AN INDICATOR SPECIES APPROACH TO MONITORING FOREST FRAGMENTATION IN NEW BRUNSWICK, CANADA

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ABSTRACT

Concern about forest fragmentation has emerged in recent decades with the accumulation of scientific literature supporting the notion that biodiversity is negatively influenced by anthropogenic changes to landscape pattern. We measured the extent and rate of habitat loss and fragmentation in the Fundy Model Forest (FMF), eastern Canada as it applies to potentially fragmentation-sensitive local indicator species. Maps were developed using Geographic Information Systems (GIS) and satellite imagery change detection for three time periods: 1984, 1993, and 1999. We report on four general categories of fragmentation metrics in the FMF: habitat cover, patch size, edge effect and nearest neighbour.

Between 1993 and 1999 20,450 ha of forest land was classified by satellite image analysis as having >30% of canopy cover removed. This is 4.5% of the total Fundy Model Forest land area and 5.6% of the forested land within the FMF. Of the five habitat types examined, mixedwood and spruce-fir types are under the most serious harvesting pressure. Habitat removal is below replacement rate for all habitat types expect for pine.

Large mixedwood patches have declined the most substantially in number (11% over 7 years). Nearest neighbour distances reveal that the majority of habitat patches fall into the most proximal category (0-500 m). However, since 1993 the number of proximal patches has declined for all habitat types except spruce-fir and pine habitat. Edge density has increased for most habitat types over the 1993-1999 period.

Without actively planning for contiguous patches of habitat types, there will likely be a continued decline in mean patch sizes and the number of patches that meet spatial requirements of indicator species. Because habitat spans land ownership boundaries, it will be increasingly important to develop trans-boundary approaches to forest management planning – particularly on private woodlots where landscape change is occurring at the greatest rate.

Keywords: Fragmentation, landscape pattern, habitat loss, indicator species, change detection, landscape metrics

1.0 Introduction

Habitat loss and fragmentation have been identified as two of the major threats to the ecological integrity of Canada's parks (Parks Canada Agency 2000). The "Degree of forest fragmentation or connectedness of forest ecosystem components" is also one of the principal indicators of forest biodiversity in the Fundy Model Forest (Etheridge *et al.* 1999). Concern about forest fragmentation has emerged in recent decades with the accumulation of scientific literature supporting the hypothesis that landscape-scale biodiversity is negatively influenced by anthropogenic changes to landscape pattern (e.g. timber harvesting, urban sprawl, agricultural development)(for reviews see: Andren 1994; Paton 1994; Beier and Noss 1998; Bender *et al.* 1998; Mazerole and Villard 1999). For this reason it is critical that the extent and rate of changes to both forest pattern and composition be monitored. Quantifying landscape pattern and composition with the use of landscape metrics has several advantages: (1) Landscape development can be documented and trends can be established, (2) Hypotheses may be generated about the population health of potentially fragmentation-sensitive local species.

A growing amount of literature reports quantitative information on landscape change (Zheng *et al.* 1997; Kitzberger and Veblen 1999). However, landscape metrics have been reported in the past with little comment on what the ecological implications of certain metrics values may be. Many metrics are not necessarily relevant to species or ecological processes (Hulshoff 1995; Betts 2000).

In this project we measured the extent and rate of habitat loss and fragmentation in the Fundy Model Forest as it applies to potentially fragmentation-sensitive local indicator species (New Brunswick Department of Natural Resources and Energy [NBDNRE] 2000).

2.0 Methods

2.1 Study Area

The Fundy Model Forest is part of a Canadian Federal Government program to promote research and demonstrate sustainable forestry. The area of the Fundy Model Forest extends north of the Bay of Fundy in New Brunswick, Canada to encompass about 4,500 km^2. Landownership in the FMF is 63% small private woodlots, 17% large private holdings, 15% provincial Crown land, and 5% National Park. All of the Model Forest lies within the Acadian Forest Region (Rowe 1972). The FMF area is characterized by 89% forest cover, a maritime climate, and rolling topography (Woodley 1998). The forest cover is primarily intolerant hardwood (white birch, aspen, poplar) or tolerant hardwood (sugar maple, yellow birch, American beech) and mixedwood communities (red spruce, balsam fir, yellow birch, sugar maple, American beech). However pure softwood communities (red spruce, black spruce, balsam fir) exist in low-lying areas and along the Bay of Fundy coast. Intensive forestry activities are common in all areas of the FMF except for Fundy National Park.

