Fundy Model Forest

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Report Title: **A DISTURBANCE HISTORY ANALYSIS OF THE FUNDY MODEL FOREST AREA**

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Year of project: 1995

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File Name:
biodiversity_1995_methven_a_disturbance_history_analysis_of_the_fundy_Model_forest_area

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A DISTURBANCE HISTORY ANALYSIS
OF THE FUNDY MODEL FOREST AREA

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Methven, I.R., and M. Kendrick 1995. A disturbance history analysis of the Fundy Model Forest area. Report submitted to the Fundy Model Forest, Sussex, NB.

INTRODUCTION

Traditional forest management has tended to concentrate on the flow of commodities with emphasis on fibre, with little regard for the structure and pattern of the forest landscape and its values. In other words, landscape structure and pattern have been radically altered with little regard for the consequences in terms of other values, since sustained yield of fibre was the driving concept. Sustained yield represented a purely quantitative approach to resource availability with little regard for quality. This era was followed by one featuring constraint management, designed to meet political imperatives, and to avoid endangering the flow of habitats for certain featured or umbrella wildlife species. Constraints were placed on forest practices in terms of maximum harvest block sizes, adjacency constraints and such values as riparian zones and deer wintering areas. These original constraints have now been expanded into explicit wildlife management objectives for fish habitat, deer populations, and those species occupying particular habitats such as "*mature conifer forest habitats*". In spite of this important advance in integrated resource management, forest management still fails to address the ecosystem as a whole, and the many species and processes that can not be explicitly incorporated into the management objectives. To achieve this requires a move into sustainable or landscape ecosystem management.

Sustainable forest management attempts to capture the many values of the forest through a macrofilter or landscape approach where management goals and objectives are expressed initially in terms of landscape structure and function. This is based on the assumption that conservation of biodiversity and sustainability in all their aspects can only be achieved by reflecting the environment in which the constituent organisms evolved. It should be emphasized that the word 'reflect' is used consciously to emphasize that there is no need to copy or mimic the natural or undisturbed landscape; only to reflect some of its essential features or characteristics. Human use and need are a reality and must be accommodated. The only question is how to do it.

Landscape structure and pattern are essentially a product of the underlying or inherent geomorphological pattern and the overlying or induced disturbance pattern. The former exerts its control on species distributions and development rates, while the latter controls age class patches and their distribution over space and time.

The purpose of this preliminary study, therefore, was to try and elucidate the natural disturbance pattern in the Fundy Model Forest Region.

REVIEW OF HISTORIC DISTURBANCE REGIMES

The Atlantic provinces, like many other regions of the world, have a long history of settlement dating back to the retreat of the last glaciers in terms of indigenous peoples, and to the sixteenth century in terms of European settlement. The first recorded commercial sawmill in America was established at Lequille in Nova Scotia in 1612. This was a water powered pit saw or whip saw which used a large web saw (Johnson 1986).

The east coast of New Brunswick was the largest shipbuilding complex in the world in the nineteenth century, producing in the neighbourhood of six thousand wooden ships. Agricultural settlement resulted in the clearing of large areas of forest, and the ignition of major fires such as the one million hectare Great Miramichi fire of 1825. These activities have made a major impact on the processes and vegetation of the Acadian Forest, and made it particularly difficult to analyze and elucidate the essential characteristics of the disturbance regimes and consequent landscape patterns within which indigenous species and populations evolved, and to which they have become adapted. This problem is further exacerbated by the knowledge that all systems are in a state of transition between glacial periods, and that biogeoclimatic processes are in a constant state of change.

The major natural disturbance agents in New Brunswick are epidemics of the spruce budworm (*Choristoneura fumiferana*), fire, and wind.

Spruce budworm

Since 1760 a total of six outbreaks of the spruce budworm have been recorded with return intervals of 42 and 75 years before 1900, and every 19 to 34 years after 1900 (Blais 1983). The increase in cycle rate in the twentieth century can probably be attributed to human activity in terms of fire and insect suppression that increased the availability of mature fir across the landscape. With respect to patch size, spruce budworm epizootics occur at regional to continental scales, and are only limited by the availability and distribution of the host species. Thus patches may occur over thousands of square kilometres.

From the point of view of time and space, therefore, budworm disturbance would indicate a rotation cycle linked to the longevity of balsam fir, and a spatial scale of thousands of square kilometres in which the landscape would be dominated by a single age class of fir that would advance over time until the next outbreak.

