1

Fire and the boreal forest: the process and the response

Fire behavior in the boreal forest (Figure 1.1) has at least four characteristics which are important in understanding the dynamics of its populations: crown fires, the size of the area burnt, the frequency with which areas burn, and the amount of the forest floor which is ashed.

More precisely, fires in the boreal forest have high frontal intensity (heat output in $kW\ m^{-1}$) or flame length at the flaming front. The high intensity results in a crown fire regime shared by only a few other North American ecosystems e.g. grasslands, chaparral and montane conifer forests. Some of the largest fires in the world have been reported in the boreal forest. Murphy and Tymstra (1986) give the size of a 1950 free-burning fire in northern British Columbia and Alberta as 1.4 million hectares. Fires greater than 100 000 ha are common with the interval between fires being on average about every 100 years. The forest floor of upland boreal forest has a depth, moisture content and bulk density which makes it very flammable so that large amounts of mineral soil are exposed.

These four fire behavior characteristics affect the population processes of recruitment and death. The high frontal fire intensity causes crown scorch and cambial death which results in both canopy and understory tree mortality. Rapid rates of fire spread lead to large areas burnt and greater dispersal distances for trees that do not have serotinous cones and must seed-in from outside the burn or from unburned patches within the burn. The frequency of fire is about half the trees' non-fire life span. The mineral soil exposed by the fire gives higher recruitment for most boreal trees than does a duff-covered surface. Buried viable seeds are not an important regeneration strategy after disturbance because of the large amount of duff consumed.

The tree population dynamics reflect the mortality and recruitment forces of fire. The age class distributions have a cohort structure in which the understory does not generally replace the canopy. This results in a time-lag in canopy replacement, the lag being related to the fire frequency, fire intensity and duff removed. Consequently, the local population dynamics over several generations appear to fluctuate at least in part as a result of the stochasticity of the fire behavior.

The objective of this book is to examine the coupling between fire behavior and populations. In the first part of this chapter, I gave a very general blueprint of the process–response approach which will be used. In the remaining chapters I will attempt to construct this coupling more precisely. The conceptual framework involves coupling the fire to the biophysics of the organism, and this in turn to the population dynamics (cf. Johnson 1985). In order to do this, concepts of heat transfer and combustion of forest fires must be understood. Relevant variables, coefficients and parameters of forest fire ignition and spread can then be chosen which cause biological effects in the individual organisms. This in turn can be related in a direct manner to the recruitment, mortality and age class distributions of the populations.

Hopefully, the readers will find many things I say unsatisfactory so that they will be driven into the field and laboratory to correct these confusions and misunderstandings. I have tried to resist the temptation to speculate or give hypothetical arguments based on casual observations.

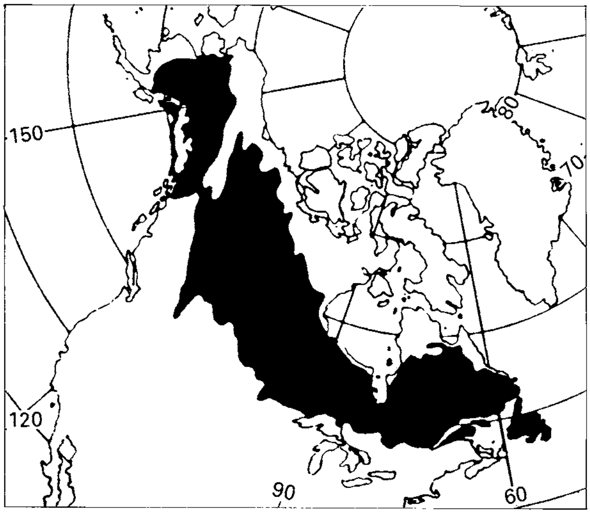


Figure 1.1. The boreal forest in North America (from Hare and Ritchie 1972).

2

Fires and climate

Weather and climate control fire occurrence and spread in the boreal forest. As we shall see in this chapter, airstream movements and boundaries limit the length of the fire season and determine the seasonal geographic progression of fires. Further, a critical synoptic weather pattern of upper level (50 kPa) ridge build-up and breakdown is often responsible for the ignition and spread of large and widespread fires. The weather determines these patterns by generating the principle ignition source (lightning), controlling the most significant variable of fuel flammability (fuel moisture) and providing the high winds required for rapid spread.

