residual Patches > .25	42	20	2139	277.24	391.71	3.099	12.039
(Num Resid. Patch < .25 ha)/100	42	1	32	11.10	7.16	.996	.642
Residual Area (ha)	42	17	6143	882.83	1297.46	2.387	6.468
Residual Edge (m)	42	11570	2040870	280638.57	3.90E05	2.671	9.291
Residual PA-1 (m/ha)	42	1306	3671	2255.98	563.02	.730	.381
Residual NASQ	42	.395	.551	.46070	3.36E-02	.493	.737
Residual Mean Patch Area (ha)	42	.523	18.543	2.73698	2.77	4.748	26.966
Residual Mean Patch Edge (m)	42	388	3021	920.94	430.48	2.921	13.229
Residual MPFD	42	1.094	1.135	1.11372	9.26E-03	.170	-.001
Residual AWMPFD	42	1.127	1.273	1.17730	3.54E-02	.985	.738

GIS-based tools to characterize and assign habitat values to landscape patterns

As forest planning begins to adopt emulation of natural disturbance as spatial objective in harvest cutblock layout, forest planners will be faced with the difficult task of developing and assessing management plans in terms of specific spatial objectives (Elkie et al. 1999; Rempel et al. 1999a, b; Rempel 1999b, c). This new approach to forest management will require analysis and planning tools capable of assisting planners with such ecological objectives as emulating patterns of natural disturbance, and protecting habitat for both ecotone and interior forest species. Such tools must be accessible to resource specialists, and not be restricted to systems and GIS specialists. They should also integrate easily within the corporate GIS, and should be capable of analyzing data in its native GIS format, without the need for complex and time consuming exports and reformats. We have developed 2 complementary landscape pattern analysis tools that operate as extensions in the ArcView environment: Patch Analyst (Fig. 3) and Habitat Analyst (Fig. 4). The functions operate seamlessly on both vector (Shape and Coverage) and raster (Grid and Image) data formats. Patch Analyst performs pattern analysis of landscape patches, and includes data manipulation functions such as patch dissolve and create-core areas. Habitat analyst assigns values to landscape patterns based on interspersion, juxtaposition, and isolation of seral vegetation stages. It includes data manipulation functions such as attribute assignment and modelling. Pattern evaluations are conducted within a user-defined hexagon grid. Together, these tools provide the planner with desktop tools to analyze and interpret landscape patterns and projections of alternative planning scenarios.

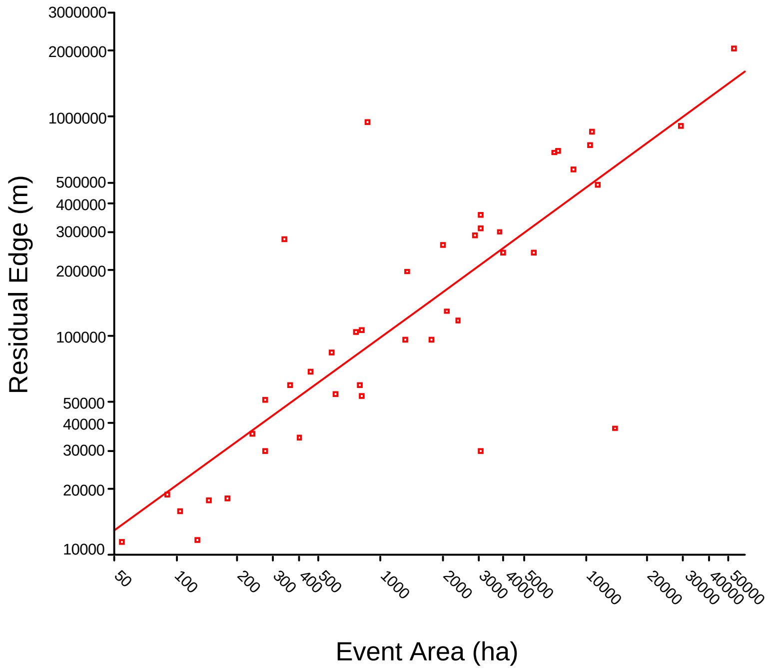

Fig. 2. Regression plot (log-log) of fire event area (defined by a convex polygon surrounding outer extents of the burn) versus total residual (unburned mature forest) within the fire event boundaries. Data is from digitized historical aerial photography (1920s - 1940s). Regression plot provides forestry planners with a suggested amount of edge to leave within proposed cutblocks of any given size. Regression graphs are also available to predict residual area.

