

## CHAPTER 4

# *Fire Behaviour in Northern Conifer Forests and Shrublands*

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### ABSTRACT

This chapter begins with a review of northern fuels and fire behaviour, and stresses the general uniformity of all spreading fires in vegetation, the two limiting criteria being the rate of forward heat transfer and fuel quantity. Five classes of fire and examples are listed with their approximate intensity ranges, from smouldering fires ( $< 10$  kW/m) to high-intensity spotting fires ( $> 150\,000$  kW/m). The elements of a fire regime, including fire intensity, depth of burn, and fire frequency, are discussed. The link with ecology in the boreal forest is mainly through the process of forest renewal, and the distinction is drawn between species that can regenerate and those that survive fires, and also between those species that require mineral seedbeds and those that regenerate vegetatively. The relationship between forest age and flammability is examined, with the conclusion that conifer forests are generally most flammable at a young age and again during stand breakup, with a period of lesser flammability during maturity. Finally, the observation is made that increased interest in the ecological role of fire in the boreal forest will lead to more sophisticated fire management and a greater desire and need for better prediction of fire behaviour.

### 4.1 INTRODUCTION

This chapter deals with the behaviour of spreading fires in northern ecosystems. It is confined more to forests than to shrublands, and it is mainly based on experience with fire behaviour in the central and eastern Canadian boreal forest as found east of the Rocky Mountains. In this chapter I will try to stress the links between the behaviour of fires and their effects.

### 4.2 FIRE BEHAVIOUR PRINCIPLES

Certain universal principles apply to all spreading fires in vegetation, living or dead. These have really nothing to do with biology but are based purely on the physics and chemistry of combustion:

- (1) There must be sufficient fuel of appropriate size and arrangement in space.
- (2) This fuel must be of sufficient dryness to support a spreading combustion reaction.
- (3) There must be an agent of ignition.

In practical terms, the primary requirement is a continuous layer of finely divided fuel or minor vegetation on the surface of the ground. This material may be conifer needles, hardwood leaves, grass, lichen, moss, finely divided shrubs, or other minor vegetation. However, it must be present and it must be continuous, or the possibility of spreading fire does not really exist. The second requirement is that the material be dry enough. The maximum moisture content at which fire will spread is hard to specify; for any given fuel or vegetation complex it will depend on the amount of fuel, its arrangement in space, and the wind speed. Thus fire spreads poorly or not at all in surface litter of various kinds at moisture contents over 25% or 30% (dry weight basis), whereas fine shrubby fuels or conifer foliage may support fast-spreading fires at moisture contents of 100% or more. The two limiting criteria common to all spreading fires are:

- (1) The fire must transfer enough heat forward to dry out the unburned fuel and raise it to ignition temperature by the time the flame front arrives.
- (2) Enough fuel must pass through the moving flame front to produce a continuous solid flame.

The behaviour of any fire is the result of a complex process that results in a dynamic equilibrium among all elements of mass and energy flowing in and out of the flame zone. However difficult this whole process may be to describe and predict, the above two criteria run like threads through the whole range of fires in vegetation, whether the fuel itself be dead or alive.

### 4.3 FIRE DESCRIPTION

A quantitative means of describing fires is the starting point of the science of fire behaviour. The first and most obvious parameter is the so-called 'rate of spread', a somewhat ambiguous term that usually means rate of advance. Convenient units are m/min or km/h. Byram (1959) provided a concept of fire intensity that has proved to be the most complete fire description that can be expressed as a single quantity. This is the energy output rate per unit length of fire front, convenient units being kW/m. This quantity cannot be measured directly, but can be computed as follows:

$$I = HWR \quad (4.1)$$

where

$I$  is energy output rate per unit length of front (kW/m);

$H$  is low heat of combustion of the fuel (kJ/kg);

$W$  is weight of fuel consumed per unit area (kg/m<sup>2</sup>); and

$R$  is rate of spread (m/s).

Of the factors in this equation,  $R$  has the greatest range, varying perhaps 1000-fold from 0.1 to 100 m/min.  $W$  may vary about 10-fold, from about 1 to 10 kg/m<sup>2</sup>.  $H$ , however, has little bearing on variation in fire intensity, being constant ( $\pm 10\%$ ) at about 18 000 kJ/kg. Fire intensity,  $I$ , thus has a practical range of perhaps 10 000-fold from about 10 to over 100 000 kW/m.

