An index to fire incidence

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Received June 23, 1986
Accepted February 23, 1987

Quinby, P. A. 1987. An index to fire incidence. Can. J. For. Res. **17**: 731–734.

To support the development and use of an index to fire incidence, historical data from modern fire records and forest resource inventory maps were used to test the null hypothesis that fire incidence within pine, intolerant hardwood, and tolerant hardwood forests does not differ significantly. The null hypothesis was tested with (*i*) the χ^2 test of goodness of fit applied to species dominance type data within burned plots and randomly chosen plots and (*ii*) a *t*-test to identify significant fire incidence differences among the 10 overstory species and the three forest types. The first test showed a significant difference between expected and observed results. The second test showed that, although not significantly different themselves, the pine and intolerant hardwood forest types had a significantly higher fire incidence than the tolerant hardwood type. Although no one overstory species had a fire incidence significantly different from all others, each species differed significantly from at least two others. Because both post- and pre-fire data were used, it was impossible to distinguish vegetation flammability from species regeneration strategy as an explanation for fire incidence as measured. However, since crown fire is a rare event in the temperate forests of eastern North America, it is likely that most postfire vegetation samples represented the vegetation that was present at ignition. Thus, it is also likely that the majority of data indicate species flammability rather than species regeneration strategy. Finally, a method for calculating the index to fire incidence is presented.

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Dans le but d'aider à l'élaboration et à l'emploi d'un indice de l'incidence des feux, on s'est servi de données historiques provenant de dossiers d'incendies récents et de cartes d'inventaires des ressources forestières pour vérifier l'hypothèse de nullité à savoir que l'incidence du feu dans les forêts de pins, de feuillus intolérants et de feuillus tolérants ne diffère pas significativement. Cette hypothèse de nullité fut vérifiée au moyen (*i*) d'un test de χ^2 appliqué aux données du type forestier dominant dans des places d'étude incendiées et des places choisies au hasard et (*ii*) d'un test de *t* en vue d'identifier des différences significatives dans l'incidence du feu parmi les dix espèces dominantes identifiées et les trois types forestiers. Le premier test a montré l'existence d'une différence significative entre les résultats escomptés et ceux observés. Le second test a montré que les forêts de pins et celles de feuillus intolérants, bien que non significativement différentes en soi, avaient une incidence de feu significativement plus grande que les forêts de feuillus tolérants. Bien qu'aucune des espèces dominantes n'aient eu une incidence de feu significativement différente de toutes les autres, chaque espèce différait significativement d'au moins deux autres. Etant donné qu'on a utilisé à la fois les données après feu et avant feu, il a été impossible de distinguer l'inflammabilité de la végétation sur la base de la stratégie spécifique de régénération pour expliquer l'incidence du feu telle que mesurée. Toutefois, étant donné que les feux de cime surviennent rarement dans les forêts tempérées de l'Est de l'Amérique du Nord, il apparaît que la plupart des échantillons de végétation après feu représentaient la végétation présente au moment de l'ignition. Ainsi, il est également vraisemblable que la majorité des données indiquent l'inflammabilité des espèces plutôt que leur stratégie de régénération. Enfin, l'article présente une méthode pour calculer l'indice d'incidence des feux.

[Traduit par la revue]

Introduction

When assessing environmental influences on community structure and dynamics, it is necessary to consider the role of natural disturbance (Harmon et al. 1983; Sousa 1984; Canham and Marks 1985; Pickett and White 1985). The influence of naturally caused fire is often a very important factor in explaining forest composition within the mixed forest region of eastern North America. The most suitable methods presently available for assessing the role of naturally caused fire in this region include (*i*) paleoecological analysis of lake sediments for influx of charcoal, aluminum, vanadium, varve thickness, and the charcoal/pollen ratio (Swain 1973; Cwynar 1978), (*ii*) fire scar dating and mapping (Heinselman 1973; Cwynar 1977), (*iii*) use of stand origin and age information from even-aged stands (Heinselman 1973; Cwynar 1977; Van Wagner 1978), and (*iv*) the use of historical documents and modern fire records (Spurr 1954; Wein and Moore 1977, 1979; Fahey and Reiners 1981).