Wind

Wind has received little attention in New Brunswick, and the historical evidence is minimal. It is well known that strong winds in the area of 140 to 180 km/hr can cause 20% to 50% blowdown, while gusts in excess of 180 km/hr can cause greater than 60% removal of the canopy (Dunn et al 1983; Frelich and Lorimer 1991). Flannigan *et al* (1989) reported on a major wind storm in northwestern Ontario in 1988 that resulted in a 21, 000 hectare area of blowdown within a 170 km. corridor. A similar storm in the region in 1973 provided fuel for a 32,000 hectare fire in 1974. Hurricanes strike southern and central New England every 20 to 40 years, with storms that affect forests occurring every 100 to 150 years (Foster 1988). Such catastrophic winds have been considered more influential than fire in the northern hardwood-pine-hemlock forests of New Hampshire (Foster 1988), and Wisconsin (Canham and Loucks 1984); while Lorimer (1977) concluded that wind was the second most important natural disturbance after fire in northeastern Maine. The balsam fir forests of New England above 800 metres regenerate after wind-driven waves of mortality (Sprugel 1976; Sprugel and Bormann 1981).

In the pre-settlement forest of Wisconsin approximately 4828 hectares or 0.08% of the 5,840,000 study area was blown down annually for a cycle of 1250 years. In a mixed forest in Maine the cycle was estimated to be 1,150 years (Lorimer 1977). Mean patch size in Wisconsin was 93.2 hectares, while the maximum size was 4828 hectares (Canham and Loucks 1984). In the 1938 New England hurricane, blowdown patches were irregularly shaped and ranged in size from 0.003 to 325 hectares. Strong winds associated with hurricanes have been recorded in New Brunswick in 1635, 1815, and 1944, but damage may not be comparable to that in New England because of progressive loss of energy as hurricanes cross land (Boose et al 1994). However, on November 7-8, 1994 an area of 15,413 hectares in New Brunswick suffered greater than 50% blowdown in a storm in which gusts attained 165 km/hr.

Apart from the wind-driven wave phenomenon in balsam fir forests of New England, the wind cycle or rotation appears to be in excess of one thousand years. Spatial extent or patch size varies from that of single trees to thousands or even tens of thousands of hectares.

Fire

Fire has played a significant role in New Brunswick, particularly in the eastern half of the province, as evidenced by historically extensive stands of jack pine, upland black spruce, white pine and red pine, as well as aspen and birch. Assessing the role of fire in recent history is difficult with the suppression activities of the last 60 years. However, several hundred fires occur in the province each year, and while most of these are of human origin, some are of lightning origin. For example, from 1929 to 1975 the average annual percentage of fires starting from lightning was 7%, although a high of 21% was achieved in 1948 (Wein and Moore 1977). Fires of lightning origin have burned large areas of the province, and have accounted for 4 of the 12 fires that exceeded 4000 hectares.

Information on the role of aboriginal peoples in the fire regime of New Brunswick is sparse. However, considerable evidence exists that they played a significant role in the New England states (Day 1953; Denevan 1992). The prevalence of fire adapted species in New Brunswick, including the extensive stands of jack pine, upland black spruce, and red and white pine, suggests strongly that the aboriginal peoples may have played an equivalent role here as well.

An analysis by Wein and Moore (1977) of fire data in New Brunswick gave the following results (Table 1).

Table 1. Fire dimensions and cycles based on all fires > 20 hectares from 1931 to 1975 (adapted from Wein and Moore 1977)

ECOREGION	ANNUAL BURN (ha)	MEAN FIRE SIZE (ha)	# FIRES/ YEAR	FIRE CYCLE (yrs)
1	68	230	1	7676
2	731	149	3	1375
3	2569	115	2	644
4	253	295	1	779
5	5418	681	7	476
6	1219	385	5	2061

The weakness of such analyses becomes apparent when one considers that the vegetation includes extensive stands of fire adapted species such as jack pine, black spruce, white pine and red pine which could never survive under fire cycles that greatly exceed the longevity of the species. However, a more detailed analysis by ecodistrict rather than ecoregion using data from Beall and Lowe (1950) showed that the fire cycle in the equivalent of ecodistricts 14 and 15 of ecoregion 5 in New Brunswick was 232 years. From 1938 to 1946, 33 lightning-origin fires burned 30,863 hectares (9354 hectares/year), in which the average fire size for all fires over 20 hectares was 663 hectares (Methven and Forbes 1995).

