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Natural Disturbance Rate and Patch Size Distribution of Forests in Northern British Columbia : Implications for Forest Management

Abstract

A common theme in current forest management policy is that harvesting should be designed to achieve the landscape patterns and habitat conditions that are maintained in nature by natural disturbance regimes. This study was undertaken to determine the influence of climate and topography on disturbance rate and patch size associated with stand replacement wildfire. The purpose was to provide new information to improve forest management guidelines based on approximating natural disturbances currently being implemented in British Columbia.

I modified stand age-class data from inventory records within a geographic information system in order to determine annual disturbance rate and patch size distribution for 9 areas differing in regional climate and topography (plateau vs montane). Regression analysis was used to determine the influence of climate and gross topography on fire cycle. Patch size distribution was compared graphically and statistically.

Annual disturbance rate and patch size distribution in northern natural forests in British Columbia were clearly related to regional climate and topography. In montane landscapes, a decrease in disturbance rate, a decrease in mean patch size and a decrease in proportion of area in patches > 1,000 ha was associated with increasing precipitation. For plateau areas, topographic units with intermediate precipitation regime had higher disturbance rates and a greater proportion in patches > 1,000 ha. Montane areas which were climatically similar to adjacent plateau areas had a lower disturbance rate and less area in larger patches.

Current biodiversity guidelines appear to underestimate the fire cycle for many areas. Maximum allowable patch size in the current guidelines was lower than the maximum natural disturbance patch size determined for any of the landscapes examined. Current recommendations also suggest to manage for more area in 40-250 ha patches then was evident from the data.

Introduction

Public criticism of past practices and better understanding of natural systems have resulted in the emergence of new ideas about forest management (Maser 1988, Franklin 1989, Hansen et al. 1991). One such idea is that managed disturbances should be designed to achieve the landscape patterns and habitat conditions that are maintained in nature by natural disturbance regimes. This suggestion is derived in part from emerging evidence that disturbance has a key ecological role in many forested ecosystems (Zackrisson 1977, Van Wagner 1978, Hessburg et al. 1994). The underlying assumption is that the biota of a forest is adapted to the conditions created by natural disturbances and thus should cope more easily with the ecological changes associated with timber harvest if the patterns created resemble those of natural disturbances (Hunter 1993, Swanson et al. 1993, Bunnell 1995, DeLong and Tanner 1996).

Natural disturbances maintain plant and animal diversity over time and space by maintaining structural complexity within stands and by influencing the size, distribution, edge characteristics, and dispersion of stands across the landscape (Zackrisson 1977, Hansen et al., 1991, Hessburg et al. 1994). The size, shape, and location of individual forest patches or stands profoundly affect forest community stability and productivity (Franklin and Forman 1987, Frank and McNaughton 1991). The impacts of forest management appear now to exceed and confound those of natural disturbance agents (DeLong and Tanner 1996). Hence, understanding how the forested landscape was affected by natural disturbance is needed to develop alternative management systems which more closely approximate natural disturbance in their effects.

Within sub-boreal and boreal forests wildfire is the dominant natural disturbance regulating disturbance rate and patch size at the landscape scale (Rowe and Scotter 1971; Zackrisson 1977; Van Wagner, 1978; Heinselman, 1981). Climatic variation in time and space, and topography exert a strong influence on fire disturbance rate and fire patch size distribution (Heinselman 1981; Romme 1982, Barrett et al. 1991). A large body of literature exists on the wildfire disturbance rate for sub-boreal and boreal forests,(e.g., Zackrisson 1977, Heinselman 1981, Foster 1983, Payette et al. 1989, Vasbinder et. al. 1997) and some literature exists on patch size distribution (e.g., Foster 1983, Payette et al. 1989, Hawkes et. al. 1997). However, there is no evidence that these studies were intended to assist in the development of more ecologically based forest management. Recently, using natural variability as a basis for forest management has received considerable attention (Hunter 1993, Swanson et al. 1993, DeLong and Tanner 1996). In British Columbia, the Biodiversity Guidebook (British Columbia Ministry of Forests 1995), a supporting document for the Forest Practices Code Act of British Columbia (Province of British Columbia 1994), uses natural variability as a basis for recommending seral stage and patch size distribution for different natural disturbance types. Natural disturbance types are meant to recognize different natural disturbance regimes under which ecosystems have developed and were formed by grouping biogeoclimatic units (areas of relatively homogeneous regional climate that are recognized within the Biogeoclimatic Ecosystem Classification system in use in British Columbia (Pojar et al. 1987)) that were assumed to have similar disturbance intensities and frequencies (Table 1). However, limited data were available from which to derive these recommendations. Numbers for disturbance return interval and recommended patch size distribution were based on expert opinion and are meant to be altered as new data becomes available.

In this paper I examine the variation in annual disturbance rate and patch size distribution between different areas of relatively homogeneous macroclimate and topography within forests of northern British Columbia. My objective is to provide new information about the influence of climate and topography on large-scale disturbance pattern that may ultimately be used to improve forest management guidelines based on approximating natural disturbance contained in the Biodiversity Guidebook (British Columbia Ministry of Forests 1995). Specifically, I will test the hypotheses that annual disturbance rate is significantly related to certain climatic variables and that patch size distribution is significantly different among distinct units of homogeneous macroclimate and gross topography. I will also examine the implications of the findings to assumptions inherent in the guidebook and the placement of particular biogeoclimatic units within natural disturbance types.

Study Area

The study was conducted in British Columbia within a large area which included rolling plateau and mountainess terrain near Prince George. The study area extends between 53 - 57°N and 120 - 126°W. Areas included in the study fell within either the Sub-boreal Spruce (SBS), Engelmann Spruce - Subalpine Fir (ESSF) or Boreal White and Black Spruce (BWBS) zone (Meidinger and Pojar 1991). Forests within the drier portions of the study area are dominated by lodgepole pine (*Pinus contorta*) or hybrid white spruce (*Picea glauca* x *engelmannii*) while forests within the wetter portions are dominated by hybrid white spruce at elevations < 1,000 m and either Engelmann spruce (*Picea engelmannii*) or subalpine fir (*Abies lasiocarpa*) at higher elevations. At elevations < 1,000 m throughout the study area there are localized areas dominated by trembling aspen (*Populus tremuloides*) or black spruce (*Picea mariana*), and scattered patches dominated by Douglas-fir (*Pseudotsuga menziesii*) or paper birch (*Betula papyrifera*). Throughout most of the study

TABLE 1. Description of Natural Disturbance Types and current placement of units examined in this study.

