The history and pattern of fire in the boreal forest of southeastern Labrador

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The fire history of the wilderness of southeastern Labrador is marked by a patchy distribution of large fires in time and space. During the 110-year period encompassed by this study, major fires occurred in four decades, 1870–1879, 1890–1899, 1950–1959, 1970–1979. From 1900 to 1951 only 1125 km^2 burned; this represents approximately 10% of the total area consumed from 1870 to 1980. Fire records indicate an asynchroneity of the important fire years in southeastern Labrador and adjacent provinces and within Labrador itself. This observation suggests that the meteorological conditions controlling fire occurrence in this portion of the eastern boreal forest are local in nature and extent. The fire rotation for southeastern Labrador is calculated at approximately 500 years, significantly longer than that estimated for other regions of boreal forest. The rare occurrence of large fires is explained by high levels of precipitation and by the preponderance of fire breaks, primarily lakes and peatlands. On the basis of physiographic criteria the region is subdivided into two types of landscape displaying contrasting fire regimes. The large interior plateau, which is covered by extensive peatlands and numerous lakes, has a low fire incidence and extremely long fire rotation. In contrast, large fires are common in the watersheds of the Alexis, Paradise, and St. Augustin rivers where the topographic relief is quite varied and peatlands are scarce. The regional pattern of fire activity has important phytogeographical implications. The lichen woodlands and birch forests are fire-dependent vegetation types; their distribution in the modern landscape is strongly correlated with the historical occurrence of fire during the past 110 years. In addition it is postulated that the historical absence of fire across the large plains in southeastern Labrador has contributed to the development of extensive peatlands in these areas.

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L'histoire des feux dans le sud-est du Labrador est caractérisée par une répartition inégale des feux importants dans le temps et dans l'espace. Durant la période de 110 ans couverte par cette étude, des feux importants se sont produits au cours de quatre décennies: 1870–1879, 1890–1899, 1950–1959 et 1970–1979. De 1900 à 1951, 1125 km^2 seulement furent brûlés; cela représente environ 10% de toute la superficie incendiée de 1870 à 1980. Les inventaires montrent un asynchronisme des années où il y a eu des feux importants dans le sud-est du Labrador et les provinces adjacentes, ainsi qu'au Labrador lui-même. Cette observation suggère que les conditions météorologiques contrôlant la présence des feux dans cette partie de la forêt boréale sont de nature et d'étendue locales. La périodicité des feux au sud-est du Labrador est d'environ 500 ans, ce qui est beaucoup plus long què la périodicité estimée pour d'autres secteurs de la forêt boréale. La rareté des feux importants peut s'expliquer par les précipitations élevées et par l'abondance de coupe-feu naturels, surtout des lacs et des tourbières. D'après des critères physiographiques, la région peut être subdivisée en deux types de paysages qui ont des régimes de feu différents. Le vaste plateau de l'intérieur, qui est couvert de nombreux lacs et de grandes étendues de tourbières, présente une faible fréquence et une périodicité très longue des feux. Au contraire, les feux importants sont fréquents dans les bassins des rivières Alexis, Paradise et Saint-Augustin, où la topographie est très variée et où les tourbières sont rares. Le patron régional des feux a d'importantes conséquences phytogéographiques. Les pessières à lichens et les forêts de bouleau sont des types de végétation qui dépendent du feu; leur répartition actuelle est fortement corrélée avec la présence historique de feux au cours des 110 dernières années. De plus, l'auteur émet l'hypothèse que l'absence de feux durant cette période historique à travers le grand plateau du sud-est du Labrador a pu contribuer au développement des grandes étendues de tourbières dans cette région.

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Introduction

Fire is a natural process operating on a wide range of temporal and spatial scales within the boreal landscape. To a great extent fire determines the regional vegetation pattern and local community dynamics. In turn, fire is largely controlled in extent, distribution, and effect by the physiographic and biotic features of the landscape.

As a whole, each region displays a fire regime characterized by a particular fire type and intensity, size of typical significant fires, and return intervals for specific land units (Heinselman 1981). Fire is a complex phenomenon, however, and the regional and historical picture that emerges consists of a composite of independent events and episodes.

Focus of the study and selection of the study area

In this study an attempt is made to integrate the local and short-term characteristics of fire in southeastern Labrador within a regional and historical perspective. The range of interest extends from the behavior of individual fires to the pattern of fire frequency and distribution that has developed over the past century. In similar manner the results from the study of community

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dynamics following fire will be applied to the discussion of the interrelationship of fire and broad vegetation patterns.

The area under investigation was selected to best accommodate this holistic approach. The interior of Labrador is an uninhabited wilderness where natural forces govern ecosystem process and pattern. According to the available records lightning is the sole ignition source for fire across this broad area (J. Thomas, personal communication). With the exception of limited efforts at fire control, initiated in 1959 around coastal settlements, fires burn unimpeded without modification by man. The study area in southeastern Labrador forms a physiographically delimited corner of the large plateau that extends across the bulk of the Labrador peninsula. The region is small enough to exhibit general uniformity in flora, climate, bedrock, and surficial geology. However, it also encompasses sufficient variation in topography, landforms, and vegetation to enable an investigation of the interrelationship of these features and fire. The sample area and historical scope of this study have been extended as far as possible to provide a broad platform for contrast as well as generalization. The results of this study are intended to provide a comprehensive assessment of the fire regime of southeastern Labrador and afford a basis of comparison with well-documented studies from the central and western boreal where more continental climatic conditions prevail.

Description of the study area

Labrador comprises the northeastern extension of the North American boreal region. The study area in the southeast forms a rough rectangle, approximately 300 by 160 km, extending east from the St. Augustin River to the coast and south from the Mealy Mountains to the Quebec border at 52° N latitude (Fig. 1).

Geology and climate

Labrador forms the eastern portion of the Precambrian Canadian Shield. In southeastern Labrador the Grenville province consists of quartzofelspathic gneisses with intrusions of granite and granodiorites (Greene 1974). The entire region was covered by the Laurentide ice sheet during the last glacial period; retreat from coastal positions commenced approximately 12 000 years BP (Ives 1978).

The cold Labrador current exerts a dominant influence on this coastal region, producing a climate characterized by long, cold winters and short cool summers. Precipitation levels are among the highest for the North American boreal forest. Approximately 90 cm precipitation is equally distributed through the year (Hare 1950).

Vegetation

The vegetation consists primarily of communities dominated by black spruce (*Picea mariana*) and fir (*Abies balsamea*). Birch (*Betula papyrifera*), and to a lesser extent white spruce (*Picea glauca*), are locally important, whereas tamarack (*Larix laricina*) is generally restricted to open peatlands. Across the interior of the study area a species-poor black spruce – *Pleurozium* forest forms a nearly continuous cover interrupted only by innumerable mires, lakes, and streams. This forest is characterized by a low ericaceous shrub layer composed of *Ledum groenlandicum*, *Vaccinium angustifolium*, and *V. myrtilloides* and a sparse herb layer of *Cornus canadensis*, *Gaultheria hispidula*, *Trientalis borealis*, and *Empetrum nigrum*. *Pleurozium schreberi* forms a continuous mat 5–20 cm thick on the forest floor.