2.2 Landscape Metrics

While many metrics have been used to quantify landscape fragmentation, it is important to focus on the ones most likely to be relevant to native biodiversity. A wide range of metrics may be used to explain the distribution and abundance of species

(Saveraid *et al.* 2001). Total proportion of suitable habitat, edge effects, and patch size are the most frequently cited as ecologically-important landscape features. However, configuration metrics (e.g. connectivity, isolation, and contagion) have also been reported as being significant features (Mazerole and Villard 1999). Certain effects seem to be more common within particular taxa. For example, most of the landscape-level bird studies reported patch size to be an effective predictor of incidence and reproductive output (Robbins *et al.* 1989; Edenius and Sjoberg 1997; Roberts and Norment 1999). On the other hand, amphibians seem to be most commonly affected by configuration (Gibbs 1998; Marsh *et al.* 1999; deMaynadier and Hunter 2000). Edge effect is the most common significant factor in plant studies that have found landscape fragmentation effects (Matlack 1994; Jules 1998, Burke and Nol 1998).

No single metric is capable of reflecting the diversity of landscape composition and pattern. At least four general categories of metrics are central to the analysis of fragmentation in the FMF: habitat cover, patch size, edge effect, and configuration. We report the following landscape fragmentation metrics:

(1) **Habitat area** is the amount of habitat within a landscape that meets the requirements of particular indicator species (Section 2.3).

(2) **Patch size metrics** relate the maximum, minimum, mean and the frequency distribution of contiguous habitat patches within a landscape. Patches were mapped according to pre-defined criteria for indicator species habitat (Section 2.3).

(3) **Edge density** is the amount of 'hard' edge per unit area. Hard (high contrast) edge was defined as edge with an easily identifiable boundary between 'habitat'

and 'non-habitat' (see Appendix A). We express edge density in terms of 'km edge per km^2 of total land area'.

(4) **Landscape configuration**. The proximity of habitat patches to one another is potentially an effective way of measuring connectedness of a landscape. We report the mean proximity of forest patches of the five habitat types for the Fundy Model Forest. Because such averages can be misleading, we also provide frequency distributions of nearest neighbour values for each habitat patch within the landscape.

All maps were developed with the use of a Geographic Information System (GIS). To generate landscape metrics we used Patch Analyst (Rempel 1999), an extension of ArcView Spatial Analyst (ESRI 2000). To determine nearest neighbour distances we applied the ArcView extension "nearest.ave". All distances are reported are the distance from edge to edge of habitat patches.

2.3 New Brunswick Habitat Objectives

Forest and wildlife management objectives for New Brunswick Crown land were developed with the use of an indicator species approach. This approach rests on the assumption that if the habitat requirements of a set of mature forest specialists are met, populations of other more generalist species should also be maintained. The New Brunswick Department of Natural Resources and Energy has identified six major habitat types for New Brunswick: 'Old Tolerant Hardwood Habitat' (OTHH), 'Old Hardwood Habitat' (OHWH), 'Old Mixedwood Habitat' (OMWH), 'Old Spruce-Fir Habitat' (OSFH), 'Old Pine Habitat' (OPIH), and 'Large Mixedwood Habitat' (LMWH). An additional category 'Any Old Forest' was established for species that are old forest specialists, but do not require a particular tree species composition[1]. For each habitat type, a suite of indicator species has been identified. The detailed structural requirements of these species form stand-level habitat criteria (Appendix A). A set of landscape-level habitat requirements was also developed (Table 1). (However, only softwood (OSFH) objectives must be implemented by Crown forest licensees in the 2002-2007 management plans.) All of this information on habitat requirements was gleaned from a review of the scientific literature for North America. Where information gaps existed, NBDNRE developed habitat estimates based on local anecdotal evidence.

Table 1. Spatial requirements and indicator species by NBDNRE habitat type

Because many of the structural features associated with each habitat type are not available in the New Brunswick Forest Development Survey GIS inventory (NBDNRE 1986)(e.g. number of cavity trees, number and size of snags, presence of shrub layer), it is not possible to assess habitat without detailed on-the-ground surveys. We made assumptions about which GIS cover types were most likely to contain these structural features (Appendix B). These assumptions were based on a 'forest community group' classification derived from an algorithm developed to assign stands from the forest inventory to a forest community category (NBDNRE 2000). The algorithm is applied based on the percent composition of the five most common tree species in forest stands.