Fire occurrence

The occurrence of forest fires in the boreal forest of Canada is given in Figure 2.1. This map was constructed from over 40 000 individual forest fires from all causes for 1961–6. Although the period is short, and not all areas are covered with the same thoroughness (some areas, e.g. northern Quebec, have no records at all), the map still presents the characteristic pattern of fires in the boreal forest (Simard 1975). Because of the scale of the map, the localized high fire occurrence in Figure 2.1 associated with population centers (e.g. La Ronge, Saskatchewan and Chicoutimi, Quebec) and transportation corridors (e.g. south from Moosonee, Ontario) have been removed. Also less obvious is the higher fire occurrence in the summer cabin region running from north of Toronto to north of Montréal and the large area of reduced fire occurrence southeast of North Bay, Ontario caused by Algonquin Provincial Park. However, when these man-caused effects on the fire occurrence are removed, a clear decrease in fire occurrence can be seen from the southern to the northern boundary of the boreal forest and from west to east.

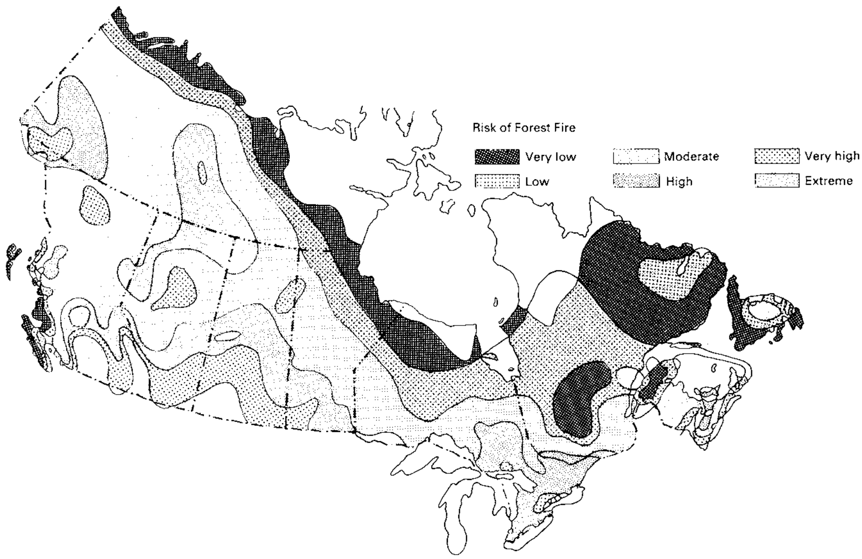


Figure 2.1. Wildland fire occurrence in Canada (cf. Simard 1975).

Indian-caused fires

The effect of indigenous peoples on fire occurrence in the boreal forest before European influence can only be speculated on at this time. However, any argument on Indian-caused fires must be based on an understanding of the Indians' life ways and how these were changed by the arrival of Europeans. Since ecologists are not usually familiar with Indian life ways, I will spend a few pages outlining them and their significance in man-caused set fires.

European arrival did not destroy the boreal forest Indians' culture as thoroughly as it did the eastern deciduous forest and plains Indians' culture. This was because in the boreal forest there was no serious competition between Europeans and Indians for land or natural resources. In fact, both the French-Canadian traders from Montréal and the Hudson Bay Company were interested in having the Indians devote themselves completely to trapping and discouraged or actively opposed any European activities which might have turned the Indians away from trapping (Heidenrich and Ray 1976).

The Indians' seasonal cycle of activities appears to have remained largely unchanged from at least the 1600s until about 1945. Most boreal forest

Indians lived in small, multiple family hunting groups which were organized into loose regional bands. They seasonally moved to areas of resource concentration. The seasonal cycles differed depending on the kind of game hunted but generally were as follows (cf. Bishop 1974, Ray 1974, Gillespie 1975, Jarvenpa 1980, Yerbury 1986). Winter was spent in small family groups either hunting (before European trading), or hunting and trapping (after European trade began). In the subarctic forest barren-ground caribou were an important resource in the winter and in the southwestern boreal forest wood buffalo were important. Throughout the southern boreal forest moose and deer were the primary large game. Summer was spent in bigger settlements usually near large lakes where fishing and opportunistic moose or deer hunting supplied their food needs. Fall allowed berry collecting and duck, goose and bear hunting. Spring saw intense beaver trapping and hunting of the returning waterfowl. In recent years all of these subsistence activities have been supplemented by wage earning and government treaty payments.

