BAP REPORT #4:
FIRE REGIME SIMULATION OF THE WHITECOURT FOREST USING LANDIS

**Prepared for Millar Western Forest Products'
Biodiversity Assessment Project**

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4.1 INTRODUCTION

BAP is based on two principles: (1) biodiversity should be assessed at several scales (species, ecosystem, and landscape) and (2) the range of variation associated with the natural disturbance regime (NDR) should be considered when comparing the potential effects of management activities. This report addresses the second principle which is justified by the assertion that organisms inhabiting specific ecosystems have co-evolved and adapted over thousands of years to function under the shifting mosaic of habitats generated by the disturbance regimes operating regionally (Denslow 1995). In the boreal forests of North America, the predominant agent of natural disturbance has been fire (Heinselman 1973). Fire regulates most of the processes related to forest dynamics (Payette 1993; Whelan 1995). Since wildlife species have adapted to the landscape patterns resulting from large-scale and frequent fire, in these fire-adapted ecosystems, wildfire is responsible for the maintenance of biodiversity (Duchesne 1994). Conservationists have proposed that silviculture systems should be designed such that the structure of the forest, at a landscape scale, resembles, as closely as possible, the structure that would remain following wildfire. It is thought that this practice will allow the environmental conditions required by all species adapted to wildfire to be maintained following harvesting, thereby, maintaining biodiversity (Hansen *et al*. 1991).

To fully appreciate the potential impact of a forest management strategy on biodiversity, we must understand the impacts that the NDR of the region has had on these forests for centuries (Hunter 1993). Based on this understanding, the effects of an artificial disturbance regime imposed by forest management can be compared with the NDR that a region has previously experienced. The modelling approach used in BAP simulates the effects of both forest management scenarios and the NDR over a long period. The comparison is made by quantifying the deviation between the outcomes of the biodiversity indicator models for each forest management scenario and the range of variation under the NDR simulation.

This report describes the production of the baseline NDR scenario. Descriptions of the forest management scenarios can be found in BAP Report #1: Background and Structure (Duinker et al. 1997).

With the use of a NDR simulator, we are able to understand the natural range of variation in landscape pattern without the difficulties related to reconstruction of landscape-level disturbance events over hundreds of years (Andison 1997). The simulator cannot be valuable, however, unless accurate information on natural disturbance processes is available to realistically represent the system of interest. LANDIS, a spatially explicit model designed to simulate landscape change over long periods by reproducing succession and disturbance processes (Mladenoff *et al*. 1996), was used in BAP. An analysis of the fire history and lightning strike pattern for the Whitecourt region and a synthesis of available information from fire regime studies of areas of similar environmental condition are presented to support the assumptions used to set the parameters of the model.

4.2 DESCRIPTION OF LANDIS

Structure

LANDIS is a stochastic, spatially explicit process-based model designed to simulate succession and disturbance over large heterogeneous landscapes and long periods (Mladenoff *et al*. 1996). Although it uses the same basic model algorithms as LANDSIM (Roberts 1996), a polygon-based model, they are transposed to function in a raster-based mode. LANDIS uses modular programming structure (C++) and runs on PC and UNIX platforms.

There are two main modules in LANDIS: a succession module and a disturbance module. The succession module is based on interactions between tree species life-history traits, site conditions, and disturbance regime. The disturbance module is based on fire and windthrow frequency, fuel accumulation, landtype susceptibility, and species age-class susceptibility to disturbances (Figure 4.1). Detailed information on LANDIS is described in Mladenoff *et al*. (1996), He *et al*. (1996), He and Mladenoff (1999), and He *et al*. (1999).

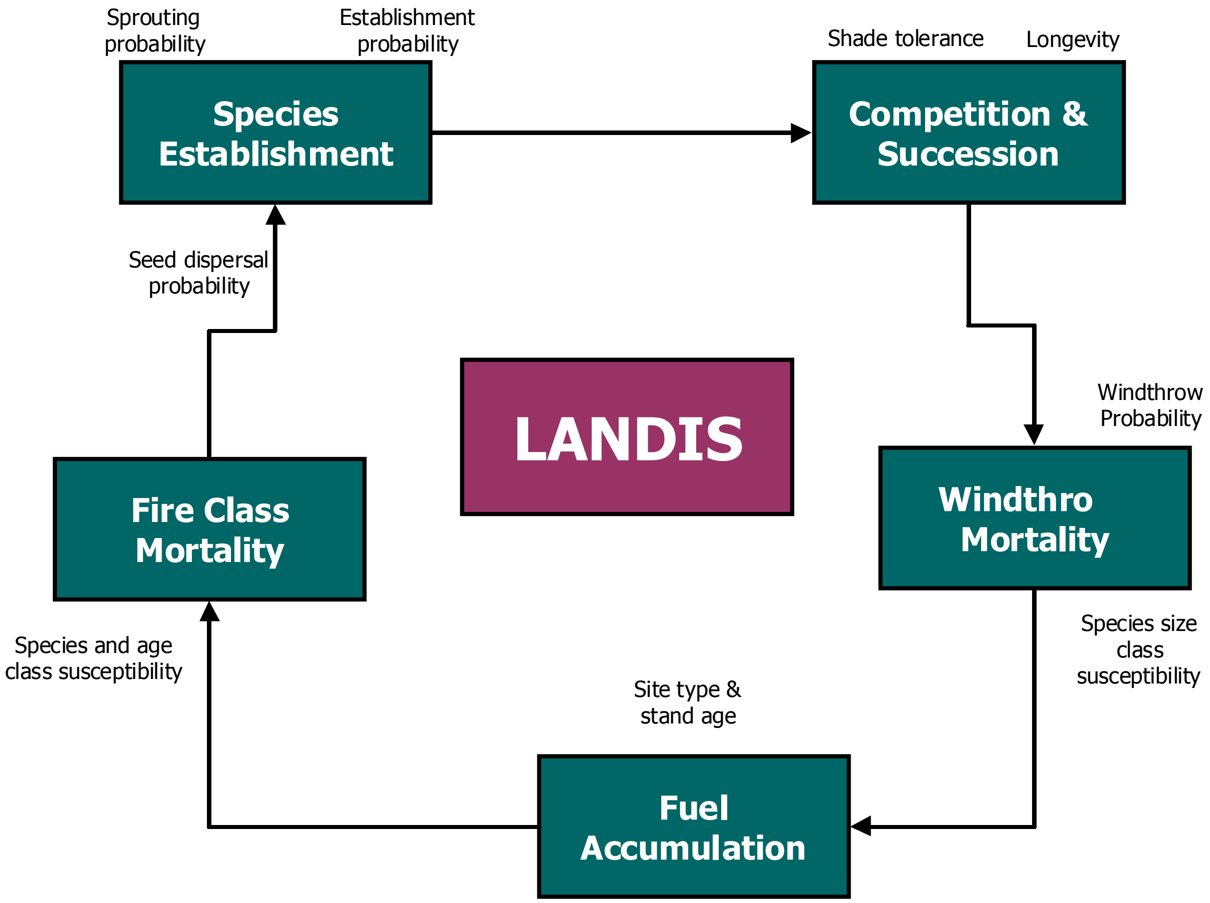

Figure 4.1. Modular structure of LANDIS. The upper boxes show processes of stand dynamics and the lower boxes show processes of disturbance. Parameters regulating each process are displayed as satellites of the boxes.

Operating LANDIS

LANDIS reproduces landscape dynamics in ten-year steps. At each of these steps, the model verifies the information passed from the previous simulation and runs the disturbance and succession modules (inner loop, Figure 4.2). After re-classifying the resulting forest, maps are logged in output files to be used in the next iteration and later shown as part of the summary outputs.