The implications of this tremendous range of fire intensity are of great consequence to the ecology of boreal ecosystems. In Canada, for example, fires of 10 000 ha or more account for probably 90% of the area burned in the boreal forest. Intensities of over 100 000 kW/m are not uncommon. To become large, a fire must spread quickly at high intensity, killing the trees. Nevertheless, all large fires contain areas of low as well as high intensity, usually in a complex mosaic depending on vegetation type, topography, wind variations, and time of day the fire passed a particular spot.

#### 4.4 NORTHERN FUELS

Fuel in northern ecosystems is mainly of four kinds. First, the essential continuous surface fuel is seldom a simple litter layer of dead foliage as in many temperate forests, but generally a blend of one or more of:

- (1) Dead foliage litter;
- (2) Moss or lichen that may become quite dry even in the live state; and/or
- (3) Fine shrubs with a component of fine dead twigs.

Second, it is common, especially in forests, for fairly deep organic layers composed of partially decomposed vegetative remains to form. This fuel, which may be 15 cm or more in depth and 20 kg/m<sup>2</sup> or more in dry weight, is not generally available to the main fire front; the upper several centimeters may burn quickly, but the rest, if it burns at all, is consumed by smouldering after the main front passes. The total extent to which this organic layer burns is therefore somewhat independent of the spread rate and surface fire intensity. The depth of burn depends rather on moisture content throughout the organic layer, which in turn is linked to the weather history for several weeks prior to the fire.

Third, fallen dead trees may account for a significant amount of fuel in some forests. These may cause the fire to flare up, but will usually not affect the average behaviour of the fire appreciably unless the fallen dead trees are present in sufficient numbers to cause the fire to crown.

The fourth major fuel category is, of course, the live foliage. Because of the prominence of crown fires in the northern coniferous forest, this fuel has particular importance. Four features of it have a bearing on crown fire behaviour. These are:

- (1) Total weight per unit ground area;
- (2) Bulk density within the crown space;
- (3) Moisture content; and
- (4) Flammable wax, oil, and resin content.

A seasonal cycle in moisture content has been identified, both in northern Europe (Molchanov, 1957) and in Canada (Van Wagner, 1967), which probably has a considerable effect on the incidence of crown fires. This includes a marked decrease in foliar moisture content in early spring and summer before the new foliage is well developed. The reason, according to Little (1970), is not so much a reduction in the amount of water in the needles but rather a temporary increase in their starch content. Either way the moisture content on a dry basis is less and the foliage more flammable.

#### 4.5 WEATHER AND CLIMATE

Whatever fuel is present in a vegetative ecosystem, it cannot burn without the appropriate weather. In the natural system, the weather provides not only the necessary fuel dryness but also the ignition agent itself (lightning). The usual weather requirements for fire in the northern forest are:

- (1) Rainless periods of at least one or two weeks;
- (2) Occasional days of low relative humidity, high temperature, and high wind; and
- (3) Lightning storms of limited extent.

The frequency and degree of such weather constitutes the fire climate, which, over long periods of time, will determine to a large extent the kind of forest or other vegetation present in any given region. High latitudes have a strong seasonal fire occurrence pattern, with most large fires in June and July when day lengths are very long and there may be strong winds. During these months fine fuel may be flammable for most of the 24-hour cycle. Later in the season, the low angle of the sun hinders serious fire conditions from developing even with long day length. In eastern and central Canada the climate becomes drier as one proceeds from east to west, a trend that is readily apparent in the frequency of fires and in the composition of the boreal forest. For example, balsam fir (*Abies balsamea* [L.] Mill.) and black spruce (*Picea mariana* [Mill.] B.S.P.) increase eastwards, jack pine (*Pinus*

*banksiana* Lamb.) and trembling aspen (*Populus tremuloides* Michx.) increase toward the west (Rowe, 1972).

#### 4.6 KINDS OF FIRE

Forest fires may be classified into various degrees of complexity (e.g., Davis, 1959; Kurbatskii, 1970; Sofranov, 1971). A simple breakdown from the viewpoint of physical behaviour suggests five main kinds of fire, with the following approximate intensity ranges:

- (1) Smouldering fires in deep organic layers (less than 10 kW/m).
- (2) Surface backfires (burning against the wind) (100–800 kW/m).
- (3) Surface headfires (burning with the wind) (200–15 000 kW/m)
- (4) Crown fires (advancing as a single front) (8000–40 000 kW/m).
- (5) High-intensity spotting fires (up to 150 000 kW/m).

