



PROJECT SUMMARY

Ecosystem
Management

Forest Productivity

Public Involvement

Adaptive
Management

The ecosystem management component of the Morice & Lakes IFPA has embarked on several projects that assess biodiversity, ecological attributes, and fish and wildlife habitat. These projects will provide important ecological data that will be used in learning scenario development for the IFPA's Sustainable Forest Management Plan.

Measuring Landscape Pattern

Introduction

The IFPA Ecosystem Technical Advisory Committee is charged with evaluating the potential impacts of alternative land use plans on coarse filter biodiversity. This paper analyses the usefulness of landscape pattern metrics for these evaluations.

Assessing the ecological merits of alternative land use plans requires the selection and comparison of indicators of ecological condition. Numerous metrics have been developed to quantify aspects of landscape pattern (McGarigal 2002), however, the ecological relevance of these metrics is poorly documented. Good metrics must be (1) ecologically relevant, (2) sensitive to management actions, (3) easy to interpret and (4) mathematically appropriate (Beasley and Wright 2001, Yamasaki et al. 2001).

1. Ecologically relevant metrics measure a landscape property that is known to influence ecological function (including the abundance and distribution of species). Total habitat abundance, patch size, patch spacing and edge area emerge as ecologically relevant landscape properties. Both population size (Fahrig 2002) and species richness (Preston 1962) decrease as habitat abundance decreases. Habitat abundance also exerts considerable control over landscape pattern (Daust 1994, Andren 1994). Patch size affects colonization and extinction rates (McArthur and Wilson 1967) and influences terri-

tory formation (Chapin et al. 1998). Patch spacing influences colonisation rates (McArthur and Wilson 1967) and interactions among subpopulations (Levins 1969, 1970, Hanski 1994). Edge effects include changes in microclimate and consequently in plant distributions; animals respond to the juxtaposition of habitats and to changes in predation rates near edges (Kremsater and Bunnell 1999).

The positive influence of increased habitat area on biodiversity is clear in general, but less clear when habitats share similarities, as is the case with different forest age classes. Similarly, the influence of landscape pattern on biodiversity is clear in general, but less obvious in forested ecosystems (Bunnell 1999). Despite difficulties in drawing clear inferences about the effects of landscape condition on biodiversity in forested ecosystems, the four landscape properties—habitat abundance, patch size, patch spacing and edge—provide the best basis for coarse filter pattern analysis.

2. For a metric to be sensitive to forest management, its value should change in response to the amount and type of harvesting, provided that the changes caused by harvesting are ecologically significant.
3. Metrics should be easy to interpret and convey. For example, they should focus on a single aspect of pattern rather than confounding different aspects of pattern and should be based on com-



Fraser Lake Sawmills



monly used statistics (e.g., means and standard deviations). Sometimes, however, a more complicated metric can provide useful information that is not provided by simpler metrics.

4. Metrics describing patch size should be weighted according to the proportion of area in each patch (e.g., area-weighted mean patch size) because ecological value correlates with area (Preston 1962) and because area-weighted metrics are not overly sensitive to the number of small patches on the landscape. Variation in land classification techniques and in the scale or resolution of the analysis can greatly alter the estimated number of small patches.

Our study assessed 35 single-number metrics and three graph-based metrics. We subjectively evaluated metrics against the features of a good metric described above and then assessed their ability to distinguish fire-induced from logging-induced patterns on simulated landscapes.

Subjective evaluation

Of 38 metrics, 19 single-number and three graph-based metrics had an ecological basis; that is, they measured habitat abundance, patch size or patch spacing (Table 1 and 2). Metrics describing edge habitat have already been explored by the IFPA and, thus, were beyond the scope of this study. Twelve of 19 single-number metrics and one of the three graph-based metrics ranked as easy to understand.

Mean patch size and patch size distributions based on the number of patches in each class are not area-weighted. Thus, they inappropriately give equal weight to small and large patches, and are sensitive to errors in estimates of the number of small patches.

One mathematical concern applied to all single-number metrics: a single number does a poor job of capturing the heterogeneity of patterns across a landscape.