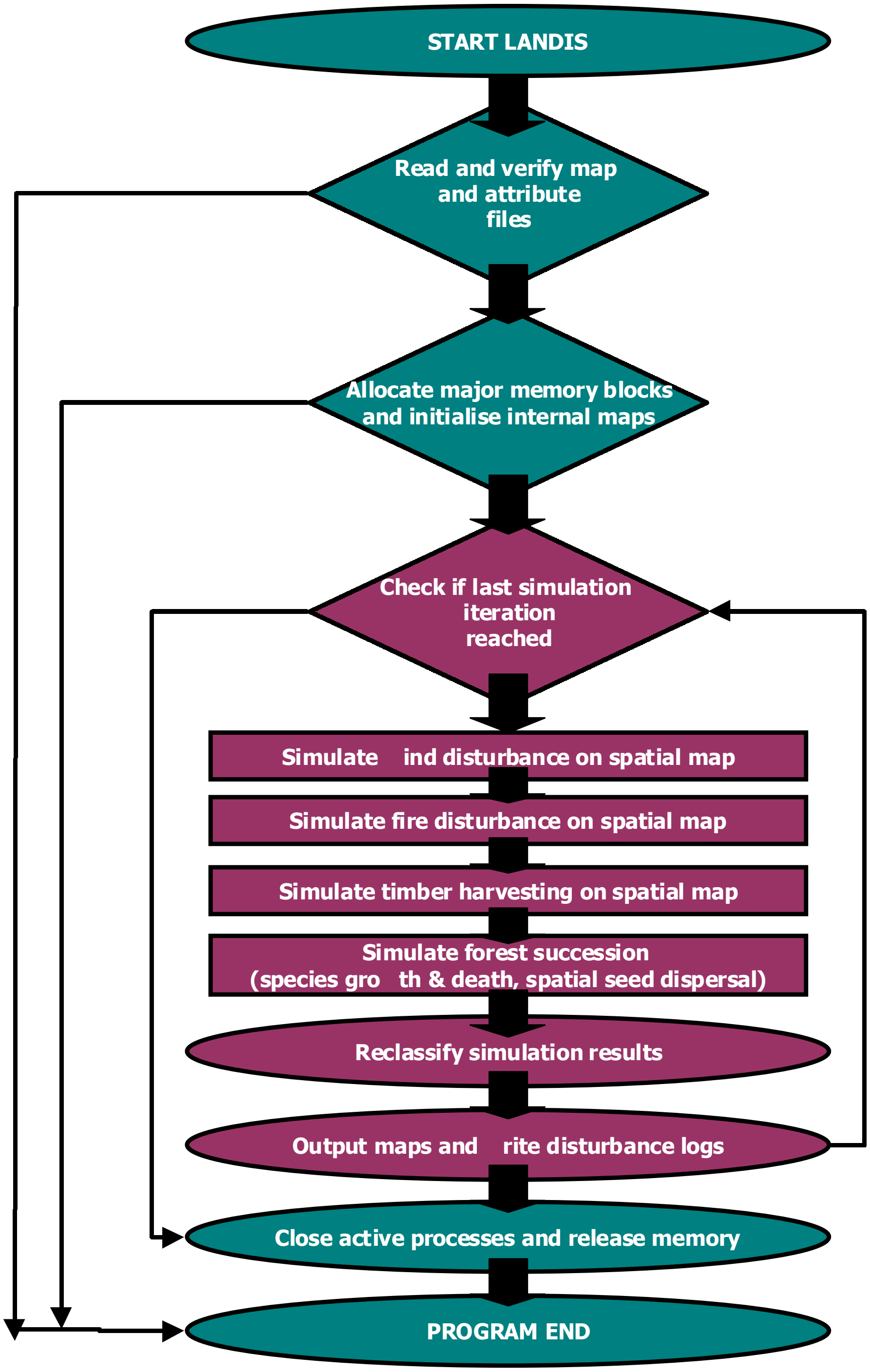

Figure 4.2. Flow chart of a simulation session with LANDIS. Disturbance processes are run prior to execution of the succession processes.

Input information

Input files that describe the current condition of the forest landscape and the instructions to be used for the simulation session are required prior to execution of LANDIS.

Forest landscape conditions

Five input files are used to describe current forest landscape conditions.

- The life history file includes information on longevity, age of sexual maturity, effective and maximum seed dispersal rates, ability to establish by vegetative propagation after disturbance and age of last sprouting, shade tolerance, and fire tolerance.
- The land type attribute file includes information on abiotic site conditions including geology, soil, climate, and topography. Stratification of the landscape by these variables is critical as fire return interval, fuel accumulation processes, and species establishment and succession are defined by land types. Land types can be changed over time or can be set as 'non-active'.
- The land type attributes such as size (minimum, maximum, and mean) and frequency of windthrow and fire disturbances are generalised within a third input file.
- Two map files contain all of the above information in spatially explicit form as GIS images. They represent the spatial distribution of different combinations of abiotic and biotic conditions that form the landscape. Each combination is described by one number that refers back to the attribute files where the corresponding biotic and abiotic conditions are listed.

Simulation instructions

- The parameter input file includes the name of the landscape condition input files, the desired location of outputs, instructions for simulation (e.g. number of iterations, cell size), and information on different methods of seed dispersal and disturbance.
- Other files control frequency and format of outputs.

Output information

Outputs are supplied in the form of maps and logs (Figure 4.3). Maps of disturbance patterns, tree species and age classes, and stand types (based on the reclassification scheme used to define forest stands) are produced at the last iteration corresponding to the frequency of output required. Log files for the wind and fire disturbance patterns contain a list of all fires and windthrows that occurred throughout the simulation. The log files are useful for quick evaluation of the behaviour of the model.

Function

Each pixel of the map is referred to as a site object. Site objects are defined by a species age list for each species (*i.e.*, the presence or absence of each species by ten-year cohort is recorded). The length of time since the last fire or wind disturbance is also recorded along with the land type of site. This information is also used to describe the conditions of the landscape at the start of the simulation.

Succession

For each iteration, at each site, the pattern of succession varies with tree species composition since different species have different attributes related to succession. Succession is driven by:

- Spatial seed dispersal;
- Differential establishment on the land types;
- Shade tolerance;
- Susceptibility to disturbance;
- Ability to establish by vegetative reproduction;
- Age of sexual maturity; and
- Longevity.

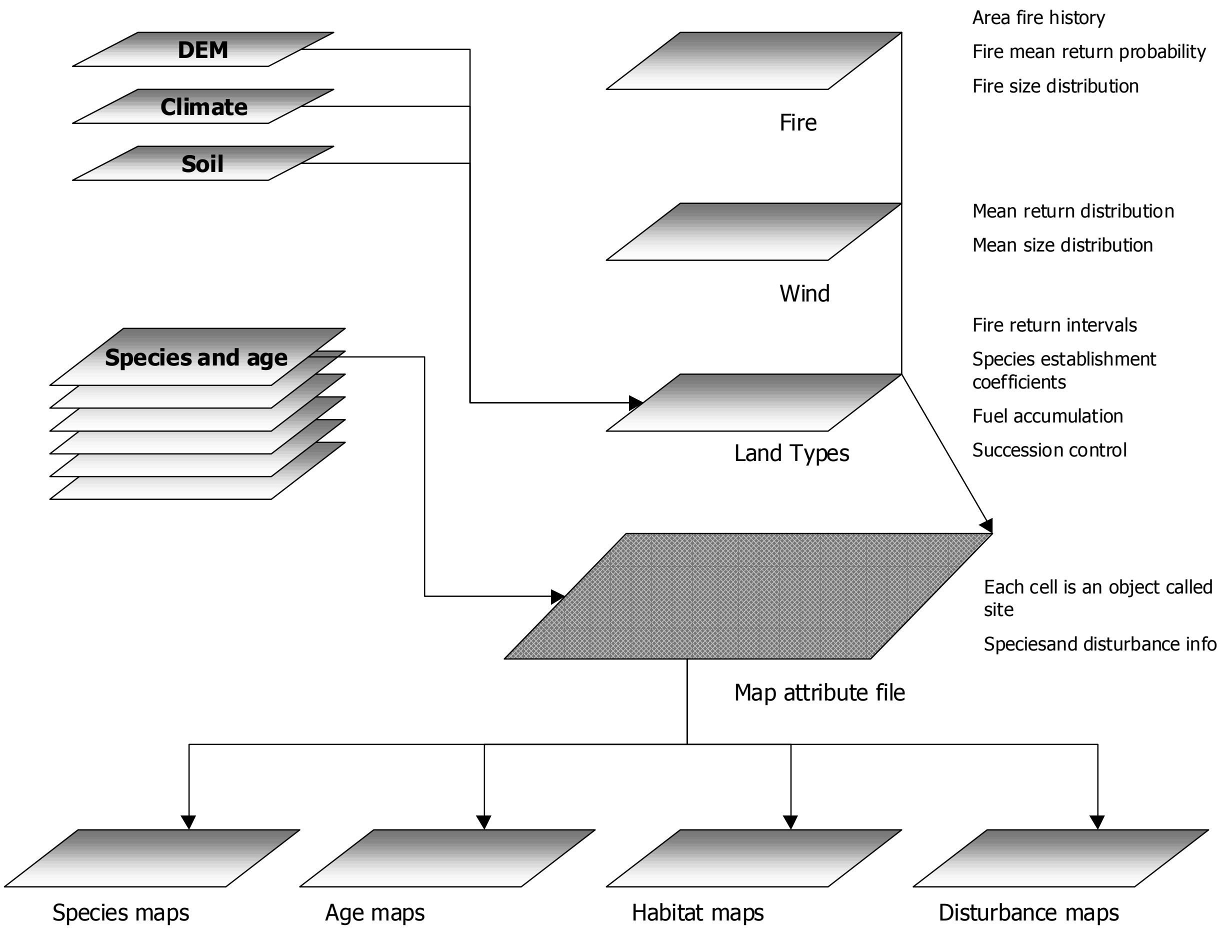

Figure 4. . Organisation of inputs and outputs in LANDIS.

There are several rules implicit in LANDIS that control succession. Succession begins with seeding. Following disturbance, seeding is controlled by the species' age of sexual maturity and dispersal parameters, as well as the distance between a recently cleared site and a seed source. The ability of a seed to establish on a recently disturbed site depends on its establishment coefficient on that land type, its shade tolerance, and the presence of other cohorts. Shade-intolerant species will not establish under the canopy of other plants. Conversely, tolerant species will only establish under the canopy of a nurse cohort. The number of years that must pass before the shade-tolerant trees can establish is defined by the land type. Vegetative reproduction will always be successful provided there is an active source of propagation. Once established, a species-age cohort will grow unless it is eliminated by a disturbance or until it has reached old age as defined by its longevity.