On richer sites, especially at low elevations and on moist slopes bordering streams, tree growth improves in a fir – black spruce – feathermoss forest. The vascular understory in this vegetation is fairly diverse and includes *Viburnum edule*, *Amelanchier bartramiana*, and *Alnus crispa* in the shrub layer and the herbs *Clintonia borealis*, *Maianthemum canadense*, *Trientalis borealis*, and *Linnaea borealis*. A deep carpet of mosses is composed of *Sphagnum girgensohnii*, *Ptilium crista-castrensis*, *Hylocomium splendens*, and *Pleurozium schreberi*. On steep slopes along the major river valleys distinctive stands composed nearly exclusively of paper birch provide a sharp contrast to the surrounding conifer forest.

Methods

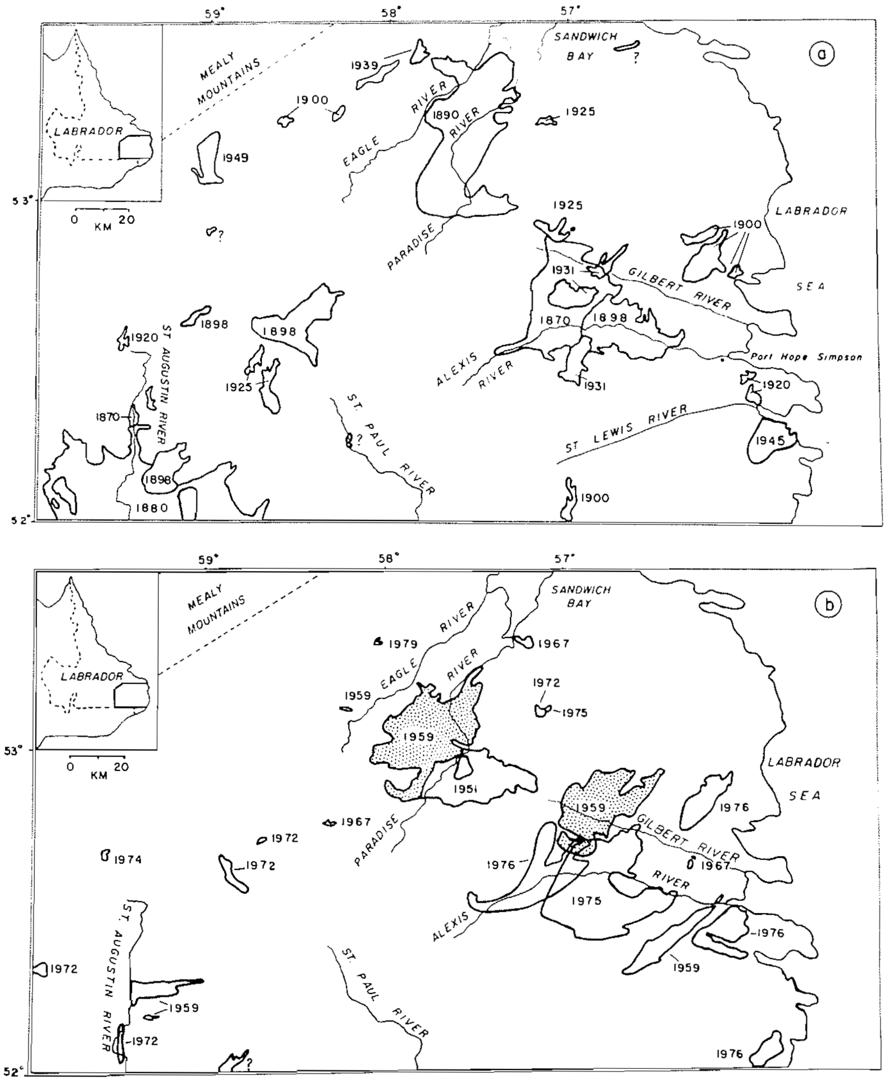
The fire-history study consists of two aspects, mapping and dating. Many of the techniques developed in other studies, for example stand origin mapping and the correlation of fire chronologies (Heinselman 1973; Arno and Sneck 1977; Tande 1979), were either impractical or ill suited for this investigation. Alternative methods were employed that were better adapted to the size of the study area and the fire regime of southeastern Labrador.

Several sources were used for the mapping portion of the study. The outline of an individual burn is detectable for approximately 90–100 years on aerial photography. Air photo interpretation provided the largest and most accurate record of fire occurrence. Aerial coverage flown in 1968–1972 was available for the entire study region at a scale of 1 : 60 000 (Canadian National Air Photo Library, Ottawa).

For the eastern region (east of 57° W), where numerous, overlapping fires have occurred in the past 45 years, 1951 air photo coverage (1 : 40 000) was additionally used. The earlier and larger scale photos extended the fire-history record, provided greater resolution in mapping older burns, and increased the detail in landform mapping.

For fires postdating the aerial photographs (1968–1972 to present), information was obtained from fire maps compiled by the Newfoundland Forest Service (NFS). These maps record all detected and reported fires on 1 : 250 000 topographic maps. Some additional mapping was done by the author through nonsystematic aerial observation. The fires mapped in this manner were mostly small and of recent origin. For all fires the outlines were transferred to topographic maps (1 : 250 000).

Once the basic fire map was complete, the historical analysis was undertaken concurrently with vegetation studies in the field. An initial survey of the region was made in 1979, with the bulk of the fieldwork occupying the summers of 1980 and 1981. Certain limitations were imposed on this portion of the study by the large size of the region and the requirement of



FIGS. 1*a* and 1*b*. Fire-history maps for southeastern Labrador covering the periods 1870–1949 and 1950–1980, respectively. Note the preponderance of fires in the watersheds of the Alexis, Paradise, and St. Augustin rivers. The 1959 Gilbert River and Paradise River fires discussed in the text are stippled.

accessibility by floatplane. Where possible, sites located at the overlap of two or more fires were selected to increase the efficiency of flight time and fieldwork. Emphasis was placed on dating large fires and covering as complete a range of fire years as possible. Accurate dating was accomplished for all major fires (>130 km^2) as well as many smaller burns occurring in the last 110 years in southeastern Labrador.

Dating of fires relied exclusively on aging fire scars on trees. Along the margins of the forest encompassing a burn and in unburned enclaves within a burn there occurs a narrow strip where light surface fire may damage trees without killing them. At each site the borders were searched until two or more scarred individuals were located. Cross sections of trees less than 15 cm basal diameter and wedges across the fire scar of larger individuals were obtained. Annual increment rings that represent the growth after fire were initially counted in the field to verify that the scars on different individuals recorded the same event. The sections were then taken to the lab, where the surface was sanded smooth and then counted beneath a dissecting scope (6–25×).

For fires not investigated in the field, dates were obtained by other means. NFS fire maps provide dates on all detected fires occurring after 1958. In addition historical accounts of fire, primarily derived from Newfoundland newspapers, have been compiled for the period 1619 to 1960 (Wilton and Evans 1974). For Labrador this information is incomplete, and it was used principally to verify dates obtained by fire-scar analysis.

Small burns not visited or covered by NFS maps were dated through aerial observation or air photo interpretation. These methods, which are the least reliable employed, were utilized on fires accounting for less than 1.5% of the total area burned. Age estimates were made from comparison with burns of known age and based on the following criteria: color and albedo of the ground surface and standing snags, amount and size of the arboreal regeneration, and composition and extent of the cryptogam cover. The last criterion proved to be the most accurate during the first 60 years following fire. During this period the cryptogams follow a regular and predictable succession and are identifiable from the air (cf. Ahti and Hepburn 1967).

