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FIRE PROBABILITIES IN ONTARIO'S BOREAL FOREST

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The boreal forest, comprising the most extensive part of the vast forested region of Canada, sweeps in a broad 1000 km wide U-shaped swath from the Yukon Territory to Newfoundland (Rowe, 1972). The northern half of the boreal forest, fronting on the arctic tundra, consists of park-like patches of trees surrounded by lichen-covered rock and muskeg. Unfavorable climatic conditions, sparse soil and frequent fire serve to limit the size and reduce the abundance of tree species there. In the southern half of the boreal forest, improved climatic conditions encourage a closed forest consisting primarily of fire adapted species such as jack pine (Pinus banksiana), black and white spruce (Picea mariana and glauca), birch (Betula papyrifera) and aspen (Populus tremuloides). Without fire, the composition of the boreal forest would be quite different (Koslowski and Ahlgren, 1974; Van Wagner, 1973). Jack pine, for example, is relatively short lived and requires fire to prepare a seedbed; without fire it would become rare within a few hundred years.

Various studies have been conducted to determine the historical fire frequency in the Great Lakes-St. Lawrence Region, south of the boreal forest. Swain (1973) from a study of charcoal deposited in lake sediments in northeastern Minnesota over the past 1000 years, finds an average age of 60-70 years. Heinselman (1973), in a study of fire in the virgin forest of the Boundary Waters Canoe Area of Minnesota, determined an average natural fire recurrence of about 100 years in presettlement times, with the recurrence on any individual site being dependent on the prevalent species and the exposure of the site. Cwynar (1977) found a presuppression fire rotation period of 70 years in a portion of Algonquin Park. Prior to extensive human interference, the probability of fire was approximately 1.5 percent per annum. Given that fire occurrence was a random, independent variable, the average age of the forest was approximately 70 years.

In the spring of 1976, the Forest Fire Research Institute (FFRI) of the Canadian Forestry Service joined an ongoing research study of post-fire ecology in the Ontario boreal forest being conducted by the Petawawa Forest Experiment Station (PFES), the Great Lakes Forest Research Centre (GLFRC), and the Ontario Ministry of Natural Resources (OMNR), Fire Control Branch. In the course of the investigation, the FFRI with the cooperation of research staff from the GLFRC and the OMNR, prepared a fire history map for the province of Ontario. All fires 200 hectares and larger, as reported to the OMNR on official fire report forms for the years 1920 to 1976, constituted the data set from which the map was prepared. According to Lockman*, figures for the area burned in Ontario during the period 1961 to 1975 indicate that these fires constituted 95.3 percent of the total area burned. A few fires were reported but could not be located. A few other fires were not reported because the locality in question was outside of the area under protection or because fire detection aircraft were occupied with more important fires. The largest fires account for the preponderance of area burned. These are rarely missed. It is unlikely, therefore, that more than one or two percent of the total area burned within the protected area is missing from the data set. The only major omission is of fires which occurred during the 1920's and early 1930's. In particular, no fires were reported in the Northern Coniferous Section for the years 1920 to 1927.

The percentage of the area burned annually in each Section of the Ontario Boreal Forest Region and in the Quetico Section of the Great Lakes-St. Lawrence Forest Region is shown in Table 1. The percentages in Table 1 were computed under the assumption that the portion of the surface covered by water within the boundaries of the burned areas was equal to that in the region at large. Lake Nipigon and portions of the Great Lakes were excluded. The figures are averaged for each decade from 1920 onward. During the 1920's and 30's more than 0.3 percent of the total boreal forest in Ontario was consumed by fire annually. From 1940 to 1976 that figure was reduced to one-half. If the Northern Coniferous Section, in which fire control has been minimal, is excluded, the annual area burned figures are even more dramatic; 0.32 percent in the 20's, 0.25 percent in the 30's and 0.09 percent in the period 1940 to 1976. A similar trend occurred in the Quetico Section of the Great Lakes-St. Lawrence Region. The area burned decreases from the presuppression estimate of 1.5 percent per annum to 0.55 percent in the 20's and 30's and to an average of only 0.04 percent in the period from 1940 to 1976.

An estimate of the spatial distribution of age since the last burn (not necessarily of trees) can easily be obtained if one assumes that the occurrence of a burn is an independent, random event. This assumes that the probability of a

* Lockman, M. R., FFRI, Dept. of the Environment, Ottawa, Ontario, personal communication.