Paleoecological methods result in broad temporal and spatial generalizations that are usually based on evidence from one or a few sites and, therefore, are not capable of providing site specific fire measures for a series of individual stands distributed across a broad landscape. Fire scar evidence is most abundant and reliable on coniferous trees. Accurate aging of a stand that has resulted from a destructive crown fire requires the presence of even-aged stands. Because the mixed forest region of North America is populated by substantial amounts of uneven-aged deciduous forest, the use of fire scars and stand aging to study fire are not entirely suitable. Historical documents provide only very rough fire size and location estimates, while for modern fire records, the fire size data do not reflect the role of naturally caused fire because of the modifying influence of suppression.

The purpose of this study, therefore, was to develop a method of quantifying the occurrence of naturally caused (lightning-caused) fires that (*i*) could be applied to both deciduous and coniferous dominated stands, (*ii*) would not be subject to the confounding effect of fire suppression, and (*iii*) could be calculated for any stand or community type sampled within the study area. Development of this method was based on testing the null hypothesis that fire incidence within pine, intolerant hardwood, and tolerant hardwood forest types does not differ significantly. Each forest type included a unique set of three species dominance types and fire incidence was defined as "one fire event taking place within a designated area during a designated time" (Romme 1980, p. 135).

Methods

Fire records (Archives of Ontario 1930–1979) for a 50-year period were analyzed to determine the location of 252 lightning-caused fires within a two township wide and eight township long transect, which

TABLE 1. Abundance of tree species and forest types and their associated fire probabilities

	Abundance in entire transect area		Relative abundance in burned areas (%)	Raw probability	FIP[a] × 10^{-3} (40 ha/50 years)	Species with significantly different FIP[a] ($p < 0.05$)
	Absolute (ha)	Relative (%)				
Tree species						
White birch (1)	13 525	4.1	9.7	0.097	0.287	4, 5, 6, 7, 8, 9, 10
Red pine (2)	8 247	2.5	4.8	0.048	0.233	6, 7, 8, 9, 10
Jack pine (3)	3 629	1.1	1.9	0.019	0.209	7, 8, 9, 10
Yellow birch (4)	19 463	5.9	8.4	0.084	0.172	1, 10
White pine (5)	58 058	17.6	22.7	0.227	0.156	1, 10
Red oak (6)	8 577	2.6	3.0	0.030	0.140	1, 2, 10
Poplar (7)	51 790	15.7	15.3	0.153	0.118	1, 2, 3
Hemlock (8)	15 504	4.7	4.1	0.041	0.106	1, 2, 3
Others (9)	46 512	14.1	12.3	0.123	0.106	1, 2, 3
Sugar maple (10)	104 570	31.7	17.8	0.178	0.068	1, 2, 3, 4, 5, 6
Forest types						
Pines (11)	69 934	21.2	29.4	0.294	0.598	13
Intolerant hardwoods (12)	73 892	22.4	28.0	0.280	0.545	13
Tolerant hardwoods (13)	139 537	42.3	30.3	0.303	0.346	11, 12

[a]Fire incidence probability.

traversed the 72-km east–west width of Algonquin Park, Ontario (see Appendix I in Archives of Ontario 1939–1979 for fire information). To determine the species composition of the overstory vegetation at the fire sites, the method of Fahey and Reiners (1981) was used. This involved sampling the vegetation on Forest Resource Inventory (FRI) maps (Ontario Ministry of Natural Resources 1959, 1978) at the 252 fire locations using the latitude and longitude coordinates of each fire. Those fires that occurred during or before 1967 were located on the 1959 FRI maps and those occurring after 1967 were located on the 1978 FRI maps. The fire boundary locations obtained from these records, however, did not reflect the results of natural fire because of the modifying influence of fire suppression.