The use of fire by boreal forest Indians has been carefully and systematically studied only by H.T. Lewis. Lewis (1977, 1982) has used ethnographic studies to show that the Cree Indians of northern Alberta regularly and systematically burned certain habitats to improve game and plant resources at least as far back as the mid-1800s. These fires differed in seasonality, frequency, size and behavior from lightning-caused fires. The upland boreal forest was *not* systematically burned because of the difficulty in managing the fire spread and its limited resource benefits. Generally the areas burned were along the margins of lakes, sloughs, bogs, meadows and swamps. These fires were set mostly in spring and sometimes in late fall. The fires were of small flame length and were intended to kill shrubs and trees and encourage grass and herbaceous growth of value to wildlife. By burning in spring or late fall the surrounding shaded woods would have been wet or still snow-covered, thus controlling the fire spread. Trails in swamps were also kept open by spring burning. These spring fires were not necessarily annual but as frequent as was required to keep the brush down. Thus, Indian fires had *specific* purposes and were set at *specific* times, were of low intensity and small in size.

Significantly, the Indians burned habitats which tended not to burn during the lightning fire season (June–August) and the fires were much smaller in size than lightning-caused fires. In short, they were management burns with specific objectives and a clear understanding of the effect desired. The lightning fire season was considered a foolish time to burn since fires could not be controlled (Lewis 1982).

Given the vegetation similarity of the boreal forest and the similarity of subsistence life ways between Indians in the boreal forest, Lewis's studies of the use of fires by the Cree of northern Alberta may give a general view of Indian use of fire in the boreal forest. However, it may be that regional and tribal differences did play a more important role in their use of fire. Further, the change starting in the 1500s from subsistence hunting to hunting and trapping, the population movements, and the population reduction caused by disease (in many cases reductions by as much as three-fourths: cf. Heidenrich and Ray 1976) all could have resulted in changes in the numbers and kinds of Indian-caused fires. At present, we do not know.

Lightning-caused fires

Lightning is the most significant cause of fires in the boreal forest accounting for about 90% of *the area* burned (Hardy and Franks 1963, Requa 1964, Barney 1969, 1971, Stocks 1974, Johnson and Rowe 1975, Stocks and Street 1983). Lightning-caused fires decline northward (e.g. Figure 2.2. for Ontario) generally as the frequency of thunderstorm days declines (Figure 2.3).

Three areas in the southern boreal forest are known to have higher lightning occurrence and more lightning-caused fires: the Sault Ste Marie–Sudbury, Red Lake–Kenora–Quetico Park areas of Ontario (Chapman and Thomas 1968) and north central Alberta (Harvey 1977). These areas appear to be associated with increased cyclogenesis. The lightning locating system (Krider *et al.* 1980) which now covers large areas of the boreal forest should offer greater possibilities for examining the relative importance of the density of lightning strikes and fuel moisture to the number of lightning fires.

Airstreams and the fire season

The seasonal variation in climate of the boreal forest is controlled by the interaction of the Arctic, cool Pacific, mild Pacific and North Atlantic airstreams (Hare and Hay 1974). The Rocky Mountains block the westerly flow of the Pacific airstream from penetrating uninterrupted over the eastern extent of the boreal forest. Only the boreal forest in the interior of Alaska is exposed to the Pacific airstream directly and then only during the summer.