Hierarchical (multiscale) analysis of landscape patterns in boreal Ontario

The practice of emulating natural disturbance must be embedded in principal theories of landscape ecology. A major premise underlying the concept of emulating natural disturbance is that we can substitute logging for fire in terms of creating landscape patterns. A fundamental principle of landscape ecology is that landscape patterns may be hierarchical in nature (i.e., patterns nested within patterns), and therefore if we are to use logging to emulate natural pattern creation, then we must understand whether these patterns are indeed nested, and the critical scales at which pattern structuring occurs. These critical scales then become the focus of forest management.

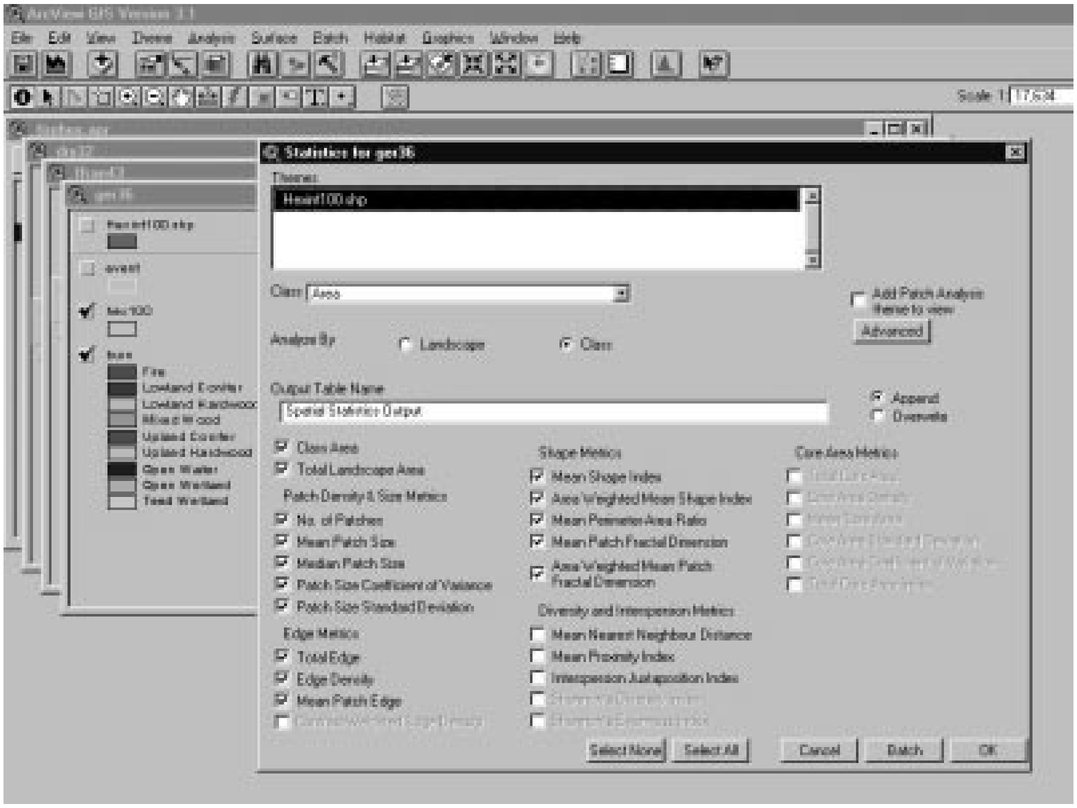

Fig. 3. Spatial statistics dialog box from Patch Analyst. Dialog box allows user to request common landscape metrics necessary for setting and evaluating spatial objectives in SFM planning. Patch Analyst is available as an extension to ArcView, and allows user to interact directly, and through a simple interface, with ArcInfo database structures, including ArcLibrary, ArcLibrary, and SDE holdings.