In order to provide a better estimate of fire generated patches, an age/area analysis of mature and overmature, fire-origin pine (jack, white, and red pine) stands was carried out (Table 2).

These estimates are undoubtedly crude, and will tend to be an underestimate because of post-establishment human disturbances. However, studies of this nature are not designed to establish a model, but to increase understanding of the dynamics of disturbance under particular conditions of climate, vegetation and geomorphology. The next step is to construct simulations in which these three variables are altered within reasonable limits, to determine the consequences in terms of process and pattern.

Table 2. Patch size analysis of mature and overmature pine stands (after Methven and Forbes 1995)

ECOREGION	# PATCHES	AVERAGE PATCH SIZE	MAXIMUM PATCH SIZE
1	3	1490	2170
2	1	2600	2600
5	5	5046	10100
6	4	1285	2400

METHODS AND APPROACHES

To obtain a preliminary picture of the historical fire regime in the Fundy Model Forest area, five approaches were used:

1) examination of historical records of fire occurrence, size and location;
2) current inventory information on age class distributions from the provincial GIS attribute lists, and provincial Permanent Sample Plots (PSP) and the Forest Development Survey (FDS), Fundy National Park PSPs, and the regional Ecological Land Classification Project.
3) sampling of stands containing fire adapted species to determine age and fire origin dates;
4) search for fire scarred trees to establish fire dates; and

5) simulation of fire on the landscape to determine fire sizes and patterns.

Historical Records

Historical records included information from the Kings County Record, which commenced publishing in 1887, and historical fire records from the Fire Management Branch of the Department of Natural Resources and Energy. The latter were in three different formats. Forest fires larger than 20 hectares in size have been reported since 1931, and most of these fires were recorded on a map showing the location and area burned. Fires between 1968 and 1981 were grouped into size classes. More detailed records were available for the period since 1982. However, none of these records were available from a computer database, which made the task considerably more time consuming than expected.

Current Inventory/Age Class Information

Unfortunately, the age class information from the forest inventory found in the GIS attribute files was unusable, since the resolution was too low for the purposes of this study. Even where the development stage classifications had been translated into specific ages, the data were not reliable. This required searching out age class information from other sources including the Forest Development Survey (FDS), the Permanent \Sample Plots (PSP), and the regional Ecological Land Classification (ELC) work. A total of 1839 FDS plots, 104 PSP plots, and 27 ELC plots were included in the analyses.

Sampling for Age

In order to compensate for the inadequate quality of the inventory age class information, and to complement the PSP, FDS, and ELC data, more plots were sampled. Since the purpose of the study was to determine disturbance history, the GIS database was searched for stands containing fire dependent or adapted species. These included jack Pine *(Pinus banksiana*), red pine *(Pinus resinosa*), white pine (*Pinus strobus*), and black spruce (*Picea mariana*). Stands were selected if they contained at least 50% black spruce and/or 20% pine, were relatively easy to access, and were well distributed across the area. A total of 179 stands were sampled.

Four to ten increment cores from stump height were obtained from each apparent age class in each stand (most were even-aged), placed in straws, and returned to the laboratory for age analysis. Age was measured using a binocular microscope where necessary. The age of the stand was based on the oldest core.

During the field sampling, trees with fire scars were sought out and the scars analyzed to provide precise fire dates. A few of the samples were treated and mounted to provide a permanent record and display.

Computer Backcasting of Age Class Patches

The long history of human disturbance combined with the interaction of fire, wind and spruce budworm made it impossible to recreate the presettlement boundaries of natural disturbance. Much of the area, in fact, was dominated by old field succession or reforestation of early settlement farms. A computer algorithm in ARC/INFO was used to connect all adjacent points in the same age class, through a progressively older series by progressively eliminating younger age classes. Five runs were carried out by ten year age classes from all stands (points) older than 55 years to all points older than 95 years. The resultant polygons were then plotted to determine changes in age and size class distributions.

Computer Simulation of Fire

Simulations were carried out on 16000 hectares in central New Brunswick where the landscape and thus the fuels remain relatively undisturbed by human intervention. The simulations were carried out in two steps: i) simulation of disturbance (fire) under specified weather, topographic and fuel conditions by ecodistrict; and ii) simulations of harvest blocking in which maximum size, adjacency constraints and riparian buffers were treated as variables within the tactical planning level.

