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Spatial and temporal patterns of natural and human-caused forest disturbance on the J.D. Irving Ltd. Black Brook District: past, present and future

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Patterns of natural and human-caused forest disturbance in northwestern New Brunswick and assessment of risk of extirpation of vertebrate species

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INTRODUCTION

The strong move towards ecosystem management that developed through the 1980s and into the 1990s was accompanied by an equally strong focus on conservation of biodiversity. The 'natural disturbance paradigm' can be summed up as: if disturbances shape the composition and dynamics of vegetative communities (Pickett and White 1985); and the character of vegetative communities defines biodiversity (Huston 1994); then forest management strategies that are guided by an understanding of natural disturbance processes will maintain forests with attributes that conserve biodiversity (Attiwill 1994; Patch 1998). In essence, this could be described as 'designing with nature'. The basic premise behind the natural disturbance paradigm relates to structural and interstitial diversity (Huston 1994). Disturbances, including management actions, control structural species such as trees, that provide habitat for the generally smaller interstitial organisms such as understory plants, epiphytes, insects, birds, fishes, and mammals. Therefore, if the changes in forest structure wrought by management are guided by natural disturbance (in terms of patterns and distributions of components), then biodiversity will be accommodated. While this is a reasonable assumption, it must be framed in testable hypotheses about the functional relationship between structural and interstitial diversity, or between forest structure and species populations. This becomes even more critical given that management is dealing with non-equilibrium systems in which there is a high degree of variability in disturbances such as spruce budworm and fire.

In this study, the 190,000 ha J.D. Irving Ltd. Black Brook District in northwestern New Brunswick was used as a case study to examine effects of natural and human-caused distrurbance on forest landscapes, and to assess the relative 'management concern' (risk of extirpation) for all individual vertebrate species that occur on the landbase. The District represents some the most intensively managed forestlands in Canada, containing >60,000 ha of spruce and pine plantations, ca. 50,000 ha of shade-tolerant hardwoods managed by single-tree selection and patch cuts, and ca. 7,000 ha of scientific reserves established in cooperation with WWF Canada. Previous certification by the Forest Stewardship Council (since voluntarily returned) and current certification by ISO14001 and Sustainable Forestry Initiative (SFI) reflect the high standards of forest management achieved. Scenario planning (MacLean et al. 1999) was used to quantitatively analyze forest landscapes under managed and natural disturbance conditions.

The value of this research lies in empowering the manager with a measurable basis for designing or building the future forest to support specified non-timber values (Pelletier et al. 2002). That management process is literally the designing, and creation, of the future forest in the context of its dynamically evolving temporal/ spatial pattern of stand types and stages of stand development. That design will provide the forest manager with a structure for choosing appropriate management from time to time, and from stand to stand, to create the target forest.

Key Questions: What would have been the dominant features of stands and landscapes in the study area if they had evolved under natural disturbance regimes over the last 50 years? How can harvest regimes and silviculture treatments be modified to result in forest structure that will promote maintaining biodiversity? Are there silvicultural or management thresholds that should not be exceeded, in maintaining a naturally functioning forest? What modeling and scenario planning tools and processes can facilitate implementation of the natural disturbance paradigm?

Objectives: To analyze natural and human-caused disturbance effects on forest structure and function in the Black Brook District as a case study, by:

1) assessing the risk of extirpation (degree of management concern) on individual vertebrate species that potentially occur on the landbase;
2) characterizing historical natural disturbance regimes (spruce budworm outbreaks);
3) establishing the state/structure of vegetation patterns on the Black Brook District before JDI began actively managing the forest about 1945;
4) modeling the current and future forest states with and without natural disturbance and harvesting/silviculture; and
5) analyzing management and disturbance effects on species composition, patch size, and age class distributions and within-stand structures.

1. ASSESSING RISK OF EXTIRPATION OF VERTEBRATE SPECIES

Sustainable forest management requires us to maintain healthy populations of native forest vertebrates. Ranking species by relative risk of extirpation (i.e., local extinction) allows managers to establish priority with regards to management and conservation actions. We describe a new procedure used to rank vertebrate forest wildlife species for their relative risk of extirpation on an industrial forest landscape in northwestern New Brunswick, Canada. Based on published range maps and expert consultation, a list of 157 vertebrate species that potentially occur on the landbase was compiled (Higdon et al. 2003). Each species was assessed for risk of extirpation using a categorical ranking system known as the Species-Sorting Algorithm (SSA – Reed et al. 2001). The SSA places each species into one of four relative risk categories (Class I, Class II, Class III and Unknown), based on the scores of four variables, related to potential abundance, percent landscape suitable, species-specific habitat connectivity, and population growth potential. The variables use a mix of spatial and non-spatial data, with data derived from a spatial analysis of the landscape and a review of published life-history parameters.

Habitat Associations

Each of the 157 species (105 birds, 39 mammals, 8 amphibians and 4 reptiles) that potentially occur within the Black Brook District (based on range maps and consultation with wildlife and biodiversity experts) was assigned to one or more of 8 forest habitat types, with 5 development stages, and 4 non-forest types. Development stages were Regeneration, Young, Mid-Age, Old and Large (Old with an abundance of stems ≥ 45 cm). Much of this was based on previous research by the New Brunswick Department of Natural Resources and Energy (NBDNRE). The estimates of vulnerability are habitat based, and thus the assignment criteria for habitats play a large role in the species risk classification.

We examined two different methods of defining the Old and Large development stages:
Method A: an age-based assessment, using age ranges provided by NBDNRE, which defined the Old stage for softwood dominated forests as beginning at age 60 to 90 years, depending on species composition; and
Method B: a volume-based assessment, where staff at NBDNRE assigned the Old development stage to each of JDI's timber volume yield curves based on the age at which a stand reaches 85% of its peak volume. Due to the high yields associated with forests in the District, in comparison to much of the province, the ages at which the Old stage began for some of the yield curves was significantly lower than the age-defined classes from NBDNRE. This assessment also included treated stands such as commercial thins, which may or may not constitute suitable habitat for

certain species. We did this assessment as a 'what if' scenario (including and excluding silviculturally treated stands as habitat), to help guide managers with respect to management options to protect species of concern. If commercially thinned stands or plantations are not currently providing habitat, it may be possible to manage them to do so in the future.

The Species Sorting Algorithm

The SSA (Reed et al. 2001) is a coarse-filter, spatially explicit categorical ranking system that assesses the risk of extirpation of individual terrestrial (forest-dependant) vertebrate species (Table 1). Species are placed into a risk category (Class I, II, III or Unknown, where Class I species have the highest level of management concern) based on their score for four variables, including potential abundance, the amount of suitable habitat, connectivity, and the population growth potential (based on reproductive output). Advantages of the SSA include: 1) it does not rely on a small subset of indicator or umbrella species, rather it is applied individually for each species; 2) any landscape, of any size, simulated or real, can be evaluated; 3) it facilitates the quantification of biodiversity tradeoffs under different management scenarios; and 4) it complements a natural disturbance emulation approach to ecosystem management, by allowing an evaluation of the ecological value of alternative landscape management scenarios.