2.4 Habitat Mapping

Using the criteria listed above (Table 1), we developed habitat maps for three GIS databases:

1. **1993 New Brunswick Forest Development Survey inventory:** This inventory is based on photo-interpreted data of 1993 origin.

2. **1999 updated forest inventory:** This inventory was updated with the combined use of two approaches. (i) All cuts on both Crown land and J.D. Irving freehold land are updated with the use of Global Positioning Systems (GPS) on an annual basis. (ii) Satellite imagery (Landsat TM) was used to update the 1993 inventory to include cuts and other clearings on small private woodlots over the 1993-1999 period. Only clearings with >30% of forest cover removal were used in this work. We accounted for forest growth and the consequent development of new habitat in 1999 by including as habitat all stands that were defined as "young" in the 1993 New Brunswick Forest Development Survey (FDS) (NBDNRE 1986). This is an overestimate of the amount of 'new' habitat because the "young" age class extends for 10 –20 years (Appendix B). The majority of "young" stands may have remained in this age category until 1999. However, in the absence of spatially explicit forest growth models, this method provides a coarse estimate of habitat replacement over this period. Because habitat change estimates based on this approach are quite conservative, we have reported both (a) habitat changes incorporating forest growth (reported as '1999[a]') and (b) habitat changes with no inclusion of "young" age classes (reported as '1999''). These data can be seen as 'confidence intervals' within which actual forest fragmentation levels actually lie.

Unless otherwise stated, results reported in the text incorporate potential forest growth. For 1993, 1999 and 1999[a] inventories we applied the method described in section 2.3 to determine and map habitat areas (Fig. 2).

3. **1984 'back-cast' forest inventory:** Differences in interpretation and in definition of forest cover types from a 1984 photo-interpreted inventory were too great to allow for comparison with 1993 data. We used dated cuts from the 1993 forest inventory to 'back-cast' to the 1984 forest condition. Cuts and regenerating stands identified in the 1993 inventory as being less than 9 years old were added to the 1993 inventory as 'mature' stands. The assumption was made that only older stands would have been selected in harvest schedules. Because we were not able to determine the habitat type that had been cut, only landscape-level metrics (rather than habitat class level) are provided for the 1984 forest landscape[2].

2.5 Satellite Imagery Change Detection

Landsat TM satellite imagery acquired in 1992, 1995, 1997, 1998, and 1999 were processed digitally to produce the change detection map layers for area compilation as follows (after Franklin *et al.* 2000; Franklin *et al.* 2001):

1. Atmospheric correction: Using the Richter (1990) model for standard atmospheres, each image was corrected to reflectance values. First, an estimate of scene visibility was developed based on pseudoinvariant features such as gravel pits and dark lakes. Second, this estimate was used to create a lookup table in which raw digital numbers in the image could be related to reflectance factors. Finally, the imagery were adjusted for adjacency

effects and solar illumination conditions. Clouds were removed manually by digitizing boundaries and shadows on the image display.

2. Geometric correction: Using standard polynomial transformations based on a minimum of 20 ground control points, each image was brought into registration with the GIS database independently.

3. Computation of Tasseled Cap Transformations: The brightness/greenness/wetness transformation of TM data (Crist 1985) was used to reduce data dimensionality and to capture forest variations in a single 'wetness' dimension which could be linearly transformed to the enhanced wetness difference index (EWDI) used in change detection over time. A threshold, based on known changes such as roads and clearcuts, was developed for each of the EWDI images available in the sequence. Subsequent compilation of changes was accomplished by creating a binary map (change/no-change) and comparing the changed areas to the available GIS database; changes in agricultural areas, for example, were excluded from the compilations.

3.0 Results

3.1 Habitat Area

Between 1993 and 1999 20,450 ha of forest land was classified by satellite image analysis as having >30% of canopy cover removed (Fig.1). This is 4.5% of the total Fundy Model Forest land area and 5.6% of the forested land within the FMF. In 1993, 7,423 ha (2.0%) of forest was classified as ‘young’ – a proportion of which will have moved into old forest habitat categories. Of the five habitat types examined, mixedwood and spruce-fir types are under the most serious harvesting pressure (Table 2). Both habitats have been reduced by nearly 1% per year. Further, majority (63%) of new mixedwood habitat contains shade intolerant species. Thus, even when accounting for forest growth, mixedwood habitat made up of tolerant species ('tolerant mixedwood') has declined by 9.6%. In all cases, as of 1999, the total amount of habitat in each category constitutes less than 20% of the FMF landscape.