Results

Temporal distribution of fire

Fire-history information is compiled in two ways. All fires detected within the study area are listed in chronological order (Appendix 1). Large fires are depicted in two fire-history maps that cover the period 1870–1949 and 1950 to present (Figs. 1*a* and 1*b*). The oldest fire was dated to 1870. Earlier fires are unrecognizable on aerial photographs, as the regenerating forest assumes the stature and density of mature vegetation and blends into the adjacent unburned forest.

A total of 80 fires encompass an area of 10 161 km^2, roughly 21% of the study area (48 500 km^2). The fire rotation (*sensu* Heinselman 1973) for the study area is estimated as slightly longer than 500 years. The temporal distribution of major fires is highly variable (Fig. 2). The fire history of southeastern Labrador is characterized by long periods of low fire incidence interrupted by an occasional year when numerous large fires consume vast areas of upland forest.

Three decades (1890–1899, 1950–1959, 1970–1979) account for approximately 70% of the region burned during the last 110 years. Within each decade one or two major fire years are primarily responsible for the area burned (Appendix 1). During the past decade numerous fires occurred in the eastern region in the summers of 1975 and 1976. From 1950 to 1959 fires were only recorded in 1959, when 1828 km^2 were consumed in four burns, and in 1951, when approximately 630 km^2 burned in a single fire. During the period 1890–1899 the years 1890 and 1898 were major fire years.

The 51-year period from 1899 to 1950 was a time of low fire incidence and is noticeably lacking in large burns. Some small to moderate sized fires occurred during this time, the largest covering 195 km^2. The total for 51 years (1164 km^2) represents only 11% of the area burned from 1870 to 1980. A shorter period marked by the similar absence of large fires occurred from 1960 to 1971, during which only 44 km^2 were consumed.

The long period required to burn extensive tracts of land necessitates relatively low levels of precipitation throughout the burn season and the relationship between the recent fire history and summer precipitation was consequently examined. Precipitation data at Cartwright, a coastal station, extends back to 1935. Mean precipitation for May–October on this record is fairly high (47.4 cm). Yearly fluctuations are great, with a range from 28.7 (1959) to 70.6 cm (1977) (Fig. 3).

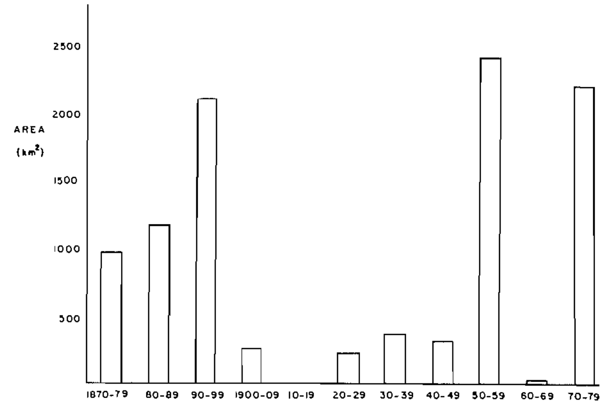


FIG. 2. Distribution of fires by decade during the past 110 years. Three decades (1890–1899, 1950–1959, 1970–1979) account for most of area burned. Fire occurrence was low between 1900 and 1950.

The correlation between major fire years and low summer precipitation is good but not exact. The year of the greatest area burned that is covered in this study (1959) is associated with the lowest summer rainfall on record. Two other fire years, 1975 and 1976, were marked by below-average levels of precipitation. The four large fires of 1976 occurred in June and July during an early summer drought when only 3.13 cm of rain fell. The 1951 fire burned approximately 610 km^2 in June, which was a month of relatively low precipitation.

The spatial distribution and pattern of fire

The regional distribution of fire is noticeably patchy. Several large areas (the southeast, central, west, northwest, and northeast) remain remarkably free of large burns (Figs. 1*a* and 1*b*). The scattered fires that have occurred have been small and undoubtedly of short duration. In contrast, the watersheds of three major river systems draining the study area, the Alexis, St. Augustin, and Paradise rivers, have been subject to many fires exceeding 300 km^2.

The relatively great number of extensive fires in these three watersheds has produced a pattern of large reburns at relatively short intervals. This is true near the Paradise River, where much of the region burned in 1951 and 1959 had been burned previously in 1890. Even more striking is the Alexis River valley, where six major fire years are represented, forming a complex overlapping pattern. Substantial areas burned in 1898 and 1975, 1870 and 1959, and 1870 and 1975. One region just north of the river was burned in 1870, 1931, 1959, and 1975.

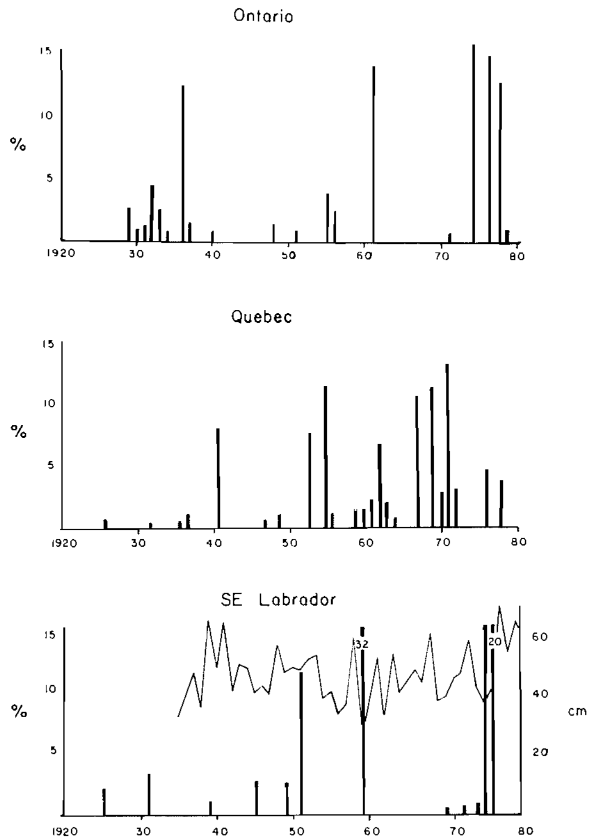


FIG. 3. Comparison of recent fire activity in Ontario, Quebec, and southeastern Labrador. For each region the total area burned from 1923 to the present was calculated. The area burned during each year is graphed as a percentage of this total. The precipitation levels for May to October for each year since 1934 at Cartwright are recorded on the graph for southeastern Labrador.

Fieldwork and inspection of the aerial photographs show that the reburns occur in the open, regenerating forests on previous burns rather than in the mature, unburned forest. In fact, examination of the burn pattern suggests that fire preferentially consumes the young and open vegetation. Frequently only the fringes of the dense, mature forest are consumed.

Historically, most of the fires are small. These include lightning ignitions that fail to spread, spot fires rapidly extinguished by ensuing precipitation, and burns that initiate on uplands and then fail to carry across adjacent wetlands or other physiographic firebreaks.

Large fires burn patchily as governed by changes in wind speed and direction and as influenced by the distribution of landforms and vegetation. The result is a fire scar that is uneven in outline and internal detail. Large unburned enclaves and long and narrow stringers occur but are too small to depict at the scale of the fire-history maps. The stringers are frequently located downwind of firebreaks, but the larger enclaves often appear almost random in their distribution.