Disturbance

In general, LANDIS uses similar methods to simulate wind disturbance and fire disturbance. There are two important differences, however. The mean return interval for fire disturbance is defined by land type. The mean return interval for wind disturbance is the same for the entire landscape. In addition, fire is considered a bottom-up disturbance and wind is top-down. Fire first consumes young or small trees and can only remove older, larger trees from the stand if intensity is great. Conversely, wind first removes trees from the oldest age classes.

Initiating a disturbance event first involves the random selection of a site and determination of its disturbance probability through comparison of the time since last disturbance and the mean return interval for the disturbance. Once disturbance has occurred, the extent of its spread is determined by the disturbance probability of surrounding sites. This process continues until the maximum disturbance size is reached or until no additional sites remain to be checked. The size of the area affected by a disturbance event is randomly chosen from the lognormal distribution of disturbance sizes in the disturbance attribute file. The number of cells disturbed in an iteration depends on the fire ignition coefficient for wildfire or the wind breakout coefficient for windthrow given in the parameter input files. The starting disturbance coefficients decrease randomly and exponentially for each site disturbed until they reach zero, allowing no further disturbance. Severity of fire disturbance depends on the amount of fuel accumulated on the site since the last fire. This parameter differs with land type. Wind disturbance severity depends on the age-dependent susceptibility classes of the site's oldest cohort. Following computation of disturbance severity for each cell, each species is affected by the disturbance differently depending on its susceptibility to the disturbance and its age class distribution.

4. PARAMETERISATION OF LANDIS FOR THE CENTRAL-WEST ALBERTA BOREAL FOREST

Species life history attributes file

Several sources of information were used to define the life history attributes of the eight most regularly encountered tree species of west-central Alberta's boreal forest. Local silviculturalists were asked to describe the life history attributes of these species under each of the categories used in LANDIS. These results were adjusted after being compared to the published literature (Loehle 1988; Anonymous 1990; He *et al*. 1996, Table 4.1).

Greene and Johnson (1999) classified methods of post-fire colonisation into asexual reproduction within the burn, aerial seed banks within the burn, and dispersal from the unburned edge into the burn. With LANDIS, vegetative propagation and colonisation from a nearby seed source can be simulated, but seeding from an aerial bank is not allowed since no seeds can disperse from an area burned if all cohorts have been destroyed. To account for the serotinous and semi-serotinous nature of lodgepole pine and black spruce, respectively, these two species were given values for vegetation propagation potential (Table 4.1).

Land type file

As mentioned in the Description of LANDIS section above, land-types can either be changed over time or can be set as non-active. Six non-active land types were used in BAP's NDR simulation. From the descriptions of non-forest polygons included in the AVI, non-active sites were defined as the following:

- Empty;
- Water;
- Wetland (marsh);
- Bog (treed muskeg);
- Lowland (thicket); and
- Non-forest (meadows, barrens and anthropogenic development).

Table 4.1. Life history characteristics of selected tree species.

Tree species	Longevity (years)	Sexual Maturity (years)	Shade tolerance (1-)	Fire tolerance (1-)	Effective seed dispersal distance (m)	Maximum seed dispersal distance (m)	Vegetation propagation potential (0-1)	Maximum age of vegetative reproduction (years)
Aspen	160	20	1	2	-1*	-1	1	120
Poplar	200	20	1	2	-1	-1	1	120
Lodgepole Pine	200	20	2	4	12	275	1**	200
White Birch	90	40	2	1	200	5000	0.4	70
Black Spruce	200	18	4	4	30	200	0.4**	200
White Spruce	300	20	4	3	30	200	0	0
Balsam Fir	70	30	5	1	30	130	0	0
Larch	180	45	1	2	30	160	0	0

* -1 means there is no distance limit

** post-fire seed rain is allowed for species with serotinous cones

The empty land type represents the area outside the FMA area. Active land types were defined using the ten ecosite groups obtained from the ecological classification (GDC 1999). For each ecosite group, the BAP team defined:

- Establishment coefficient of each species;
- Mean fire return internal ;
- Minimum age of a cohort before a species with a shade tolerance of five could establish; and
- Fuel accumulation curves after fire or wind disturbance.

The species establishment coefficient was determined in a manner similar to the species life history attribute input file. As suggested by He *et al*. (1996), the abiotic conditions of the site, in part, determine the minimum age of a cohort before a species with a shade tolerance of five could establish. The more a site deviated from the species' optimal growth conditions, the older the nurse cohort would have to be to allow establishment of a species with a shade tolerance of five. Mean fire return interval was obtained as explained in the section entitled Fire Disturbance Regime Analysis for the Whitecourt Area Forest and with information from a literature review. Fuel accumulation curves were created based on our understanding of dead organic matter production and decomposition by land type. In addition, the BAP team utilised the published work of He *et al*. (1996) and personally consulted Mike Weber and Kelvin Hirsch, forest fire specialists with the CFS in Edmonton, as support in the development of realistic curves (Table 4.2). Dead organic matter production information from the ecosite classification guide was also used for this purpose (Beckingham and Archibald 1996; Beckingham *et al*. 1996).

Map input and map attribute files

For input to the LANDIS simulation, the current condition of the FMA area had to be translated into map attribute format. Therefore, the species age list, land type, and time since last disturbance had to be defined for each pixel. Before initiation of LANDIS, a habitat classification scheme had already been defined for BAP; it applied a habitat type to each polygon shown in the AVI (Doyon 1997). Information on the tree species composition and age of the primary and secondary storeys was used to produce the species-age lists for each habitat type. Age was obtained from the AVI attribute named ORIGIN. Only the two most dominant species were used to characterise the polygon composition. The habitat map was then rasterised with a pixel size of 25 m and a minimum patch size of 1 ha. The ecosite map and fire history map were also rasterised. These three maps were overlaid to compose the LANDIS map types. After removing the types that were non-significant, 94 map types remained for use in the simulation.

Disturbance file

The disturbance file holds information vital to the LANDIS simulation as it controls the size and frequency of disturbances over the landscape. Prior to human settlement, the pattern of forest mosaics of west-central Alberta's boreal forest was caused mainly by wildfires (Rogeau 1996). Relative to fire, windthrow is a minor component of the NDR in the area. Therefore, we did not model its effect on landscape dynamics.

As mentioned in the introductory section of this report, successful simulation of the NDR by LANDIS requires an adequate understanding of the characteristics of the regional fire regime. According to Flannigan (1993), a fire disturbance regime is characterised by the type, severity, seasonality, intensity, frequency, and size of the disturbances and is the result of interactions between climatic, edaphic, hydrologic, and biotic (plant life) conditions. The model requires the minimum, mean, and maximum disturbance sizes, the fire return interval, and the probability of ignition for each land type.

Fire size parameters were obtained from the databases of the Provincial Forest Fire Centre of Alberta (PFFCA) in Edmonton. The method of determination of the fire return interval is based on the forest inventory data from the AVI and is explained in the next section. Using our results and those of Rogeau (1996) and Andison (1997), the minimum, mean, and maximum fire sizes for the LANDIS disturbance file were set at 0, 355.4, and 15,000 ha, respectively. Fire ignition was set at 1.445 lightning strikes per km^2 per year. Therefore, since the total area of the FMA area is 2999.5 km^2, there were 43,342 fire ignition events allowed per ten-year iteration over the whole landscape.

Table 4.2a. Establishment coefficient parameters used in the land type input file for LANDIS simulation.

	Ecosites								
Tree Species	Labrador tea mesic	Lichen	Blueberry	Hairy wild rye	Lowbush cranberry	Labrador tea sub-hygric	Labrador tea hygric	Bracted honeysuckle	Blackspruce bog
Trembling Aspen	0.4	0.1	0.3	0.5	0.5	0.1	0.2	0.4	0.1
Balsam Poplar	0.0	0.0	0.0	0.3	1.0	0.1	0.4	0.8	0.0
Lodgepole Pine	1.0	0.8	0.9	0.8	0.5	0.8	0.3	0.1	0.1
White Birch	0.3	0.2	0.5	0.8	0.8	0.0	0.2	0.6	0.0
Black Spruce	0.9	0.7	0.6	0.6	0.5	1.0	0.9	0.4	0.7
White Spruce	0.5	0.5	0.6	1.0	1.0	0.3	0.8	1.0	0.3
Balsam Fir	0.3	0.0	0.0	0.1	0.5	0.1	0.4	0.8	0.0
Larch	0.2	0.0	0.0	0.0	0.1	0.5	0.4	0.4	0.7

Table 4.2b. Nurse cohort age parameters used in the land type input file for LANDIS simulation.

Ecosite	Nurse Cohort Age (years)
Labrador tea mesic	40
Lichen	60
Blueberry	50
Hairy wild rye	50
Lowbush cranberry	40
Labrador tea sub-hygric	40
Labrador tea hygric	30
Bracted honeysuckle	30
Blackspruce bog	50

Table 4.2c. Mean fire return interval parameters used in the land type input file for LANDIS simulation.