Table 2. Change in habitat area 1993-1999. 1999[a] data incorporate potential forest growth.

3.2 Patch Size

Congruent with declines in total habitat area, the size of habitat patches has tended to decline in the 1993-1999 period. Mean patch size, has been reduced for all habitat types except pine (Table 3). Hardwood habitat mean patch sizes have decreased the most markedly. Incorporating the increase in habitat area over the 1993-1999 period due to aging of "young" stands made only a marginal difference in mean patch size for four of five habitat categories. This reflects the isolated nature of young stands in the Fundy Model Forest. The increase in the mean size of pine patches is partially the result of aging older jack pine plantations.

The number of 'large' habitat patches (according to NBDNRE patch size criteria) has also decreased for pine, hardwood, tolerant hardwood, and mixedwood indicating that the decline in mean patch size is not simply due to the splitting of small patches (Table 4). Old mixedwood habitat patches have been the most heavily influenced. Over the seven year period, 9 of 121 patches of mixedwood greater than 60 ha have been removed or reduced in size (a reduction of 11.6 % in total mixedwood patch area). Spruce-fir patches have decreased in size, but not in total number. All six mature OSFH patches are located in the far eastern end of the FMF and along the Bay of Fundy coast (Fig. 3).

Table 3. Change in mean patch size 1993-1999. 1999[a] data incorporate potential forest growth.

Table 4. 1993-1999 Change in number and area of habitat patches according to NBDNRE spatial criteria. 1999[a] data incorporate potential forest growth.

The patch size distribution for all habitat patches combined reveals that large patches of mature forest have declined in number (Fig.4), and in most cases area (Fig. 5) since 1984[3]. Small patches (<5 ha and 5-10 ha) declined from 1984 – 1993 indicating substantial attrition (complete removal) during this period. However, from 1993 to 1999, patches less than 5 ha increased in both number and area. This is largely due to the splitting of large patches by new roads and cuts. From 1984 – 1999 the rate of attrition is greater for large patches than for small patches (Fig. 6). While a small percentage of the total *number* of patches are large, they still constitute a substantial part of the Fundy Model Forest land base (44% of mature forest habitat area is in patches greater than 50 ha). Nevertheless, the amount of mature forest in large patches (>50 ha) has declined by 13% since 1984 (Fig. 7).

Fig. 4 Patch size distribution by patch frequency for 1984, 1993, 1999[a] landscape

Fig. 5 Patch size distribution by area for 1984, 1993, 1999[a] landscapes

Fig. 6 Change in area occupied by large (>50 ha) and small (<50 ha) habitat patches 1984 – 1999[a]

Fig. 7 Proportion of habitat area that exists in large (>50 ha) and small (<50 ha) patches 1984-1999[a]

3.3 Nearest Neighbour

Results of mean nearest neighbour (MNN) statistics indicate that the distance between habitat patches increased in the 1984 – 1993 period, but actually decreased between 1993 and 1999 (Fig. 8). This is the combined result of (a) the splitting of single large patches into two or more adjacent smaller patches that have low nearest neighbour distances, (b) the emergence of ‘new’ habitat in close proximity to existing habitat patches, and (c) the attrition of distant patches that may have previously boosted MNN values. However, when MNN was calculated for only patches greater than 15 ha[4], values increased over the 15 year period, and at a sharper rate from 1993-97. The decreasing MNN values for all patch sizes over the 1993-1999 period was thus highly dependent upon small fragmented patches in the landscape. The difference in these results indicates potentially misleading nature of ‘mean’ statistics in landscape analysis.

Fig. 8 Mean nearest neighbour for all habitat types 1984-1999

A more fruitful approach to nearest neighbour analysis is to report the full range of nearest neighbour values (the distance from each patch’s edge is calculated to its nearest neighbour’s edge). Further, rather than lumping all mature forest into a single ‘habitat’ category for nearest neighbour computation (which does not reflect ecological reality), we have reported these values in terms of NBDNRE habitat types. Only patches larger than the spatial requirements of indicator species for each habitat type were included in this analysis (Table 1) (i.e. OMWH: 60ha, OTHH: 40ha, OSFH: 375ha, OPIH: 15ha). Histograms of nearest neighbour distances reveal that the majority of patches fall into the most proximal category (0-500 m) (Fig. 9). This is well within the 1000 m nearest neighbour distance identified for all NBDNRE indicator species. However, since 1993, the number of patches in the 0-500m category has declined for all habitat types except Old Spruce-Fir Habitat and Old Pine Habitat. Even when accounting for forest growth, in mixedwood, hardwood, tolerant hardwood and pine habitats, large percentages of habitat are beyond NBDNRE's suggested minimum neighbour distances for indicator species (OMWH: 32.9%, OPIH: 47.9%, OTHH: 18.6%). Hardwood (OHWH) is the least fragmented of the habitat types with only 10.5% in nearest neighbour categories greater than 1000m.