Surface headfires may attain quite high intensities in brush, in open forest where trees are sparse or crowns are high above ground, or in leafless hardwood stands. These fires are very sensitive to wind speed.

Crown fires can be divided into three classes according to Van Wagner (1977), called 'passive', 'active', and 'independent'. Passive crown fires are those in which trees torch as individuals, reinforcing the spread rate, but are not basically different from surface fires. Active crown fires are those in which a solid flame develops in the crowns, but the surface and crown phases advance as a linked unit dependent on each other. An independent crown fire is one that advances in the crowns alone. The criteria determining what class of crown fire will result on a given day in a given stand are:

- (1) Height of crown layer above the ground;
- (2) Bulk density of foliage within the crown layer;
- (3) Crown foliar moisture content;
- (4) Initial surface intensity; and
- (5) Rate of spread after crowning.

Probably most crown fires are of the active class; the fire crowns only after the development of a substantial surface fire, and thereafter the two phases spread as a linked unit. Strong wind is first required to intensify the surface fire until the fire crowns. The fire will then fall back to the surface if the wind drops. Crowned-out patterns in large burned areas often reflect such wind variations, even in a uniform forest stand. Similar conclusions were drawn in the USSR by Molchanov (1957) and Kurbatskii (1970).

Extremely fast-spreading, high-intensity fires in northern forests are generally the result of high winds that throw flaming brands ahead of the main front. The coalescence of these spot fires at certain distances and frequencies

enhances the rate of spread in a very complex manner. The best known Canadian example of such behaviour is the 1968 Lesser Slave Lake fire in northern Alberta, which spread all day at about 100 m/min with intensities of 50 000 to 150 000 kW/m (Kiil and Grigel, 1969).

Whatever its type or intensity, a fire's behaviour is ultimately governed by (1) the requirement for a continuous layer of finely divided fuel or minor vegetation on the surface of the ground and/or (2) the requirement for the material to be dry enough to support combustion.

#### 4.7 PREDICTION OF FIRE BEHAVIOUR

The interest in better quantitative prediction of fire behaviour in North America is increasing steadily. The impetus, of course, is the new concept of fire management, with its awareness that all fires are not economic and/or ecological disasters. No longer can the fire control organization justify the open-ended goal of simply detecting and suppressing all forest fires. Both in managed forests and in large parks or wilderness areas, fire officers may now have to decide when to light a prescribed fire or to withhold attack from an accidental fire. Their desire for good predictive information on fire behaviour has naturally intensified.

The ability to predict fire occurrence in various fuel complexes requires not only a knowledge of the principles of fire behaviour but also some means of linking rate of spread and fire intensity with weather and fuel moisture content. There are two possible approaches: modelling or empirical observation.

The literature provides some empirical observations on wildfires as well as experimental fires. In addition to the Lesser Slave Lake fire mentioned above, here are a few recorded examples of how fire behaves in certain northern vegetation types in North America:

- (1) Hardy and Franks (1963): Several case histories of large fires in Alaska, mainly high-intensity fires in black spruce forest spreading at rates of from 10 to 50 m/min.
- (2) Barney *et al.* (1978): Observations of low-intensity surface fires in several Alaskan vegetation types, compared with the output of Rothermel's 1972 model. Spread rates of up to 5 m/min.
- (3) Sando and Haines (1972): An account of the Little Sioux fire in the boreal forest types of northern Minnesota, with a spread rate of 30 m/min sustained over several hours.
- (4) Stocks (1975): An account of the 1974 fire season in northwestern Ontario. One fire in standing timber spread at 45 m/min for 6 h with an estimated intensity of 30 000 kW/m.
- (5) Stocks and Walker (1973): Descriptions of four well known historical

- fires in Ontario, with two records of fire spreading for many hours at average rates of about 65 m/min through northern conifer forest types.
- (6) Kiil (1975): Report on behaviour of an experimental fire in northern Alberta in sparse lowland black spruce, which was basically a surface fire in moss and low shrubs, spreading at 7 m/min with intensity 4000 kW/m.

Obviously, fast-spreading, high-intensity fires are commonplace in the North American boreal forest. On this evidence alone, one could be justified in assuming such fires to be a normal feature of the ecological environment.