Hierarchy theory suggests that complex systems will develop hierarchical structure that can be reflected in multiple levels of organization in landscape patterning (Elkie and Rempel 1999). A hierarchy of processes operating at different spatial and temporal scales form landscape pattern and changes to the patterns can have impacts on forest dwelling species. The influence of forest management on forest landscapes requires evaluating changes to pattern at relevant scales. Managing landscapes under the auspices of sustainable forest ecosystems and emulation of natural disturbance requires: i) knowledge of current relevant scales of landscape patterning and ii) forest management guidelines that give sound direction while still providing enough flexibility to address variability across landscapes. We use thematic landcover maps derived from satellite imagery, and lacunarity analysis (Fig. 5) to evaluate the hypothesis that there are no differences in the relevant scales and nested hierarchies of forest pattern between two regions, northwest and northeast Ontario. We define a relevant scale as the spatial level where non-random patterning of landscape structure occurs, and such spatial scales are therefore relevant to forest management. Similar nested hierarchies occurred in the northwest in both the forest and wildfire disturbance classes. In contrast, the scales of spatial patterning detected in the northeast occurred at fewer levels, and in the disturbance class, which was the result of forest harvest, at only one level. The results provide evidence that by emulating natural disturbance at multi-levels nested hierarchies of forest pattern can be maintained, but ignoring such complexities can also result in simplification of the forest landscape. Forest management guidelines that provide enough flexibility to address the variability in natural disturbance patterns across Ontario landscapes will be the most beneficial in sustaining forest ecosystems.

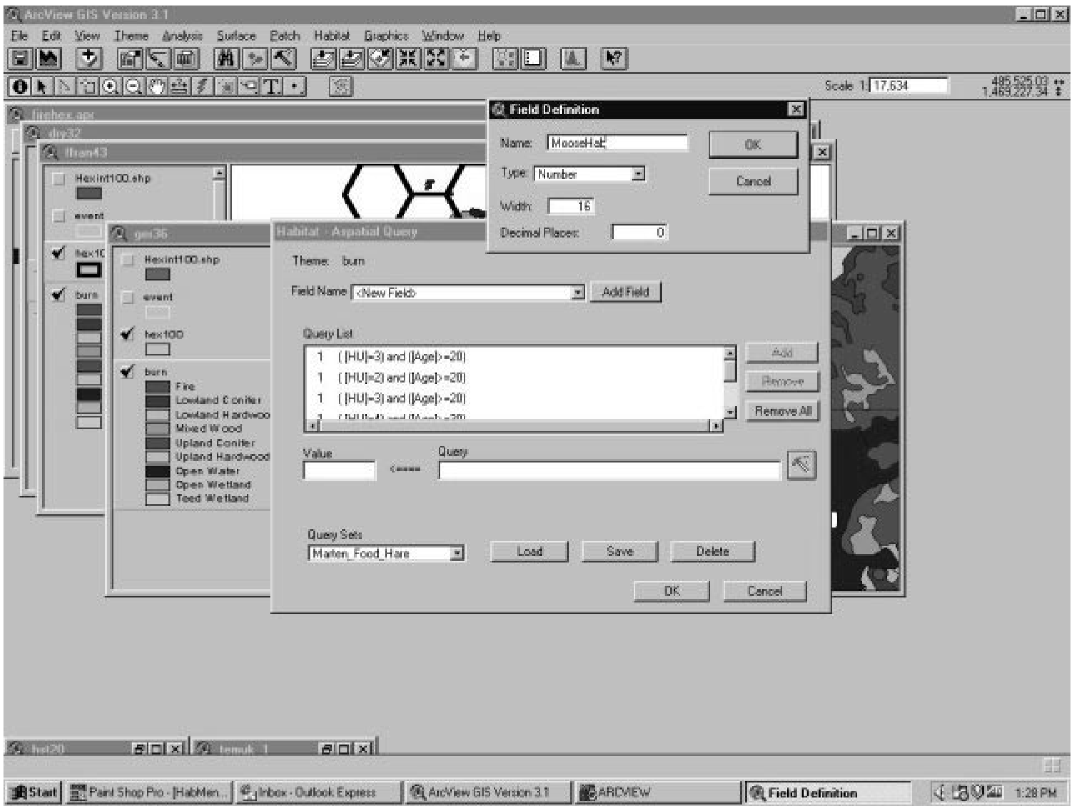

Fig. 4. Attribute modelling dialog box from Habitat Analyst. Dialog box allows users to create, edit, or import algorithms that assign habitat values based on stand attributes, such as age, species composition, and site class. This ArcView extension interacts closely with Patch Analyst.

Applying decision support tools to analyze economic versus ecological trade-offs of spatial objectives in SFM planning.