Fire

Fire was applied to the landscape using the fire growth model FIRE-NB (RemSoft Inc.) The landscape was defined by the following layers of information:

- ecodistricts as established by the Ecological Land Classification process;
- weather using 589 station years of historic weather data;
- current vegetative cover as transformed into the relevant fuel types of the Canadian Forest Fire Behaviour Prediction (FBP) System (Forestry Canada 1992); and
- digital terrain data.

Ignitions were then applied to the landscape at random, and those fires with a rate of spread exceeding 1 metre per minute were allowed to burn. In this exercise, 250,000 ignitions burned 1,946 km^2. The effect of climate change on weather and vegetation can be simply inserted into the model to determine the impact on the fire regime and landscape pattern. The combination of ecological understanding, historical studies, and simulation modeling can provide sufficient insight into processes and patterns to provide guidance for the design of human interventions that will maintain diversity, long term productivity and resilience. The next question is how to implement such designs.

Harvest Blocking

A fundamental question is whether patterns derived from studies of natural disturbance can be implemented through current management planning tools designed for generating commodity flows. The answer is yes, but not directly. In other words, a specific design algorithm cannot yet be accommodated. On the other hand, playing with current constraint rules can result in a wide variety of designs and patterns that can be explored for their congruence with disturbance design criteria, for their impact on such values as diversity, and for their flow of commodities such as timber.

In the simulation exercise, the spatial planning tool STANLEY (RemSoft Inc.) was applied to the same 16,000 piece of landscape. Three constraint rules associated with harvest blocking were used to generate sets of landscape patterns. These were: i) maximum size; ii) adjacency constraints; and iii) riparian buffers. It was demonstrated that a great deal of flexibility is associated with manipulating these constraints, and that many possible scenarios can be run in a very short time.

RESULTS

1. Historical Records - King's County Record

The Kings County Record contained many references to fire throughout the years. It is apparent that fire was common in the region through the early part of the century, and that fires were sometimes large, and burned for extended periods. A selection of references can be found in Table 1.

Table 1. References to forest fires in the Kings County Record for the period 1900 - 1920

DATE	FIRE REFERENCE
June 1, 1900	Fire burned a portion of Studholm between Millstream and Roachville. A large tract of woods was destroyed.
June 1, 1900	Fire started in Irish Settlement, ran through to Belleisle Creek, and destroyed great quantities of standing lumber in the parish of Springfield
June 5, 1903	Fire started between Urney and Springdale, then shifted and ran along the valley south of the Picadilly spool factory.
August 18, 1905	Fire started at Dingley Couch and Miller Brook at the head of Millstream. It burned for roughly five days, consumed a house, and burned large tracts of valuable lumber.
August 24, 1906	Fire started near Keohan, and burned a wide section to Smith's Creek.
August 24, 1906	A fire has been burning all week in back of Apohaqui.
June 21, 1907	Fire started at Smith's Creek and burned 800 acres.
July 17, 1908	Fire raged all week in Whites Mountain.
July 17, 1908	Fire burned at the head of Millstream and did a lot of damage.
June 4, 1909	Fire started near Southfield, and burnt to an are between Norton and Southfield. Covered mostly a previously burnt area so did little damage.
May 19, 1911	A fire at Newtown but caused little damage.
May 19, 1911	A fire at the head of Millstream.
May 19, 1911	A fire at Brown's Flat.
August 11, 1911	Fire started in back of Sussex, crossed the Picadilly road, and moved towards Penobsquis. At one time the head of the fire was four miles across, and it burnt an area over 1000 acres.
June 6, 1919	An elderly gentleman recalls that the spring of 1871 was dry and forest fires burned in many sections of the province. A freak snowstorm on May 24th helped to suppress the fires.
May 21, 1920	Two fires burned at the upper end of Thorne Brook in back of Perry Settlement.
May 28, 1920	Numerous fire reported throughout Kings County and surrounding areas.
May 28, 1920	Fire started just south of Norton and burned valuable lumber land.
June 4, 1920	A fire at Parlee Brook (near Waterford) burned over considerable valuable timber land.

2. Historical Records - Fire Records

Fire records were not easy to access and were not consistently organized. From 1930 to 1968 only those fires greater than 20 hectares in size were recorded Figure 1), while from 1968 to 1982 only summarized records were available (Figure 2). From 1982 to 1994 complete records were available (Figure 3). In general, number of fires tended to decrease with size, while area burned by different size classes increased with size. The period between 1968 and 1982 was somewhat anomalous in this respect in that there were no fires in the >200 hectare class, and fewer fires in the 40 to 200 hectare class than in the 4 to 40 hectare class (Figure 2). Given that probably 95 percent of these fires were ignited by humans, the data does not provide much useful information with respect to the natural fire regime, except in terms of demonstrating that the climate and fuels will support a fire regime.