For the boreal forest east of the Rockies, the cold, dry Arctic airstream

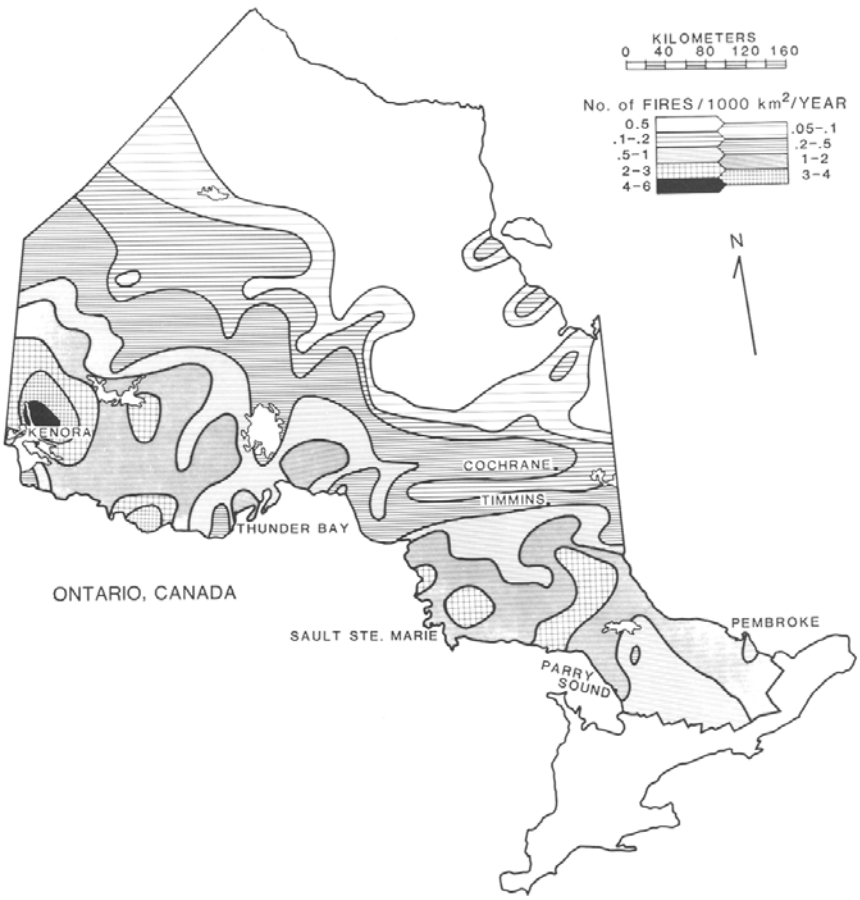


Figure 2.2. Pattern of lightning-caused fires in Ontario, Canada from April to September for 1965–76. (cf. Stocks and Hartley 1979).

flows south during the winter when radiation input into high latitudes is at its lowest and snow cover increases the albedo (Hare and Ritchie 1972). By February, this airstream usually covers all of the boreal forest (Figure 2.4). With the increasing radiation of spring and melting of the snow cover, the Arctic airstream retreats and is gradually replaced by Pacific and North Atlantic airstreams. Summer, the fire season in the boreal forest, finds the Arctic airstream positioned near the boreal forest–tundra boundary (Bryson 1966). A large wedge of mild Pacific air (Figure 2.4) occupies the boreal forest with varying frequency as far east as James Bay (Figure 2.5)