Table 1. The Species Sorting Algorithm for rating risk of extirpation of species (Reed et al. 2001).

Variable category and scores		Potential Abundance (PA)	% Landscape Suitable (%LS)	Species-Specific Habitat Connectivity (SSHC)	Population Growth Potential (PGP)
Highest Risk	**1**	< 50	< 5	≤ 5	< 2.9
	2	50-150	5-20	6-50	3-5.9
	3	151-500	21-50	51-94	6-11.9
Lowest risk	**4**	> 500	> 50	≥ 95	11.9

Class I Species - if any row is true, the species is potentially at higher risk of extirpation in the landscape

	PA	%LS	SSHC	PGP
	1	--	--	--
Or	--	1	--	--
Or	--	2	1	1
Or	≤ 3	--	1	--
Or	≤ 3	≤ 2	--	1
Or	Provincial or Federal listing			

Class III Species - if any row is true, the species is likely at lower risk of extirpation in the landscape

	PA	%LS	SSHC	PGP
	4	≥ 2	--	--
Or	≥ 3	4	--	--
Or	≥ 3	≥ 3	≥ 3	≥ 3
Or	--	4	--	≥ 3
Or	--	≥ 3	4	--

Class II Species - All remaining combinations for which sufficient data exist.

Unknown-Risk Species - Species for which insufficient data exist for accurate categorization.

PA - Number of reproducing females that can be supported, estimated as the total area of suitable habitat in patches large enough for the target species divided by mean female territory size (based on published information on territory size, or territory size interpolated from density measures, and minimum patch size for occupancy if applicable).

%LS - proportion of total area in the landscape that was suitable habitat for each species.

SSHC - calculated as the percent of the distribution of nearest-neighbor distances for the habitat patches used by the species of interest that fall within the species dispersal distance.

PGP - average number of young produced by a breeding female per year, divided by age of first reproduction.

Each vertebrate species was assigned to one or more forest type/development stage combinations. In total, 68 unique combinations of habitat use (termed 'habitat assemblages') occurred for the 157 vertebrate species (Fig. 1). Total area per habitat assemblage was calculated using both the age-based (Method A) and volume-based (Method B) habitat definitions.

Using Method A, a total of 45 species (29%) were ranked as Class I, including six mammals, 38 birds, one reptile and no amphibians (Fig. 2, Table 2 - Higdon et al. 2003). The majority of species (91, 58%) were rated as Class III. Only seven species were classed as Unknown, based on missing data for at least two of the four SSA variables. For species missing only one variable, a risk category could still be determined using other available information. Using Method B, only 28 species were Class I (Fig. 2, Table 2).

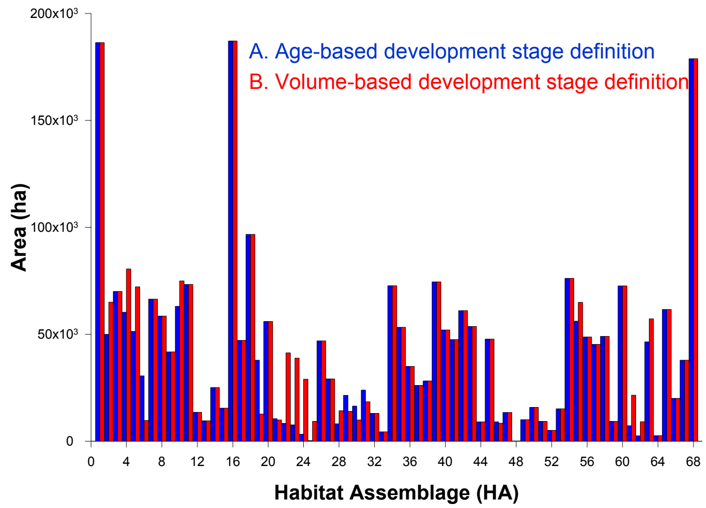

Fig. 1. Habitat availability on the Black Brook District in northern New Brunswick.