As we move towards emulating natural disturbance as an SFM practice, it becomes increasingly necessary to quantify the effects of various spatial patterns of harvest cutblock layout in terms of both ecological and economic objectives. Rather than comparing one spatial objective versus another, it may be more useful to evaluate a matrix of alternative objectives (Kaufmann and Rempel 1999). If these are then presented on 3-D response surface graph (Fig. 6), the planner can determine a more general effect of moving towards, say a smaller cutblock size and greater spacing of patches, on both habitat and wood supply.

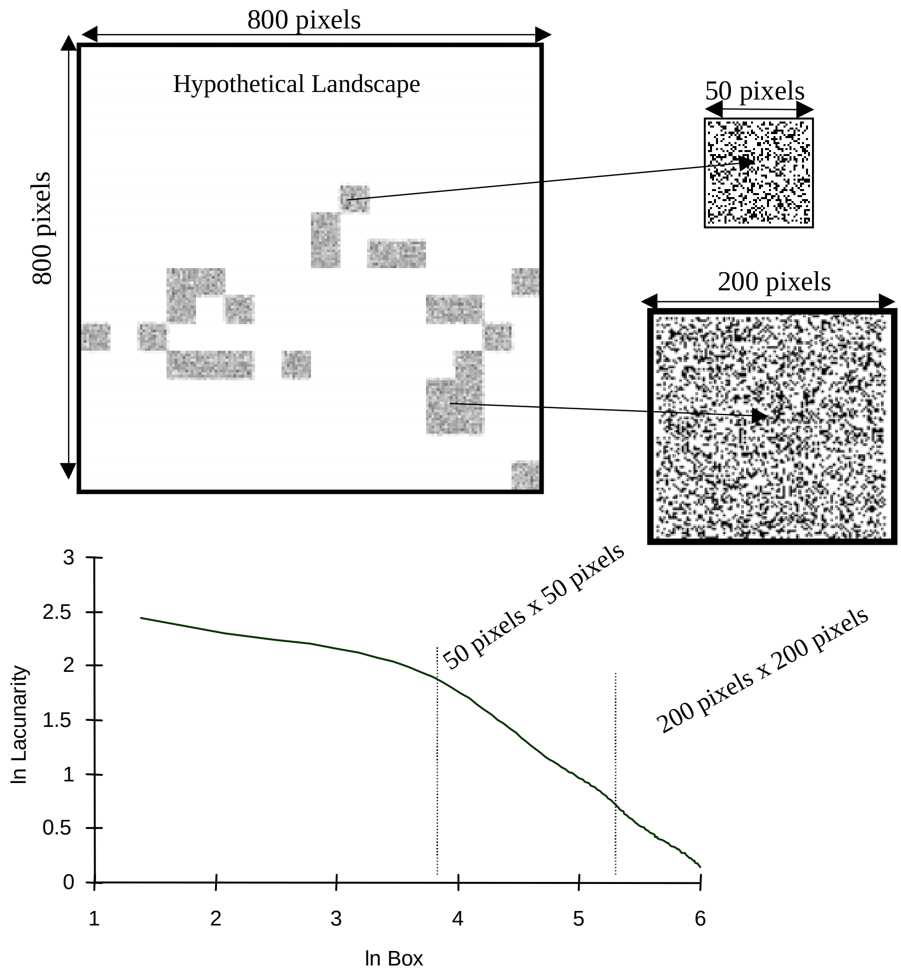

Fig. 5. A simple hierarchical 800 pixel^2 hypothetical landscape and its corresponding lacunarity response curve. The black pixels represent the class of interest. The response curve indicates inflections that are interpreted as relevant scales where non-random pattern emerges. Here a strong inflection occurs at 50 pixels^2(ln 3.90). If pixel size was 25 m, then this indicates that 1.25 km is a important spatial scale at which to characterize and emulate natural disturbance patterns.