Ecosite	Mean Fire Return Interval (years)
Labrador tea mesic	84
Lichen	50
Blueberry	75
Hairy wild rye	78
Lowbush cranberry	100
Labrador tea sub-hygric	160
Labrador tea hygric	140
Bracted honeysuckle	110
Blackspruce bog	250

Table 4.2d. **Data indicating the expected Fire severity at different lengths of time since last fire disturbance by ecosite parameters (used in the land type input file for LANDIS simulation).**

Ecosite	Age	Fire Severity
Labrador tea mesic		
	10	1
	20	2
	40	3
	55	4
	70	5
Lichen		
	10	2
	20	1
	60	3
	90	4
	120	5
Blueberry		
	10	3
	20	2
	40	3
	60	4
	100	5
Hairy wild rye		
	10	1
	40	2
	50	3
	60	4
	90	5
Low bush cranberry		
	20	2
	30	3
	50	4
	70	5
	0	0
Labrador tea sub-hygric		
	10	3
	20	2
	70	3
	90	4
	120	5
Labrador tea hygric		
	10	2
	30	3
	40	4
	100	5
	0	0
Bracted honeysuckle		
	10	2
	30	3
	40	4
	75	5
	0	0
Blackspruce bog		
	10	3
	20	2
	70	3
	110	4
	160	5

Table 4.2e. **Data indicating the expected fire severity at different lengths of time since last wind disturbance (used in the land type input file for LANDIS simulation).**

Ecosite	Age	Fire Severity
Labrador tea mesic		
	10	5
	20	2
	30	3
	40	4
	50	5
Lichen		
	10	4
	20	3
	50	4
	75	5
	0	0
Blueberry		
	10	5
	20	3
	50	4
	75	5
	0	0
Hairy wild rye		
	10	3
	20	2
	50	4
	75	5
	0	0
Low bush cranberry		
	10	5
	20	3
	40	4
	50	5
	100	0
Labrador tea sub-hygric		
	10	4
	20	3
	60	4
	80	5
	0	0
Labrador tea hygric		
	10	5
	20	3
	30	4
	60	5
	0	0
Bracted honeysuckle		
	10	5
	20	3
	30	4
	50	5
	0	0
Blackspruce bog		
	10	4
	30	3
	80	4
	100	5
	0	0

4.4 FIRE DISTURBANCE REGIME ANALYSIS FOR THE WHITECOURT FOREST

Data source and methods

Fire size and mean return interval

We obtained two fire databases from PFFCA. One includes all class E fires (>200 ha) from 1932 until 1996 in a digitized format (accessible as Arc/Info coverages). The second database starts in 1961 and includes fires of all sizes. Therefore, we limited our analysis of disturbance patterns to only the past 34 years. We are aware that this fire era does not represent the natural fire disturbance regime since fire suppression was fully active during the period. The smallest fire (spot fire) is 0.1 ha. In the second database, the size and ignition point location are described. To locate the fires that were not digitised, we drew a circle, of size equivalent to that of the fire, around the ignition point. Through this procedure, all undigitised fires were made circular in shape. We are aware that most fires do not have a round shape, however, it was necessary to use this method such that we would not bias the process with assumptions of fire spread. The new coverage, which includes classes A to D fires that burned between 1961 and 1995 (spot fires, fires £ 0.05 ha in class A, have been removed from the analysis) was combined with the fire coverage of class E fires of the same time period.

We used fire data to infer a mean fire return interval and fire size for the forest located between latitudes 53° and 56° N, and longitudes 114° and 120° W. We deemed this area, hereafter called the west-central, sufficiently homogeneous in terms of regional climate and fire regime, based on a qualitative observation of the distribution of fire events. Only land that is able to be burned was included in the analysis. Therefore, lakes, towns, and agricultural lands were removed from the area of concern after digitizing them from the provincial land use map (1:1 000 000: Alberta 1990). The resulting area covers 9,690,800 ha. To compute the mean fire return interval, we added all the burned areas over the past 35 years and divided the sum by the total burnable area and the elapsed time. In addition, the same exercise was conducted by Natural Region, elevation class, aspect class, slope class, and slope-aspect class in order to see if any of these factors could be good predictors of fire occurrence. Natural Regions (Boreal Mixedwood, Lower Foothills, Upper Foothills and Subalpine (and Montane included in one class)) were digitised by Strong (1992). Information on elevation, aspect, and slope was received from the Digital Elevation Model (DEM) dataset. The DEM dataset was limited to an area around Whitecourt, which included 300 townships (2,821,000 ha). Using the DEM data, we produced the three required coverages with the module TIN (ARC/INFO 1995). The elevation surrounding Whitecourt ranges from 392 m to 1,428 m. This range was split into four equivalent elevation belts (375 to 631 m, 632 to 887 m, 888 to 1,143 m, and 1,144 to 1,400 m). The slope classes were 0 to 1%, 1 to 5%, 5 to 15%, 15 to 30%, and 30+%. The aspect classes were 1 = 22.5° to 67.5°, 2 = 67.5° to 112.5°, and 337.5° to 22.5°, 3 = 112.5° to 157.5°, and 292.5° to 337.7°, 4 = 157.5° to 202.5°, and 247.5° to 292.5°, 5 = 202.5° to 247.5°, and 0 = no slope (Figure 4.4). Therefore, the southwest angle got the maximum value because trees facing that direction will receive the maximum amount of sunlight.

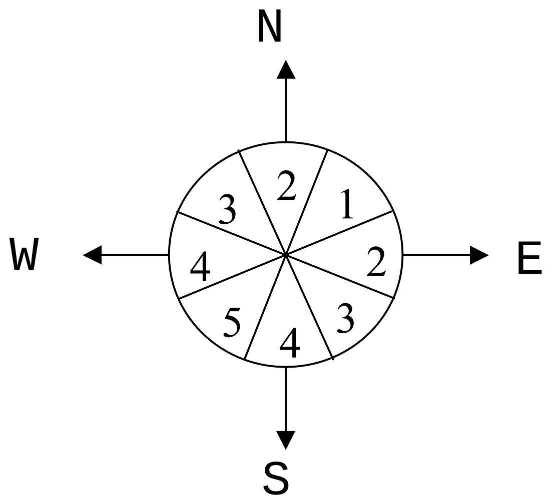

Figure 4.4. Aspect classes defined by the wind rose.

Finally, the slope-aspect coverage was built using the following formula inspired by Stage (1976):

[1] SAI = 1 + slope*cosine (aspect angle+22 °).

This index magnifies the aspect effect by the importance of the slope. Therefore, a pixel facing northeast with a strong slope will get a high negative value while a pixel facing southwest with a strong slope will get a high positive value. We divided the SAI into five classes (1: SAI<-25, 2: -25<SAI<-5, 3: -5<SAI<5, 4: 5<SAI<25, 5: SAI>25).

Fire ignition

For the fire ignition analysis, we used the lightning strike database from the PFFCA. All lightning strikes that occurred betweedn 1992 and 1995 have been digitised in ARC/INFO. In the analysis, we first divided the west-central region into squares of 100 km^2 (hereafter called pseudo-townships). Then, we computed the mean number of lightning strikes per year per km^2 (lightning strike density, LSD) in each of the pseudo-townships. Classes of LSD were then obtained using quartiles. Each pseudo-township was assign to one of the four LSD classes. Fire return interval was computed as before for the four LSD classes. In a second analysis, we compared the LSD among Natural Regions, elevation belts, slope, aspect, and aspect-slope index, for the Whitecourt area. Each of the four years was considered a sample.

Mean fire return interval by land type

To get a good indication of the mean fire interval for each land type, we used the "roll-back technique". All of the stands in the AVI forest inventory that did originate from timber harvest were candidates for analysis. For each land type, the areas of all these stands are summed by age classes of 20 years (the "peeling" period). With this technique, "the proportion of the area underneath in each of the other age-classes is identical to the proportion of those age-classes existing on the landscape today" (Andison 1997). It is therefore possible for each peeling period to grossly evaluate the burned area. Six peeling periods were used, representing stands of ages from 60 to 180 years. This period starts before fire suppression and spans a range of years that we believe to be sufficiently accurate for the purposes of the exercise. Mean fire return interval was obtained using the average of the six 20-years periods.

Results and discussion

Fire size

Over the past 35 years, there were 4,005 fires > 0.05 ha. Most of them were small, resulting in a strongly skewed size-class distribution. Even the distribution of the log of the fire size was left-skewed (Figure 4.5). The average fire size was 375 ha. In fact, 90% of the burned area came from fires over 200 ha in size. Large catastrophic fires were rare events, the largest one being 141,950 ha. This result does not include the last large fire in Swan Hills of May 1998 that covered 129,800 ha. Armstrong (1999) stressed the importance of these stochastic and catastrophic event in the fire disturbance regime. Although these results were derived from fire data collected during the fire suppression and systematic timber harvest period (after 1950), they are comparable to what we can approximate using Andison's (1997) "roll-back" technique. By using the median of the size classes, we obtained the number of patches of approximately that size and then derived a mean patch size of 355 ha.