Natural Disturbance Type	Description	Current Placement of Units Examined
NDT1	Ecosystems with rare stand-initiating events	
NDT2	Ecosystems with infrequent stand-initiating events	wet cool montane, very wet cool, moist very cold subalpine
NDT3	Ecosystems with frequent stand-initiating events	dry warm plateau, moist cold plateau, moist cool plateau, moist cool montane, wet cool plateau
NDT4	Ecosystems with frequent stand-maintaining fires	
NDT5	Alpine tundra and subalpine parkland	

area commercial forest harvesting has been limited to the last 40 years. Based on intensive field studies by Andison (1996) and DeLong and Tanner (1996) in a mesic portion of the study area and by DeLong (unpublished data) in a wetter portion of the study area it appears that larger disturbances (i.e., > 5 ha) are generally a result of stand replacement wildfire.

The main portion of the study area encompasses a strong precipitation gradient from west to east and considerable topographical variability while maintaining consistency within a climatic forest context (i.e., all within one biogeoclimatic zone), and fire type (i.e., primarily stand replacement crown fires). This allows an opportunity to examine the effects of climate and topography on fire disturbance rate and patch size distribution while minimizing the effects of forest composition and fire type. The study also includes some units from other biogeoclimatic zones for comparison. A summary of climatic data for the 7 biogeoclimatic units included in this study is shown in Table 2.

Methods

The study area was subdivided into units of relatively homogeneous macroclimate and topography in order to determine the effect of these factors on disturbance rate and patch size. The subzone and variant levels of the zonal classification of the Biogeoclimatic Ecosystem Classification (BEC) (Pojar et al. 1987) were used to delineate areas of relatively homogeneous macroclimate. The zonal classification breaks the landscape up into biogeoclimatic units which are classes of geographically related ecosystems that are distributed within a vegetationally-inferred climatic space (Pojar et al. 1987). Subzones and variants are mapped in large part using distributional information for sampled zonal climax ecosystems. Using a set of pre-defined rules a different subzone or variant occurs where a different plant association is represented for a zonal climax ecosystem. Zonal ecosystems are those in which the integrated influence of climate on vegetation, soil, and other ecosystem components is most strongly expressed and thus best reflects the regional climate of an area (Pojar et al. 1987). Where little data existed for zonal climax ecosystems, relationships between these ecosystems and forest cover, topography and/or elevation were used to map biogeoclimatic lines.

The Nechako River variant of the moist cool Sub-boreal Spruce (SBSmk1) and Willow River variant of the wet cool Sub-boreal Spruce

TABLE 2. Correspondence of topoclimatic units with units according to Biogeoclimatic Classification and summary of climatic data for the units.

Topoclimatic Unit	Biogeoclimatic Unit[1]	MAP[2]	MSP[2]	MWP[2]	MAT[2]
Dry Warm Plateau	Blackwater variant of the dry warm Sub-boreal Spruce (SBSdw3)	494	259	270	2.7
Moist Cool Plateau	Mossvale variant of the moist cool Sub-boreal Spruce (SBSmk1)	727	273	444	1.8
Moist Cool Montane	Mossvale variant of the moist cool Sub-boreal Spruce (SBSmk1)	727	273	444	1.8
Moist Cold Plateau	Kluskus variant of the moist cold Sub-boreal Spruce (SBSmc3)	506	261	263	0.6
Wet Cool Plateau	Willow variant of the wet cool Sub-boreal Spruce (SBSwk1)	898	346	536	2.7
Wet Cool Montane	Willow variant of the wet cool Sub-boreal Spruce (SBSwk1)	898	346	536	2.7
Very Wet Cool Montane	Very wet cool Sub-boreal Spruce (SBSvk)	1250	472	763	1.9
Dry Cool Boreal	Stikine variant of the dry cool Boreal White and Black Spruce (BWBSdk1)	418	221	222	-0.3
Moist Very Cold Subalpine	Nechako variant of the moist very cold Engelmann Spruce - Subalpine Fir (ESSFmv1)	no data	no data	no data	no data

[1] see Meidinger and Pojar (1991) for further description.

[2] MAP = mean annual precipitation (mm), MSP = mean seasonal precipitation (May 1 – Sept 30) (mm), MWP = mean winter precipitation (Oct. 1 – April 30) (mm) , MAT = mean annual temperature (° C)

(SBSwk1) were subdivided into plateau and montane topography types (Table 2). Existing digital biogeoclimatic lines were modified in a geographic information system (GIS) in order to produce a digital overlay of polygons of relatively homogeneous macroclimate and topography. This layer will subsequently be referred to as the "topoclimatic" layer.

Polygons of forest age were generated from existing digital forest inventory age information by a GIS in order to examine relative disturbance rate and patch size. Regeneration after disturbance was assumed to be prompt (i.e., within 5 years), therefore disturbance age and size could be derived from stand age data (Agee 1994). This assumption is supported by age data collected throughout a portion of the study area (Andison 1996).