To be of any use, observational data on forest fires must be correlated somehow to the burning conditions. To this end, systems of forest fire danger rating have developed in many countries (e.g., the United States, Australia, the USSR, and Canada). Generally, these systems yield relative indices of spread rate or intensity, based on daily weather observations. The ultimate step, namely quantitative prediction of fire behaviour in different kinds of forest, has only been partly accomplished.

In Canada, following the empirical approach, several studies have been completed that match fire behaviour in a given kind of forest with the indices of the Canadian forest danger rating system. The most studied fuel type is the jack pine and lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) forest (Van Wagner, 1973a; Lawson, 1973; Quintilio *et al.*, 1977). In mature, well-stocked forest of these species, fire spread rate  $R$  is given by the equation

$$R = 0.04 (\text{ISI})^{1.8} \text{ m/min} \quad (4.2)$$

where ISI is the Canadian Initial Spread Index (Van Wagner, 1974); this relationship holds reasonably well throughout the entire known range of fire behaviour in this kind of forest. By contrast (Van Wagner, 1973a), spread rates in leafless aspen forest in spring are better matched by the simple relation

$$R = 0.3 (\text{ISI}) \text{ m/min} \quad (4.3)$$

In the USSR, many investigators have studied the relationship between fire spread and weather (e.g., Molchanov, 1940; Vonskii, 1957; Amosov, 1964; Frank, 1964; Telitsyn, 1965; Kurbatskii, 1966; and Ryzhkov, 1971). Most of the relationships developed have been for low- to moderate-intensity surface fires. Indeed, according to data given by Artsybashev (1967), crown fires account for only about 25% of the burned area in the USSR; this is certainly a lower percentage than in the boreal forest of North America.

With respect to modelling, the most promising advance is the mathematical model derived from theory and laboratory test fires by Rothermel (1972), and further developed by Albini (1976). It has been field-tested with reasonable success in certain kinds of uniform fuel such as grass and brush. However, it has two limitations that apply to northern vegetation in particular. One is that

it cannot take into account the different kinds of fuel of varying height within the same complex; for example, moss or lichen with substantial shrub cover. The other limitation is that the model cannot deal with fuel in two separate layers, the important example being surface and crown fuel in conifer forests. Further advances in the modelling approach are to be expected, and a combination of the empirical and modelling approaches will no doubt provide the best progress in the future.

Although quantitative relationships are not available for all vegetation types in the Canadian boreal forest, a good many qualitative impressions are available. For example:

- (1) Among the conifer forest types, jack and lodgepole pines have the highest flammability throughout the fire season, both for surface and crown fire.
- (2) Black spruce forest is less prone to surface fire than the pines, but when conditions are severe, fires in both forest types crown with equal vigour.
- (3) Trembling aspen and white birch (*Betula papyrifera* Marsh.) forests in spring have the highest flammability with respect to surface fire because their litter layers dry quickly as they are completely exposed to the sun.
- (4) In summer, hardwood stands are less flammable than conifers because their litter (now shaded) becomes matted and compact, and their crowns will not support crown fire.
- (5) Lowland forests, usually black spruce, require a longer drought to render them flammable than do upland pine or spruce forests.

Fire behaviour in the sparsely wooded or treeless tundra is obviously a much gentler phenomenon than in the fully stocked forest. Fuels north of the tree line are mainly dead grasses, lichens, mosses, shrubs with a dead twig component, and other minor vegetation that may occasionally dry out enough to carry fire. Fuel in the open tundra is exposed to full sunlight for long day lengths and, during fires, the wind may reach much higher speeds than in the forest. On the other hand, sun angles are low and much of the vegetation has too high a moisture content to contribute very much to fire behaviour. An August 1968 fire near Inuvik (latitude 68°N) was observed by Hill (1969) and quoted by Wein (1974) as spreading at 3 km/day in light forest and 2 km/day in tundra. To judge from other data given, the fuel consumption was probably about 0.5 kg/m<sup>2</sup>. At a rate of spread of 3 m/min (say, 3 km in 18 h), such a fire would have an average intensity of about 500 kW/m, a gentle fire indeed by boreal forest standards. This fire started after a rainless period of 86 days, and burned for 10 days over 35 000 ha.

Enough data now exist (Rowe *et al.*, 1974; Wein, 1974, 1976), to conclude that lightning fire is a standard feature of the Arctic environment. These authors, as well as Rowe and Scotter (1973), provide many qualitative

observations and speculations about fire behaviour in the sparsely wooded or treeless zones.