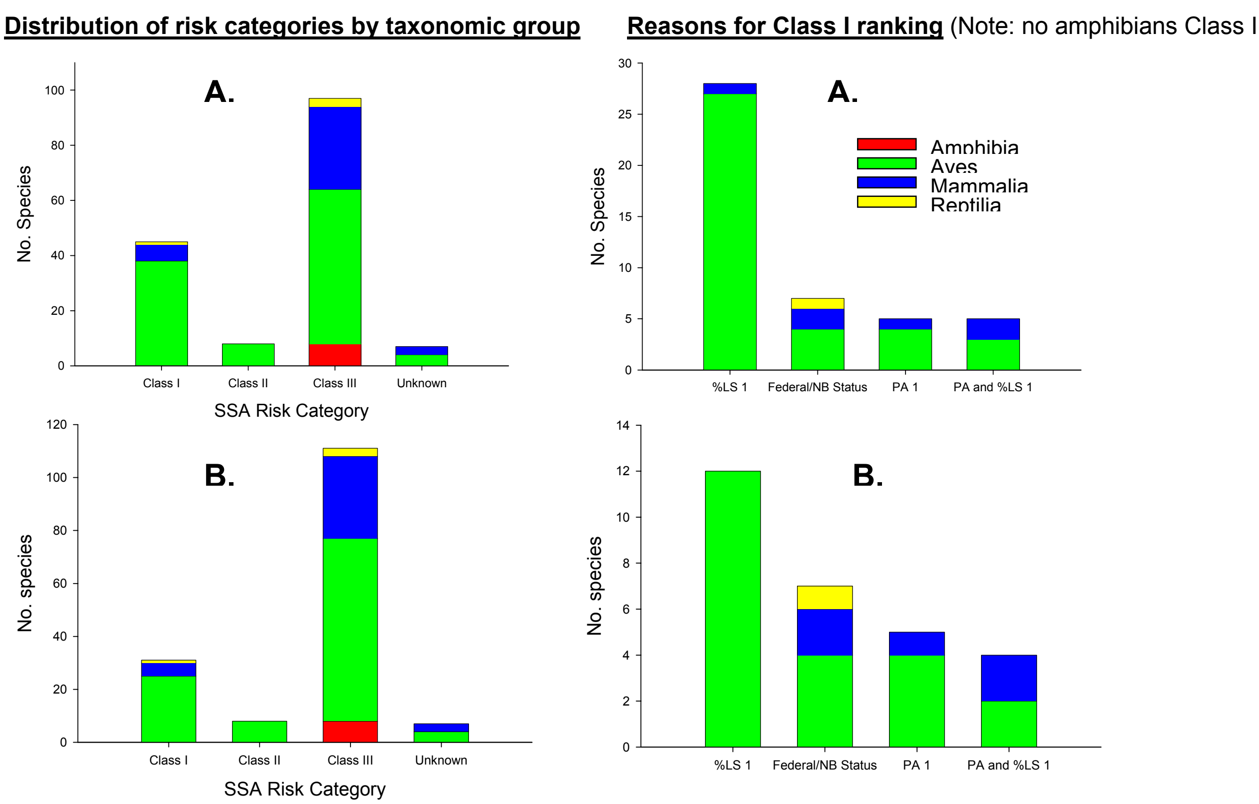

Fig. 2. Results using A. age-based development stage definitions (Method A), 45 Class I species; and B. volume-based development stage definitions (Method B), 28 Class I species.

Table 2. List of 45 Class I species using age-based habitats (Method A). Species in bold were Class I using both age- and volume-based habitats (Method B) (28 species).

Species	Class I Reason	Species	Class I Reason
Gaspé Shrew	FED and NB Status [1]	Boreal Chickadee	%LS 1
Northern Flying Squirrel	%LS 1	Red-Breasted Nuthatch	%LS 1
American Beaver	PA 1	Winter Wren	%LS 1
American Marten	PA 1 %LS 1	Golden-Crowned Kinglet	%LS 1
Fisher	PA 1 %LS 1	Ruby-Crowned Kinglet	%LS 1
Lynx	NB Status	**Veery**	%LS 1
Wood Turtle	FED Status	Swainson's Thrush	%LS 1
Great Blue Heron	%LS 1	**Bicknell's Thrush**	%LS 1 NB Status
Green Heron	%LS 1	**Wood Thrush**	FED, NB Status
Black-Crowned Night-Heron	%LS 1	Solitary Vireo	%LS 1
Wood Duck	%LS 1	**Philadelphia Vireo**	%LS 1
Common Merganser	%LS 1	Cape May Warbler	%LS 1
Hooded Merganser	PA 1 %LS 1	Blackburnian Warbler	%LS 1
Bald Eagle	NB Status	Bay-Breasted Warbler	%LS 1
Sharp-Shinned Hawk	PA 1	**Blackpoll Warbler**	%LS 1
Northern Goshawk	PA 1	**Mourning Warbler**	%LS 1
Merlin	PA 1	**Rose-Breasted Grosbeak**	%LS 1
Ruffed Grouse	%LS 1	**Vesper Sparrow**	NB Status
Boreal Owl	PA 1 %LS 1	**Brown-Headed Cowbird**	NB Status
Northern Hawk-Owl	PA 1	Pine Siskin	%LS 1
Three-Toed Woodpecker	%LS 1	White-Winged Crossbill	%LS 1
Black-Backed Woodpecker	PA 1 %LS 1	Evening Grosbeak	%LS 1
Olive-Sided Flycatcher	%LS 1		

[1] Any species listed as rare or threatened by federal (FED) or NB agencies is automatically Class I.

Classifying species for risk of extirpation is a complex issue, because different species are at risk (of management concern) for a variety of reasons. The SSA provides a simple framework for systematic evaluation of forest management effects. Many high-risk species were not necessarily in that class as a direct consequence of forest management actions. However, for species at risk that are forest-dependant, managers have a responsibility to ensure that their actions do not contribute to population declines. Sustainable forest management requires that managers protect biodiversity, and while vertebrate species are by no means the only facet of biodiversity, the provision of abundant, well-connected habitats for these species is clearly important.

The SSA framework is best viewed as a triage approach, to simplify and focus attention on those species that managers should be most concerned with (Higdon et al. 2003). It is not meant to generalize or replace fine-filter management strategies such as the indicator or umbrella species concepts. We view our methodology as one step in a decision making process, one that assists land managers in improving their management actions to help protect vertebrate forest wildlife. J.D. Irving, Ltd. has begun using our results to prepare a list of species of concern in the Black Brook District and to improve their management strategies for older mixedwood and softwood habitats. Ultimately, suitable habitat, dispersal and habitat connectedness, and large-scale processes are key to local persistence for the majority of at-risk species.

2. NATURAL DISTURBANCE: INPUT INTO HARVEST AND SILVICULTURE

Spruce budworm (*Choristoneura fumiferana* (Clem.)) outbreaks are a major, recurrent disturbance in eastern North America. As such, they are believed to have an important formative influence on evolved adaptations of native species. However, spruce budworm competes with humanity for a necessary timber resource, and is typically suppressed by the application of insecticides. Consequently, there is an incentive to find ways to reproduce the forest characteristics created by spruce budworm outbreaks through altered harvest methods, while continuing traditional budworm control practices. MacLean (2003) suggested three harvest classes, which would remove roughly one-third, two-thirds, and 85% of the stand, in stand types that would sustain patch replacing, partial stand replacing, and stand replacing mortality levels, respectively. These differing spruce budworm-caused tree mortality levels occur in stands with differing species compositions and age classes (MacLean 1980). Establishing the proportion of the three harvest strategies to assign across the forest requires a landscape-level assessment of the effects of uncontrolled spruce budworm outbreaks.

The general objective of this study was to predict the development of stand structure attributes and abundance of stand classes across a forest landscape under the influence of spruce budworm outbreaks (Porter et al. 2003). Specific objectives were: 1) to determine the natural spruce budworm defoliation regime for a 190,000 ha area of northern New Brunswick, 2) to model the development of the forest under budworm outbreak scenarios without human intervention, and 3) to characterize the resulting forest landscape and compare it with a managed landscape.

Methods

The current GIS-based forest inventory for the Black Brook District provided a spatially explicit database representing the forest condition in 2001. A historical benchmark was derived from aerial photographs of New Brunswick taken by the Royal Canadian Air Force in 1944-45. All photographs covering Black Brook District were acquired, photo-interpreted, and digitized to provide a reference forest condition with the spatial boundary, disturbance (if any), species composition, and maturity class for each stand in 1945. The interpretation and digitizing procedures were the same as used in the modern process. Hardwood species were grouped as shade tolerant or intolerant and identification of spruce was not always possible beyond the genus level. Qualitative comparisons of the 1945 inventory with current inventory for the same pieces of land suggested that the stand typing for 1945 was reasonable.