The following procedures were used to generate annual disturbance rate and patch size distribution. For the purposes of this study the definition of a patch is meant to correspond to that currently being used by forest planners for assessing existing patch size distribution for comparison to that recommended in the Biodiversity Guidebook (British Columbia Ministry of Forests 1995). The definition of a patch within the Biodiversity Guidebook is any contiguous area affected by individual or multiple stand replacement disturbance(s) (e.g., harvesting, wildfire) within the current 20-year period. For this study, a patch is defined as any polygon that was entirely within the same 20-year age-class. For the forest inventory, forest age of a map polygon is interpreted from 1:15,840 black and white aerial photographs by comparing height, crown closure and crown condition with adjacent polygons. Periodic ground-truthing is performed to verify stratification and standards require polygon age to be within 15% of actual age (British Columbia Ministry of Forests 1992). The estimated age of each polygon is subsequently assigned to an age-class which forms a portion of the information included for each map polygon in a GIS. From the digital files, maps of age-classes 3 (41-60 yrs old) and 4 (61-80 yrs old) were generated. There were several reasons for using these age-classes based on a previous study done by DeLong and Tanner (1996) within a portion of the present study area. This study indicated that fire control had significantly reduced disturbance related to wildfire in stands younger than 40 years of age and a significant portion of stands older than 80 years had been disturbed by subsequent wildfire. In addition, results from the study indicated that age-class 3 and 4 represented the range in disturbance rate over five 20-year periods prior to effective fire control. Also, there is little chance that age-class 3 and 4 patches have been altered by harvesting due to the lack of this activity in stands < 80 years of age. Using only age class 3 and 4 data also reduces the chance of significant overlap in areas disturbed which is one of the limitations of using stand age-class distributions to predict fire cycles (Andison 1996).

The topoclimatic layer and the age-class layer were overlaid to produce resultant polygons. A database containing area and perimeter of each polygon was produced for each of the 18 1:250,000 map sheets in the study area. Prior to the final database being generated, an automated GIS function was used to remove any forest age-class polygon where over 20% of the edge of the polygon was bordered by cultivated land. This was done to avoid inclusion of polygons that represent fragments of larger patches which have been subdivided by recent land clearing related to agriculture. In contrast to forest harvest operations, stands of all ages have been cleared for agriculture. Polygons removed by this function covered up to a maximum of approximately 3% of the total area of an individual 1:250,000 map sheet in the study area.

Maps of each 1:250,000 map sheet were used to further modify the generated databases. Areas of any polygons which had been arbitrarily subdivided by 1:250,000 map sheet edges were amalgamated into one total area. In order to eliminate artificial patch sizes created by the topoclimatic lines, the total area of any polygon which was subdivided by a topoclimatic line was entered into the unit in which it covered the most area and subsequently eliminated from the other unit. Polygons such as strips of forest cover types that are not assigned an age-class (e.g., non-commercial brush) or clearing for roads or power lines which are indicated as a more recent cultural disturbance can bisect age-class polygons that should be considered all one disturbance patch. In addition, wildfire intensity often varies spatially leaving a bands of trees separating small polygons from the main disturbance. For these reasons, areas of polygons of the same age-class which were less than 250 m apart were summed to produce one total area. Similar procedures are currently being used to join polygons for analysis of existing patch size distribution in order to implement recommended patch size distribution guidelines found in the Biodiversty Guidebook (British Columbia Ministry of Forests 1995).

Once final databases were produced for each topoclimatic unit, I calculated summary statistics for polygon area by age-class for each topoclimatic unit. I then subdivided databases for each topoclimatic unit/age-class combination into individual databases using different patch size cutoffs. The sum of polygon area for each age-class and patch size was subsequently calculated. Using this data, I generated histograms of proportion of total disturbance area by patch size.

I calculated annual disturbance rate (dr) for any given time period, either 20 or 40 years, as an average percent of total forested area disturbed in a year. The inverse of this result, 1/(dr/100), is equal to the fire cycle (Johnson 1992). Total forested area was calculated for each topoclimatic unit using the inventory database.

Climatic data for each topoclimatic unit were extracted from Reynolds (1996) which summarizes climatic data for all biogeoclimatic units in British Columbia. Climate within topoclimatic units that resulted from splitting of a biogeoclimatic unit based on topography were assumed to have the same relative climate as the entire biogeoclimatic unit.

Analysis

I used multiple linear regression analysis to model the relationship between fire cycle and climatic and topographic variables. The climatic variables evaluated for inclusion in the model were mean annual precipitation (MAP), mean seasonal precipitation (MST), mean winter precipitation (MWP), and mean annual temperature (MAT). Gross topography was included as a dummy variable and coded as either 0 for plateau or 1 for montane (Wilkinson et al. 1996). I screened the independent variables by conducting a stepwise regression and selected the final models on the basis of the equations which minimized the relative mean square residual (1 minus adjusted R^2), had unbiased residuals, and required the fewest independent variables (Wilkinson et al. 1996). For all final regression models, I examined a plot of the residuals against predicted variables in order to assess homogeneity of variance of the residuals (Wilkinson et al. 1996).

Graphical output was used to make comparisons of patch size distribution between different topoclimatic units. In addition, I tested for differences in patch size distribution between different topoclimatic units using the continuous form of the Kolmogorov-Smirnov 2-sample test (2-tailed) which tests whether the patches in the two areas could have been drawn from the same distribution (i.e., same mean, standard deviation and shape) (Wilkinson et al. 1996).

Results

Annual disturbance rate and the frequency distribution of patch size varied considerably over the units examined (Table 3). The amount of disturbance from 1931 to 1950 was consistently lower than from 1911 to 1930 (Table 3). Mean annual disturbance rate over the total 40-year period ranged from 0.06 to 0.96% of the total forested area per year which is equivalent to a range in fire cycle of 104-1,667 years (Table 3). The lowest annual disturbance rate was for the very wet cool montane unit and the highest was for the moist cold plateau unit (Table 3).

For the 7 topoclimatic units examined within the SBS, 93% of the variation in mean fire cycle could be accounted for by mean seasonal precipitation and gross topography (plateau vs montane) (Table 4). Mean seasonal precipitation alone could account for 91% of the variation and was a superior predictor to mean annual precipitation (Table 4).

Using the data from 1910 to 1930, three of the nine units studied had patch sizes > 10,000 ha and for the moist cool plateau unit they accounted for 60% of total disturbed area. The proportion of disturbed area in patches 101-1,000 ha in size varied considerably from a low of 12.3% for the moist cold plateau unit to a high of 61.5% for the very wet cool montane unit. The boreal and subalpine units included in the analysis had a similar patch size distribution to the wet cool plateau sub-boreal unit but annual disturbance rate was lower (Table 3).

Mean annual disturbance rate and mean, maximum and SD of patch size for montane sub-boreal topoclimatic units decreased with increasing precipitation (Tables 2,3&5). For the same units,

TABLE 3. Disturbance extent and rate and patch size distribution for topoclimatic units examined.