Fire frequency

For the last 35 years, 402,065 ha burned in the west-central area. Ninety percent of the this burned area was the result of fires over 200 ha in size. Therefore, based on the fire maps, 0.101% of the burnable lands are burned every year, giving a fire return interval of 909 years. If we now consider the previous 30 years (1932 to 1960), even if the small fires were not systematically recorded, the probability then increases to 0.268%, with a fire return interval of 373 years. This is likely quite different from the expected pre-settlement fire regime. Using Weibull-model curve fitting in the Foothills Model Forest area, Andison (1997) found a mean fire return interval ranging from 84 to 92 years and 95 to 113 years respectively for the Lower and the Upper Foothills Natural Subregions for the year 1950. Using the fire maps, we also noticed a difference between the percentage of land burned by Natural Region (Table 4.3), particularly between Boreal Mixedwood and the other regions. However, using each year as a sample, the difference was not significant (*P*=0.2976), due to the large variation among the years (Table 4.3). Percentage of land burned every year did not differ among elevation belts (*P*= 0.472, Table 4.4). However, there is a tendency for the lowest elevation to burn more (Table 4.4) as Andison (1997) found. Portions of land with different slope class, aspect class, and SAI class also did not differ in their percentage burned (P>0.95, Table 4.5, 4.6, 4.7). Our results show that none of the factors studied could discriminate mean fire return intervals. However, elevation belts and Natural Regions were the most powerful in such differentiation. As land types indirectly include such considerations because ecosites are a function of elevation and Natural Region, we decided not to differentiate the landscape *a priori* and based the distinction of the mean fire return interval on the land type only.

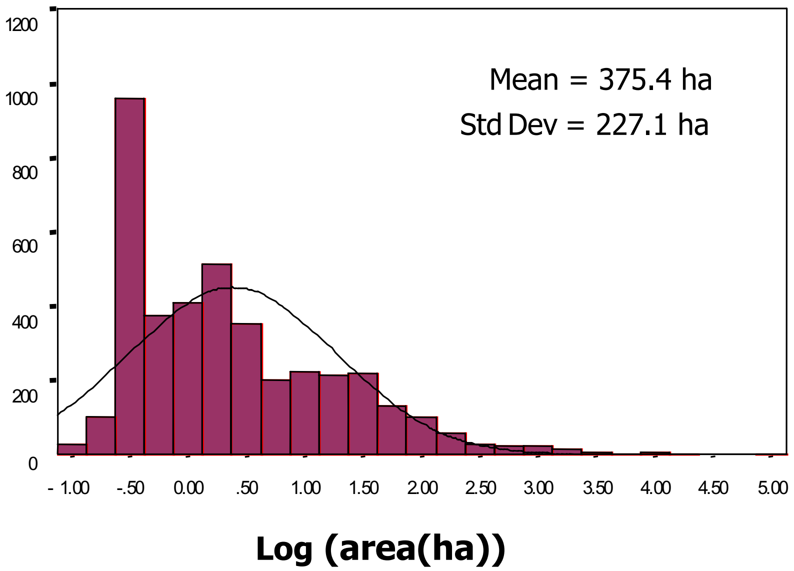

Figure 4. . Fire size frequency distribution in Alberta central-west area between 19 1 and 199 . Sizes are on a logarithmic scale.

Table 4. . **Percentage of area burned every year between 19 0 and 199 in the area between Latitudes ° and ° N, and Longitudes 114° and 120° W for the five Natural Regions.**

Natural Region	Area (ha)	Mean % burned	Std
Boreal Mixedwood	1,634,700	0.3406	1.5079
Dry Mixedwood	261,600	0.0332	0.1033
Lower Foothills	4,298,800	0.0981	0.2631
Upper Foothills	1,645,200	0.0353	0.1332
Subalpine	1,850,500	0.0152	0.0309

Table 4.4. **Percentage of area burned every year between 19 0 and 199 in the Whitecourt area for four elevations belts.**

Elevation classes (m)	Area (ha)	Mean % burned	Std
375-631	102,081	1.0900	5.8300
631-887	1,344,676	0.2400	1.1700
887-1143	940,277	0.0900	0.2400
1143-1400	164,572	0.1600	0.7800

Table 4. . **Percentage of area burned every year between 19 0 and 199 in the Whitecourt area, by slope class.**

Slope classes (%)	Area (ha)	Mean % burned	Std
0-1	705,995	0.1390	0.4450
1-5	1,384,175	0.1670	0.5650
5-15	6,341,778	0.2110	0.9650
15-30	89,001	0.1660	0.5610
30 +	7,583	0.1340	0.4310

Table 4. . **Percentage of area burned every year between 19 0 and 199 in the Whitecourt area, by aspect class.**

Aspect class	Area (ha)	Mean LSD	Std
1	403,409	0.2100	0.8940
2	782,908	0.2360	1.0450
3	693,204	0.2020	0.8080
4	619,908	0.1460	0.5120
5	287,549	0.1090	0.3760
6	33,955	0.2310	1.1460

Table 4. . **Percentage of area burned every year between 19 0 and 199 in the Whitecourt area, by slope-aspect index (SAI) class.**

SAI classes	Area (ha)	Mean % burned	Std
1	48,532	1.4750	0.7850
2	544,462	1.4810	0.7470
3	1,623,780	1.4150	0.6730
4	553,808	1.4990	0.7640
5	50,350	1.5210	0.7950

Lightning strikes

In this area, each square kilometre of land is struck by lightning more than once, on average (mean=1.445 ls•year^{-1}•km^{-1}, Std. Dev.=0.332 ls•year^{-1}•km^{-1}, n=299). Andison (1997) found a mean of 4.6 hits/km$^{2.}$ However, the period over which this frequency was computed was not stated, thus comparisons are difficult to make. The percentage of land burned did not differ with the LSD (*P*=0.213). In fact, there was no regression relationship between area burned and LSD in each pseudo-township (Figure 4.6).

LSD did not differ among Natural Regions (*P*=0.702). However, the Dry Mixedwood Natural Region seemed to receive fewer lightning strikes than the others (Table 4.8). LSD also did not differ among elevation belts (*P*= 0.789) but there was a tendency for the lowest elevation to receive fewer lightning strikes (Table 4.9). An inverse pattern was observed by Andison (1997) in the Foothills Model Forest where strikes increased from the Alpine Natural Region to the Lower Foothills. The strength of the slope, and aspect index did not affect the likelihood of a lightning strike (*P*>0.95, Table 4.10, 4.11).

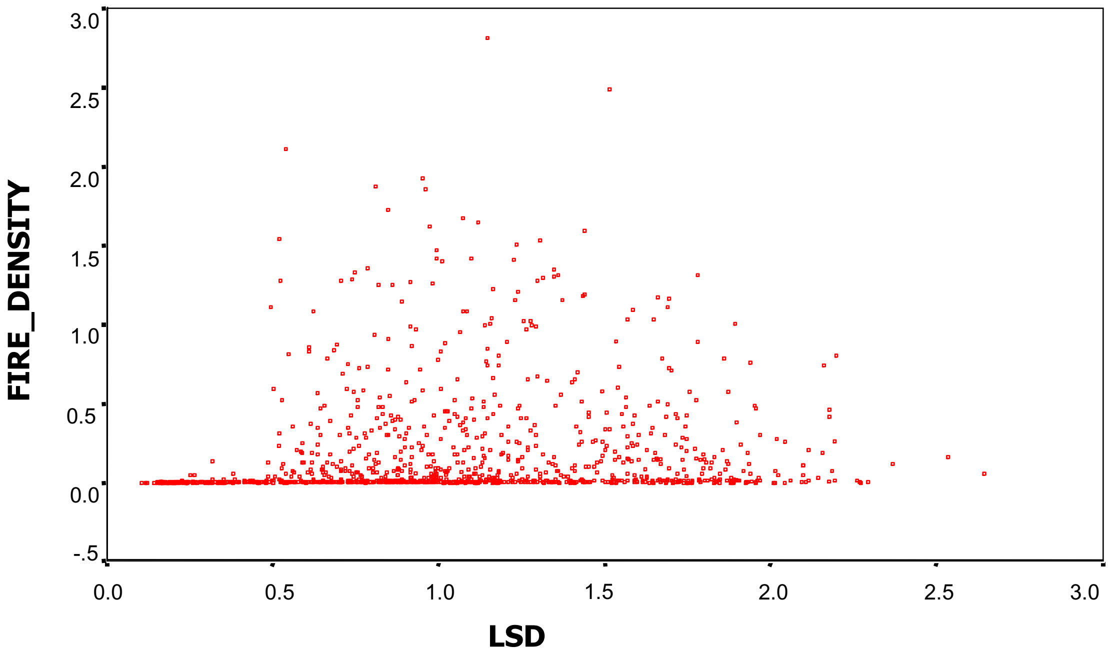

Figure 4. . Scatterplot of LSD and percentage area burned in west-central Alberta for pseudo-townships of 100 km^2.