Fig. 9 Nearest neighbour frequency histograms for four NBDNRE habitat types. No change occurred for OSFH patches. Analysis was performed only on patches sizes identified as sufficient to meet spatial requirements of indicator species for each habitat type (OMWH: 60ha, OTHH: 40ha, OSFH: 375ha, OPIH: 15ha, OHWH: 30ha).

3.4 Edge

As with other landscape metrics, edge density was substantially affected by landscape change over the 1993-1999 period. With forest growth taken into account, tolerant hardwood and hardwood exhibited the greatest increase in edge (31% and 20% respectively), while edge density in pine habitat actually decreased by 9.4% (Fig. 10). Increases in edge density in OMWH, OHWH and OTHH as a result of incorporating potential forest growth indicates that 'new' emerging habitat patches are rarely adjacent to old patches.

Fig. 10 Edge density 1993-1999 by habitat type.

3.5 Landscape Change by Land Tenure

To determine whether the rate of landscape change (canopy cover removal) varied by land ownership, we overlaid the land tenure GIS layer with the satellite imagery-derived change detection layer. While no substantial differences existed among the FMF's three major landowner groups (Crown, industrial freehold, private woodlots), private woodlots appear to be the most heavily cut over the 1993-1999 period (Fig. 11).

Fig. 11 Percent mature forest area removed on major FMF land tenures 1993-1999. Total change is the sum of both bars, change incorporating forest growth is shown by the dark gray bar.

4.0 Discussion

Results of this study should be placed in the context of two information gaps. First, because an up-to-date forest inventory was not available for 1999, we had to accommodate the development of new habitat by 'growing' stands characterized as "young" into mature forest categories. The drawback to this approach is that we have probably over-estimated the amount of emerging mature habitat in the Fundy Model Forest. To avoid this problem, it would be necessary to have a complete up-to-date forest inventory rather than only an update of forest harvest and developed areas from satellite imagery change detection analysis. We recommend that when the inventory for the FMF is available (in 2003), this analysis be conducted again using the same methods. Key to future fragmentation monitoring will be consistency both in terms of forest characterization and categorization in the forest inventory. Unfortunately, differences in cover type definition in 1984 and 1993 GIS databases made comparison infeasible.

Second, due to the extensive land base of our study area, we were not able to collect on-the-ground data about the structural features of habitat types. Such structures had to be inferred from the age class data available in the GIS forest inventory data. As we adopted a broad definition for what encompasses 'habitat' it is likely that we have overestimated the amount of mature forest habitat available in the Fundy Model Forest.

4.1 Landscape Analysis

In terms of habitat loss, we found that softwood and mixedwood are under the most serious threat from harvesting in the Fundy Model Forest. It is interesting to note that tolerant hardwood forest has the lowest rate of change. This low rate might reflect the comparatively poor markets for hardwood forest products. However, this result could also indicate a shift in management practices toward smaller-scale patch cuts and other partial cuts in this habitat type. Nevertheless, declines in mixedwood (4.9 %) and tolerant hardwood (2.4 %) over the 1993-99 period should be of some concern due to the poor capacity of tree species associated with these forest types for regenerating from stand-replacing disturbances such as clearcutting (Archambault *et al.* 1998). With forest growth taken into account, Old Pine Habitat appears to increase over the 1993-1999 period. However, this result should be interpreted with caution due to the fact that a portion of 'new' pine habitat is made up of old jack pine plantations. It is questionable whether pine plantations have the same structural attributes as unplanted old pine forest.

No habitat types were found to cover more than 20% of the total FMF landscape. In a modeling exercise, Fahrig (1998) predicted that fragmentation effects should not affect population survival until breeding habitat for an organism covers less than 20% of the landscape. Many species probably use several of the habitat types identified by NBDNRE and thus may be unaffected by fragmentation because the total available habitat is still greater than 20%. However, species that specialize on a single habitat type are the most likely to be sensitive to the effects of fragmentation over and above the effect of habitat loss alone.