		Disturbance extent and rate			Patch size distribution[2]				
Topoclimatic Unit	Total Forested Area (ha)	Period 1 (1931-50)	Period 2 (1911-30)	Total Period (1911-50)	<10	10-100	101-1000	1001-10,000	>10,000
			(ha) **(% of total forested area/yr)**				(% of total disturbance area)		
Dry warm plateau	637,662	45,368 **0.36**	95,983 **0.75**	141.351 **0.55**	2.5	13	29	55.5	0
Moist cool plateau	577,658	48,919 **0.42**	133.311 **1.16**	182,230 **0.79**	1.5	7.7	12.7	18	60.1
Moist cool montane	547,738	31,139 **0.28**	59,226 **0.54**	90,365 **0.41**	0.9	7.5	18.1	55.7	17.8
Moist cold plateau	280,416	37,611 **0.67**	69,966 **1.25**	104,981 **0.96**	0.8	4.5	12.3	40.7	41.7
Wet cool plateau	341,776	19,728 **0.29**	30.097 **0.44**	49,825 **0.37**	2.3	16.5	43.7	37.5	0
Wet cool montane	241,924	7.213 **0.15**	11,692 **0.24**	18,905 **0.20**	3.6	22.0	36.0	38.4	0
Very wet cool montane	395,603	1,515 **0.02**	8,321 **0.1**	9,836 **0.06**	4.4	21.1	61.5	13.0	0
Dry cool boreal	633,381	28,443 **0.22**	47,284 **0.38**	75,727 **0.30**	1.8	19.1	55.7	23.4	0
Moist very cold subalpine	172,327	6,511 **0.19**	16,836 **0.48**	23,347 **0.34**	0.7	7.6	30.5	61.2	0

[2] patch size distribution show in the table is based on data for 1910-1930.

the proportional amount of total disturbance area in patches > 1,000 ha decreased with increasing precipitation (Figure 1). In each of the montane sub-boreal topoclimatic units, patch sizes > 100 ha dominated the landscape (Figure 1). Using the patch size distribution for 1931-1950 significant differences in patch size distribution were apparent. The Kolmogorov-Smironov 2-sample test (2 tailed) indicated significant differences between the moist cool montane unit as compared to the wet cool and very wet cool montane units (p=0.002 and p=0.000 respectively). There was no difference between the wet cool and very wet cool montane units (p=0.119).

TABLE 4. Summary of regression output for final regression models for fire return using different climatic variables and gross topography.

Model	Adjusted R^2	F-Ratio	p
FC[1] = 1.063 x MAP[1] - 537.915	0.763	20.311	0.006
FC = 3.849 x MSP[1] - 928.916	0.907	59.78	0.001
FC = 3.409 x MSP + 117.189 x GT[1] - 839.085	0.927	39.184	0.002

[1] FC = fire cycle, MAP = mean annual precipitation (mm), MSP = mean seasonal precipitation (May 1– Sept. 30) (mm), GT = gross topography 0 = plateau 1 = montane.

TABLE 5. Mean, maximum and standard deviation of patch size for different sub-boreal topoclimatic units using age data from 1910-1950.

Statistic	Topoclimatic Unit						
	Montane			Plateau			
	Moist Cool	Wet Cool	Very Wet Cool	Dry Warm	Moist Cold	Moist Cool	Wet Cool
Mean	213	74	62	76	296	179	96
Maximum	10,458	1,931	1,082	7,693	19,030	41,787	2,514
SD	906	224	146	418	1,602	1,858	270

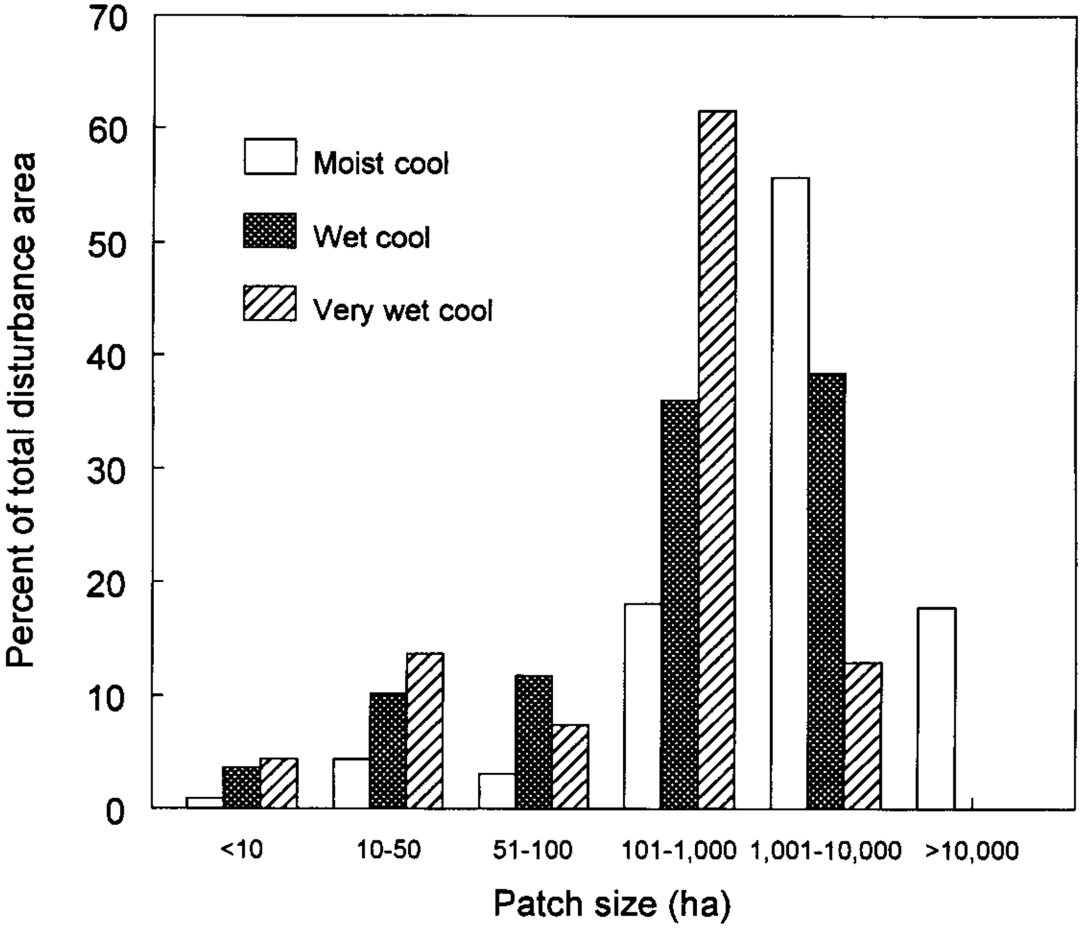

Figure 1. Percentage of total disturbance area in patch sizes for the moist cool, wet cool, and very wet cool montane topoclimatic units.