Discussion

Temporal distribution of fire

Although fires occur throughout the summer from early June to late October, NFS records indicate that the distribution of large fires is skewed, with peaks in ignition occurring in late June – early July. Autumn fires are generally of short duration and are extinguished by rain or early snowfall before destroying large quantities of timber. Historically large fires typically start early in the season and burn under favorable conditions for many weeks or even months while consuming vast expanses of forest. For example, two of the largest burns in recent times occurred in 1959 on the Paradise River and Gilbert River watersheds. The fires were first reported on July 15 (Wilton and Evans 1974) and are attributed to a single weather system as ignition source. A third fire on the St. Lewis River apparently ignited later that week. Through the months of July and August precipitation was light and temperature high. On July 29, having traveled nearly 40 km, the St. Lewis fire burned through the town of Port Hope Simpson. It was contained at the mouth of Alexis River, which served as a major firebreak. The two larger fires continued to burn and flare up through the 1st week in October. The total area burned by the three fires exceeded 1700 km^2.

Many studies have indicated that major fires are preceded by fairly long droughts, including winter seasons of low snowfall (Stocks and Walker 1973; Sando and Haines 1972; Huff and Agee 1980). In southeastern Labrador fire occurrence appears to be more strongly correlated with seasonal droughts, when fire activity is closely controlled by precipitation levels during the actual month of the burn. Many summers of below-average precipitation exhibit little to no fire activity. It must be supposed that during these years the lack of ignition is the factor limiting the occurrence of major fires.

Major fire years in the eastern boreal forest

In many regional reviews of fire ecology it has been suggested that synchroneity of major fire years is often exhibited over a broad geographical area (Arno 1976; Viereck and Schandelmeier 1980; Heinselman 1981; Viereck 1982). This hypothesis would suggest that the meteorological conditions that control the distribution of fire may be uniform on a regional scale. Komarek (1966) has shown that the movement of a frontal system associated with thunderstorm activity may generate a series of fires along a line exceeding 1600 km in length.

A comparison of the fire-history records from adjacent provinces and within Labrador, however, shows that fire occurrence in southeastern Labrador, and by inference the weather patterns influencing it, is extremely local in character. Good records of lightning-caused fires for Quebec and Ontario extend back to 1929 (Barney and Stocks 1982). With the exception of 1976 there is nearly complete disharmony in major fire years for these provinces and the study area (Fig. 3). The years 1951, 1959, and 1975, which exhibit extensive areas burned in southeastern Labrador, were insignificant in Quebec and Ontario. In fact these years were not major fire years in any of the boreal forest areas included in Heinselman's (1981) review. As well, it is interesting to note a general lack of harmony in the distribution of major fire years of Ontario and Quebec.

On a smaller scale a similar disharmony is noted within Labrador. Although records are not complete and only extend to 1958, they attest to relatively local patterns of fire history (NFS records). Along the northern shore of Lake Melville and within the Hamilton River watershed numerous large fires occurred in 1967 and 1972. In western Labrador, within the physiographic region designated the Labrador Trough, four large burns in 1964 and three in 1967 are the only record of major fire activity. Around Harp and Snegamook lakes in central Labrador 1964 as well as 1974 are well-represented years, whereas 1973 is the only year recorded farther north in the vicinity of Davis Inlet and Zoar. Thus there is a complete asynchroneity of important fire years in the southeast and the rest of Labrador.

An explanation of the regional variation in forest fire history should be sought in the two factors required for a large fire: an ignition source and suitable antecedent weather conditions. The lack of conformity between regions may reflect asynchroneity in either factor. Unfortunately the meteorological data necessary to test the relative importance of these factors are extremely limited.

The records of thunderstorm activity indicate a decreasing occurrence of storms with increasing latitude within the Labrador–Ungava peninsula (Fig. 4). This observation supports the findings of other studies (e.g., Johnson and Rowe 1975) and would predict a northward decrease in fire activity. However, it does not specifically address the problem of regional variation in fire years.

NFS records, the observations of local foresters (J. Thomas, personal communication), and studies of lightning activity (Komarek 1966; Kourtz 1967) indicate that a single storm may provide the ignition source for numerous fires across a variable-sized area. Many of the larger fires in the study area have multiple ignition points. Therefore the development and movement of an individual storm across a region during a period of favorable fire weather will largely control the distributional pattern of lightning occurrence.

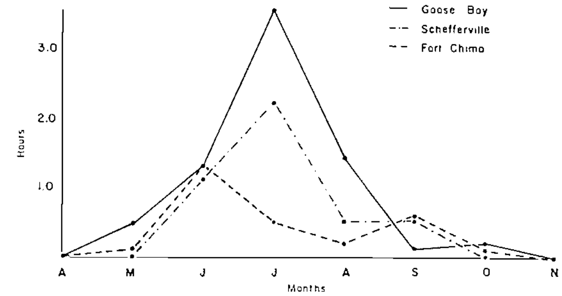


FIG. 4. The mean number of hours of thunderstorm activity as recorded at Goose Bay (53°19′ N, 60°33′ W), Schefferville (54°52′ N, 65°01′ W), and Fort Chimo (58°18′ N, 68°08′ W). Adapted from Peach (1975).

The moisture level of the fine fuels and duff layer determines whether a lightning strike results in fire. Each thunderstorm produces a rainfall area along with larger lightning area that includes some rain-free regions. As precipitation produces an immediate rise in fine-fuel moisture, the two areas exhibit drastically different ignition probabilities (Fuquay 1978). The regional pattern of annual lightning ignitions might therefore be expected to exhibit significant patchiness, because of the relatively stochastic nature of the many factors that control the movement and precipitation patterns of individual storms.

Variation in regional patterns of precipitation is difficult to assess. The oldest reliable meteorological records are from coastal stations, whereas records exist for Goose Bay from the early 1940's and western and central Labrador only for the past decades.

Although Goose Bay and Cartwright are separated by only 230 km, a comparison of precipitation records for May to October from the two stations demonstrates a fair amount of variation (Fig. 5). Despite some general agreement in trends over a period of several consecutive years, the overall pattern and actual amounts of precipitation are quite different.

The complex interaction of four air masses (Pacific, Atlantic, Gulf, Arctic) during the summer months in the eastern boreal forest may contribute to the variable weather patterns and consequently to the disharmony in fire history. Within Labrador there is a pronounced increase in continentality and severity of the climate towards the interior (Peach 1975). Atmospheric circulation does not favor the deep penetration of Atlantic air (Bryson 1966). Although occurring with a summer frequency of approximately 50% along the southeast coast of Labrador, its influence decreases rapidly to the west and is less than 20% on the east coast of Hudson Bay. It may be postulated that this maritime influence generates weather patterns of sufficient contrast with the rest of the eastern boreal to produce the observed asynchroneity in fire history.

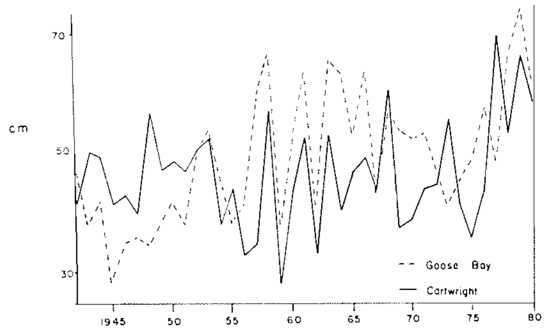


FIG. 5. May to October precipitation patterns from 1943 to present at Goose Bay (53°19′ N, 60°33′ W) and Cartwright (53°36′ N, 57°00′ W).