Fires in the natural system are, of course, started by lightning. There is an obvious paradox here, since lightning is usually accompanied by rain. Probably lightning fires are most common around the edges of the heavy rain zones, or in lightning storms which release little or no rain. When rain does occur at the point of ignition there are three requirements for a lightning fire of substantial area to develop:

- (1) There must be some protected dry fuel available for ignition, such as partly decomposed or 'punky' wood in stumps or logs, or as pockets of deep organic matter at the base of trees.
- (2) This fuel must have the ability to smoulder slowly for up to several days while the local surface fuel dries out enough to carry fire.
- (3) There must be a large adjacent area on which little rain has fallen for some longer period of time.

Although complete information does not exist, there are obviously many fuels that can be ignited by lightning. According to lightning-fire data compiled by Kourtz (1967), tall trees or dead snags are most susceptible, but nevertheless lightning may strike anywhere, including trees live or dead, short or tall, or on open treeless ground. The prediction of lightning ignitions depends, then, on (1) a current estimate of the moisture state of the susceptible fuel and (2) a record of the areas struck by lightning as the storms pass by.

#### **4.8 FIRE REGIMES AND ECOLOGY**

Three aspects of fire are important from the ecological viewpoint: intensity, depth of burn, and frequency. The fate of all aboveground plant parts is directly dependent on the fire intensity as expressed in terms of energy output rate per unit of fire front (i.e., kW/m). While minor vegetation may be killed outright by fire of almost any intensity, fires in forest can be split into three relative intensity classes:

- Class 1: Fires so gentle that trees are not scarred (surface vegetation may be killed);
- Class 2: Fires intense enough to kill some trees within a small given area but not all (some trees may be scarred); and
- Class 3: Fires intense enough to kill all trees over a wide area.

Fires of class 3 (lethal intensity) may kill trees either by crowning, by girdling the stem near the ground, or by scorching the entire crown foliage. Boreal

forest trees are generally small; therefore from consideration of scorch height alone (Van Wagner, 1973b) there are probably few boreal forest stands that could survive a fire of intensity greater than 1500 kW/m, which then constitutes the approximate boundary between intensity classes 2 and 3. At the low end of the intensity scale, the boundary between classes 1 and 2 is probably about 300 kW/m. The major part of the intensity range encountered in the North American boreal forest thus lies within the lethal class 3.

An aspect of fire behaviour of great ecological importance is the total consumption of surface organic material, the so-called 'depth of burn'. Since it depends mainly on the length of drought, depth of burn may be somewhat independent of the rate of spread and thus of fire intensity. Depth of burn is best predicted from the moisture content of the organic layer, or in turn, through a fuel moisture index of the appropriate reaction time or time-lag. For example, consumption of organic layers in eastern Canadian pine forest can be predicted (Van Wagner, 1970) from the Duff Moisture Code, a component of the Canadian fire danger system (Van Wagner, 1974). Consumption by fire of the deep forest floors of the boreal forest has not as yet been quantitatively analysed. This work should be conducted, since the mineral soil may or may not be bared during these fires. The quality of the resultant seedbed and the fate of plants whose underground regenerating parts lie within or just below the organic layer are highly dependent on the depth of burn.

The frequency of fires in a given area depends on both the climate and the rate at which potential fuels accumulate following each fire. The fire frequency must be in some rough long-term equilibrium with the longevity of the main tree species and the ages at which they are able to reproduce after fire.

The historical averages of these three attributes of fire (intensity, depth of burn, and frequency) together constitute the fire regime. For every ecosystem that depends in some way on periodic fire for its perpetuation there will exist an optimum fire regime that best fulfils the ecological requirements.

With respect to fire-adapted forests, the tree species can be separated into two types that correspond to the fire intensity classes listed above:

- (1) Those species able to regenerate even though all individuals are killed over a wide area; and
- (2) Those species of which some individuals must remain alive to provide seed for the next generation.

Species of the first type may be either conifers that store mature seed in insulated serotinous cones, hardwoods that either sucker from roots or sprout from the root collar, or species that bank seeds in the soil. Species of the second type are conifers whose seed is released every year when the cones

mature. It is worth noting that the conifer species of northern Europe and Asia are not generally considered serotinous. It could be generalized, therefore, that fires in the Eurasian boreal forest are generally not of lethal mean intensity. The lesser proportion of area burned by crown fires accords with this idea.