Table 4. . **Lightning strike density (LSD) every year between 1992 and 199 in the Whitecourt area, by Natural Region.**

Natural regions	Area (ha)	Mean LSD	Std
Boreal Mixedwood	632,825	1.2490	0.4990
Dry Mixedwood	106,123	0.8940	0.2980
Lower Foothills	1,626,927	1.5660	0.8030
Upper foothills	437,078	1.4430	0.7650

Table 4.9. **Lightning strike density (LSD) every year between 1992 and 199 in the Whitecourt area, by elevation class.**

Elevation classes (m)	Area (ha)	Mean LSD	Std
375-631	150,934	1.0650	0.6480
631-887	1,562,984	1.4120	0.6590
887-1143	942,442	1.5580	0.7790
1143-1400	164,572	1.4960	0.8640

Table 4.10. **Lightning strike density (LSD) every year between 1992 and 199 in the Whitecourt area, by slope class.**

Slope classes	Area (ha)	Mean LSD	Std
0-1	705,995	1.3570	0.6190
5-10	1,384,175	1.4660	0.7270
5-15	634,178	1.4990	0.7590
15-30	89,001	1.5060	0.7880
30 +	7,583	1.5130	0.8530

Table 4.11. **Lightning strike density (LSD) every year between 1992 and 199 in the Whitecourt area, by aspect class.**

Aspect class	Area (ha)	Mean LSD	Std
1	403,409	1.4750	0.7080
2	782,908	1.4410	0.7070
3	693,204	1.4240	0.6930
4	619,908	1.4530	0.7140
5	287,549	1.4820	0.7520
6	33,955	1.3400	0.6060

Mean fire return interval by land type

The mean age of patches originating from fire within the entire FMA area is 78.33 years. This mean stand age is 10 years younger than the mean fire return interval obtained from the rollback technique for all of the land types pooled (Table 4.12). This is an expected result because younger disturbances have overlain areas previously disturbed. The 88-year mean fire return interval that we obtained for the whole forest is comparable to the 80 and 101 years evaluated for the Lower and the Upper Foothills Natural Region in the Foothills Model Forest (Andison 1997). It is also similar to the mean fire return interval of 91 years obtained by Armstrong (1999) for east-central Alberta. However, it is far from what we computed with the fire maps, suggesting that the fire coverage for the time period used was incomplete. Percent of the landscape disturbed was highly variable among the 20-year periods in each land type. The fire return interval based on the average of the percent disturbed in 120-year period ranged from 50 years for the lichen bearberry land type to 251 years for the bog/black spruce-larch tamarack land type. Defining different mean fire return intervals for different land types concords to what has been proposed by Rülcker *et al.* (1997) with the ASIO model.

Table 4.12. Rollback estimates of 20-year disturbance rates (%) for each land type in MWFP W09FMU. (See Table 4.2 for Land Type Abbreviations).

Period	BB	Bog	BHS	HWR	LTM	LTSH	LTH	LBB	LBC	Total
1918-37	38	9	28	43	35	19	26	58	32	39
1898-17	25	12	11	20	19	10	20	27	15	19
1878-97	30	6	16	29	30	12	6	48	31	24
1858-77	35	8	33	21	29	18	15	38	21	26
1838-57	20	10	20	30	17	7	16	30	18	18
1818-37	11	3	1	10	11	10	4	38	7	11
Average	**2**		**1**	**2**	**2**	**1**	**14**	**40**	**21**	**2**
MFRI*	**.4**	**2 1.1**	**109.**	**.**	**.2**	**1 9.1**	**1 .**	**0.2**	**9 .4**	**.**

* Mean fire return interval (years)

4. LANDIS CALIBRATION.

Calibration of LANDIS is accomplished by checking three aspects of its behaviour. First, species composition should follow a predictable pattern from one iteration to another (aspen may sometimes exhibit chaotic behaviour). Sporadic behaviour in the absence of a catastrophic disturbance could indicate an error in the seeding algorithm (see He *et al.* (1996) for an explanation of the different dispersal methods offered) or the species life history attribute file. For BAP, we used the seeding method SIM_RAND_ASYM, which allows each species to seed to its maximum seed dispersal distance and a small random chance beyond that.

While observing the change in species composition from the LANDIS simulation outputs for FMU W09, we did not detect any aberrations in the species behaviour, regardless of which species overtakes and dominates the landscape (Figure 4.7). This result suggested that the parameters were well balanced.

It is also important to check that the disturbances respect the range of the characteristics defined by the parameters in the input files. Verification is done using the disturbance log files created by LANDIS. In these files, all of the disturbances that have occured during the simulation are presented by land type for each year of simulation. From this dataset, it is possible to verify that fire size and frequency distribution reflect the parameters given in the input files. For the disturbance size, a *Z* test can then be applied to verify that the mean is significantly different from the theoretical mean disturbance size. If it is significantly different, the disturbance size coefficient in the Parameter Input File will have to be altered to compensate for the deviation. An increase of the coefficient will increase the size of disturbance.

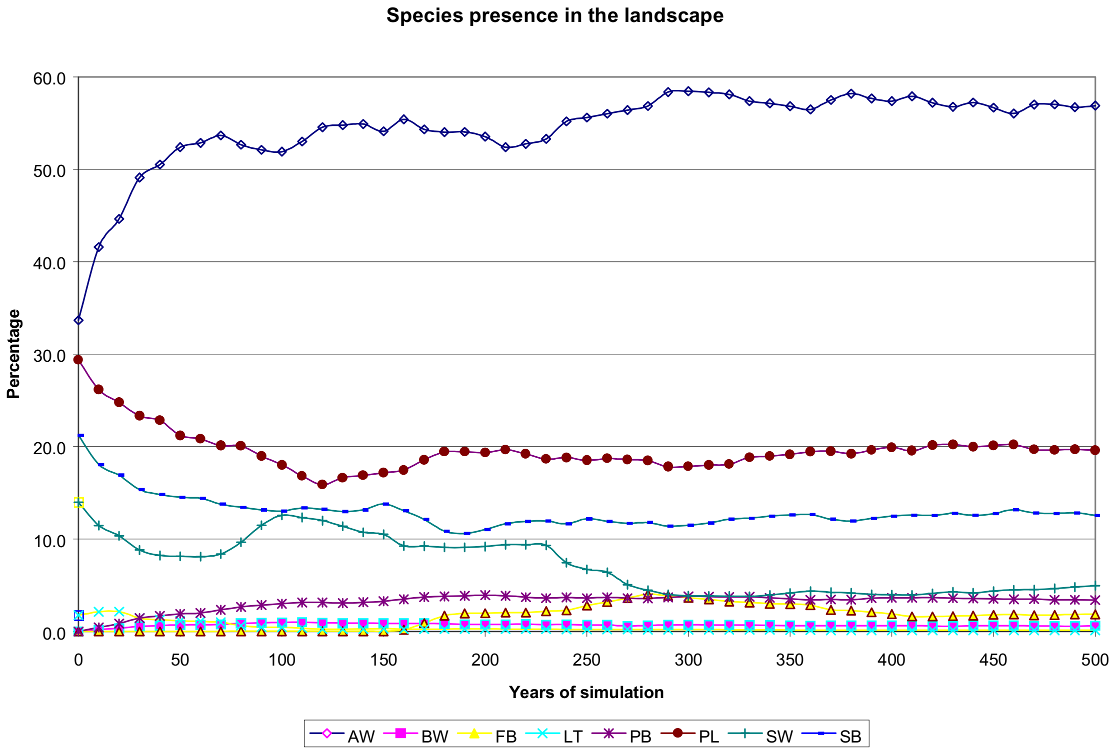

Figure 4. . Species presence in the landscape in a LANDIS simulation of Millar Western's FMU W09 using the parameters defined herein.

To verify the fire return interval, we again used the disturbance log file. We compared the simulated total disturbance sizes summarised for each land type with the expected total disturbances sizes calculated for each land type using the following formula:

[2] Expected total disturbance size = Area * Years /MFRI,

where Area is the total study area, Years is the final simulated year, and MFRI is the mean fire return interval for the land type in question. The same Z test can be used to check for significant differences. If there is a significant difference, one can increase or decrease the observed MFRI by modifying the disturbance probability coefficient in the Parameter Input File. An increase in the coefficient will increase the MFRI. This adjustment can be long and fastidious since only after many trials can one be sure of the best combination of the disturbance probability and the disturbance size coefficients. Moreover, LANDIS is extent-sensitive. Therefore, the model will need to be recalibrated when using it for landscape with a different extent.

4. RESULTS

Fire

Size

Over the 500 years 4,113 fires occurred. Fire size ranged from 0.06 ha (1 pixel) to 10 867 ha in 500 years, with a distribution that follows a log-normal distribution (Figure 4.8). Large fires control the landscape; fifty percent of the total area that burned over the 500 years came from fires greater than 860 ha and 25 % is due to fires that burned 2,076 ha.

Proportion burned

In average, 8.9% of the landscape burns every 10 years (MFRI = 112 years) (Figure 4.9). However, as fire is a stochastic event, total area burned per period ranged from 5 to 15% of the landscape.