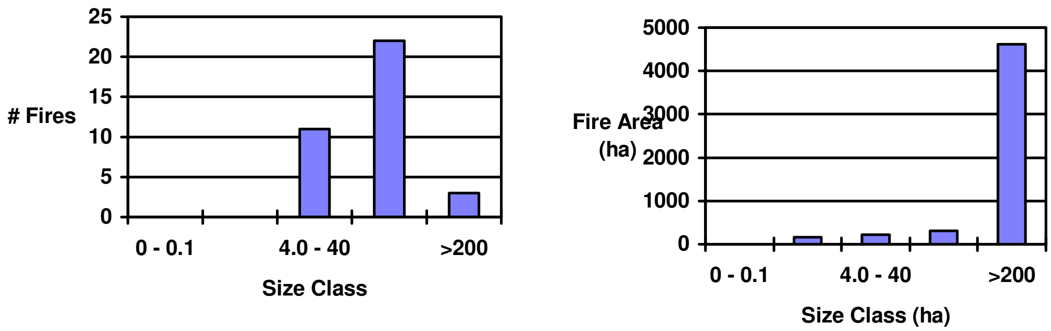

Figure 1. Number of fires and fire area by size class >20 hectares occurring between 1931 and 1968.

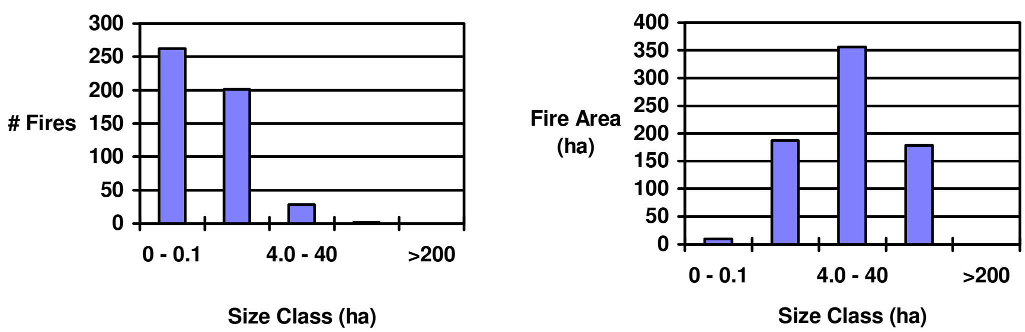

Figure 2. Number of fires and fire area by size class occurring between 1968 and 1982

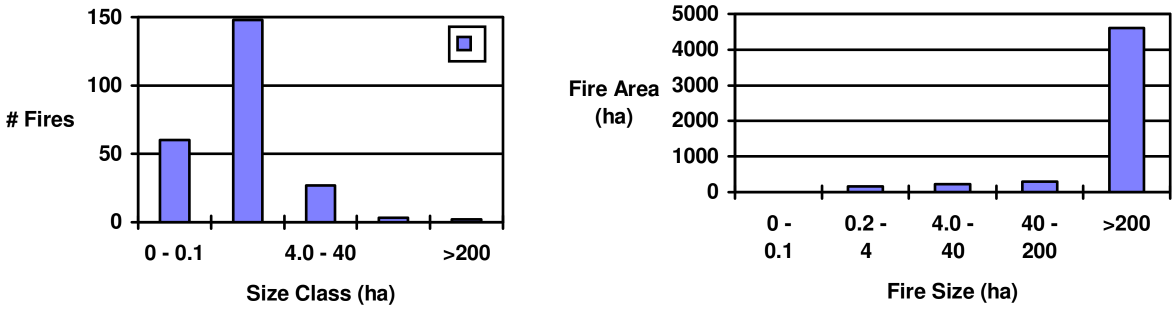

Figure 3. Number of fires and fire area by size class for fires occurring between 1982 and 1994

2. Fire Scars

Only two stands were found with fire scars, and both were red pine. One was in the Cherryvale area just south of the Canaan River, and east of the 1986 Canaan river fire. A tree was identified with four fire scars, and with the date of origin provided the dates for five fires. These were: 1874, 1886, 1894, 1904, and 1920. That is five fires over 46 years for a mean fire return interval of 11..5 years. The other fire-scarred stand was found just outside Penobsquis, and here the dates were: 1894, 1908, 1932, and 1975, yielding a longer fire return interval of 27 years. While this is a minimal data set it does provide some insight into the frequency of fire in the region during the late nineteenth and early twentieth century.