For plateau sub-boreal topoclimatic units, annual disturbance rate and mean, maximum and SD of patch size was highest for units with intermediate levels of precipitation (Tables 2,3&5). The proportional amount of total disturbance area in patch sizes < 1,000 ha was higher for the dry warm and wet cool units than the 2 moist units (Figure 2). Using the patch size distribution for 1911-1930 significant differences in patch size distribution were apparent. The Kolmogorov-Smironov 2-sample test (2 tailed) indicated significant differences ($p<0.05$) between all units except the moist cold and moist cool units.

The Kolmogorov-Smironov 2-sample test (2 tailed) indicated significant differences in patch size distribution between the plateau and montane portions of the moist cool unit using data from both the 1911-1930 ($p=0.000$) and 1931-1950 ($p=0.008$) time periods. The proportion of disturbed area in patch sizes > 10,000 was higher for the plateau portion then for the montane portion (Figure 3). Patch size distribution for montane versus plateau portions of the wet cool unit was only significantly different using age-class 3 data ($p=0.018$).

Discussion

In order to compare the annual disturbance rates estimated from this study to those for similar forest types, it is valuable to determine if the estimates from this study are reasonable. The annual disturbance rates for the time period examined (i.e., 1910-1950) may not be representative of the historic disturbance cycle of the units examined.

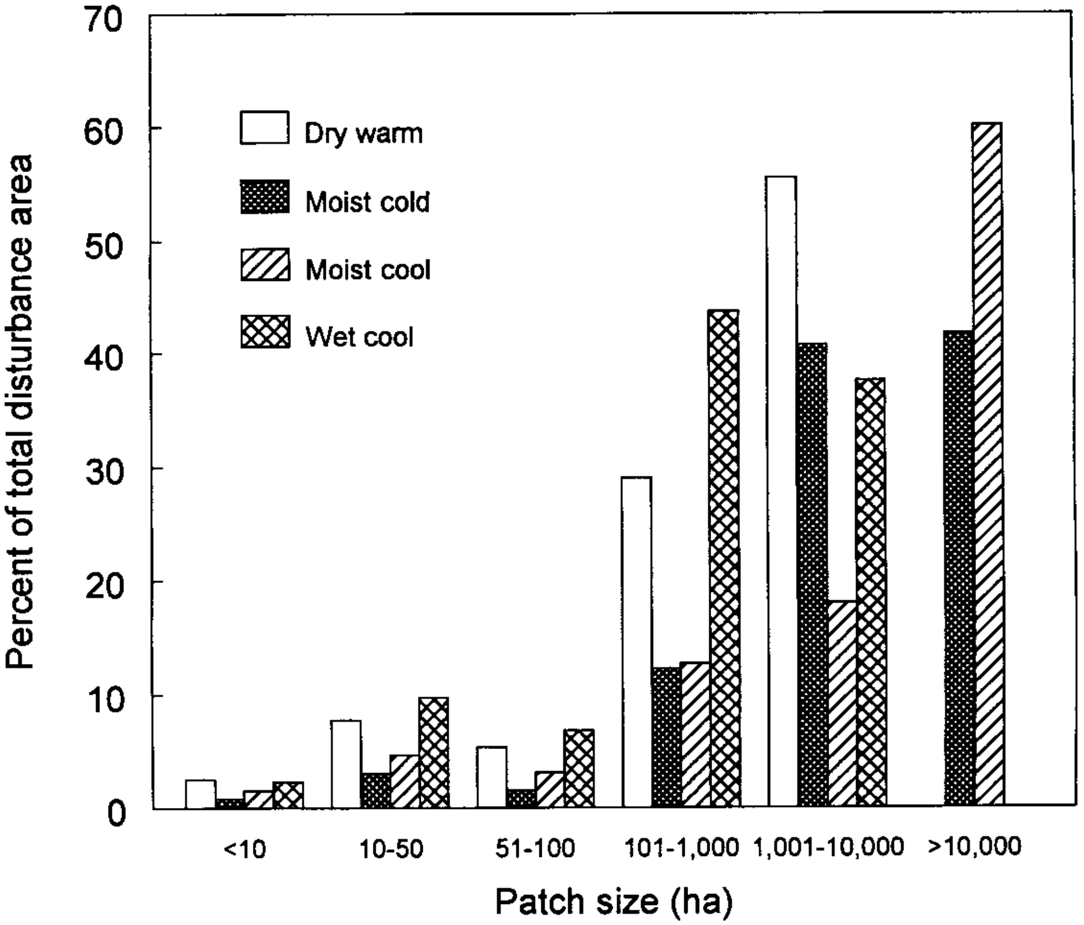

Figure 2. Percentage of total disturbance area in patch sizes for the dry warm, moist cold, moist cool and wet cool plateau topoclimatic units.

Rates of disturbance, especially wildfire, are variable between one time period and another and therefore the cycle computed over a relatively short period will not accurately reflect the true disturbance cycle (Heinselman 1981). A detailed examination of the fire cycle for an area nearly equivalent to that of the moist cool topoclimatic unit was conducted by Andison (1996) using data from all age-classes of forest. Andison (1996) estimated an average disturbance rate of 22.2 - 23.3% over any 20-year period or an average annual disturbance rate of 1.11 - 1.17%/year. The annual disturbance rates of 0.42% and 0.79%/year estimated for the periods 1931-50 and 1911-50 respectively, are below this range. However, the estimate of 1.16%/year for the period of 1911 to 1930 is just within the upper limit. The low annual disturbance rate for 1931-50 could be related to some limited fire suppression activities. Consequently I will focus on making comparisons using the estimate for the period of 1911 to 1930.