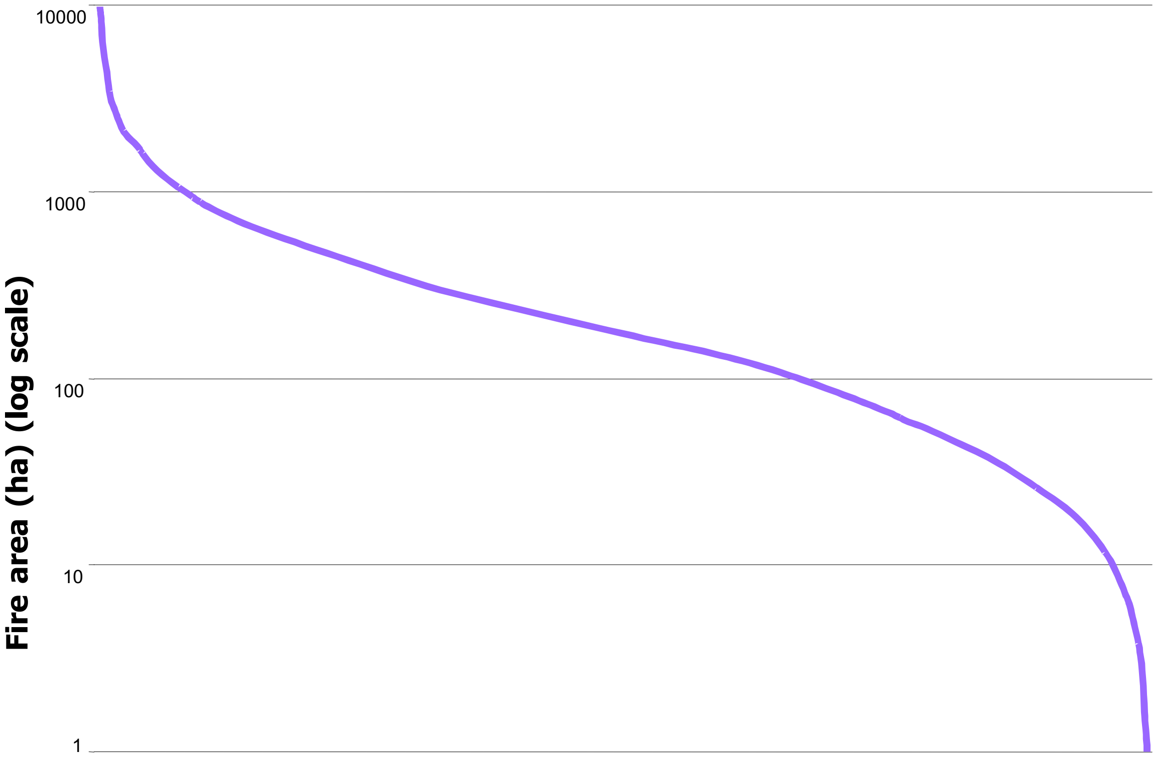

Figure 4. . Fire size distribution of the LANDIS simulation for Millar Western's FMA area.

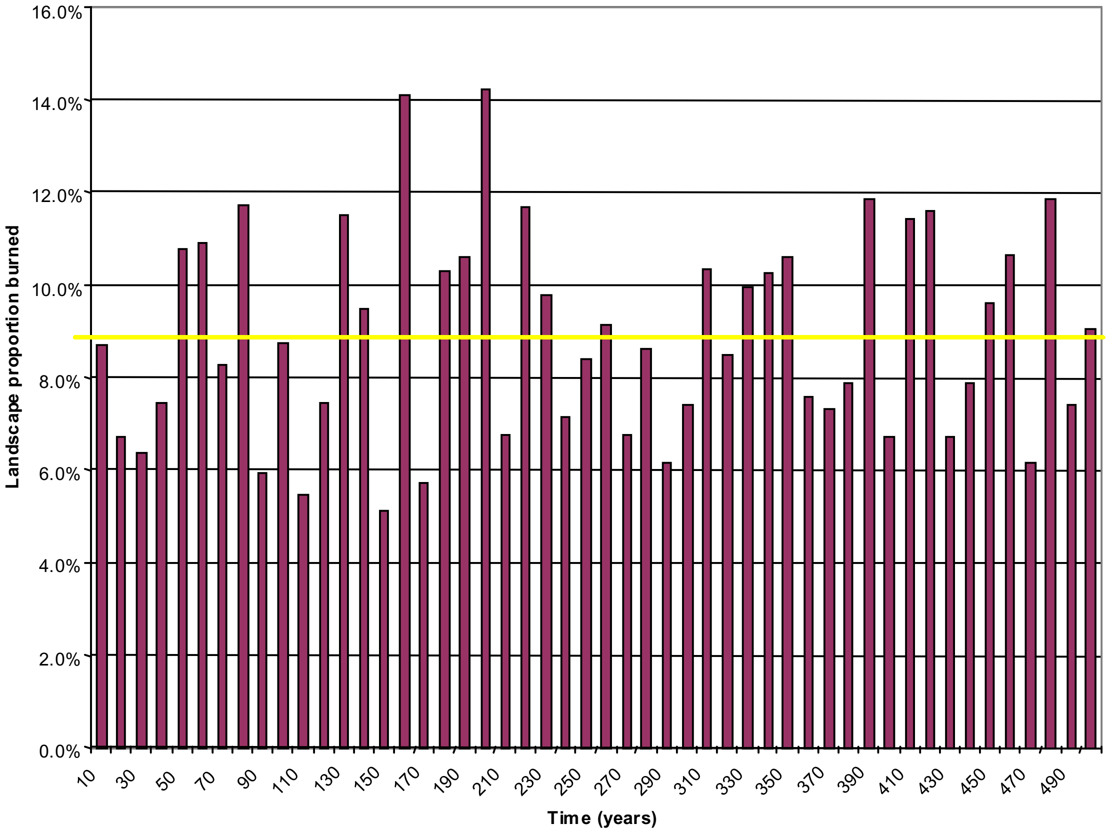

Figure 4.9. Proportion of Millar Western's FMA area burned, by ten-year periods during the 00 years simulation.

Forest

Composition

Despite a high occurrence of fire in the landscape, presence of fire-adapted forest tree species diminished to about half of what they were at the beginning of the simulation (Figure 4.7). Black poplar and balsam fir, two species that were barely present at the start of the simulation became more important. The landscape seemed to move towards an equilibrium in composition after 300 years of simulation. At that time, the landscape was highly dominated by trembling aspen, which was present in nearly 60% of the forest. Coniferous species were present in no more than 40% of the forest.

However, even with such change in species presence, broad habitat type proportion did not change much during the first 200 years (Figure 4.10). Hardwood-dominated stands covered more than 60% of the forest.

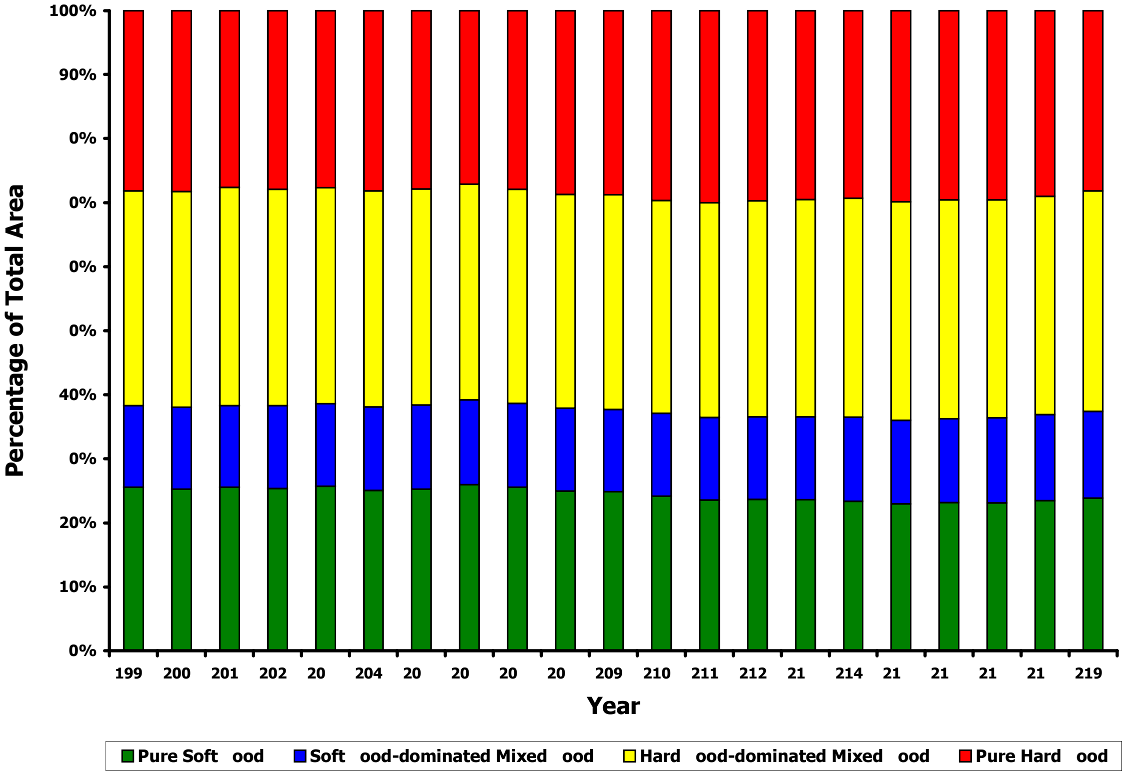

Figure 4.10. Broad habitat types regardless of developmental stage for the first 200 years of the simulation.