3. Current Inventory/Age Class Information

Only mature or potentially seed-bearing stands were sampled, in order to provide an age class picture emanating from earlier disturbances. The net result was that only stands in the 30 to 40 year age class and older were sampled and included in the analyses. The pattern of the age class distributions was relatively consistent across all databases (Figures 4 -8), with a bell-shaped curve centering on the 70 to 80, and 80 to 90 year age classes, and descending negatively exponentially into the 200 year age class. This suggests a peak of disturbance during the 1910s and 1920s, also reflected in the many references in the King's County Record (see above). Disturbance effects declined in the area from the 1930's, when serious fire suppression was implemented, until the 1960s. The declining number of stands established prior to 1900 or so, merely reflects an increasing elimination of these earlier stands by disturbance, either natural or human caused.

Figure 4. Ten year age class structure in the Fundy Model forest based on PSP data.

Figure 5. Ten year age class structure in the Fundy Model forest based on ELC data.

Figure 6. Ten year age class structure in the Fundy Model forest based on FDS data.

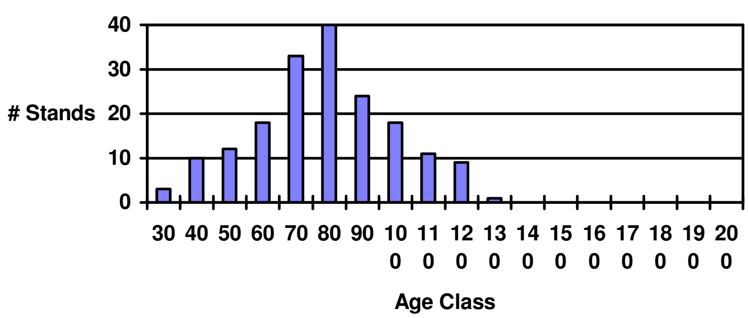

Figure 7. Ten year age class structure in the Fundy Model forest based on UNB data.

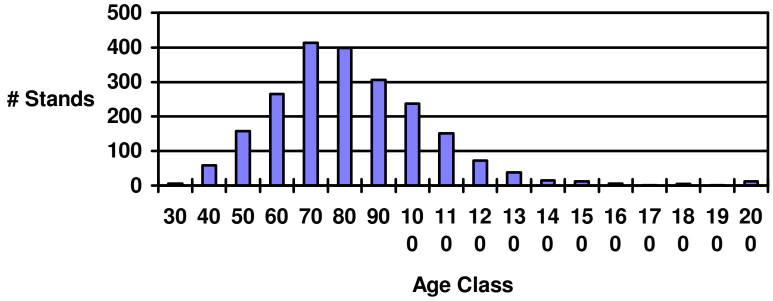

Figure 8. Ten year age class structure in the Fundy Model Forest based on all data sources.

4. Computer Backcasting of Age Class Patches

In an attempt to elucidate patch size distributions as well as age class distributions, adjacent sample points within the same age class were joined using a computer algorithm. A number of runs were attempted in which both five and ten year age classes were used, and where the youngest age class was continually increased from 55 to 95 years. Examples can be found in Appendix I, which represent the output from runs that included all ages greater than 85 and 95 years respectively. As expected from the age class distribution data, the patches are dominated by the younger age classes, since these are close to the age class distribution peaks. Of interest also, is the fact that most of the oldest patches are located in Fundy National Park, showing that the Park is fulfilling it role of maintaining a full complement of age or development classes.

As younger age classes were eliminated, leaving remnants of older age class stands, size of patches increased (Figures 11-13), and this became particularly marked where only ages above 95 years were included, and the largest patch size increased from 3000 hectares at 75 years to 9000 hectares at 95 years and above (Figure 13). It must be remembered that these are ten year, not single year, age classes. This does suggest, however, that the underlying pattern emanating from earlier disturbance periods dating back to the late seventeen hundreds may have been of a coarser grain, with larger patches, than is found today.