TABLE 1. ANNUAL PERCENTAGE BURNED IN VARIOUS ONTARIO FOREST SECTIONS

Name	Area (ha.)	1920-29	1930-39	1940-49	1950-59	1960-69	1970-76	Average Per Year
Boreal Forest Region								
Northern Clay	5,393,731	.17	.03	.05	.08	.00	.03	.06
Missinaibi-Cabonga	4,356,112	.44	.16	.49	.19	.02	.02	.22
Central Plateau	10,069,299	.42	.19	.03	.05	.03	.15	.15
Superior	2,368,455	.08	.88	.25	.02	.00	.01	.21
Nipigon	486,024	.17	.02	.27	.69	.00	.00	.19
Upper English River	4,123,646	.19	.46	.08	.00	.12	.13	.16
Lower English River	1,438,817	.58	.16	.05	.05	.04	.02	.15
Northern Coniferous	5,078,048	.23	.46	.16	.03	.81	.67	.39
Total	33,314,132	.30	.28	.14	.07	.15	.18	.19
Great Lakes-St. Lawrence Forest Region								
Quetico	4,353,343	.51	.60	.03	.01	.01	.14	.22

burn is independent of the composition of the forest, previous burn history, the burn history of adjacent areas, topography, human activity, logging, patterns of lightning activity, and other factors. None of these is strictly true; for example, the strong relationship between fire starts and human habitation is undeniable (Simard, 1975). Another example of the nonrandom nature of the data is afforded by fire occurrence in the 1920's, when a majority of all area burned occurred along one particular CNR railway line. Yet, despite the obvious nonrandom nature of fire starts, the combination of man-caused and lightning-caused fires and of suppression and no suppression, has produced a mosaic of fires across the Ontario boreal forest having a remarkably random appearance. As long as the limitations of the data are understood, there can be no harm in deducing a postfire age distribution based on the assumption of randomness and independence.

The binomial distribution should describe the frequency of discrete, independent, random events. Where the probability of an occurrence is extremely small, the binomial distribution can be approximated by the Poisson distribution. Let the probability of fire occurrence per hectare per year be γ and the probability of no fire from t (0,t) be $p_o(t)$. Then the probability of no fire in $t(0,t+\Delta t)$ will be:

$$p_o(t+\Delta t) = p_o(t)\ (1-\gamma\Delta t) \qquad (1)$$

Rearranging and finding the limit as $\Delta t \to 0$ gives,

$$p_o'(t) = -p_o(t)\gamma \qquad (2)$$

Integration of Eq. 2 gives the exponential relation:

$$p_o(t) = e^{-\gamma t}, \qquad (3)$$

where the constant term is zero because,

$$p_o(0) = 1 \qquad (4)$$

It is seen that the cumulative probability of no fire on a given hectare follows an exponential decay curve with time, Fig. 1(A). The frequency function of no fire occurrence is:

$$p_o'(t) = -\gamma e^{-\gamma t} \qquad (5)$$

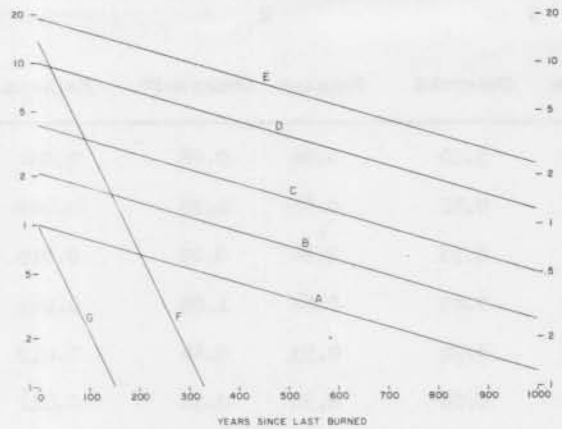

Fig. 1. The probability of no fire on a hectare for the period shown; A, when γ = 0.21 percent and G, when γ = 1.5 percent; and, the percentage of the area in an age class starting with the age shown for a class width of 10 years (B), 20 years (C), 50 years (D), and 100 years (E) for γ = 0.21 percent and of 10 years (F) for γ = 1.5 percent.

The mean age of a hectare since the last fire is the average value of $p_o'(t)$,

$$\int_0^\infty \gamma t e^{-\gamma t} dt = \frac{1}{\gamma} \qquad (6)$$

When the probability of fire is 1.5 percent per annum, the average age of a hectare since the last burn will be about 67 years. For probabilities of 0.2 percent, 0.1 percent and 0.04 percent, the average ages are 500, 1000 and 2500 years respectively.