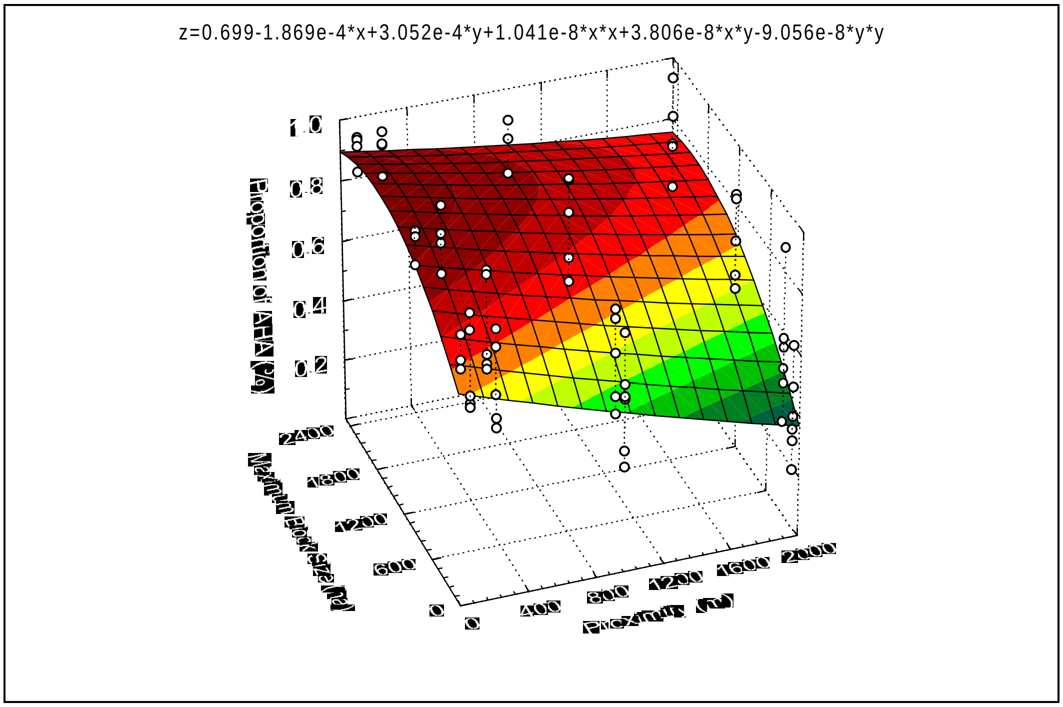

Fig. 6. Surface response graph showing economic response (z-axis), defined as % of annual allowable harvest achieved after applying spatial constraints on harvest. Spatial constraints are defined as cutblock proximity (x-axis) and maximum block size. Same tone of gray represents a similar response on the z-axis.

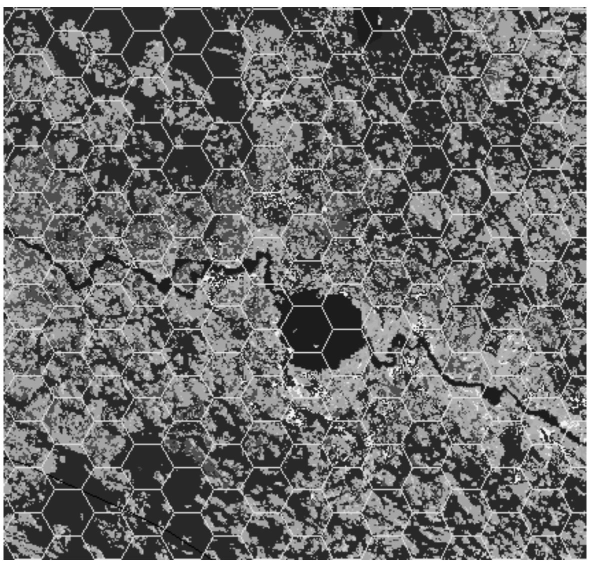

Fig. 7. Overlay of 100 ha hexagon grid on landcover map to characterize landcover dispersion. Proportion of caribou habitat is calculated within each hexagon cell, and then presented as a frequency histogram.