Table 1. The ecological basis and ease of understanding of single-number metrics

Metrics (grouped by ecological basis)	Ecological basis	Understanding
Patch size (mean, standard deviation, coefficient of variation, max.) and largest patch index (largest patch / landscape area)	patch size	easy
Nearest neighbour distance (mean, standard deviation, coefficient of variation, maximum) and mean centroid distance (nearest neighbour distances are taken from patch edges; centroid distances are taken from patch centres)	patch spacing	easy
Number of patches (NP) and patch density (NP / landscape area)	habitat abundance, patch size	easy
Minimum spanning tree (total and mean per patch) and minimum planar graph (total and mean per patch); these metrics find the shortest path among all patches	patch spacing	mod. to difficult
Centroid Connectivity Index ($CCE = \sum(\text{patch size}_i * \text{patch size}_j) / \text{centroid to centroid distance}_i^2$; mean and max per patch); CCE measures interaction among patches.	patch size, patch spacing	mod. to difficult
Contagion (based on probability that adjacent cells are similar)	raster spacing	mod. to difficult

Table 2. The ecological basis and ease of understanding of graph-based metrics.

Metric Name	Ecological basis	Understanding
Patch size distribution (number or area of patches in different size classes)	patch size	easy
Mean cluster size versus correlation distance (a cluster is a group of patches, each located within a specified “correlation” distance of their nearest neighbour)	patch size & spacing	difficult
Expected cluster size versus correlation distance (“expected” is calculated as an area-weighted mean)	patch size & spacing	difficult

Simulation study

Methods

We evaluated 19 single-number and three graph-based metrics (identified above) against two criteria that assess sensitivity to management and ecological relevance: (1) ability to distinguish fire-induced from logging-induced patterns and (2) ability to match results (i.e., follow same trends) of a territory-dispersal model. The territory-dispersal model was used primarily to confirm that the patterns generated by the different disturbance processes were ecologically different. Thus, the first criteria—distinguishing disturbance processes—is the most important one.

We generated 72 maps of landscape pattern at nine different levels of habitat abundance (Table 3), simulated territory use and dispersal on selected maps, calculated a suite of landscape metrics for each map and evaluated metrics against the criteria discussed above. Because habitat abundance was included as a variable in the disturbance model, a specific habitat abundance metric was not required.

We simulated territory use and dispersal at three spatial scales: 10, 100 and 1000 ha territory sizes. Territories required a minimum of 70% habitat. Dispersal ability was set to 40 times territory width. We did not simulate reproduction or mortality because our focus was movement and connectivity.

Table 3. Combinations of variables used to generate landscape patterns.

Base Landscape	Disturbance Models	Habitat Abundance*	Replicates	Total
Square	Fire	9 levels	2	18
	Logging	9 levels	2	18
Morice	Fire	9 levels	2	18
	Logging	9 levels	2	18
				72

* 1, 5, 10, 15, 20, 30, 40, 60, 80%

Results

Landscapes with different disturbance regimes (amount and type of disturbance) differed in ecological value as measured by the territory-dispersal model. Territory abundance increased with habitat abundance at all spatial scales (Figure 1). Fire disturbed landscapes had more territories than logged landscapes (Figure 1). Fire-disturbed landscapes also had higher dispersal success below 60% habitat abundance.

Patch size distributions can distinguish fire from logging, but do not match the results of the territory-dispersal model well. Logged landscapes have relatively more area in two patch size classes than do fire-disturbed landscapes: 11-100 ha and 101-1000 ha (Figure 2).

Patches of habitat coalesce into 100 and 1000 ha clusters more readily (i.e., patches are closer together so clusters form at smaller correlation distances) on fire-disturbed landscapes than on logged landscapes (Figure 3). Patches coalesce into one large cluster covering the entire landscape more readily on logged landscapes.

Patch density emerges as the best single-number metric (Figure 4). It strongly distinguishes logging from fire and is the only metric that generally matches results of the territory-dispersal model (i.e., less difference at low and high habitat abundance; see Figure 1).