Annual aerial survey maps of spruce budworm defoliation from 1945 to the present were digitized and analyzed to characterize past disturbances and to provide a spatial chronology of outbreaks for input to a stand growth model. The STAMAN stand table projection model includes relationships of spruce budworm defoliation to growth and mortality, allowing stand forecasts to be made for user-defined defoliation sequences (Erdle and MacLean 1999). This was used to simulate effects of observed defoliation patterns (Fig. 3) on stand and forest development. To permit the display of detail normally lost at smaller map scales, the results were compiled for a 5 x 6 km subset area of the District, in addition to the whole forest results.

Spruce Budworm Outbreak Patterns

Two discrete budworm outbreaks occurred, from 1949-1958 and 1971-1987. Up to 97% of the 190,000 ha landbase was defoliated in 1955 and 1957 (Fig. 3). The estimated area of defoliation, adjusted to remove the effect of insecticide spraying, is shown in Fig. 3c. This represents the natural budworm outbreak regime, or the defoliation condition on the landbase in the absence of human influence. The difference between Fig. 3a (actual observed) and 3c shows the strong effect of insecticide spraying (Fig. 3b) on reducing defoliation in the District.

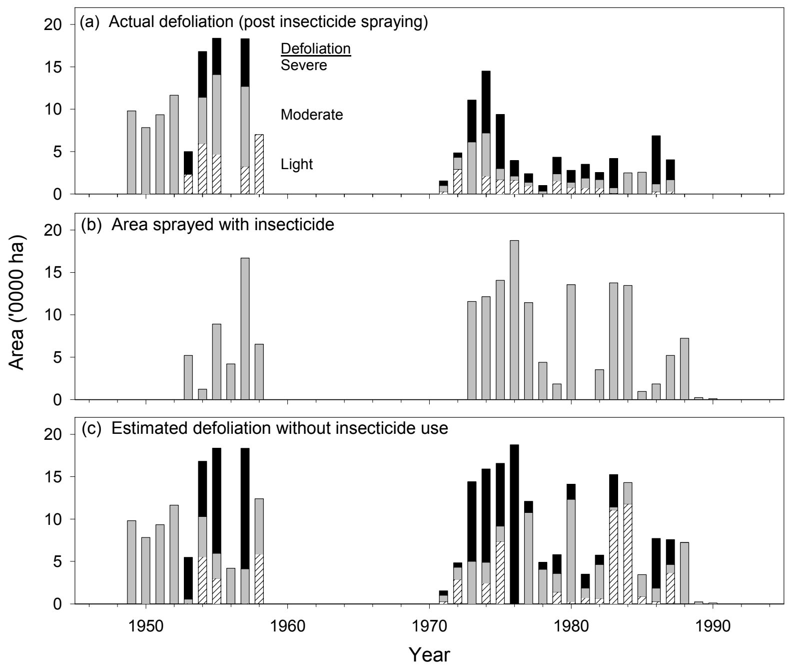

Fig. 3. (a) Historical area of light (10-30%), moderate (31-70%), and severe (>70%) spruce budworm defoliation in the Black Brook District from 1945-1995. (b) Area protected with insecticide for the same time period. (c) Estimated defoliation if there had been no protection applied (from Porter et al. 2003).

Effects of Spruce Budworm Outbreaks on Stand Structure

Simulated stand structure changes resulting from a severe budworm outbreak scenario for three representative stand types in the Black Brook District are shown in Fig. 4. The annual defoliation sequence was based on observed budworm population cycles in stands showing severe mortality (MacLean et al. 2001). These simulations show an average reduction of 92% among diameter classes of balsam fir in a mature balsam fir stand (Fig. 4a,b); a 92% reduction in fir and a 74% reduction in spruce in a mature spruce-fir stand (Fig. 4c,d); and an 80% reduction in fir in a mature fir-hardwood stand (Fig. 4e,f). The resulting post-outbreak stands had very different species/diameter compositions than they would have without budworm. The non-outbreak mature fir stand was composed of 69% balsam fir and 31% hardwood, but a severe budworm outbreak left 15% balsam fir and 85% hardwood.

An alternative stand structure visualization of the effects of a budworm outbreak in a mature balsam fir stand using the Stand Visualization System (SVS - McGaughey 1997) is shown in Fig. 5. Fig. 5a corresponds to the mature balsam fir stand in Fig. 4a, while Fig. 5b depicts the post-budworm outbreak condition (Fig. 4b). Mortality of balsam fir yielded a stand dominated by hardwoods after the outbreak, with substantial coarse woody debris (budworm-caused mortality) evident on the forest floor.

Effects on Landscape Composition

The forest landscape in 1945 was dominated by spruce-fir mixed, balsam fir, and spruce stands (Fig. 6a). In the 3400 ha area shown, there were 886 ha of mixed spruce-fir stands, 1065 ha of

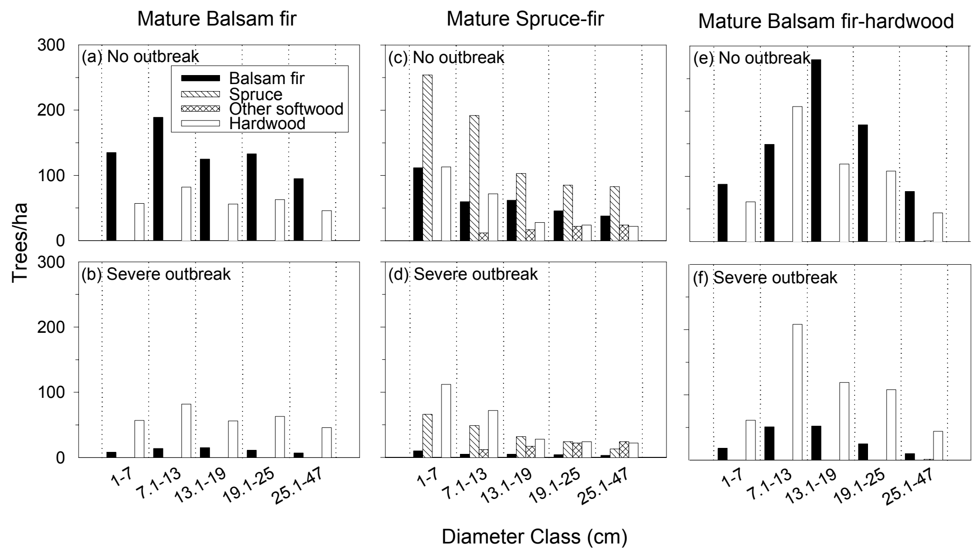

Fig. 4. Diameter distributions simulated using the STAMAN stand growth model, with and without spruce budworm outbreaks, for three stand types. Simulations were projected 15 years with no budworm outbreak (a, c, e), and with a severe budworm outbreak (b, d, f), consisting of 10 years of moderate-severe defoliation followed by 5 years of nil-light defoliation (MacLean et al. 2001) (from Porter et al. 2003).