On two northwestern Ontario forest management units, we modeled the effects of alternative forest management scenarios and spatial constraints on both the supply of suitable wildlife habitat and the ability to achieve non-spatially defined timber harvest volume objectives (Kaufmann and Rempel 1999). The result is a decision surface model that identifies thresholds in the ecological and economic response variables, and that allows managers to determine the "spatial domain" where both ecological and economic objectives converge. Such a model may be a useful approach for initial policy screening in an adaptive management cycle. The Ontario Ministry of Natural Resources' (OMNR) Strategic Forest Management Model (SFMM), a linear programming optimization model, and Remsoft's Stanley, a spatial harvest allocation program, were used to explore alternate forest management scenarios. Timber supply and habitat supply for both interior and ecotone wildlife species were examined after five 10-year terms of harvest using various spatial constraints (cutblock size, proximity, and greenup delay). Habitat Analyst and Patch Analyst were used to evaluate habitat supply where both non-spatial (landcover composition) and spatial (patch pattern) analyses were conducted. A hexagon grid was used to assist analysis of habitat dispersion (Fig. 7), which was presented as a histogram of hexagon frequency (Fig. 8). Consistent with other studies, a green-up constraint had an adverse effect on the amount of available harvest area that could be allocated and blocked spatially ($p<0.0001$). Forest management scenarios using a caribou stratification process of restricting harvest in large (>10,000 ha) blocks also had an adverse effect on the amount of available harvest area that could be allocated and blocked spatially ($p<0.0005$).

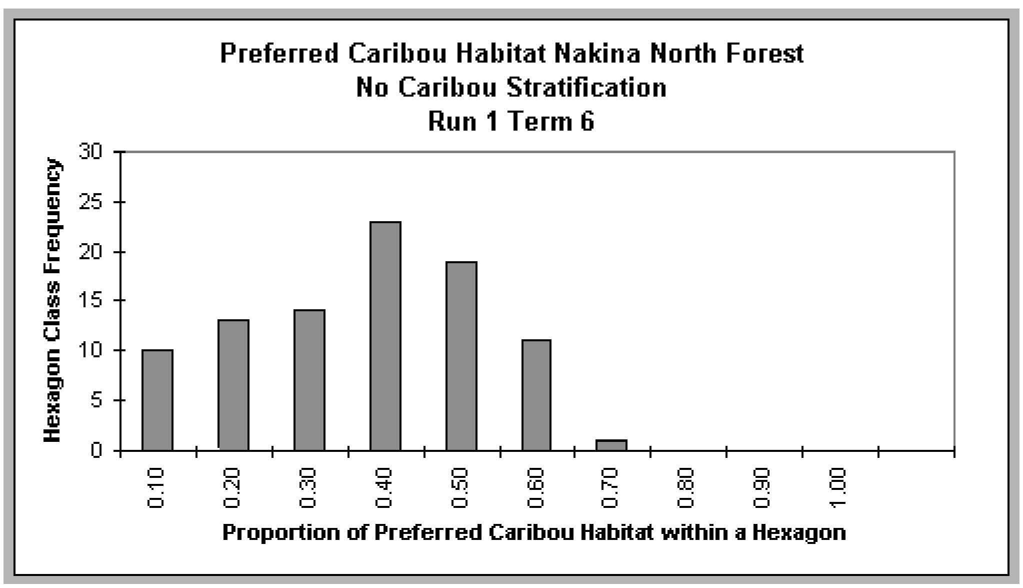

Fig. 8. Dispersion of preferred caribou habitat throughout the Nakina North Forest management unit. Proportions (x-axis) are amounts of preferred habitat within a hexagon cell, and frequencies (y-axis) are occurrences of preferred habitat cells throughout the management unit.

Applying decision support tools to support Criteria & Indicator analysis of National Parks ecological-integrity objectives.

Assessing and evaluating ecological integrity is a complex and often subjective task. However, recent legislative changes have forced ecosystem managers to develop more quantitative techniques to measure ecological integrity, particularly in Canada's national parks. Using a combination of measures for forest sustainability and existing regional data sets, a suite of indicators have been structured into a hierarchical framework for monitoring broad-scale, ecological forces (referred to as "drivers of change"), as well as ecosystem, habitat and species dynamics for the Pukaskwa National Park ecosystem. The project's focus is on gaining a measurable understanding of the spatial and temporal aspects of the ecological integrity of the park and its broader ecosystem (Promaine and Rempel 1999).

The indicators reveal that: (1) Pukaskwa National Park may be more unique than representative of the central boreal uplands, and (2) increasing human demand for natural resources, particularly timber, is playing a significant role in the ability of park management to maintain the park's ecological integrity. Road construction in the greater park ecosystem may play a significant role. These are important results that shape the park's management approach and priorities.

Continued use of this structural framework for ecological integrity will allow Pukaskwa National Park to be used as a benchmark for environmental change and contribute to the understanding required for mitigating such changes.