The annual disturbance rates computed for the dry warm, moist cool and moist cold plateau units are within the range of rates calculated for similar forest types throughout the boreal forest (Tables 3 & 6). The wet cool plateau, moist cool montane, and moist very cold subalpine have annual disturbance rates which are more comparable to rates calculated for Acadian and high elevation spruce subalpine fir forests (Tables 3 & 6). The remaining units had annual disturbance rates lower than those found in the literature.

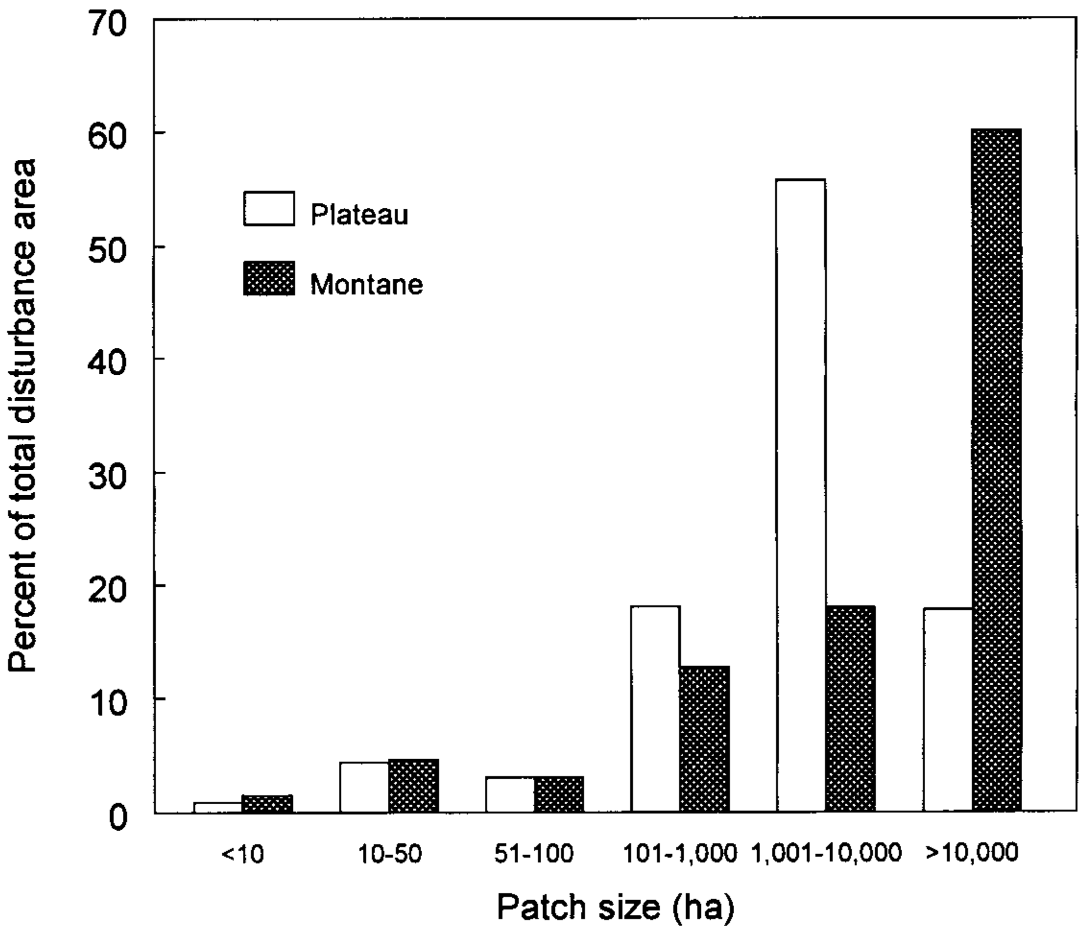

Figure 3. Comparison of percentage of total disturbance area by patch size for the plateau moist cool unit versus the montane moist cool unit.

The finding that the dry cool boreal unit had a lower annual disturbance rate than other boreal forests reported in the literature is likely related to its physiography. This unit is restricted to valley bottoms in the north central mountain ranges in British Columbia whereas boreal units examined in previous studies have been situated on plateaus or rolling hills.

The patch size distributions for the landscapes examined are more heavily skewed to patches under 10,000 ha than those calculated for the same time period for a portion of the boreal forest in Quebec (Payette et al. 1989). Using data from Payette et al. (1989), for the same time period as this study (i.e., 1910-1950), 93.3% of the total area disturbed were in patches >10,000 ha. Only the moist cool and moist cold sub-boreal units had patches >10,000 ha with a high of 60.1% for the moist cool plateau unit (Table 3). The patch size distribution of the moist very cold subalpine unit was reasonably close to that for subalpine forests in Banff National Park. Using data from White (1985) from 1910 to 1930 for fires >40 ha, there were 2.8. 14.8, and 82.4% of the total disturbance area in patches of 40-100, 101-1,000, and 1001-10,000 respectively versus 4.4, 31.7, and 63.9 for the moist very cold subalpine unit during the same time period.

The finding of a lower annual disturbance rate and significantly more area in smaller patches within the montane versus the plateau portions of the moist cool sub-boreal units may be due in large part to the relative proximity to other climatically and structurally different forests. On a

TABLE 6. Disturbance rate estimates from other studies in forest types similar to that of the study area.