The interaction of fire regime and the regeneration characteristics of the tree species accounts in large part for the kind of forest found in any region. Thus, a lethal fire regime (class 3) and species type 1 generally prevail throughout the Canadian boreal forest. It is no accident that most of the main trees, namely black spruce, jack and lodgepole pines, trembling aspen and white birch, are all species of type 1 above, adapted to regenerate after lethal fire. The other conifers, namely white spruce (*Picea glauca* [Moench] Voss), balsam and alpine firs (*Abies lasiocarpa* [Nook.] Nutt.), and tamarack (*Larix laricina* [Du Roi] K. Koch.), all species of type 2, depend for their presence on variable fire intensity; they survive in areas of intensity classes 1 and 2, or in unburned pockets protected by topography. Worthy of note is that the seed of none of the common Canadian boreal tree species (conifer or hardwood), except that of the firs, will germinate and survive well except on burned or bared surfaces.

The immediate physical effects of fire are:

- (1) killing of all or some of the overhead canopy;
- (2) removal of all or some of the soil's organic layer; and
- (3) some degree of control over minor vegetation.

The plant species, including trees, that benefit from periodic fire, have regeneration needs that match one or more of these physical effects. Chemical effects, such as on the nutrient regime, may also play some part, but it is these direct physical effects of fire that principally influence the success of a given species after fire.

Some of the possible interactions among all these factors (intensity classes, physical fire effects, regeneration mechanisms), are

- (1) A short fire interval on a given site may promote hardwoods over conifers in the next generation because the ability to sprout or sucker appears at an earlier stage than abundant seed.
- (2) A long fire interval, during which the hardwoods die out, may promote the conifers because of their greater longevity.
- (3) Intense fire in a young conifer stand may provide good opportunity for hardwood invasion by seed. Trembling aspen seed, in particular, can travel long distances on the wind to take advantage of mineral seedbed when there is no other competition.
- (4) Multi-aged stands of conifers may form in areas burned by the nonlethal

intensity classes 1 and 2. The pines especially recover well from partial girdling by fire.

- (5) Because lowland areas become flammable only after a greater length of drought than do uplands, it follows that fire is generally more frequent and mean age of stands is lower in the upland forest than in the lowland.
- (6) Because of the great dependence of most boreal species on mineral seedbeds for successful germination, variation in depth of burn on a given area may produce great differences from generation to generation in the conifer density.
- (7) Where a mixture of hardwoods and conifers occurs, a lethal fire that fails to burn deeply may promote the hardwoods over the conifers in the post-fire forest, since their vegetative regeneration mechanisms are independent of seedbed.

It is, in fact, hard to exaggerate the importance of seedbed in the northern upland conifer forest. Fire researchers at the Petawawa National Forestry Institute have repeatedly observed plentiful healthy black spruce and jack pine seedlings on bared mineral surfaces, but few or none on thick residual organic matter. It may be that the northern limit of tree distribution is simply the latitude at which fires fail to produce appreciable mineral seedbed. This is not to deny that climate is the ultimate control, but simply to suggest that the first factor coming into play as one goes north may be the failure of the organic layer to dry enough to burn, rather than a direct climatic limitation on growth or winter survival.

Whatever the variations in fire regime and their effects on the ebb and flow of tree species from point to point, it seems that the majority of fires are followed by a forest not unlike the original one. It is, in fact, very difficult to find throughout much of the North American boreal forest a stand in which the first trees that followed the last fire are not still present. According to Zackrisson (1977) this principle would also apply fairly well to the Scots pine and Norway spruce forest in northern Sweden, at least in its natural state. Looking on the forest as fuel, from the viewpoint of fire behaviour prediction, it is therefore its age as much or more than its species composition that warrants study.

#### 4.9 FLAMMABILITY VERSUS AGE

In a region affected by periodic fire, vegetation develops in cycles from one fire to the next. It follows that the fuel available for combustion follows a cyclic pattern as well. The relative flammability of the vegetation throughout this cycle is of great interest ecologically because of its effect on age-class distribution, a major feature of the forest landscape and of certain treeless vegetation as well.