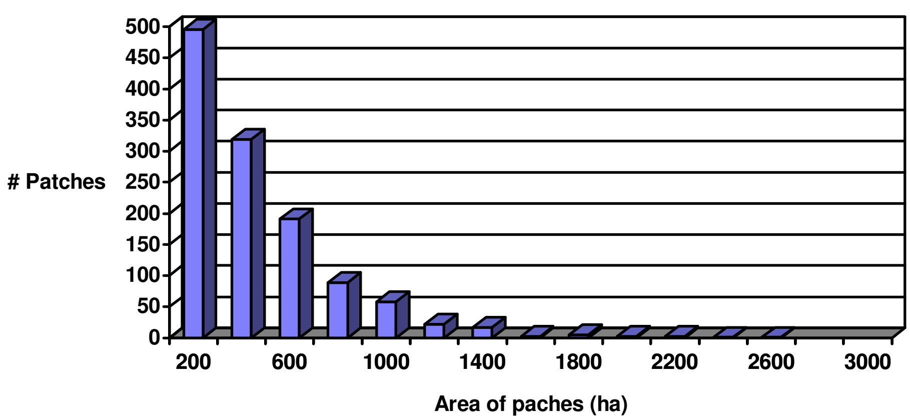

Figure 9. Area distribution of patches generated by joining adjacent age points greater than fifty five years within ten year age classes.

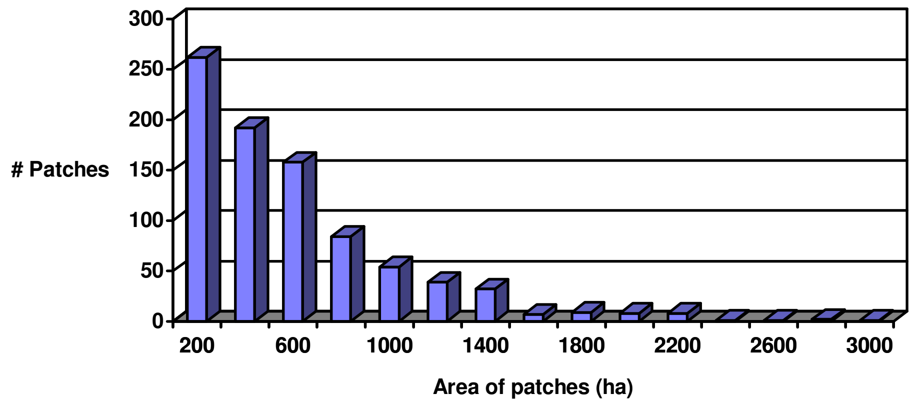

Figure 10. Area distribution of patches generated by joining adjacent age points greater than seventy five years within ten year age classes.

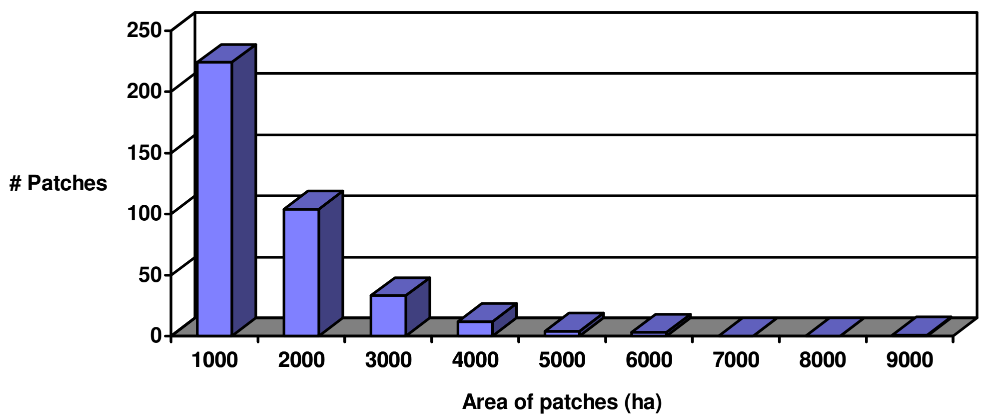

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Figure 11. Area distribution of patches generated by joining adjacent age points greater than ninety five years within ten year age classes.

5. Computer Simulations

The average fire size was 788 ha while the largest fire was 111,000 ha. The number of fires by size class tended to follow a positive exponential, while area burned by size class formed a positive exponential.