While results of FMF fragmentation metrics are variable, it is clear that the process of fragmentation is continuing. For some metrics the rate of fragmentation is increasing. This analysis indicates that the relationship between habitat removal and fragmentation is not linear. The rate of decline for habitat loss is generally exceeded by the rate of fragmentation.

Declines in the number and area of large mixedwood patches is one of the most significant finds of this study. Tolerant mixedwood and hardwood forest were the most predominant forest types in pre-settlement southern New Brunswick (Zelazny *et al.* 1997). In presettlement times mature mixedwood would have existed in the largest patches and was likely to have been characterized by the greatest connectivity. Species adapted to mixedwood at the stand scale could also be adapted to the landscape configuration of this forest type (Walters 1996). Indeed, mixedwood species such as northern flying squirrel (Vernes unpublished data), American marten (Payer and Harrison 1999), and Blackburnian Warbler (Betts unpublished data) appear to be sensitive to landscape fragmentation in northeastern New England and the Maritimes. Conversely, pine stands probably existed in a naturally patchy distribution across the landscape. It is less likely that species adapted to this forest type are as sensitive to habitat isolation. Such hypotheses need to be tested: (a) by determining the historical pattern of the FMF landscape with the use of stochastic modeling and ecological land classification (Fall 2000), (b) continuation of research on spatial species–habitat relations that provides information on species-specific sensitivities to fragmentation.

Distance between patches of mixedwood forest is also increasing at a greater rate than in other habitat types. As noted above, 32.9% of the forest in this habitat category is in nearest neighbour categories greater than the minimum 1 km stated by NBDNRE. Species with low vagility might have difficulty colonizing this proportion of habitat patches. However, it is important to note that this minimum distance does not include the smaller habitat patches that fall *between* the patches that meet patch size criteria. It is possible that taxa could be using such smaller patches as "stepping stones" for movement between larger patches (Forman 1998). Minimum distance between patches is a function of the matrix type. Patches that are separated by agricultural field or suburbs are more likely to be truly isolated for some species than patches separated by 10 year old clearcut (Verboom *et al.* 1991; Schmiegelow *et al.* 1997). It is unlikely that less vagile species such as salamander species and flying squirrel would be able to be able to cross 1 km of non-forested matrix (Waldick and Freedman 1999).

These uncertainties raise important questions about the ecological significance of the landscape composition and configuration changes found in this study. Detailed configuration sensitivities of indicator species are largely unknown. It is possible, for example, that White-breasted Nuthatch needs greater than 40 ha of hardwood forest. Conversely, this species could be engaging in "habitat supplementation" – maintaining a home range of a larger area of fragmented landscape to compensate for lack of contiguous habitat (Dunning *et al.* 1992). More information on the spatial requirements of landscape configuration-sensitive taxa needs to be collected if the ecological implications of landscape metrics are to be fully understood. Second, it is unknown *how many* patches of a certain size are necessary in a region to maintain a viable population. For example, it is unknown whether a decline in number of mixedwood patches from 121 to 104 will affect the population viability of flying squirrel or whether a threshold number of patches exists. Such information can only be gained with the use of a combination of detailed species life history information and population viability analysis (Menges 2000).

4.1 Management Implications

Changes to both habitat area and landscape pattern in the Fundy Model Forest over the 1984-1999 period have several management implications. On first inspection it might appear that rates of habitat removal are similar to regeneration rates. However, as mentioned above, it cannot be assumed that cutovers will regenerate to have the same tree species composition and structure that they did pre-harvest. This is particularly true for tolerant hardwood and mixedwood. Indeed the majority of 'new' mixedwood habitat is made up of shade intolerant tree species. Accounting for forest growth, tolerant mixedwood habitat has declined at a rate well below replacement (9.6% from 1993 – 1999). Forest cuts should be chosen for these stand types so that tree species composition is maintained (Woodley and Forbes 1997). Currently, several partial cut approaches are being implemented on Crown and Industrial freehold land to attempt to maintain the area occupied by these forest community groups (J.D. Irving Sussex District 2001). However, stands with low timber quality on Crown, industrial freehold and private woodlots are still prone to being clearcut – a practice that could result in the decline of habitat types comprising shade-tolerant tree species.