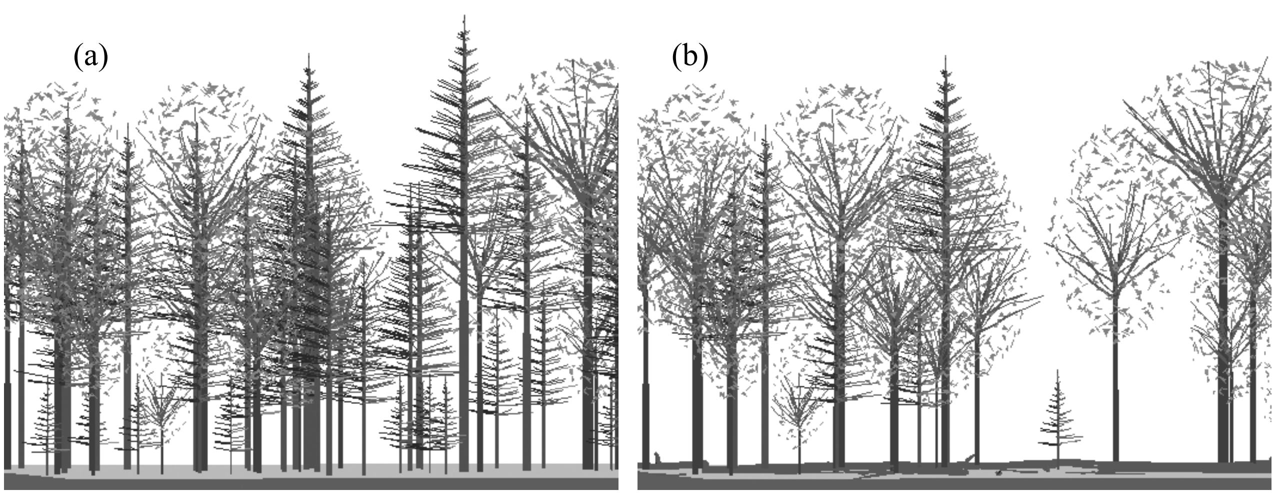

Fig. 5. Visualization of a mature balsam fir stand simulated, using the SVS (McGaughey 1997), (a) without a spruce budworm outbreak, and (b) 15 years after a severe budworm outbreak. The coniferous tree images are balsam fir and the deciduous trees are red maple (from Porter et al. 2003).

spruce-fir-dominated mixedwood stands, and 532 ha of hardwood-softwood mix or hardwood stands. The current actual forest (Fig. 6b) includes many spruce plantations, partially cut or thinned stands (largely commercially thinned plantations), and large areas of hardwoods. In the Fig. 6b area, there are 1040 ha of spruce plantations, 690 ha of commercially thinned spruce plantations, 375 ha of single-tree selection (hardwoods) and shelterwood, 310 ha of natural

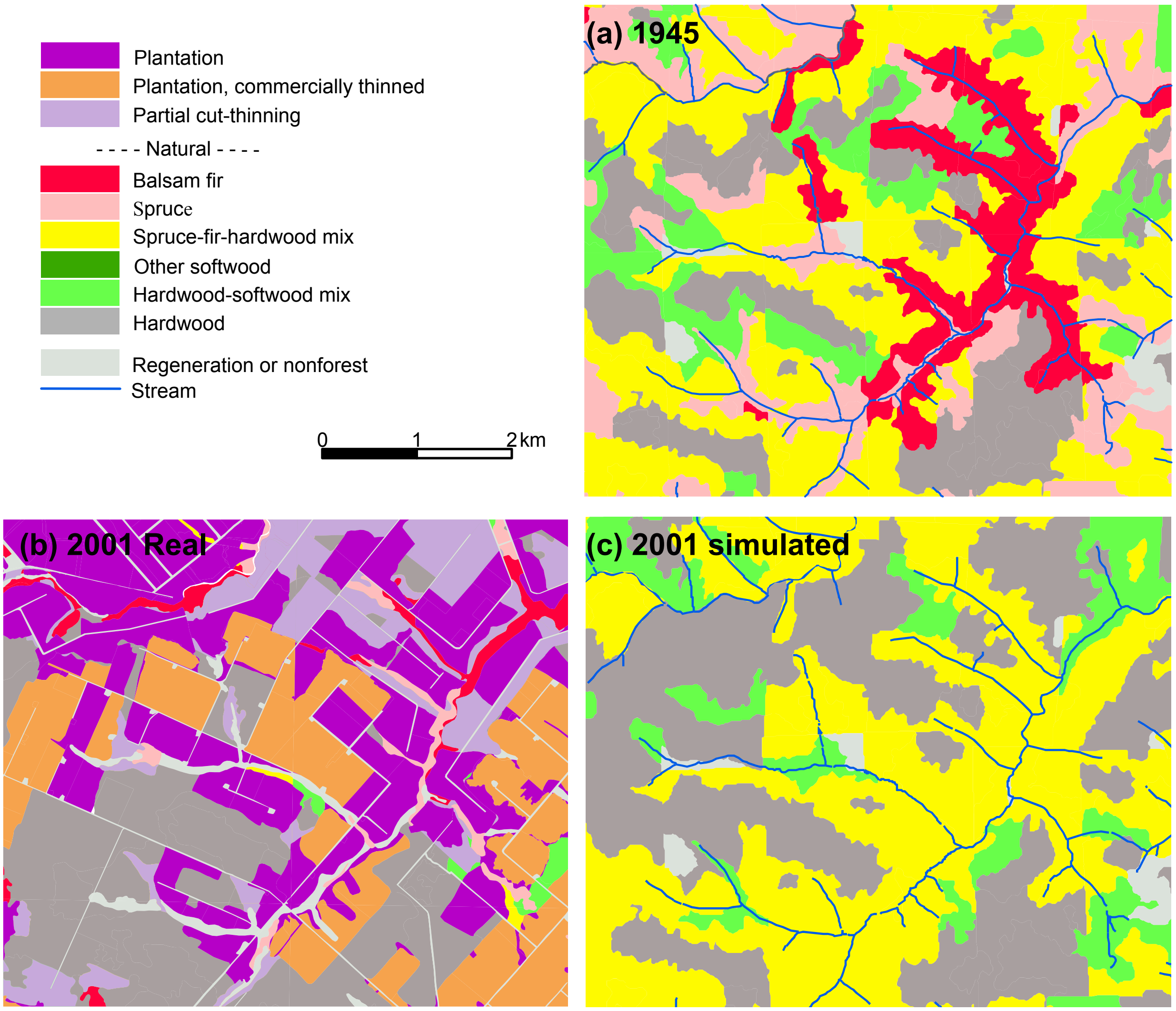

Fig. 6. Stand types for a 5x6 km area of the Black Brook District in (a) 1945, (b) 2001, and (c) simulated 2001 with no harvesting and with spruce budworm outbreaks as the only disturbances since 1945 (from Porter et al. 2003).

spruce-fir mixed and 760 ha of hardwoods.