Setting minimum and maximum block sizes of 10 and 100 hectares and maintaining adjacency constraints and riparian zones resulted in negative and positive linear distributions between 10 and 100 hectares of block number by size class and area by size class respectively. Removing these constraints resulted in a rectangular distribution of area by size class, and a negative exponential distribution of block numbers by size class. In the latter case, block sizes ranged from 10 to 670 hectares. Timber flows were found to be relatively insensitive to a wide range of patterns resulting from these simulations. For example, dispensing with maximum block size alone, as opposed to a 100 hectare maximum, raised the maximum sustainable harvest (MSH) from 134, 131 m^3 to 137,563 m^3. When riparian zones were included in the harvest planning, the MSH rose from 152,900 m^3 to 161,551 m^3. Thus playing with maximum block size and adjacency constraints alone confers great flexibility, and can result in patterns more reflective of natural disturbances.

DISCUSSION

The forest within the Fundy Model Forest has been disturbed and fragmented to such an extent by logging, agricultural clearing, settlement, and fire that elucidation of the natural disturbance regime is virtually impossible. The degree of archival work and sampling needed to produce a reasonable stand origin map based on natural disturbance is unattainable. The widespread and extensive presence of the fire adapted pines and black spruce, the occurrence of well to excessively drained soils, and the common occurrence of fire in historical times suggest strongly that fire was a significant disturbance force. It has been argued that most of the fire was caused by European immigration and settlement, and was not indigenous. However, this argument fails to explain the occurrence of the fire adapted species which only occur in closed stands where fire is a significant part of the natural environment. They were not introduced by the immigrants. It is possible however, that fire was used extensively by the aboriginal peoples, and there is considerable evidence for this from the New England States (Day 1953). The view that the nature was relatively undisturbed prior to European colonization is a myth. Investigators such as Denevan (1992) and others have gone so far as to suggest that the Americas were populated by as many as 50 million people in the fifteenth century, and that 90 percent of these people were eliminated within one hundred years of colonization.

The presence of jack pine through the region on particular sites would suggest relatively intense fires with a cycle of from 50 to 100 years. This is necessary to ensure survival of viable populations of this species. Red pine and white pine, which were also present throughout the area, depend on maintenance fires occurring every 30 to 50 years for control of competition and cone insects, with more intense, stand replacing fires every 200 to 300 years. Upland black spruce regenerates extremely poorly on upland areas in the absence of fire, which is required not only to release large quantities of seed from the semi-serotinous cones, but also to control competition and create a suitable seedbed. The fire cycle for black spruce is often linked to that of jackpine, but because of its longevity can be extended to 200 years.

The evidence from pine age classes, backcasting of age classes, and the simulation modeling suggests that disturbance patches from fire or wind were from a few hectares to tens of thousands of hectares, while it is well known that epidemics of spruce budworm can cover tens of thousands of square kilometres. While patches may be large they are far from simple. The blowdown of November 1994 in the Christmas Mountains of New Brunswick, as with other blowdown events, resulted in a complex pattern of degrees of blowdown within the overall perimeter. The same is true of fire, the complexity being a function of topography, fuel, and hazard at the time of fire. A study by Eberhart and Woodard (1987) of 69 fires in Alberta ranging from 20 to 20,000 hectares showed that the percent of area disturbed within the perimeter, number of unburned islands, median island area, and edge index all increased with fire size. Thus as patches become larger, regardless of disturbance type, complexity of the perimeter and the interior increases. This has important lessons for silvicultural design and blocking of harvest areas.

The net conclusions of this study are that:

1) natural disturbance has played a significant role in recycling and structuring the forest of the Fundy Model Forest;
2) the impact of human disturbance since settlement has fragmented the forest to such an extent that it is no longer possible to recreate the disturbance regime from direct evidence;
3) given the evidence of fire and the species composition of the forest, fire probably burned on a cycle of from 50 to 300 years depending on the geomorphology and fuel (cover) type;
4) patch sizes varied from a few hectares to as high as ten thousand or more hectares, but that complexity in terms of islands and stringers of residual vegetation, and the nature of the perimeter, increased with size; and
5) the type of complexity of pattern generated by geomorphology and disturbance can be reflected or approximated by existing planning tools.

RECOMMENDATION

Rather than focussing on trying to determine the historical pattern of disturbance, it is recommended that emphasis be placed on characterizing and quantifying the relation between geomorphology, vegetation, and hazard conditions on fire behaviour and fire pattern. Further, that fire pattern include the fire size distribution, perimeter shape, and internal geometry.

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