To minimize the influence of fire suppression, a standard FRI map area was sampled with a plot the shape and size of one lot by one concession (approximately 400 × 1000 m) at each fire location. This plot configuration was used because it was the limiting resolution of fire location information provided in the fire records.

It was necessary to assume either that lightning strikes occurred randomly throughout the transect in Algonquin Park or that a greater number of lightning strikes occurred on the park's west side that is dominated by the tolerant hardwood forest. The latter is likely the case owing to greater thunderstorm activity (Hills 1959; Brown et al. 1980). To test the null hypothesis that forest types in Algonquin Park do not differ in terms of fire incidence, the frequency distribution of the species dominance types within the 252 fire-stricken plots was compared with the frequency distribution of the species dominance types within 252 randomly chosen plots that were sampled from the same set of FRI maps. Species dominance types were designated with the name of the most abundant overstory species within each plot. The χ^2 test of goodness of fit was used to compare these two distributions.

Following the comparison of observed versus expected results, fire incidence for the 10 species dominance types was examined for significant differences. To do this, a greater degree of accuracy for species abundances was required than that obtained from the χ^2 test. For each burn plot, therefore, a list of its tree species and their abundance (percent cover) was compiled. These data were summarized by species for all 252 burn plots to estimate each species' abundance within the total area burned over the 50-year period. The relative abundance of each species within the total area burned, expressed in decimal form, represented the probability that the species would be associated with fire in the transect area during a 50-year period.

The influence of unequal aerial coverages of the 10 tree species resulted in higher burning probabilities for those species with relatively greater aerial coverage. To eliminate the influence of unequal species coverages so that probabilities would reflect only the association of the species with fire, the probabilities were expressed for a standard area. This was done by dividing the raw probability for each species by the number of hectares within which that species was dominant throughout the entire transect to obtain the probability per unit area. The number of hectares dominated by each species within the transect area was determined from a separate 15% systematic point sample of all forest stands designated on FRI maps for each of the 16 townships. This new value was called the fire incidence probability and was expressed as a function of the plot size (40 ha) and the time period represented by the data (50 years).

To test for differences between fire incidence probabilities of tree species and forest types, Sokal and Rohlfs' (1969) test for the equality of two percentages was used. A *t*-test was applied to the arcsine-transformed data, which in turn were obtained by expressing probabilities as percentages.

Results

Results of the χ^2 test of goodness of fit ($\chi^2 = 28.22$; $p < 0.005$) indicated that the frequency distribution of the species dominance types within the burned area and the distribution of the species dominance types within the randomly chosen plots were significantly different. The null hypothesis that forest types within the study area do not differ in terms of fire incidence was, therefore, rejected.

Table 1 provides a summary of species and forest type abundance values and their associated fire probabilities. Sugar maple has the second highest raw probability (0.178) of the 10 species; however, in terms of fire incidence probability it is ranked lowest (0.068×10^{-3}). This is due to its low dominance within the total area burned (17.8%) relative to its very high dominance within the entire transect area (31.7%), which results in a low probability on a per hectare basis. This contrasts with jack pine which has a much higher fire incidence probability (0.209×10^{-3}) than sugar maple in spite of its lower dominance than sugar maple in the total area burned (1.9%). Because of the lower dominance of jack pine within the entire transect area (1.1%) relative to its higher dominance in the total area burned its probability on a per hectare basis is higher than that of sugar maple. Results of the t-test indicate that although no one species fire incidence probability is significantly different from the rest, each species differs significantly from at least two others.

Using the addition rule of probability, the fire incidence probability for each forest type was calculated by summing the fire incidence probabilities of each of the three species which occurred within a forest type. The pines included red, jack, and white pine; the intolerant hardwoods included white birch, red oak, and poplar; and the tolerant hardwoods included yellow birch, hemlock, and sugar maple. Results of the t-test indicate that the fire incidence probability for the pines (0.598×10^{-3}) and the intolerant hardwoods (0.545×10^{-3}) do not differ significantly, but that their fire incidence probabilities both differ significantly from the fire incidence probability for the tolerant hardwoods (0.346×10^{-3}).