The simulated 2001 forest, based on initialization of the 1945 forest and the budworm defoliation scenario from Fig. 3c, virtually eliminated balsam fir and spruce dominated stands (Fig. 6c), due to heavy budworm-caused spruce and fir mortality. Fig. 6c represents 2001, or about 12 years following the end of the 1970s-1980s budworm outbreak, simulating natural disturbance only (no insecticide spraying). At this time, the forest was dominated by spruce-fir mixedwood (47%) and hardwood (39%), with some hardwood-softwood mixed stands, which will probably succeed to higher proportions of spruce and fir.

Table 3 summarizes landscape-level timber volume impacts of simulated 1950s and 1970s-1980s spruce budworm outbreaks (with and without insecticide spraying) for the 5 x 6 km sample area (Fig. 6). Here the effect of landscape species composition and proportion of stand types on volume losses is evident. The longer 1970s-1980s outbreak, with more severe defoliation, resulted in over double the losses of spruce-fir volume, at 107,000 m^3 out of a total spruce-fir volume of 327,000 m^3 in comparison with the 1950s outbreak (Table 3). Even with the application of insecticide simulated during the budworm outbreak, the forest lost about 11% of the spruce-fir volume. However, without insecticide, the volume loss was much higher, amounting to 33% of the standing spruce-fir volume during the 1970s-1980s outbreak. This type of loss is likely to have a substantial ecological impact on stand structure, species composition, and succession, as well as economic timber supply effects.

Table 3. Simulated spruce-fir volume impacts of 1950s and 1970s-1980s spruce budworm defoliation (from Fig. 3c) on projected development of a 5 x 6 km area of the Black Brook District (Fig. 6) from 1945 to 2001 (from Porter et al. 2003).

Susceptible stand type[a]	Area (ha)	Undefoliated volume (m³/ha)	Undefoliated volume (m³)	Protected volume[b] (m³)	Volume reduction (m³) 1950s outbreak	Volume reduction (m³) 1970s-1980s outbreak	Volume reduction (%) 1950s outbreak	Volume reduction (%) 1970s-1980s outbreak
BF, > 80 yrs	44	160	7 040	6 116	1584	3 168	23	45
BFSP, > 80 yrs	644	133	85 652	75 348	13 524	30 268	16	35
SPBF, > 100 yrs	532	101	53 732	50 008	6 384	17 556	12	33
SP, > 100 yrs	13	132	1 716	1 547	221	221	13	13
BFHW, > 80 yrs	304	91	27 664	24 016	4 864	10 336	18	37
SPHW, > 100 yrs	1 181	109	128 729	112 195	20 077	37 792	16	29
HW, 40–80 yrs	141	20	2 820	2 538	564	987	20	35
HWSF, 40–80 yrs	422	37	15 614	14 348	1 688	5 064	11	32
HWSF, > 80 yrs	117	40	4 680	4 212	468	1 404	10	30
Total	3 422		327 647	290 328	49 374	106 796	15[c]	33

[a] Species abbreviations: BF – balsam fir, SP – spruce, HW – hardwood, SF – spruce-fir.

[b] Protected volumes were calculated as the undefoliated volume minus the volume reductions resulting from the 1970s-1980s outbreak if protection was applied to the entire landbase.

[c] Total percent losses were obtained by comparing the total landscape loss to the total landscape undefoliated volume, not by summing the percent volume reduction columns.

Fig. 6 presents a subset area of only 1.7% of the 190,000 ha Black Brook District. Over the entire District, in 1945, the forest comprised 9% balsam fir, 31% spruce, 28% spruce-fir-hardwood mix, and 32% hardwood-softwood and hardwood stands. The simulated 2001 'natural disturbance only' forest included fewer stand types, 47% spruce-fir-hardwood mix and 53% hardwood-softwood and hardwoods. Less than 800 ha remained of pure fir and pure spruce stands. Heavy mortality of mature balsam fir was the most notable characteristic of spruce budworm disturbance, but conversion of pure spruce to spruce-dominated mixedwood was also considerable. There was less change in the age (maturity) class distributions between 1945 and the simulated 2001 'natural disturbance only' forest, with both dominated by mature stands. Patch size comparisons showed somewhat more (34% versus 26%) large patches (> 500 ha) in the simulated 2001 natural disturbance forest than in the 1945 forest, but the distributions were generally similar. However, the actual 2001 forest had far more small patches, especially < 50 ha, and far fewer large > 500 ha patches. The median patch size in the actual 2001 forest was 3 ha, compared to 18 and 19 ha for the 1945 and 2001 simulated forests, respectively. Average patch size increased from 46 ha in the 1945 forest to 63 ha in the 2001 simulated forest. These were much larger than the 2001 real forest, which had an average patch size of 11 ha.

Simulation of the 1945 forest under two successive budworm outbreaks in the 1950s and 1970s-1980s resulted in substantial reduction of balsam fir and spruce stands on the simulated 2001 landbase. Mature fir stands were largely killed and regenerated, while spruce stands were converted to spruce-hardwood mixed stands. However, the reduction of overstory fir from spruce budworm disturbances likely only persists for the length of time it takes regenerating fir to reach the overstory. The fact that such periodic shortages of mature fir are expected in a natural landscape may suggest that providing the condition is relatively unimportant for the persistence of most species. If plantations are to provide some of the values of a budworm-influenced landscape, special attention must be paid to their patch size distribution, especially to the provision of larger (>500 ha) patches.

The opportunity to reconcile age distributions may be more elusive. Our results suggest that a clumped age distribution would result from a natural spruce budworm regime. However, industrial users of timber demand a relatively even flow of wood, which is best supported by an even distribution of stand ages. Resolving these conflicting goals depends on the scale at which a clumped age distribution is important; by zoning the forest, it may be possible to achieve the clumped distribution in one section, while achieving a relatively even distribution overall. The key here may well lie in ensuring that sufficient older or multi-cohort stands that result from natural disturbance in specific stand types still occur on the landscape.

The simulation and subsequent stand characterizations that we used converted mature fir-dominated stands to an immature condition via mortality and regeneration, reflecting observations made in previous studies (Baskerville 1975; MacLean 1988). However, mortality in spruce stands was incomplete, owing largely to the reduced impact of defoliation on spruce mortality, and the variable extent and severity of defoliation in subsequent years. This indicates that degrees of partial harvest are likely to be more appropriate than clearcutting in a large proportion of spruce-dominated stands, as proposed by MacLean (2003). Clearcutting in mature fir, while protecting advanced regeneration, would be consistent with our simulation results.