Burn patterns and fire behavior

Once ignition occurs, the behavior of a fire is largely controlled by meteorological conditions, fuel type and amount, and physiography (Alexander 1979; Romme and Knight 1981). The broad-scale fire pattern as depicted on the fire-history maps appears to be primarily dictated by wind speed and direction. The vegetation and physiography exert a more localized effect and govern the development of local pattern.

Most of the intermediate-size fires and some of the larger burns have a strong directional component, generally SW to NE. This component corresponds to the prevailing summer wind direction (Bryson 1966). The very large fires exhibit more complex shapes that relate to numerous changes in meteorological conditions, primarily wind direction, during the long periods of burning.

The overriding influence of meteorological conditions on broad pattern is depicted in the strong agreement in the shape and even the size of the 1959 Gilbert River and Paradise Rivers burns (Fig. 1*b*). Both fires were apparently started by the same weather system. The subsequent development and spread of the fires are neatly paralleled in the two regions. Ignition occurred in the south, and the fires were first driven to the east by a westerly wind and then to the north for a short interval after a wind shift. A second change in wind direction, this time to the west, resulted in the formation of the central body of both burns. Following a subsequent wind shift the flank of the previously long and narrow fire became a broad front. This front was driven to the north and east and burned in a rough and irregular fashion during the remainder of the summer. The northern edges of the two burns display the jagged borders that characterize the latter stages of a burn. Despite topographic and vegetational differences between the two regions burned, the dominant influence of weather conditions produced remarkably similar patterns.

Whereas meteorological conditions determine the regional movement of fire, the local behavior is primarily controlled by physiography and the character of the vegetation. Because of enhanced convection and effective radiation heat transfer from the flame front to the unburned fuels, fire tends to burn rapidly upslope but slowly and at low intensity downslope. A variety of water-dominated landforms, including lakes, streams, and peatlands, serve as effective firebreaks and inhibit the movement of fire through an area.

In addition, the vegetation pattern, which is itself largely determined by topographic position and previous fire history, governs fire behavior. Different vegetation types vary in flammability, and the rate of movement and intensity of fire will reflect these differences. Broad-leaved deciduous forest, in Labrador represented by extensive hillside stands of paper birch, have a lush understory and herb layer. Because of the high moisture content of the foliage and the relatively high humidity levels within the stands, they are extremely resistant to fire and serve as effective firebreaks (cf. Van Wagner 1967). In contrast, coniferous vegetation exhibits relatively high flammability. The distribution of "ladder fuels" composed of ericaceous shrubs and conifer foliage serves to promote intense crown fires.

There exists some disagreement among fire ecologists concerning the changing flammability of vegetation with age (Johnson and Rowe 1977; Van Wagner 1967; Alexander 1979; Heinselman 1981; Kilgore 1981; Romme and Knight 1981). From the limited number of studies that address this question in detail, it appears that although flammability does change with age, it may vary in direction and rate in different types of vegetation.

Thus Yarie (1981) found that in Alaska hardwood stands exhibit the least change with age, whereas white spruce forests increase in flammability and the black spruce cover type exhibits a slight decrease in flammability with age. The decrease in flammability in black spruce stands is attributed to a change towards wetter and colder conditions as stands become paludified.

A similar pattern of decreased flammability in older black spruce – balsam fir forests appears to be true for southeastern Labrador. Open stands of lichen woodland, ranging from 40 to 90 years of age, are apparently the most flammable vegetation type. These forests are composed of scattered and well-grown conifers with a fairly luxuriant shrub cover of *Ledum groenlandicum* and *Kalmia angustifolia* and nearly continuous cover of *Cladonia* lichens. Many fires selectively burn areas covered with lichen woodland, while sculpturing around the adjacent mature stands of closed-canopy black spruce – fir – feather moss forest.

Although crown fires do not form in lichen woodlands because of the wide spacing of trees (Auclair 1982), a number of factors appear to be responsible for their high flammability. Southeastern Labrador receives one of the highest precipitation levels in the northern boreal forest. During the summer, rain is frequent and often substantial. Within this environmental setting numerous characteristics of the lichen woodland increase their propensity to burn. The fuel, composed of a thick lichen cover, ericaceous shrubs, and open-growth conifers, is prone to rapid decline in moisture content (Auclair 1982). Extremely open conditions enable penetration of solar radiation, thereby promoting a rapid reduction in fuel moisture with the onset of warm, dry weather. In addition the physiognomy of the vegetation facilitates the passage of winds to carry the fire and dry fuels and enhances radiation heat transfer.

In contrast the mature and closed forests have a sparse shrub layer and very moist, drought-resistant ground cover. The feather mosses (*Pleurozium schreberi*, *Ptilium crista-castrensis*, *Hylocomium splendens*) and *Sphagnum* (*S. girgensohnii*, *S. russowii*) form a cover 10–20 cm thick overlying an additional 15–30 cm of mor humus. The mosses and organic layer retain water effectively. Under the relatively high levels of humidity and low temperatures that exist beneath the closed canopy, this deep carpet requires an extended drought to dry sufficiently to carry a ground fire. In addition, in the spring and early summer, a thick layer of frozen soil restricts drainage and prevents desiccation of the organic layer until melting in late June to mid-July.

The local behavior of fire in relation to vegetation and physiography is demonstrated by the 1951 Paradise River fire (Fig. 6). Aerial photographs taken July 14, 1951, distinctly show the pattern of the 285-km^2 fire that probably started around June 25 (cf. Wilton and Evans 1974). Trees killed by surface fires still retained their needles at the date of the photographs, and therefore the direction of fire movement is readily discerned by tracing the long, narrow strips of crown fire that are apparent as a darker shade on the photos (Fig. 7). Directional arrows indicate the movement of fire at each location, and the result is a composite from which the history and behavior of the fire can be traced.

After ignition in the southwest the fire spread to the northwest and then, following a major wind shift, became a broad front that moved to the northeast. The main body of the burned area was formed during this phase, whereas the eastern extremities were consumed after a second wind shift, this one to the northwest.

At the northern edge the fire was contained by lakes, peatlands, the Paradise River, and two large birch stands. The fire sculptured between and around individual firebreaks until dying out or spreading to the relatively open ground in the east. Within the main body of the burn, one cluster of birch stands provided a barrier to fire movement and produced a large enclave of unburned forest.

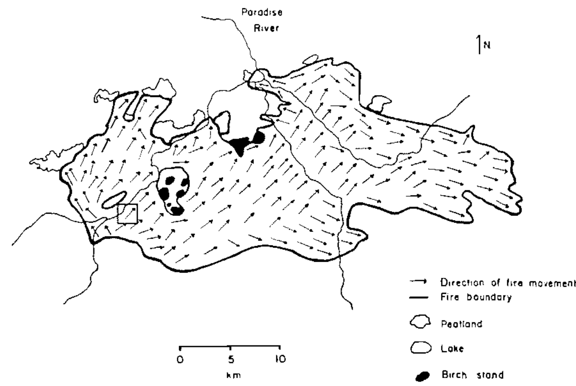


FIG. 6. Burn pattern of the June 25, 1951, Paradise River fire. The direction of the fire movement is indicated by arrows. Broad-scale pattern relates primarily to wind direction, whereas the smaller scale features reflect the physiography and vegetation. The location of Fig. 7 is indicated by a small box in the southwest part of the burn.

The fire regime of southeastern Labrador

In some important respect the fire regime of the study area resembles that of the rest of the North American boreal forest. Crown fires and intense surface fires kill the aboveground vegetation, reduce the surface organic layer, and initiate secondary succession across broad areas. Small fires are quite common, whereas ecologically significant fires are infrequent but may be extremely large. Individual burns may exceed 1000 km^2 in area.