If an ecosystem normally cycled by fire were equally flammable throughout

its life then it can readily be shown that the expected distribution of intervals between fires would be the negative exponential (Rowe *et al.*, 1975). It follows that the age-class distribution itself would also be negative exponential (Van Wagner, 1978). Age-class frequencies are then given by

$$f(x) = p \exp(-px) \quad (4.4)$$

where  $x$  is age,  $p$  is annual probability of fire at any given point, and  $f(x)$  is the frequency of single-year age classes. In such a forest, the cycle is  $1/p$ , the average age is the same as the cycle, and about one-third of the forest lives past the cycle age. If flammability is not constant throughout the cycle, then the distribution of intervals between fires should reflect this. Thus Johnson and Rowe (1977) found distinct peaks in the fire interval distributions in several areas of conifer forest in the Canadian Northwest Territories. They found that a Weibull distribution best fitted their data, given by

$$f(y) = (c/b)(y/b)^{c-1} \exp[-(y/b)^c] \quad (4.5)$$

where  $y$  is the interval between fires at any point and  $b$  and  $c$  are constants. When  $c = 1$ , this equation reduces to the negative exponential form as in Equation (4.4).

Any non-uniformity in flammability throughout the cycle may have a marked effect on the distribution of fire intervals, but not so much on the age-class distribution itself. This is because, while the fire interval distribution may show a blank at very young age and a decided peak at some other, the curve of age-class frequencies must start at a maximum at age zero; it can thereafter fall but never rise.

A long-standing assumption among forestry people is that old stands are generally more flammable than young ones, especially after they begin to break up. Nonetheless, objective evidence for this idea is hard to find. The rate of fire spread depends more on the quantity and arrangement of fine fuel than on the accumulation of downed logs or deep organic matter. Indeed, conifer stands are more prone to crown fire at young and moderate age (Van Wagner, 1977); when the canopy is high and thin they may support a slower-moving surface fire only. It may, of course, take a few years before a burned area acquires enough fine fuel to burn again, but intense fire is possible in conifer stands no older than 10 years. A well-stocked mature stand just before breakup may well represent the least flammable stage in the typical boreal forest cycle. In overmature stands, as downed trees accumulate, a certain proportion of them will always be in an ideal state for combustion.

Two conclusions can be drawn from these observations. First, fire behaviour in the boreal forest is not a simple function of age (see Figure 4.1). Potential intensity usually increases fairly quickly to a maximum within two or three decades, decreases and maintains a lower level throughout healthy

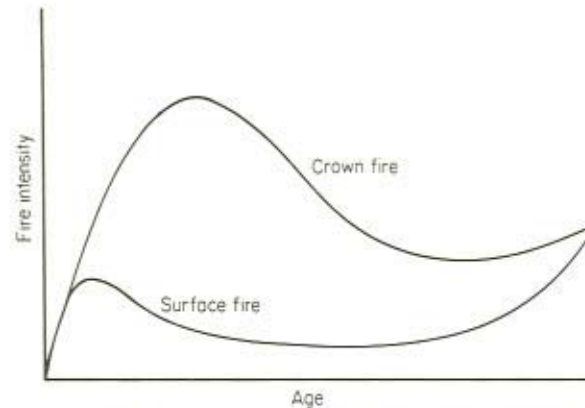


Figure 4.1 Hypothetical fire behaviour cycle in one generation of boreal conifer forest. Surface and crown fire are shown separately

maturity, and then rises again as the stand deteriorates or as younger conifers invade the original stand. Maupin (1978–1979) came to a similar conclusion about lodgepole pine in Idaho. Second, fuel buildup in the sense of simple fuel weight per unit area is not a good criterion of potential fire intensity in the boreal forest. Although surface organic matter and large downed wood may increase greatly as the stand ages, and may smoulder for some time when fire strikes after a long drought, most of this material is unavailable as fuel for the main fire front.

#### 4.10 CONCLUSIONS

The general conclusion from the foregoing is that a fair amount is known about fire behaviour in boreal ecosystems, especially in a qualitative sense; it is the quantitative aspects of the fire behaviour phenomena in which the greatest scope for progress lies. Such knowledge would be greatly desirable from two points of view. One is that of the fire management officer, who may be or soon will be committed to a policy in which some fires may be allowed to spread even though the capability exists to stop them. His particular interest is in the link between burning conditions and fire behaviour; in Canada, for example, this means the codes and indexes of the Canadian Forest Fire Danger Rating System. The other is that of the ecologist studying the effects of fire. The fire regime joins equally with climate and site quality to determine what kind of vegetation will prevail generally throughout a region. However, the great variability from fire to fire means that measurements of any fire effect may not tell the whole story unless linked directly to the behaviour of the fire that caused them.

## 4.11 REFERENCES

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