Our simulation results suggest that pure and mixed stands with a hardwood component are an important feature of a natural spruce budworm disturbance landscape, at least periodically. These stand types in many cases may be a transition stage, whereby budworm removes softwood overstory and converts a mixedwood stand to hardwood, but advanced softwood regeneration will eventually grow into the overstory. There are also cases of budworm converting spruce stands to spruce-hardwood mixed stands. Historically, pre-commercial thinning programs have favored the softwood component, converting mixedwood stands to a predominantly softwood condition. To better emulate the effects of a spruce budworm outbreak, a portion of future pre-commercial thinning efforts should include targeting a post-treatment mixedwood condition. An associated benefit may well be reduced defoliation of balsam fir in mixedwood stands (Su et al. 1996), and reduced timber losses. Needham et al. (1999) determined that when balsam fir stands undergo severe defoliation (85% of the current foliage removed) with no insecticide use, the balsam fir yield is maximized at a hardwood content of about 50%, while at moderate defoliation levels, the optimum hardwood content shifted to 20%.

This case study is really only a starting point in the evaluation of spruce budworm natural disturbance emulation. Spruce budworm makes an ideal case study because it is one of the few insects for which we have the information and models that permit simulation of natural disturbance at the stand and landscape level (Erdle and MacLean 1999; MacLean et al. 2001, 2002; MacLean 2003). However, important connections with other disturbances still need to be determined. Future work will include more in-depth analyses of forest patterns and testing of new harvesting methods inspired by natural disturbance (spruce budworm and gap replacement), including their application to the harvesting of 2600 ha of forest in the Black Brook District. We will use an extensive set of permanent sample plots to monitor a suite of specific indicators of forest structure and biodiversity before and after harvest (Pelletier et al. 2002; MacLean 2003). In addition to determining landscape-level patterns, part of the challenge is to develop harvest prescriptions that emulate the amount of mortality caused by budworm. Once developed, implementation of these prescriptions on the ground will require information on spatial, within-stand patterns of mortality, which has been shown to follow a clumped or contagious distribution (Baskerville and MacLean 1979; MacLean and Piene 1995).

This study provides a methodology that links stand-level structures together with forest-level defoliation patterns to forecast the types of stand structures that result from a spruce budworm disturbance regime, and the size, location and abundance of those structures across the landscape. If we are correct in our assumption about the dominating influence of trees on the quality of habitat for smaller organisms, then creating stand structures in similar sizes and abundances as those that develop from natural disturbances using harvesting and silviculture practice, should have a major influence on sustaining the populations of native species.

Our results suggest that both partial and clearcut harvesting of spruce and fir stands have a place in harvest methods designed to produce stand structures and forest composition consistent with spruce budworm disturbance. Mixedwood management is clearly also a valid goal, and managers should consider avoiding the conversion of mixedwood stands to a pure softwood condition. Designing harvest blocks to achieve larger contiguous areas of similar stand conditions also appears to be consistent with the natural spruce budworm disturbance regime. Data on the effects of natural disturbance will provide a good basis for selecting and justifying forest composition objectives and appropriate silviculture and harvest treatments.

There are clear roles for both even-aged and uneven-aged management in natural disturbance emulation. Clearcut treatments can be used to approximate stand-replacing disturbance, while patch-replacing disturbance can be approximated by a partial cut treatment. Thus, natural disturbance insight can provide useful input into harvest and silviculture design. A key factor is the amount of mortality within stands that will result from the disturbance. A good rule of thumb that has stood the test of time and multiple studies is average mortality levels from spruce budworm outbreaks of 85% in mature (> 50 years old) balsam fir stands, 42% mortality in immature (< 50 years old) fir stands, 36% mortality in mature spruce stands, and 13% mortality in immature spruce stands (MacLean 1980). Hardwood content within stands has been demonstrated to reduce spruce budworm defoliation of balsam fir (Su et al. 1996) and implicated in reducing fir mortality (MacLean 1980, Bergeron et al. 1995, Needham et al. 1999).

3. CHARACTERIZING FOREST CONDITIONS IN 1945

To establish the state/structure of vegetation patterns on the Black Brook District before JDI began actively managing the forest in the mid-1940s, a set of historical 1945 aerial photography that covers the entire landbase was used to develop a historical GIS-based forest inventory. This was not seen as a 'pristine', uninfluenced forest condition, but rather was a rare opportunity to create a spatial historical reference, prior to the vast majority of forest management influence. Vegetation community types were defined based on species combinations and percent species composition within stands, and these vegetative communities were then used to define patches. Using ArcToolbox™'s dissolve feature, adjacent similar vegetation community types were combined into larger patches. Microsoft Access™ and Excel™ were used to analyze vegetation community distribution, maturity class distribution and patch size distributions.

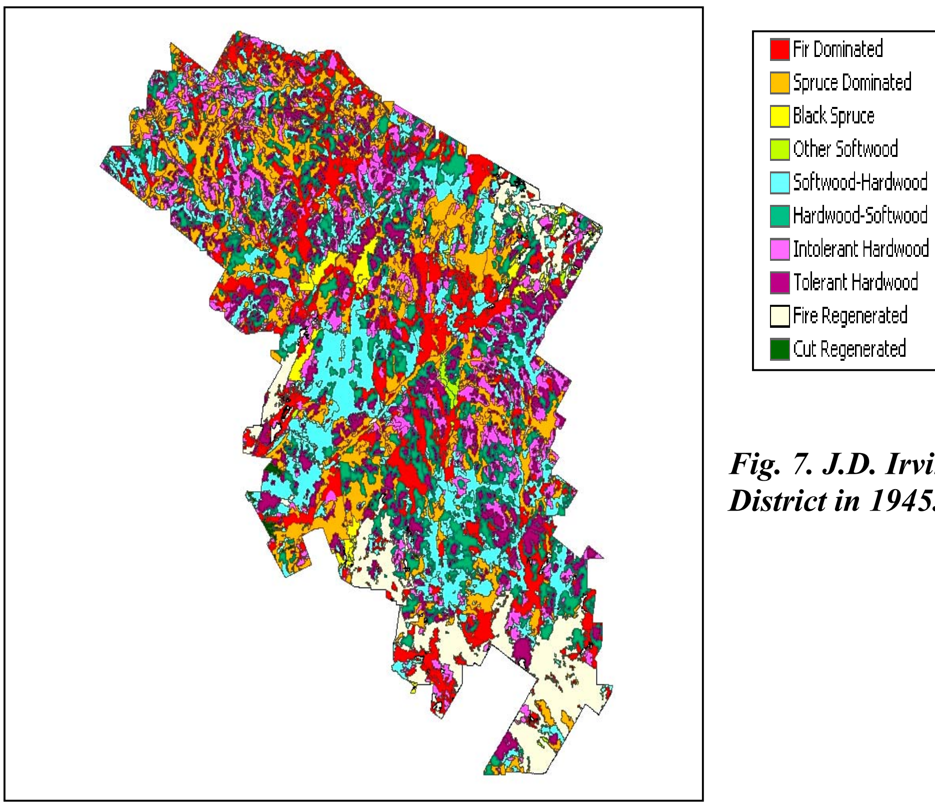

Fig. 7. J.D. Irving, Ltd. Black Brook District in 1945.