However, an examination of the fire-history map indicates that in southeastern Labrador, fire is relatively uncommon, and the fire rotation (*sensu* Heinselman 1973) is considerably greater than the 75- to 200-year period characteristic of the forest region west of Hudson Bay (Heinselman 1981). For the region as a whole approximately 21% of the land area has burned in the past 110 years. This represents a fire rotation of approximately 500 years. Such an extremely low occurrence of fire is much less than the estimated natural fire rotation for any other boreal forest vegetation (Heinselman 1981).

Within a region as large as southeastern Labrador there exists considerable variation in physiography that might be expected to exert a strong influence on fire distribution. The extensive Eagle plain south of the Mealy Mountains, the St. Lewis plain east of the St. Paul River, and the area east of Sandwich Bay are virtually free of major fires for the period investigated. Major fires have been greatly confined to the drainage basins of the Paradise, Alexis, and St. Augustin rivers which lead from the plateau down to the coast (Fig. 8). The latter regions exhibit a fairly high fire frequency and a fire regime relatively characteristic of the boreal forest.

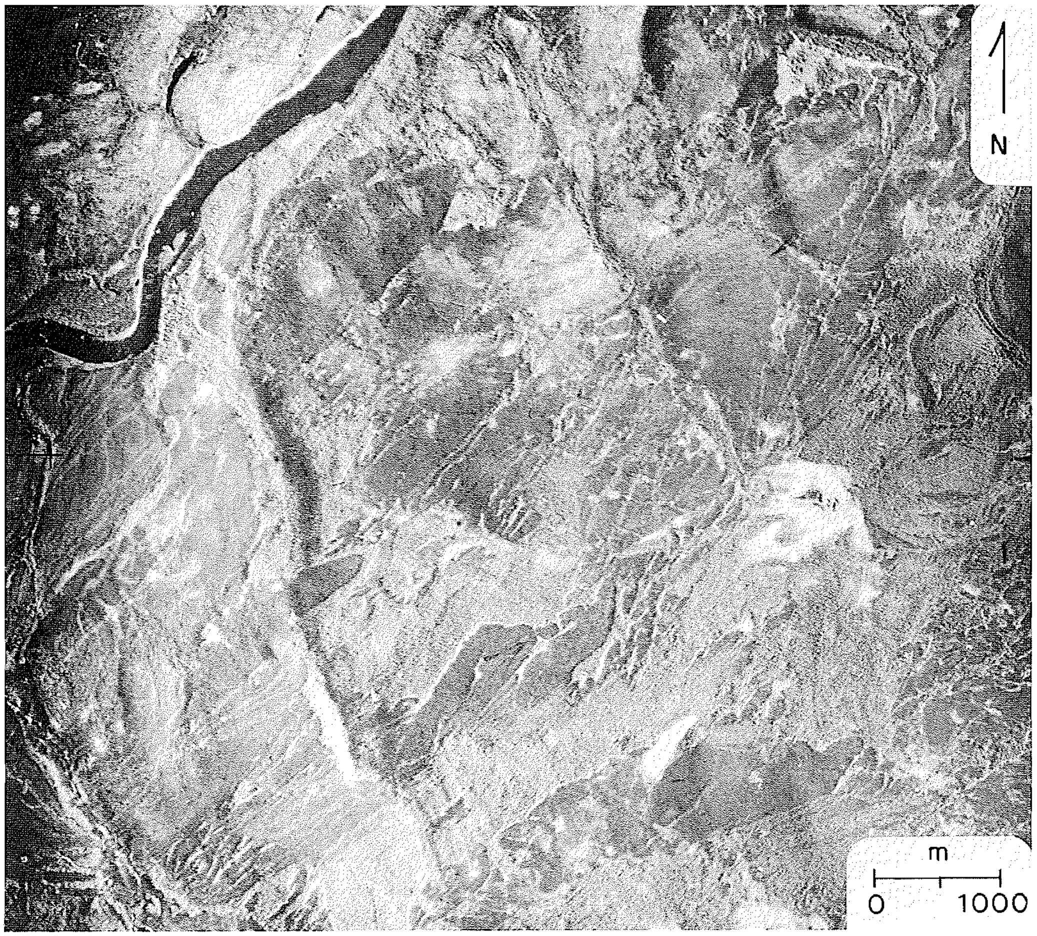


FIG. 7. Air photo of a portion of the Paradise River fire taken July 14, 1951. Darkened areas are forest consumed by crown fires spreading from SW to NE. In the NE a small birch stand (lighter shade) served as a fire break to a portion of the fire.

A major glacial feature, the Paradise moraine, trends SSW–NNE across the study area. To the west is the Eagle plain, and to the east, the St. Lewis plain (Fig. 8). The Eagle plain exhibits drumlins and other ice-directional features aligned in a fan-like arrangement leading east to the moraine. Peatlands are extensive and cover approximately 30% of the land surface. Linear patterned fens fill the swales and are separated by unproductive black spruce forest on the drumlin ridges.

The St. Lewis plain is composed of flat and relatively featureless ground moraine lying east of the Paradise moraine. Peatland, primarily plateau bogs and mixed mires, dominates this surface as well. The Paradise moraine, which represents a pause in the retreat of the Laurentide glacier, is characterized by small-scale irregular topography, dominated by ice-block depressions filled by lakes and basin mires. To the northeast of the moraine, a third and smaller plain is very similar in many respects to the St. Lewis plain.

The regions supporting extensive fires during the past century are strikingly different in physiography from the plains. Here bedrock-controlled hills are covered by a thin mantle of glacial debris and are extensively downcut by the large river systems that dissect them. Topographic relief is great and peatlands scarce. Extensive conifer forest in various stages of regeneration following fire forms the principal vegetation cover.

The preponderance of water-dominated landforms is a noticeable quality that distinguishes the large plains and the moraine from the hilly forest regions. The importance of peatlands and lakes as firebreaks that may regulate the pattern and extent of fires has been discussed earlier. It is proposed that although ignition frequency may be similar throughout southeastern Labrador, the widespread distribution of extensive firebreaks greatly restricts the spread of fire and thereby reduces the size of individual burns across the moraine and contiguous plains.

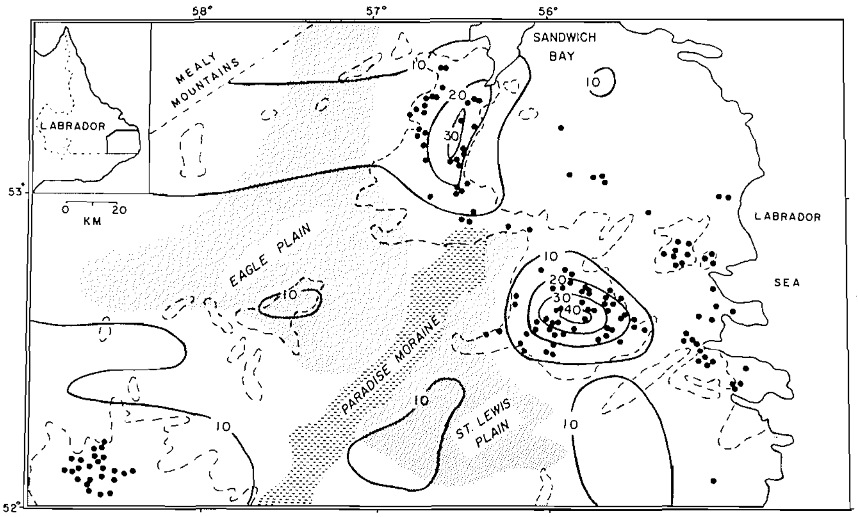


FIG. 8. The relationship between physiography, regional vegetation patterns, and fire history in southeastern Labrador. Areas burned during the past 110 years (enclosed with a broken line) are strongly correlated with birch stands >4 ha (dots) and percentage of lichen woodlands (isopleths modified from Hare and Taylor (1955)).