Disturbance rate (% of total area/yr)	Location	Size of area (ha.)	Methods and Period	Forest type	Reference
0.9	Caribou Range, N.W.T.	10,500,000	Fire reports (1966-72)	Boreal—*Picea mariana, Pinus banksiana, Picea glauca, Larix larciana, Betula papyrifera, Populus tremuloides*	Johnson and Rowe (1975)
0.7	Protected areas in N.W.T., northeastern Alb. and northern Sask. and Man.	Not Available	Fire reports (1961-64)	Boreal—*Picea mariana, Pinus banksiana, Picea glauca, Larix larciana, Betula papyrifera, Populus tremuloides*	Scotter (1967)
1.0	Boundary Water Canoe Area, Minnesota	215,000	Historic records, fire scars on trees (1727-1910)	Near boreal—*Picea mariana, Pinus banksiana, Abies balsamea, Betula papyrifera*	Heinselman (1973)
1.2	Northern Quebec	570,000	Historic records, fire scars on trees (1910-1950)	Boreal—*Picea mariana, Pinus banksiana, Larix larciana, Betula papyrifera, Populus tremuloides*	Adapted from data presented in Payette *et. al.* (1989)
0.5	Nova Scotia	5,350,000	Land survey records (1900-1910)	Acadian—*Picea rubens, Abies balsamifera, Betula aleghaniensis, Acer saccharum*	Adapted by Wein and Moore (1977) from Fernow (1912)
0.5	Banff National Park, Alberta	180,000	Fire scars on trees (1881-1940)	Subalpine—*Pinus contorta, Picea engelmanii, Abies lasiocarpa, Larix lyallii*	Adapted for this paper for period of 1900-1940 from White (1985)

plateau, fire may spread in any direction and it will still likely be burning in climatically and structurally similar forests. However, when burning in a mountain valley it is more likely the fire will burn up the valley sides into forests which are more open and have a distinctly wetter, cooler climate.

DeLong and Tanner (1996) estimated the wildfire annual disturbance rate for 1950-1970 for the moist cool plateau unit to be very low (0.025%/yr), likely in response to effective fire control. The very low rate in this period coupled with the low rate for 1930-1950 and relatively low rate of forest harvesting, estimated to be 0.17%/yr starting in the 1950's, would have significantly altered the age-class structure of these forests. Assuming this same general pattern existed throughout the study area, forest age-class structure could have been significantly affected in landscapes where fire was common (i.e., the plateau topoclimatic units). The impacts of this shift in age-class structure towards older forests in these areas are unknown. The build-up of old forest could have led to more spruce beetle (*Dendroctonus rufipennis*) activity because these insects prefer older trees. Extensive areas killed by spruce beetle, which were harvested between 1960 and 1970 within the study area, may be partially attributed to this age-class shift. Reductions in young forest would likely affect ungulates which prefer early seral habitats (e.g., moose (*Alces alces*)). However, the current harvesting rate, estimated by DeLong and Tanner (1996) at 0.6%/year for the moist cool plateau unit, should bring the age-class distribution in the dry to moist SBS back to historic levels assuming wildfire rates remain low. By comparison the same current rate of harvest, using mostly clearcutting, in the moist to wet forests would significantly increase disturbance rates over the estimated historic rates, leading to a reduction in older forests. Older forests in the wet montane regions of the study area have been linked to the provision of arboreal lichen, an important food source for mountain caribou (*Ranigifer tarandus* ssp. *montanus*) (Stevenson et al. 1994). The preceding discussion illustrates the importance of placing the effects of management, both fire control and harvesting, in context with the natural disturbance dynamics of the different forest landscapes being managed. The Blue Mountains in Oregon, where insect outbreaks have been attributed to fire control in ponderosa pine (*Pinus ponderosa*) forests, provides a useful example of the dramatic effects of ignoring natural disturbance dynamics (Hessburg et al. 1994).

The influence of climate and topography on rate of disturbance and patch size within forests of northern British Columbia is significant. These differences should be reflected in any guidelines which attempt to approximate the spatial patterns of natural disturbance.

Management Implications

Within British Columbia, disturbance rate and patch size distribution associated with forest harvesting has varied primarily according to factors such as supply and demand, cutting priorities (e.g., salvage of beetle killed or burned wood) and guidelines for single species (e.g., patch size limit of 80 ha to increase edge for moose). However there has been a recent shift in focus towards managing forests in context with natural disturbance processes. The Biodiversity Guidebook (British Columbia Ministry of Forests 1995) written in conjunction with the Forest Practices Code (Government of British Columbia 1994) in British Columbia were developed to recognize differences in natural disturbance processes during the formulation of forest development plans.

One of the objectives of this paper is to examine the data with respect to recommneded seral stage distributions and patch size distributions contained in the guidebook. Recommended seral stage distributions for each Natural Disturbance Type (NDT) are based on estimated mean fire return interval for the total area of a NDT. I made comparisons to these numbers using both the more conservative estimate for the whole period and that for the period 1910-1930. Table 7 compares the fire return interval used in the guidelines with estimates for the different topoclimatic units. Because fire return interval used to develop the guidelines was based on a negative exponential distribution of forest age, it is not directly comparable to the fire cycle computed by this study. However, there are some major differences which indicate a possible need for change. For example, the very wet cool unit has been placed in a category with an estimated fire return interval of 150 years, whereas the estimated fire cycle was over 950 years. Regardless of the accuracy of the placement of areas within an estimated fire return interval, fire return interval may not be the most suitable way to group landscapes. The methodology of estimating fire return interval requires accurate age since last disturbance data for the whole forest and is most effective where the fire cycle is short compared to the time covered by

TABLE 7. Fire cycle estimated from study, current fire return interval used in Biodiversity Guidebook (Ministry of Forests 1995), and proposed disturbance rate class for topoclimatic units examined.

	Fire Cycle			
Topoclimatic Unit	Estimated from 1910-1930	Estimated from 1910-1950	Current NDT (Fire Return)	Proposed Disturbance Rate Class[1]
Dry Warm Plateau	133	181	3 (150)	3
Moist Cool Plateau	87	127	3 (150)	4
Moist Cool Montane	185	244	3 (150)	3
Moist Cold Plateau	80	104	3 (150)	4
Wet Cool Plateau	227	270	3 (150)	2
Wet Cool Montane	417	500	2 (200)	1
Very Wet Cool Montane	952	1666	2 (200)	1
Dry Cool Boreal	267	333	3 (150)	2
Moist Very Cold Subalpine	209	294	2 (200)	2

[1] Proposed disturbance rate class with units expressed as percent of total forested area per year 1 = <0.3, 2 = 0.3-0.49, 3 = 0.5 - 1, 4 = >1.