Marked declines in patch size and nearest neighbour values for most habitat types indicate that not enough attention has been given to the spatial distribution of cuts over the past 7 years. Indeed, Crown land policies such as ‘green up delays’[5] and maximum block size[6] actually preclude the maintenance of large patches and effectively prevent the regeneration of large patches in the future. A ‘patchwork’ landscape pattern is being created that is unlikely to have existed in the pre-settlement era. Of the minimum patch size guidelines recommended by NBDNRE only the 375 ha patch size for Old Spruce-Fir Habitat is required by policy. Not surprisingly, this is the only habitat type that did not exhibit a decline in number of habitat patches over the 1993-1997 period. Without actively planning for contiguous patches of other habitat types, there will likely be a continued decline in mean patch size and the number of patches that meet spatial requirements of indicator species. An initial prediction about changes to habitat pattern on Crown and Freehold land could be generated by conducting a spatial analysis of harvest block layout in 20 year management plans. However, it is difficult to predict precisely how spatial patterns of harvest will change on private woodlots.

Because habitat patches span land ownership boundaries, it will be increasingly important to develop trans-boundary approaches to habitat planning – particularly on private woodlots where landscape change is occurring at the greatest rate. Because of its representation of multiple landowners, and an over-riding mandate for sustainability, the Fundy Model Forest is well placed to initiate such an approach.

Appendix A. Method used for determining NBDNRE habitat maps.

Habitat Type	Structural Features	Forest Community Group (FCG)	Maturity classes
Old Hardwood Habitat	- Crown closure 20-80% - Snags > 10cm - Shrub layer - Mid-story layer	Hardwood	Overmature Mature Immature
Old Spruce-Fir Habitat	- Crown closure > 40% - Cavity trees > 40 cm - Snags > 30cm - Live trees >30 cm - Shrub layer - Woody debris	Balsam fir Black spruce Other softwood Pure spruce Spruce-fir Spruce	Overmature Mature Immature
Old Mixedwood Habitat	- Cavity trees > 30 cm - Crown closure > 40%	Balsam fir Black spruce Other softwood Pure spruce Spruce-fir Spruce Hardwood Tolerant Hardwood	Overmature Mature Immature
Old Pine Habitat	- Crown closure >40%	Jack pine Pine	Overmature Mature Immature
Old Tolerant Hardwood Habitat	- Cavity trees > 45cm - Crown closure > 40% - Snags > 10cm	Tolerant hardwood pure	Overmature Mature Immature

Appendix B. Ages at which New Brunswick tree species meet age-class criteria (New Brunswick Department of Natural Resources 1986).

Species	**Regenerating**	**Young**	**Immature**	**Mature**	**Overmature**
Balsam Fir	15-25	25-35	35-50	50-70	70+
Red Spruce	15-30	30-45	45-70	70-110	110+
Black Spruce	15-30	30-45	45-70	70-110	110+
White Spruce	10-20	20-40	40-60	60-110	110+
Jack Pine	10-20	20-40	40-70	70-110	110+
White Pine	15-30	30-50	50-90	90-160	160+
Eastern Cedar	15-30	30-45	45-70	70-110	110+
Eastern Hemlock	15-30	30-50	50-90	90-140	140+
Larch	15-30	30-45	45-70	70-110	110+
Tolerant Hardwoods	15-30	30-50	50-80	80-160	160+
Intolerant Hardwoods	10-20	20-35	35-50	50-70	70+

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Endnotes

[1] Because both LMWH and ‘Any Old Forest’ are nested within other habitat types we focused analysis on five habitat types: OHWH, OTHH, OMWH, OPIH and OSFH.
[2] We attempted to use the Ecological Land Classification to determine the habitat type of harvested between 1984 and 1993 at the ecosite level. Ecosites provide an estimate of ‘potential’ stand types based on enduring features (Zelazney *et al.* 1997). However, this estimate proved to be too coarse for this purpose.
[3] Note that patch size distributions are not provided for specific habitat type because this degree of resolution does not exist for 1984 data.
[4] We chose 15 ha for this analysis as it is the smallest minimum patch size that meets the spatial requirements NBDNRE habitat (See OPIH Table 1).
[5] Green up delays require that the timing of clearcuts adjacent to existing harvest blocks should not exceed 10 years (2 management periods) (NBDNRE 2000).
[6] The maximum harvest block size on New Brunswick Crown land is 100 ha.