Softwood dominated vegetation communities (spruce, fir, and other softwood) dominated in 1945 and covered approximately 33% of the landbase (Figs. 7 and 8). Mixedwood communities (softwood-hardwood and hardwood-softwood) comprised almost 30% of the landbase. The spruce dominated community was the most abundant at 18%, and some form of fire disturbance (burned or partially burned) occurred on approximately 18,000 ha (10%). The larger contiguous vegetation community patches can be seen in Fig. 7.

An uneven maturity class distribution occurred in 1945 (Fig. 9). Little of the area was young in age or in a regenerating stage. This may be a function of historical partial harvesting and past gap-creating natural disturbances. Occurrence of regeneration and young saplings within multi-storied immature and mature stands may have made detection difficult through photo interpretation. The bulk of the area that was interpreted as being regenerating was the 18,000 ha of burned area. All tolerant hardwood communities were immature, in the 51-80 years old range.

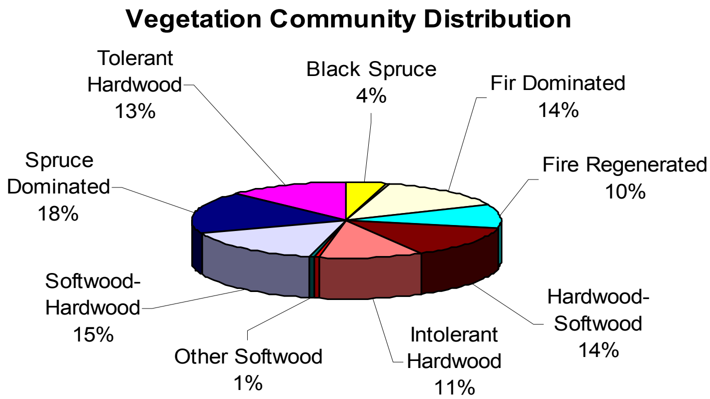

Fig. 8. Percent area cover by vegetation communities on the Black Brook District in 1945.

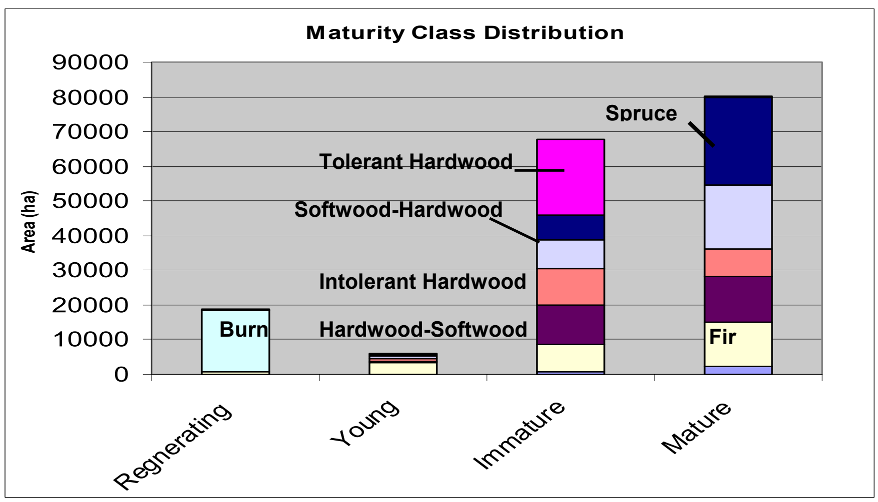

Fig. 9. Maturity class distribution for vegetation community types on the Black Brook District in 1945.

Patch size distribution followed an inverse J-shaped curve (Fig. 10), with 41% of the landbase (2,972 patches) in patches smaller than 100 ha. Five patches were greater than 1,000 ha and one mature softwood-hardwood patch was 4,500 ha. In 1945, the mean patch size was 46 ha, while the median patch was 18 ha. In comparison, under current J.D. Irving, Ltd. management practices, the average harvest opening created from 1995-99 was 18 ha and only four harvest blocks were larger than 100 ha. This provides useful data, at least for a single historical reference point, on the distribution of patch sizes for use in designing management strategies.

Having a quantified historical reference condition is valuable for characterizing landscape forest dynamics through time and assessing the impacts of forest management. The above results provide a basis for comparison with present and planned future landscape patterns, and determining how pattern has changed since 1945. Clearly one must take into consideration that the landbase had some harvesting prior to 1945 and was definitely a function of natural disturbance history (especially the major 1910-1920 spruce budworm outbreak). However, these data do provide a temporal snapshot of the spatial pattern in 1945, and a good starting point for assessing forest change.

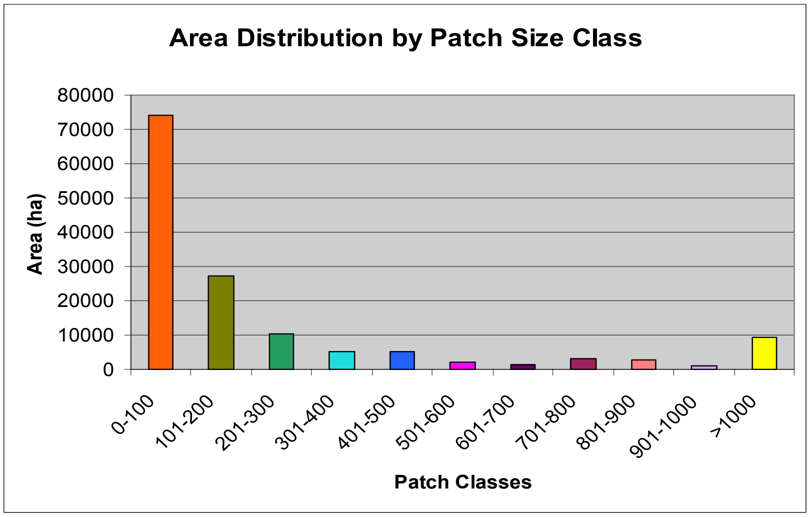

Fig. 10. Patch size distribution of vegetation communities for the Black Brook District in 1945.

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