MANAGEMENT APPLICATIONS

Mapping landscape patterns of forest residual following historical natural wildfires in boreal Ontario

Results of this project provide a template, or signature, of natural disturbance patterns that can be used in specifying spatial targets, including landscape pattern and cutblock layout, in forest management plans. Analysis also provides indicator values for landscape structure when for planning under the Criteria & Indicators approach.

GIS-based tools to characterize and assign habitat values to landscape patterns

This project will produce simple to use GIS tools to characaterize existing landscape patterns, to assign habitat or other values to landcover composition and landscape pattern, and to assess compliance of a particular cutblock layout to predetermined spatial objectives. The tools will facilitate implementation of key concepts from natural disturbance ecology into operation timber management planning.

Hierarchical (multiscale) analysis of landscape patterns in boreal Ontario

This project will help managers determine the key (relevant) spatial scales at which management and planning decisions must be focused. The procedures identify the spatial scales where patterns are nested within patterns, and thus help managers determine the spatial scales at which they must plan and evaluate timber management and habitat objectives.

Applying decision support tools to analyze economic versus ecological trade-offs of spatial objectives in SFM planning.

This project identifies and tests an evaluation procedure to estimate the trade-offs of ecological versus economic objectives. It helps the manager determine habitat and wood supply responses in a planning domain that is defined in terms of 2 key spatial constraints: cutblock proximity and maximum cutblock size. The procedure will help foresters and biologists resolve planning conflicts by identifying spatial domains where common objectives are met.

Applying decision support tools to support Criteria & Indicator analysis of National Parks ecological-integrity objectives.

This project evaluates how the concepts and techniques of sustainable forest management can be applied in park management. At the regional planning scale, parks must be included in sustainable forest management. This project seeks identify and encourage commonalties in approach by applying Criteria & Indicator approaches to the assessment of national parks ecological-integrity objectives.

REFERENCES

Elkie, P.C., R. S. Rempel, and A. P. Carr. 1999. Patch Analyst User's Manual: A tool for quantifying landscape structure. Ont. Min. Nat. Resourc., Northwest Sci. and Technol. Thunder Bay, Ont. TM-002. 16 pp + append.

Elkie, P.C., and R.S. Rempel. 1999. Identifying hierarchical structure in Ontario landscapes as a component of emulating natural disturbance. The Sustainable Forest Management Network Conference. Science & Practice: Sustaining the Boreal Forest, Edmonton, Alberta.

Kaufmann, C. and R.S. Rempel. 1999. Analysis of spatial harvest constraints on ecological (wildlife habitat) versus economic (timber harvest) objectives. The Sustainable Forest Management Network Conference. Science & Practice: Sustaining the Boreal Forest, Edmonton, Alberta.

Promaine, A. and R. S. Rempel. 1999. Applying criteria and indicators to assess ecological integrity in a boreal national park and adjacent forest management units. The Sustainable Forest Management Network Conference. Science & Practice: Sustaining the Boreal Forest, Edmonton, Alberta.

Rempel, R. S. 1999a. Emulating natural disturbance: creating designer landscapes for biodiversity. Emulation of Natural Disturbance through Forest Management: A Prince Albert Model Forest Workshop. Prince Albert, Saskatchewan.

Rempel, R. S. 1999b. Patch Analyst and Habitat Analyst: Landscape Planning Tools for Sustainable Forest Management. Innovative Applications for Natural Resource Management "The Latest Tools": A Manitoba Model Forest Workshop. Winnipeg, Manitoba.

Rempel, R.S. 1999c. Design and analysis of landscape patterns for wildlife habitat. Innovative Applications for Natural Resource Management "The Latest Tools": A Manitoba Model Forest Workshop. Winnipeg, Manitoba.

Rempel, R.S., and A. Carr, C. Kaufmann, P Elkie, and J. McNicol. 1999a. Natural disturbance analysis and planning tools: development, integration, and application of models to support forest management planning. The Sustainable Forest Management Network Conference. Science & Practice: Sustaining the Boreal Forest, Edmonton, Alberta.

Rempel, R.S., J. McNicol, J. Baker, M. Gluck, and L. Forsyth. 1999b. A new spatially-explicit approach to specifying landscape design using the hexagon-class histogram. The Sustainable Forest Management Network Conference. Science & Practice: Sustaining the Boreal Forest, Edmonton, Alberta.