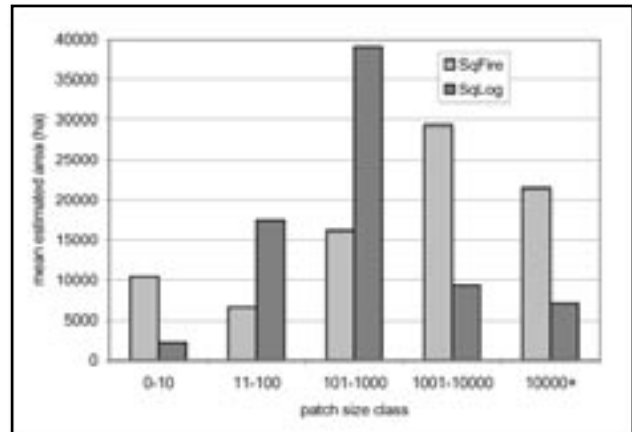


Figure 2. Mean estimated area by patch size class for fire and logging disturbances on the square landscape. Means cover all habitat abundance levels.

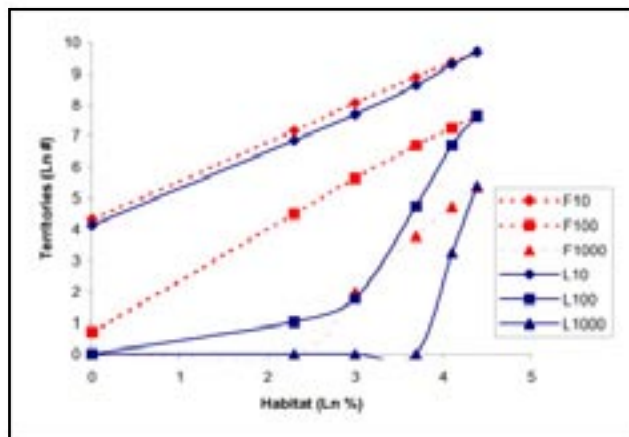


Figure 1. Natural log of number of territories formed versus natural log of habitat abundance on the square landscape. Legend text refers to fire (F) and logging (L) when territory sizes are 10, 100 and 1000 ha. Habitat abundance ranges from 1% to 80%.

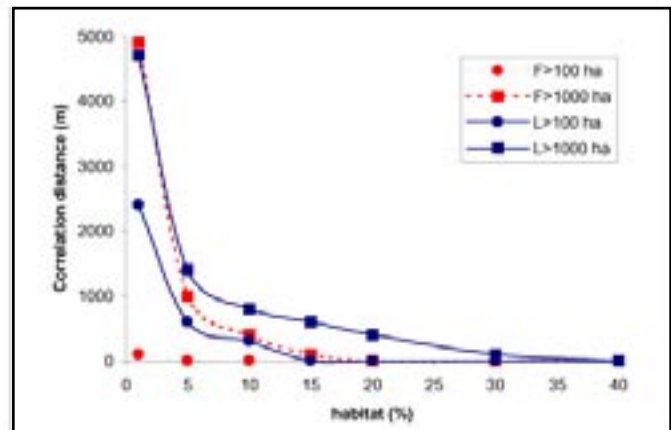


Figure 3. Correlation distance (distance between nearest neighbours) where expected cluster size exceeds 100 and 1,000 ha vs. habitat abundance for fire (F) and logging (L) disturbances on the square landscape.

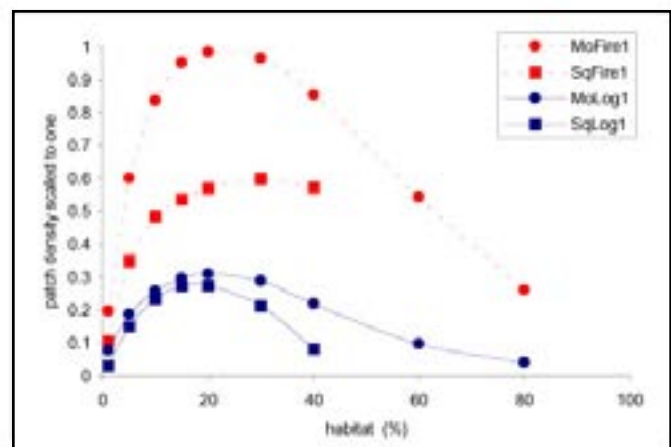


Figure 4. Patch density versus habitat abundance on the Morice and square landscapes with fire and logging disturbance.