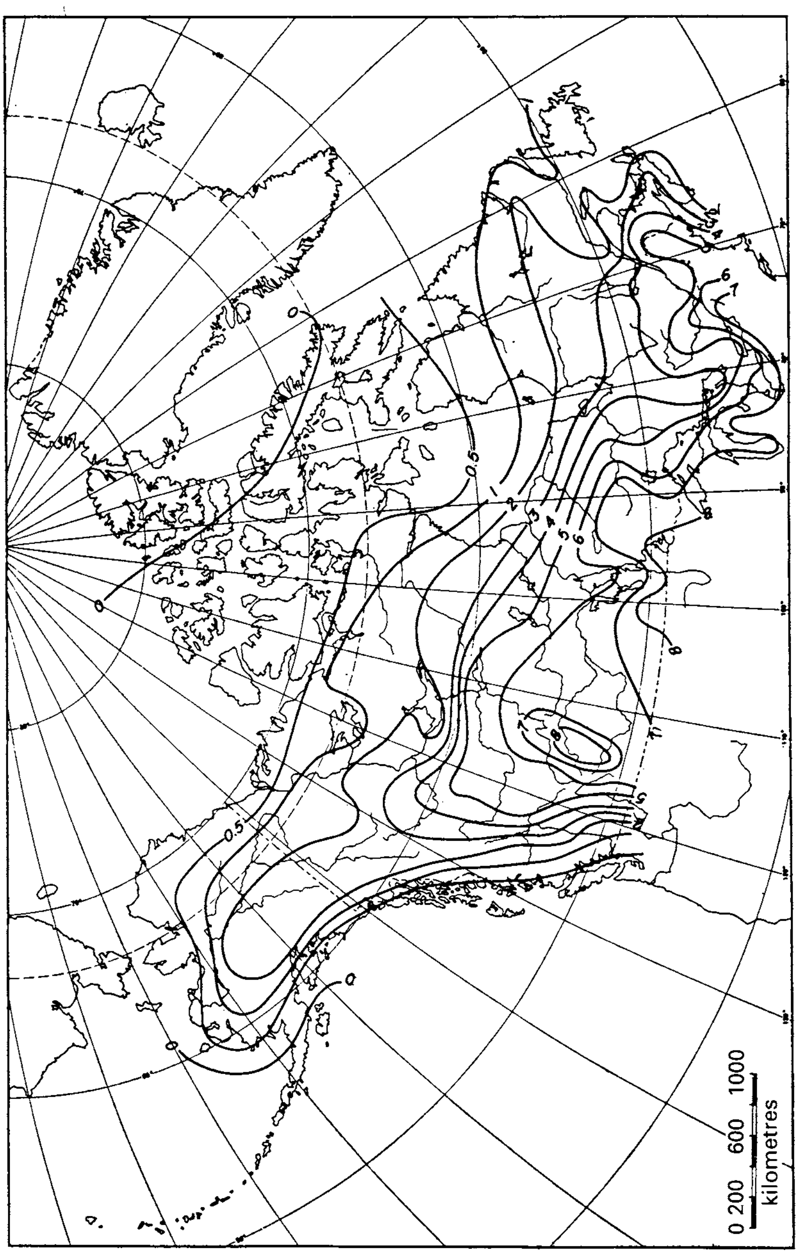


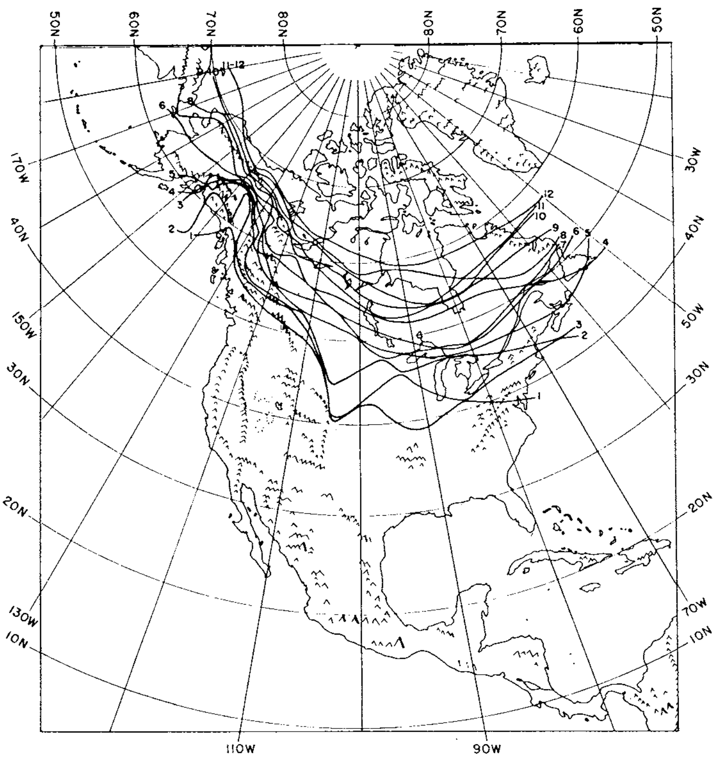
Figure 2.3. The mean number of days of thunderstorms in July for the period in Canada 1941–60 (cf. Kendall and Petrie 1962) and in Alaska 1931–60 (cf. Hare and Hay 1974).