Forest age

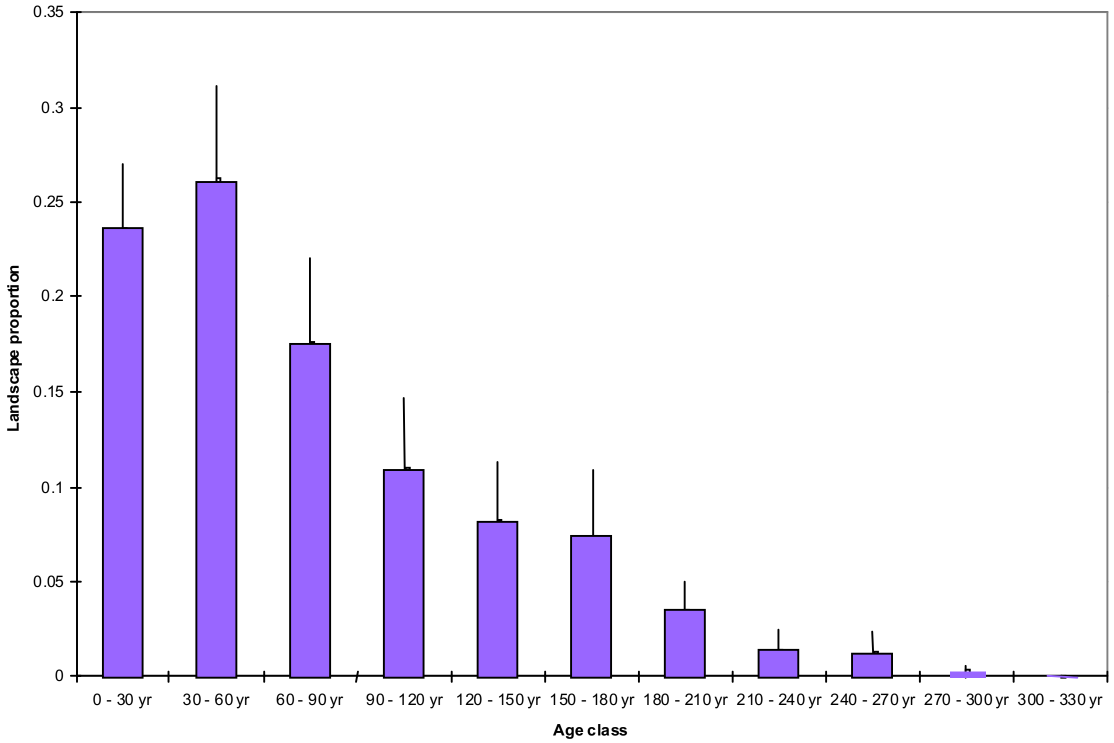

Figure 4.11. Forest age class structure of Millar Western's FMA area over the 00 year simulation. Bars indicate the 9 % confidence interval.

4. DISCUSSION AND RECOMMENDATIONS

There are three points relevant to forest management that can be obtained from these results. The first point concerns the stochasticity of a natural system like a fire disturbance regime versus the homogenization of cut size distribution and regularization of fibre crop through forest management. Based on the outputs of the simulation, it is obvious that the two-pass clearcut system is not natural with respect to size. Variety in disturbance size should be clearly stated as an objective in management planning. The simulation provided insights regarding the appropriate cutblock size distribution in the landscape. By splitting the disturbance size distribution in three classes with each representing a third of the landscape, we found that one third of the forest should be in clustered cutblocks summing to 1,500 ha, to a maximum area limited by the AAC (approximately 8,000 ha) over ten years, a second class should be between 500 and 1,500 ha, and a third smaller than 500 (10 to 500 ha) (Figure 4.12).

Our results showed that under the natural disturbance regime, fluctuations in area disturbed by ten-year period are important. Such a dynamic imposes a certain pattern on the landscape that could not be created under even-flow constraints brought about by forest management. For example, even if cut size was not ruled *per se*, an even-flow constraint would not allow a clearcut bigger than the amount of wood necessary to reach the AAC. The ecological importance of such stochasticity is not clearly understood and serious questions could also be raised regarding the realm of the decisional space for managing a forest for biodiversity under even-flow and age classes regularisation constraints. In fact, the simulation shows that regularising the forest age classes will truncate the development of habitats that are probably of importance for many species. Intensification of silviculture can exacerbate this problem by shortening rotations. However, if intensification of silviculture is embedded in a "triad"

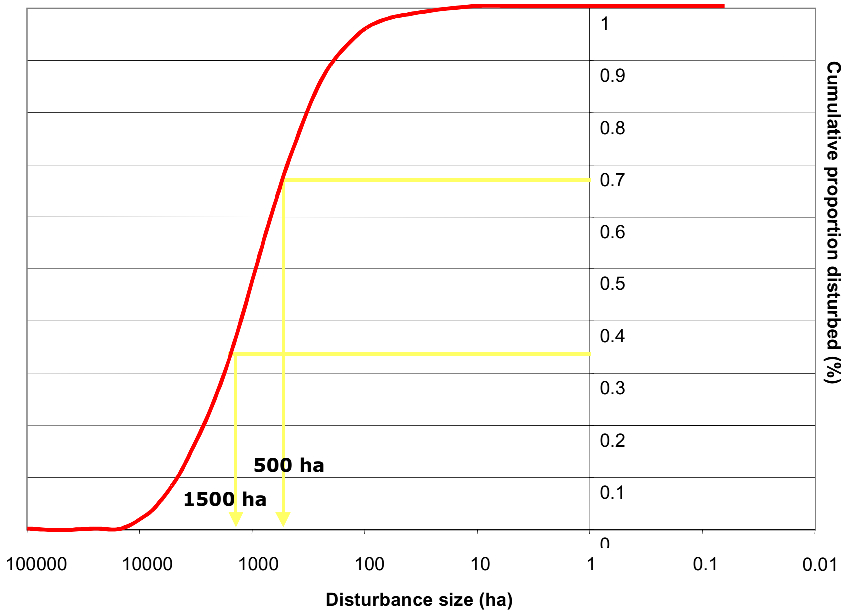

Figure 4.12. Cumulative disturbed proportion of the landscape over the 00 years of simulation by disturbance size.

forest management philosophy (Hunter 1999), each element of the triad could be adjusted to fit a more "natural" age class distribution. Armstrong (1999) found that, despite stability in the lognormal disturbance regime, stochasticity is so important that no target age class distribution could be set as a management goal. However, we advocate that in the context of timber planning, particularly where silviculture intensification is a concern, a negative exponential distribution would be more appropriate than the uniform age class distribution of a regularised forest. Our results would suggest that with 25% of the landscape managed under intensive silviculture with a rotation of 60 years, 66% of the landscape under extensive silviculture with a rotation of 120 years, and 8% of the landscape conserved unmanaged, one can recreate an age class distribution close to what has been observed in the simulation (Figure 4.13).

Forest composition is also an important point of concern. According to the simulation, forest composition is not at its equilibrium with the natural disturbance regime; hardwood species would become much more prominent in the landscape. Although this effect could be an artifact of the parameterisation of the model, it has been shown that aspen and poplar were more important in the landscape in the past. There is no way of validating or invalidating such information coming from the simulation, although doing a sensitivity analysis could help in verifying the extent to which such a result is driven by the system dynamics or by the life history traits parameters (species attributes file). However, if the simulation captures most of the landscape dynamics, serious concerns should be raised regarding Millar Western's timber production strategy pushed by the new forest management plan which goes in the opposite way with the stated goal of increasing coniferous species presence. Biodiversity indicators should help in exploring how this switch in forest composition would affect habitat suitability, especially regarding species requiring hardwood stands.

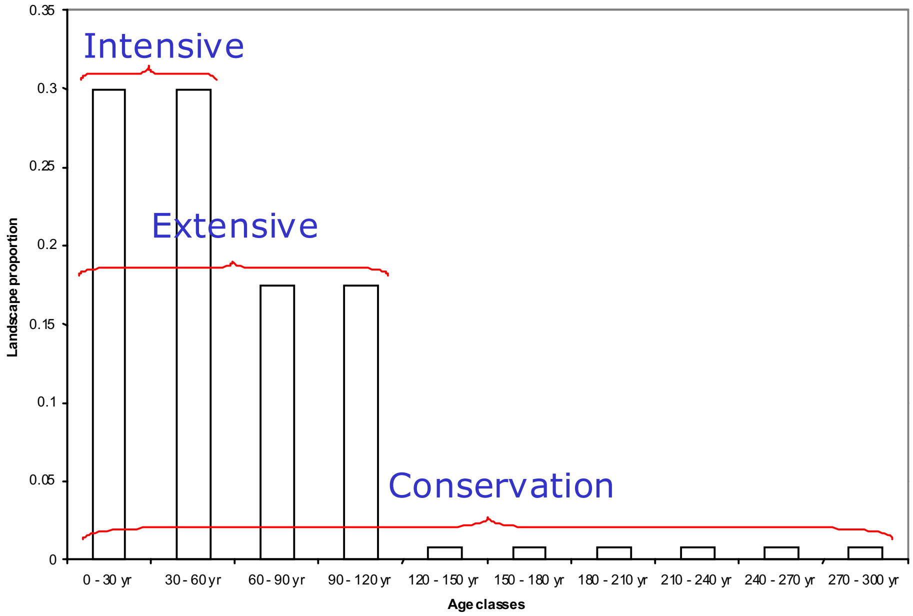

Figure 4.1 . Age class distribution proposed for emulating the natural disturbance regime as simulated by LANDIS for Millar Western's FMA area.

4. CONCLUSIONS

The value of this work lies in the confidence that we have in the model. LANDIS has proven to be a powerful model in regards of the complex dynamics it reproduces. For the purposes of BAP, more analysis should be completed to explore the sensitivity of the outputs when different parameters are used. Several things should be checked at this point:

- The importance of the establishment coefficient in regards to forest composition;
- The role of the maximum disturbance size on the stochasticity of the system; and
- Adjusting the fuel accumulation curves to the stand composition.

Moreover, with the new version of LANDIS, disturbance regimes and forest management regimes can be included at the same time and one can explore the effect of combining both on the forest landscape.

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