In the slopes of the Alexis, Paradise, and St. Augustin river valleys fires can burn relatively unimpeded through the continuous upland forest. With the exception of the rivers and scattered large lakes there is a general absence of natural firebreaks. The effect of the recent fire history is borne out in the landscape. These large regions contain a mosaic of stands that differ in tree density and height and represent different periods of postfire vegetation development. Although extremely old, mature forests are found locally, the fire regime and appearance of the forests are strikingly different from those of the plains and therefore more comparable with the rest of the boreal forest.

Fire history and the regional pattern of vegetation

The patchy occurrence of major fires in southeastern Labrador has strongly influenced the regional distribution of some important vegetation types. In particular a striking correlation exists between fire distribution over the past 110 years and the location of lichen woodlands and paper birch stands (Fig. 8).

These cover types require fire for perpetuation in the landscape. Lichen woodlands occupy an important place in the regeneration sequence following fire on upland areas. This vegetation is best developed from 40 to 90 years after fire, when the ground-covering *Cladonia* species (*C. mitis*, *C. rangiferina*, *C. stellaris*) are most abundant. Later in succession, as the canopy closes, these species are overgrown by feather mosses and *Sphagnum* species.

Large stands dominated by a continuous canopy of paper birch and scattered aspen (*Populus tremuloides*) develop on steep hills in dissected terrain following fire and to a limited extent in small lumbered areas along the major coastal rivers. Birch persists as the prominent canopy tree for approximately 80–100 years. At this point individuals senesce and are replaced by an advanced growth of fir and black spruce. After fire the surviving individuals in adjacent unburned areas provide a seed source for the establishment of a new stand, thereby continuing the process.

In the long-term absence of fire different patterns of vegetation and landform development assume prominence in the landscape. Across the uplands of the Eagle and St. Lewis plains the predominant forest of black spruce and fir is characterized by a multiaged structure, with individuals ranging to greater than 300 years in age. The curved boles of even the largest and oldest spruce indicate the predominance of vegetative reproduction by layering and the extreme age of the stands.

A continued accretion of biomass, primarily in the ground cover and mor humus layer, occurs with time. This thick insulating mat provides a water-saturated environment characterized by low temperature, decreased microbial activity, and decreased availability of important nutrients, notably N and P (Heilman 1968). Some species are unable to persist under this unfavorable environmental regime, and many others exhibit decreased vigor and annual growth.

When occurring over a large area this process of paludification is progressive, because of a negative feedback relationship with fire occurrence. The general absence of fire in the past tends to decrease the probability of future fires, as the paludified forests would exhibit reduced flammability (cf. Quirk and Sykes 1971; Yarie 1981). It may be postulated that the historically low occurrence of fire in the large glacial plains in southeastern Labrador may have been a factor contributing to their continued paludification and the development of extensive mire systems.

Conclusion

The broad scope of this study provides documentation of important spatial and temporal patterns of variation in the fire history of southeastern Labrador. Fire activity is largely controlled by weather conditions; the relationship between extensive fires and below-average summer precipitation is fairly good. Sufficient variability is exhibited, however, to emphasize the complex and often stochastic factors that control the coincidence of ignition potential and suitable fuel conditions. The observation of temporal synchroneity of fire activity over broad geographical areas may be valid for the western boreal forest, but it is untenable in the east. Towards the east coast the influence of maritime air masses produces complex and local variations in the weather patterns.

Two contrasting fire regimes are associated with physiographically distinct regions. Infrequent small fires and a fire rotation exceeding 500 years characterize the fire regime of the extensive paludified plains in the central portion of the study area. In contrast, the dissected terrain towards the coast bears numerous large fire scars and has a much shorter fire rotation. The vegetation of the two areas exhibits important differences in structure, composition, productivity, and dynamic processes. Lichen woodlands and extensive birch forests are fire-dependent vegetation types that are generally restricted to areas burned within the past 110 years. The historical absence of fire across the large glacial plains has undoubtedly contributed to the development of extensive mire systems in these areas. The modern vegetational landscape is a result of the interrelationship of the temporal and spatial pattern of fire acting within the physiographic and climatic setting of southeastern Labrador.

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Ahti, T., and R. L. Hepburn. 1967. Preliminary studies on woodland caribou range, especially on lichen stands in Ontario. Ontario Department of Lands and Forests, Research Report (Wildlife), No. 74.

Alexander, M. E. 1979. Forest fire research in Ontario. Great Lakes Forest Research Centre, Forestry Research Newsletter, Summer 1979.

Arno, S. F. 1976. The historical role of fire on the Bitterroot National Forest. USDA For. Serv. Res. Pap. INT-87.

Arno, S. F., and K. M. Sneck. 1977. A method of determining fire history in coniferous forests of the mountain west. USDA For. Serv. Gen. Tech. Rep. INT-42.

Auclair, A. N. D. 1982. The role of fire in lichen-dominated tundra and forest-tundra. SCOPE (Rep.) No. 18. pp. 235–256.

Barney, R. J., and B. J. Stocks. 1982. Fire frequencies during the suppression period. SCOPE (Rep.) No. 18. pp. 45–62.

Bryson, R. A. 1966. Air masses, streamlines, and the boreal forest. Geogr. Bull. No. 8. pp. 228–269.

Fuquay, D. M. 1978. Predicting ignition of forest fuels by lightning. Proceedings of the 5th National Conference on Fire and Forest Meteorology. American Meteorological Society, Boston, MA. pp. 32–37.

Greene, B. A. 1974. An outline of the geology of Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Information Circular No. 15.

Hare, F. K. 1950. Climate and zonal divisions of the boreal forest formation in eastern Canada. Geogr. Rev. **40**: 615–625.

Hare, F. K., and R. G. Taylor. 1955. The positions of certain forest boundaries in southern Labrador–Ungava. Geogr. Bull. No. 47. pp. 51–73.

Heilman, P. E. 1968. Relationship of availability of phosphorus and cations to forest succession and bog formation in interior Alaska. Ecology, **49**: 331–336.

Heinselman, M. L. 1973. Fire in the virgin forests of the Boundary Waters Canoe Area, Minnesota. Quat. Res. (N.Y.), **3**: 329–382.

——— 1981. Fire intensity and frequency as factors in the distribution and structure of the northern ecosystems. Tech. Rep. U.S. For. Serv. (Wash. Off.) No. 26. pp. 7–57.

Huff, M. H., and J. K. Agee. 1980. Characterization of large lightning fires in the Olympic Mountains, Washington. Proceedings of the 6th National Conference on Fire and Forest Meteorology. American Meteorological Society, Boston, MA. pp. 117–123.

Ives, J. D. 1978. The maximum extent of the Laurentide ice sheet along the east coast of North America during the last glaciation. Arctic, **31**: 24–53.