Discussion and conclusion

The results of this study indicate that fire incidence is significantly higher within both the pine forest and the intolerant hardwood forest compared with the tolerant hardwood forest. Results of this study also indicate that fire incidence for the 10 overstory species in Algonquin Park differ significantly from one another, although no one overstory species differs significantly in terms of fire incidence from all others.

The major problem with using these historical data, however, was that both prefire and postfire vegetation was sampled. Thus, it was impossible to separate species flammability, which would be indicated by sampling prefire overstory vegetation from species regeneration strategy, which could be, but is not necessarily, indicated by sampling postfire overstory vegetation. For example, it is quite possible that the high fire incidence probabilities obtained for white and yellow birch resulted from sampling their early colonization of severely burned sites where the original overstory had been eliminated. Because the 1959 FRI maps were used to sample 29 years of previously burned vegetation, there was sufficient time for an early successional community of birch to develop following a fire, which may have occurred early in this 29-year period. In this instance, the early successional birch community would be sampled rather than the community which was originally ignited.

Examining fire records and forest cover type maps in New Hampshire, Fahey and Reiners (1981) recognized this phenomenon with white birch. Maissurow (1941) found that yellow birch also exhibited early colonization characteristics on burned sites in the hardwood forests of northern Wisconsin. In cases where destructive crown fire did occur within the transect, it is likely that the birch and poplar species colonized the burned sites owing to their r-selected regeneration strategy.

However, fires that destroy the forest overstory are rare within the North American temperate forest (Chandler et al. 1983). Therefore, it is probable that on most sites in Algonquin the dominant prefire forest overstory species survived fire and remained as the dominant overstory species on the site. Thus, it is likely that the majority of postfire vegetation sampled represented the vegetation type ignited, which in turn would indicate vegetation flammability.

The relationship between fire incidence and the flammability of vegetation has been discussed extensively in the literature (Mutch 1970; Rundel 1981; Snyder 1984). The greater flammability of pine species than intolerant and tolerant hardwood species is due to a higher concentration of oils, waxes, and resins in the needles (Van Wagner 1977; Rundel 1981), a lower fuel moisture loading (Kourtz 1967; Rowe and Scotter 1973), a difference in stand structure featuring more fuel at intermediate heights and a more aerated litter layer (Van Wagner 1971; Barden and Woods 1974), and fewer natural firebreaks in areas of dominance. Intolerant hardwoods are more flammable than the tolerant hardwoods because of their lower leaf moisture content (Van Wagner 1967) and a greater proportion of volatile chemical compounds in their leaves (Philpot 1969).

The index to fire incidence can be determined for any stand within the study area once the fire incidence probabilities and relative abundances are known for the overstory species within the stands of interest. This is done by simply calculating a weighted average of fire incidence probability for the stand using the fire incidence probability of each constituent species, basing the weight of the species probability on its relative abundance. For example, the index to fire incidence for a stand in Algonquin that is composed of 60% sugar maple, 30% yellow birch, and 10% hemlock would be $[(0.60)(0.068 \times 10^{-3}) + (0.30)(0.172 \times 10^{-3}) + (0.10)(0.106 \times 10^{-3})]$, which is equal to 0.103×10^{-3}. This value can then be used in ecological analyses to represent a naturally caused fire within that particular stand relative to all other stands sampled in the study area for which the index is calculated.

Acknowledgements

I would like to thank Kevin Kavanagh for suggesting the method developed in this paper, Professors D. V. Love and T. J. Carleton for their supervisory assistance, Tom Beechey of the Ontario Ministry of Natural Resources for providing a portion of the documents necessary to carry out this work, and a number of anonymous reviewers. This study represents a portion of a Ph.D. thesis undertaken at the University of Toronto. Funding was provided from the Canadian Forestry Service Block Grant administered by the Faculty of Forestry, University of Toronto; an Edward Elsworth Johnson Postgraduate Forestry Fellowship; and a University of Toronto Open Fellowship.

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