Recommendations

Metrics should measure the three fundamental aspects of landscape pattern that influence connectivity: habitat abundance, patch size and patch spacing. They should respond to management and be easy to understand. Based on the results of our study, and for the purpose of assessing the impacts of alternative land use patterns on coarse filter biodiversity, we recommend three metrics, in order of importance:

- *Habitat abundance.* Habitat abundance should be the first metric examined because habitat abundance constrains pattern. Theoretical models show that patch size and spacing depend on abundance. The territory-dispersal model and most of the metrics examined in this study were strongly influenced by abundance. In addition, habitat abundance has the clearest ecological links, is obviously sensitive to management and is easy to understand.
- *Patch size distribution.* Patch size distribution should be the second metric examined. Patch size distributions distinguish between fire and logging disturbance, both simulated (this report) and real (Eng 2002). When considered with abundance and under certain conditions, patch size distributions also provide information about patch spacing, because spacing correlates with size and abundance (Daust et al. 2003). Unfortunately, the conditions where patch size distributions adequately describe patch spacing are somewhat unpredictable. Patch size distributions provide more information than can be conveyed by a single number, yet they are still relatively easy to understand and communicate. They also make no assumptions about underlying distributions. The area in each patch class provides more ecologically relevant information than the number of patches in each class.
- *Centroid connectivity index.* Finally, to examine patch spacing, CCE should be considered as a third metric. CCE is one of the few metrics that combines patch size and patch spacing in a relatively understandable way, however, as a single-number metric it confounds the effects of size and spacing. A third metric that just characterises spacing (e.g., nearest neighbour distance) is inappropriate because the ecological importance of spacing depends in part on the size of patches being connected. Unfortunately, we cannot strongly recommend CCE, because mean CCE and maximum CCE did not distinguish fire from logging in our simulations. Mean CCE also suffers from the problems associated with means (see evaluation criterion 4). We expect total CCE may be a better metric than mean or maximum CCE because it has better mathematical properties, but total CCE was not evaluated in this study and requires further testing.

Although it performed well in the simulation study, we do not recommend patch density (number of patches divided by landscape area) because it does not adequately describe patch size or spacing. For example, a given patch density may or may not include a few large ecologically-significant patches. In addition, patch size distributions make patch density redundant. Patch size distributions describe the number (or area) of patches in each size

class—they break down patch density into size classes. Future work should examine metrics that measure an area-based patch density metric across a range of spatial scales.

For the purposes of subsequent monitoring, where a more detailed analysis of pattern by ecological specialists may be warranted, we suggest that graphs of expected cluster size versus correlation distance be considered. While complicated to interpret, these graphs provide a comprehensive look at patch size, spacing and habitat abundance.

We have several additional recommendations based more generally on our past research and analysis related to landscape metrics:

- The definition of patch type should be considered carefully and possibly evaluated with sensitivity analysis. Changes in patch definitions (e.g., over 140 yr. versus over 250 yr; site series versus variant) can greatly influence estimates of habitat abundance.
- Metrics describing edge (or core) habitat should also be used to assess coarse filter biodiversity. Metrics describing total abundance of edge should be preferred over those describing the size of edge habitats. Assumptions about depth of edge and of types of adjacent habitats that cause edge effects are the biggest factors influencing estimates of edge effects and should be considered carefully.
- While metrics can evaluate ecologically relevant aspects of pattern, there is no context-independent way of assigning specific ecological value to a particular metric value. In several recent coarse filter ecological analyses, metrics calculated from naturally disturbed landscapes were used as benchmarks for comparison (e.g., Holt 2001). We recommend that deviations from the “natural values” of metrics be used to compare scenarios.
- In order to better capture heterogeneity in landscape patterns, we recommend that metrics be calculated by landscape unit (i.e., at a finer scale than the entire study area).

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