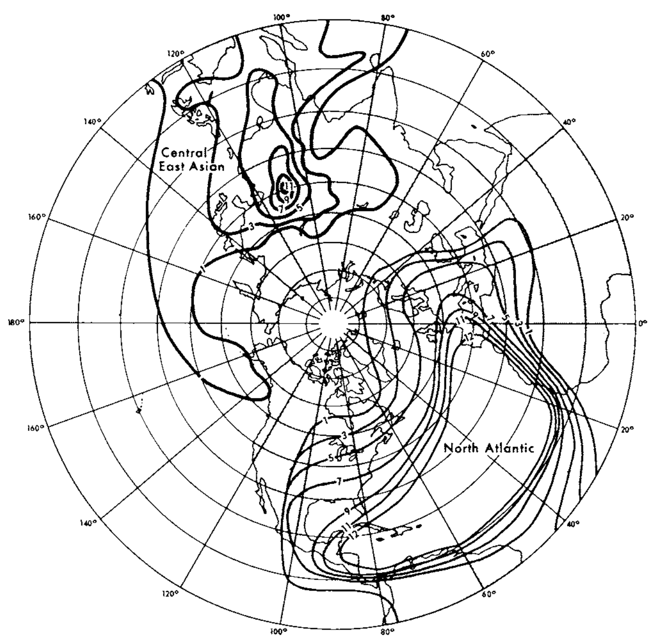
with the eastern boreal forest in Ontario, Quebec and Labrador covered by a mixture of Pacific and North Atlantic airstreams (Figure 2.4).

The airstream patterns in the interior of Alaska are somewhat different. Here the boreal forest occupies the basin and plateaux of the Yukon River and its tributaries, the forest being wedged between the Brooks Range to the north, the Alaskan Range to the south and the MacKenzie Mountains (a part of the Rocky Mountains) to the east. During the winter the Arctic airstream dominates until the summer when the cool Pacific airstream replaces it. The cool Pacific air from the Bering and Chukchi Seas and the proximity of Arctic air north of the Brooks Range give the summer a continuous series of weak cyclones which results in high summer precipitation. The Pacific air also causes a slight increase in summer precipitation in the Yukon, MacKenzie and Keewatin Districts of the Northwest Territories although the intervening Ogilvy and MacKenzie Mountains create a minor rain shadow.

The fire season in the boreal forest is determined by the summer reorganization of atmospheric circulation over the boreal forest, switching from a colder stable Arctic airstream to warmer, unstable air caused by the deep intrusion of Pacific and Tropical airstreams. The beginning and end of the fire season in the boreal forest are related to the position of the Arctic airstream. Forest fires are possible once the Arctic airstream has retreated north. This is because the warmer, unstable Pacific or North Atlantic airstreams are more effective at drying fuels, owing to their much higher temperatures, and generate more lightning as an ignition source. Consequently, 12 minus the duration of the Arctic airstream in Figure 2.4 gives the number of months during which lightning fires can occur. Another indicator of when fires can occur is the date when mean air temperature is above 0 °C (Figure 2.6). The timing of this event is tied to the retreat of the Arctic air and increasing frequency of Pacific and Atlantic airstream incursions. Winter snow cover melts rapidly after the mean air temperature is above 0 °C (Hare and Hay 1974), allowing drying of surface fuels.

An example of this airstream-caused progression of fire starts can be seen in Figure 2.7 for an area east of Great Slave Lake. In the spring, ignitions move in a wave, northeast towards the treeline following the retreat of Arctic air. In July fires occur throughout the region but only rarely in the tundra (see Wein 1976). After August the Arctic airstream again begins to flow southward. Fires already burning north of the Arctic front may continue to burn but rarely do new fires start in areas under the influence of the Arctic airstream. A similar pattern has been reported in northern Quebec by Payette *et al.* (1989).


50N
60N
70N
80N
80N
70N
60N
50N
170W
40N
150W
30N
20N
130W
10N
30W
40N
50W
30N
20N
70W
10N
110W
90W


Central
East Asian
North Atlantic
100°
80°
120°
60°
140°
40°
160°
20°
180°
0°
160°
20°
140°
40°
120°
60°
100°
80°