TABLE 8. Estimated percentage of total disturbance area compared to recommended range in the Biodiversity Guidebook (Ministry of Forests 1995) for NDT3 for different patch size categories.

	Patch Size (ha)				
Topoclimatic Unit	< 40	40 - 250	251 - 1000	> 1000	> 250 (maximum (ha))
	(percentage of total disturbed area)				
Recommended for NDT3	10-20[1]	10-20[1]	60-80[1]		
Dry warm plateau[2]	9	13.4	20.9	56.7	77.6 (7693)
Moist cold plateau	4.5	7.4	15.9	72.2	88.1 (19 030)
Moist cool plateau	5.5	7	9.4	78.0	87.4 (41 787)
Moist cool montane	4.7	9.3	12.6	73.4	86.0 (10 458)
Wet cool plateau	10.4	18.3	33.8	37.5	71.3 (2515)
Wet cool montane	12.6	25.3	23.6	38.5	62.1 (1931)
Very wet cool montane	14.4	23.5	49.1	13	62.1 (1082)
Dry cool boreal	9.3	27.5	22.4	40.8	63.2 (2691)
Moist very cold subalpine	4.1	10.3	24.4	61.2	85.6 (4171)

[1] Recommended range in percentage of total disturbance area within the patch size category for areas within NDT3 without a major component of Douglas-fir according to the Biodiversity Guidebook.

[2] Unit assigned to NDT3 with major component of Douglas-fir according to the Biodiversity Guidebook.

[3] Unit assigned to NDT2 according to the Biodiversity Guidebook.

the fire history data (Johnson and Van Wagner 1985) Also fire return interval is not really meaningful with respect to harvesting because it generally assumes disturbance will occur throughout the full range of forest ages. Annual disturbance rate classes may avoid some of the aforementioned problems and may be simpler to calculate and apply (Table 7).

Comparisons between the recommended and observed patch size distributions reveal two factors which lead to differences. One is the maximum recommended patch size and the other is the recommended relative proportion assigned to each patch size category. In general, for NDT3 units without a major component of Douglas-fir, the recommended limits for small (<40 ha) and mid-sized (40-250 ha) patches fit the data fairly well (Table 8). However, the arbitrary upper cutoff of 1,000 ha leads to large differences (Table 8). The assumptions behind setting an upper limit to patch size are that large openings may be socially unacceptable and may have undesirable short-term effects on wildlife habitat, watershed conditions, and recreational values (Hunter 1993, Swanson et al. 1993). However, these assumptions remain untested. For the topoclimatic units examined which currently fall in NDT3, extending the upper limit to 10,000 ha would account for the total natural variability in all but the moist cool and moist cold plateau units (Table 8).

For units in the NDT2 and units within the NDT3 with a major component of Douglas-fir, the recommended and observed natural patch size distributions were distinctly different (Table 9). Because the methods used in this study could only consistently detect patches down to approximately 2 ha, amount of patches < 40 ha will have been underestimated, especially where gap forming processes (e.g., individual tree death) are likely to affect a significant portion of the topoclimatic

TABLE 9. Estimated percentage of total disturbance area compared to recommended range in the Biodiversity Guidebook for different patch size categories.

Topoclimatic Unit	Actual and Recommended Range in Percent of Total Disturbance Area				
	<40 ha	40-80 ha	81-250 ha	>250 ha	>80 ha
Dry warm plateau	9 (20-30)	3 (25-40)	10.4 (30-50)	77.6	88
Wet cool montane	12.6 (30-40)	8.5 (30-40)	16.8 (20-40)	62.1	78.9
Very wet cool montane	14.4 (30-40)	10.1 (30-40)	13.4 (20-40)	62.1	75.5
Moist very cold subalpine	4.1 (30-40)	2.5 (30-40)	7.8 (30-50)	85.6	93.4

unit. In light of this, it is the percentage assigned to the 40-80 and 80-250 ha categories that appear most contrary to the observed natural distribution. The observed distribution for units assigned to NDT2 is closer to the recommended patch size distribution for the NDT3 (Table 8). When the guidebook was written it was presumed that the amount of area of mid-sized patches (i.e., 40-250 ha) created by natural disturbance would decrease with increasing fire return interval. Although the data indicates that this is true it is not to the extent that was inferred by expert opinion. The highest estimate for the 40-250 patch size range was 25% for the wet cool montane unit, which is well below the recommended range of 50-80%. There is no apparent ecological rationale for preferring 40-250 ha patches even if disturbance rates of harvesting exceed natural rates. However there may be some benefits of allowing a greater amount of larger (i.e., >250 ha) patches. Allowing some proportion of larger patches could help reduce road density by limiting the dispersion of harvesting. Decreases in road density should benefit species such as grizzly bear and wolves, which are negatively impacted by high density road networks (McLellan 1990, Thurber et al. 1994). The preceding discussion indicates that the patch size distribution recommended by the Biodiversity Guidebook (British Columbia Ministry of Forests 1995) could be improved. However, these current guidelines are preferable to the alternative option under the Forest Practices Code (Government of British Columbia 1994). If the recommendations of the guidebook are not followed, the default is a maximum opening of 60 ha. Following this option would result in a drastic alteration in patch size distribution compared with the natural landscape.

The Biodiversity Guidebook (British Columbia Ministry of Forests, 1995) represents a significant step towards managing forest harvest pattern in context with natural disturbance. Based on the results of this study there are some improvements which could be made particularly with respect to patch size distribution. Data on natural disturbance rate and patch size need to be viewed in combination with potential constraints such as visual, fisheries and water management. However, significant alterations from the natural pattern, such as an upper bound on disturbance size, need to be carefully considered and should be supported by data

The topoclimatic unit, as described in this paper, appears to be an effective unit with which to make specific recommendations for managing the pattern of forest harvest in a more ecologically sound manner. It also provides a useful unit for which to calculate annual disturbance rate and patch size distribution for the refinement of guidelines for managing biodiversity presently in use in British Columbia.

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