Johnson, E. E., and J. S. Rowe. 1975. Fire in the subarctic wintering grounds of the Beverly caribou herd. Am. Midl. Nat. **94**: 1–14.

——— 1977. Fire and vegetation change in the western subarctic. Canadian Department of Indian Affairs and Northern Development, ALUR Rep. 75-76-61.

Kilgore, B. M. 1981. Fire in ecosystem distribution and structure: western forests and scrublands. Gen. Tech. Report. WO U.S. For. Serv. (Wash. Off.) No. 26. pp. 58–89.

KOMAREK, E. V. 1966. The meteorological basis for fire ecology. Proceedings of the 5th Annual Tall Timbers Fire Ecology Conference. Tall Timbers Research Station, Tallahasee, FL. pp. 85–125.

KOURTZ, D. 1967. Lightning behavior and lightning fires in Canadian forests. Can. For. Branch Dep. Publ. No. 1179.

PEACH, J. A. 1975. The tourism and recreation climate of Newfoundland and Labrador. Atmospheric Environment Service, Department of Environment Canada. REC-2-75.

QUIRK, W. A., and D. J. SYKES. 1971. White spruce stringers in a fire-patterned landscape in interior Alaska. Proceedings of the Symposium on Fire in the Northern Environments. U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR.

ROMME, W. H., and D. H. KNIGHT. 1981. Fire frequency and subalpine forest succession along a topographic gradient in Wyoming. Ecology, **62**: 319–326.

SANDO, R. W., and D. A. HAINES. 1972. Fire weather and behavior of the Little Sioux fire. U.S. For. Serv. Res. Pap. No. NC-76.

STOCKS, B. J., and J. D. WALKER. 1973. Climatic conditions before and during four significant forest fire situations in Ontario. Can. Great Lakes For. Res. Cent. Serv. Inf. Rep. No. O-X-187.

TANDE, G. F. 1979. Fire history and vegetation pattern of coniferous forests in Jasper National Park, Alberta. Can. J. Bot. **57**: 1912–1931.

VAN WAGNER, C. E. 1967. Seasonal variation in moisture content of eastern Canadian tree foliage and the possible effects on crown fires. Canadian Forest Branch Publication No. 1204.

——— 1977. Conditions for the start and spread of crown fires. Can. J. For. Res. **7**: 23–34.

VIERECK, L. 1982. The effects of fire in black spruce ecosystems in Alaska and northern Canada. SCOPE (Rep.) No. 18. pp. 201–220.

VIERECK, L., and L. A. SCHANDELMEIER. 1980. Effects of fire in Alaska and adjacent Canada—a literature review. U.S. Bureau of Land Management, Alaska Technical Report No. 6.

WILTON, W. C., and C. H. EVANS. 1974. Newfoundland forest fire history 1610–1960. Newfoundland Forest Research Centre Information Report No. N-X-116.

YARIE, J. 1981. Forest fire cycles and life tables: a case study from interior Alaska. Can. J. For. Res. **11**: 554–562.

Appendix 1. Fire-history data, southeastern Labrador

Fires are listed chronologically. Reliability provides a code for source of the map of each fire and source of the date of the fire. Sources for the fire maps include, by decreasing order of reliability, AP, air photo interpretation; NFS, Newfoundland Forest Service records; AO, aerial observation. Sources of the fire dates by decreasing order of reliability are FS, fire scar determination; NFS, Newfoundland Forest Service records; AO, aerial observation; AP, air photo interpretation. See Methods for a complete description of the procedure in mapping and dating fires.

Location				
Latitude	Longitude	Date	Area (km^2)	Reliability (area/date)
52°33′	57°50′	1979	<1	AO/AO
52°12′	59°10′		<1	AO/AO
53°25′	58°05′		4	AO/FS
52°35′	57°10′	1976	470	NFS/NFS
52°30′	56°05′		190	NFS/NFS
52°55′	56°10′		165	NFS/NFS
52°05′	55°55′		95	NFS/NFS
53°03′	53°45′		6	NFS/NFS
52°48′	57°05′		4	NFS/NFS
52°17′	55°45′		2	NFS/NFS
52°52′	56°10′		<1	NFS/NFS
52°40′	56°45′	1975	1100	NFS/NFS
53°15′	57°10′		5	NFS/NFS
52°40′	59°30′	1974	4	NFS/NFS
52°10′	56°00′		<1	NFS/NFS
52°50′	59°35′		<1	NFS/NFS
52°18′	55°45′	1973	<1	NFS/NFS
52°40′	58°45′	1972	85	NFS/FS
53°12′	57°10′		20	NFS/NFS
52°05′	59°25′		20	AO/AO
52°20′	59°55′		8	NFS/NFS
52°45′	58°35′		3	NFS/NFS
53°22′	56°55′		<1	NFS/NFS
53°32′	56°52′		<1	NFS/NFS
53°23′	57°10′		<1	NFS/NFS
52°55′	58°17′		<1	NFS/NFS
53°13′	58°05′		<1	NFS/NFS
53°25′	58°35′		<1	NFS/NFS
52°05′	59°23′	1970	25	AO/AO
53°25′	57°12′	1967	10	NFS/NFS
52°40′	56°18′		6	NFS/NFS
52°50′	58°15′		3	NFS/NFS
52°55′	57°30′	1959	800	AP/FS
52°55′	56°45′		725	AP/FS
52°25′	56°25′		180	AP/FS
52°15′	59°15′		123	AP/FS
52°05′	59°07′		2	AP/AO
52°03′	59°12′		2	AP/AO
53°12′	58°12′		2	AP/AO
53°00′	57°20′	1951	610	AP/AP
53°15′	59°00′	1949	105	AP/FS
53°10′	58°50′		7	AP/AO
52°20′	54°15′		7	AP/AO
52°15′	55°55′	1945	195	AP/FS
53°30′	58°05′	1939	43	AP/FS
53°30′	57°50′		31	AP/AO
52°15′	58°15′		6	AP/FS
52°28′	58°00′		1	AP/FS
52°25′	59°40′	1935	3	AP/AO
53°12′	58°10′		2	AP/AO
53°15′	58°12′		2	AP/AO
52°47′	57°00′	1931	130	AP/AO
52°35′	56°55′		85	AP/FS
52°50′	56°50′		55	AP/FS
53°15′	59°18′		8	AP/AO
52°30′	58°35′	1925	55	AP/FS
52°56′	57°05′		40	AP/AO
52°33′	58°40′		28	AP/FS
53°20′	57°10′		20	AP/AO
52°27′	56°05′	1920	28	AP/AP
52°25′	55°58′		25	AP/AP
52°35′	59°30′		10	AP/AO
53°12′	58°10′		3	AO/AO
53°05′	58°10′		2	AO/AO
52°30′	56°42′		2	AP/AO
52°30′	56°42′		2	AP/AO
52°50′	56°15′	1900	135	AP/AO
52°05′	57°00′		48	AP/FS
52°56′	56°15′		41	AP/AO
53°20′	58°15′		20	AP/AO
53°20′	58°35′		20	AP/AO
52°50′	56°05′		6	AP/AO
52°35′	56°45′	1898	505	AP/FS
52°40′	58°30′		300	AP/FS
52°15′	59°15′		270	AP/FS
52°40′	59°05′		17	AP/AO
53°25′	57°30′	1890	1050	AP/FS
52°10′	59°30′	1880	1180	AP/FS
52°45′	57°00′	1870	970	AP/FS
52°20′	59°18′		30	AP/AO