The fraction of the boreal forest in various age classes can be determined by taking the difference,

$$p_o(t) - p_o(t+\Delta t) = e^{-\gamma t}(1-e^{-\gamma \Delta t}) \qquad (7)$$

The right hand side of Eq. 7 can be interpreted as being the probability of fire sometime during a period Δt followed by no fire for a period t. For any fixed period Δt, the term in parentheses will be a constant. The curve representing the distribution of age classes is a straight line on a semi-logarithmic graph parallel to the $p_o(t)$ curve. These curves are shown for illustrative purposes as B, C, D, and E of Fig. 1 for values of Δt equal to 10, 20, 50 and 100 years, respectively, and $p_o(t)$ equal to 0.21 percent. The figure 0.21 percent was chosen by adding 10 percent to the average probability of fire over the entire Ontario boreal forest, for the full period of record, 1920 to 1976. Ten percent roughly accounts for fires missed and fires smaller than 200 hectares.

A comparison of the 1.5 percent and the 0.21 percent curves, A and G of Fig. 1, respectively, give an indication of the expected distribution function for areas having various ages since the last fire. For example, half of the forest under the presuppression regime should be more than 45 years old and 80 to 100 year old forests would comprise 7.7 percent of the total. Were the 1920 to 1976 regime to continue indefinitely, half of the area would have survived 330 years without fire and only 3.7 percent would be aged 80 to 100 years.

One indication of the randomness of the original data is given by the fraction of the total area burned twice or more during a given time interval. Based on an argument similar to the one leading to Eq. 3, we obtain:

$$p_\upsilon(t) = \frac{(\gamma t)^\upsilon}{\upsilon!} e^{-\gamma t}, \qquad (8)$$

where υ is the number of occurrences of fire on a given hectare in the period t. The probability of fire occurrence one, two, or three times on a given hectare during the 57 year observation period, can be computed from Eq. 8. A comparison of this value with the observed recurrence figures is shown in Table 2. A standard t test applied individually to the columns of Table 2 shows that the Poisson distribution cannot be rejected as a fit to the observations. The duration of the measuring period was not sufficient to be able to reject the possibility that fire prone areas exist within the Section; but, there is certainly no evidence to indicate that they do exist. This data seems to indicate that, in the absence of more information, randomness of occurrence is the best hypothesis.

Fire statistics from the Province of Ontario show that during the past 57 years the probability of fire occurrence per unit area per year is less than one tenth of one percent. This statistic determines a recurrence interval of more than one thousand years. Research in the Great Lakes-St. Lawrence Forest Region indicates that a fire recurrence interval of 75 years was more typical of the presuppression era. No comparable data for the Ontario Boreal Forest Region is available, but Rowe (1975) presents data which indicates a recurrence interval of 110 years in the boreal forest near Yellowknife, Northwest Territories. It is recognized that fire is not the only forest harvesting mechanism, however, in the absence of other factors, the estimated 15 fold decrease in fire frequency in the Ontario boreal forest could lead to a complete change in its age distribution and composition.

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TABLE 2. THE PROBABILITY OF BURNS IN THE ONTARIO BOREAL FOREST DURING THE PERIOD 1920-1976 IN PERCENT

Number of Burns	0		1		2		3	
Section	Poisson	Observed	Poisson	Observed	Poisson	Observed*	Poisson	Observed*
Northern Clay	96.63	96.64	3.31	3.30	0.06	0.06	0.001	0
Missinaibi-Cabonga	88.22	88.81	11.06	9.81	0.69	1.35	0.029	0.029
Central Plateau	91.80	91.65	7.85	8.13	0.34	0.20	0.010	0.017
Superior	88.72	89.08	10.62	9.80	0.64	1.05	0.025	0.069
Nipigon	89.73	89.61	9.72	9.91	0.53	0.44	0.019	0.045
Upper English River	91.28	91.38	8.33	8.09	0.38	0.50	0.012	0.030
Lower English River	91.80	92.05	7.85	7.34	0.34	0.60	0.010	0.015
Northern Coniferous	80.07	79.06	17.80	19.61	1.98	1.29	0.147	0.042
Quetico	88.22	88.63	11.06	10.18	0.69	1.19	0.029	0.001

* Data available only from 1921 to 1976

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