FOREST FIRE EFFECTS ON ENVIRONMENT IN CANADA

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INTRODUCTION

Fire continues to create a most important and certainly the most spectacular disturbance in Canada's forests. The occurrence and recurrence of extensive wildfires have been the principal causes of forest renewal in the lightning-fire environment of the major forest regions. Observation and study of vegetative patterns and fire scars on trees, and the presence of charcoal in the soil reveal that very few areas have not been burned during the past 300 to 400 years. In recent years, technology has contributed to a reduction of fire losses and damages especially in densely populated and intensely managed areas. However, extensive fires continue to occur in all regions of the country, thereby preserving the historical role of wildfire as an important natural process in prairie, forest and tundra ecosystems. At the same time, forest managers find prescribed burning a useful tool in numerous situations. The effects of wildfire and prescribed fire are similar in principle, but circumstances of occurrence and behavior result in significant differences also.

The purpose of this paper is to summarize the impacts of wildfire primarily in northern coniferous forests, although the

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basic role of fire as an ecosystem process holds for other forest regions as well. I have tried to isolate these ecological principles and processes which determine the type, magnitude and duration of fire impacts on the environment and to compare them in a somewhat limited way with the effects of prescribed burning especially as used with timber harvesting. The historical role of fire in natural forest ecosystems has received much attention during the last decade (Kayll, 1968; Slaughter et al., 1971; Anon., 1972; 1973; Wright and Heinselman, 1973), and the considerable impact of fire on forest values and services is now generally acknowledged by research workers and resource managers alike.

HISTORICAL PERSPECTIVE ON FIRE IN CANADA

For thousands of years prior to the arrival of settlers, surveyors, loggers, trappers, miners and railroad builders in the 18th and 19th centuries, lightning was the main cause of fire in the forest. Evidence suggests that Indians started many fires, but a dramatic increase in the incidence of prairie, forest and tundra fires occurred with the establishment of homesteads and the exploitation of forest and mineral resources. Finding the forest a serious hindrance to settlement and land cultivation, combined with the belief that the forest was inexhaustible and that fire did no important damage, resulted in a somewhat irresponsible attitude toward it. When extensive land-clearing activities coincided with periods of drought as well as high incidence of fires, the results often manifested themselves in large-scale forest destruction. Many of the better-known historic wildfires occurred from the 1860's to the 1930's (Brown and Davis, 1973), a period which gave impetus to the development of organized forest fire control. Every region of Canada has experienced huge and destructive wildfires during the past 200 years, with individual fires buring in excess of 100,000 hectares and causing damages of the order of millions of dollars.

Since the advent of the modern era of fire control following World War II, fire management agencies have increasingly recognized that the key to further reduction in losses from wildfires lies in their ability to develop and maintain a well-organized and mobile fire-fighting force capable of detecting and taking quick and agressive action on individual fires. Depsite this, 7,500 fires continue to burn 891,000 hectares of forest and tundra annually, including 166,000 hectares in the Yukon and Northwest Territories (Lockman, 1969). Significantly, lightning continues to cause 25% of all fires and to burn more than one-half of the total area. It is well known that much of the total area burned and damages are attributable to a very small number of large fires. For example, during the ten-year period 1959-68, an annual average of only 200 fires exceeded 200 hectares in size but these burned more than 90% of the total area (Lockman, 1969).

A comparison of area burned with the area depleted by harvesting provides a perspective for further discussion and assessment of the importance of fire effects on the environment. Over a period 1964-68 (Manning and Grinnell, 1971), 826,000 hectares were depleted by harvesting annually to produce an average of 321 million cubic metres of wood. Of the 150 million hectares of nonreserved forest land allocated to wood production in Canada, about 224,000 hectares were burned over annually, or about 40% of the area depleted by harvesting. While detailed breakdowns of the total area burned annually by vegetation type and age class distribution are not available, it is estimated that an average of 0.22 of 1% of the total of 415 million hectares of land under some form of organized fire protection is burned annually. The corresponding figure for Crown lands allocated to wood production is about 0.15 of 1%, or about two-thirds the rate on all lands under some form of fire protection. Fires are responsible for destroying timber volume equivalent to about one-sixth of the annual harvest of merchantable timber in Canada.

IMPACTS OF WILDLIFE

Periodic random fire disturbance plays a key role in shaping the total vegetation mosaic. The frequency of large wildfires appears to be strongly influenced by the coincidence of natural fire rotation of plant communities with the dry phases of climatic cycles. Within this dynamic system, some plants succeed toward a mature condition whereas others are interrupted in the sequence by fire. The ability of boreal forest trees such as jack pine, black spruce and aspen to invade burned sites and the subsequent successional sequence depends on their pioneering characteristics, and topography, site conditions, climate, and fire severity. A burned plant community has a tendency to replace itself directly after a fire, but general successional patterns become increasingly complex on sites where permafrost-vegetation relationships create unique conditions (Viereck, 1973). The natural incidence of extensive wildfires has interrupted vegetative succession in all areas, with the result that self-reproducing climax plant communities are rare indeed.

Fire history determines the successional stage occupying any particular area. The irregular boundaries of distinct vegetation types are attributed to a combination of unburned patches within the overall perimeters of large fires and spotfires within extensive tracts of forest burned at various intervals over thousands of years. The timing and intensity of other disturbances, including blowdown, insects, disease and logging, also contribute to the patchwork nature of the vegetation. While northern plant species and communities are susceptible to fire-kill, they have developed features which ensure their survival and perpetuation. The so-called fire-dependency of these species refers to adaptive mechanisms such as release of seed from serotinous cones, flowering and fruiting of herbs and shrubs, vegetative reproduction of species and improved seedbeds for germination, and the flammability of the plant community. Fire behavior and effects vary considerably depending on fuel characteristics, topography and weather.

The three-dimensional structure of the forest creates a habitat diversity (Webb, 1973) which in turn increases the opportunities for different wildlife species to utilize a particular portion of this habitat. In fire-created plant communities, particular habitats are continuously being modified as successional patterns evolve. Each successional stage has its own fauna; hence, any disturbance such as fire will create a new environment with the consequent change in the kind and distribution of animal populations. Species specialized to live near the ground benefit from the post-fire influx of lesser vegetation whereas fire destroys the habitat of the species living in the stand canopy. On the more productive sites, regrowth of vegetation occurs within a very short period of time whereas 50 to 100 years may lapse before significant recovery of lichens occurs on mature spruce-lichen sites. The shrubs that invade a burned site are relatively high in protein and other essential nutrients and can support dense populations of common game species such as moose, elk and deer (Dasmann, 1964). Clearly, ecological succession as influenced by fire frequency and intensity helps determine whether fire is good or bad for wildlife; however, the extreme variability in environmental conditions and animal ecology preclude meaningful generalizations about these relationships. Ultimately, the goodness or badness of fire on wildlife must be judged on the basis of forest management objectives.

Fire destroys the hosts of such insects as spruce budworm and mountain-pine beetle, thereby eliminating the threat of further large-scale outbreaks until the stands again become decadent and highly susceptible. Forest parasites such as dwarf misteltoe are also kept in check by periodic wildfire. Following wildfire, wood-borers may rapidly degrade the logs and thus prevent their salvage for lumber. Fire-caused changes in species and age of forest stands may produce insect and disease problems that did not exist prior to the fire.

In northern latitudes, production of litter and other organic material on the forest floor usually exceeds the rate of decomposition; hence, fire serves as a regulator of the amount of forest humus. The rate of dry matter accummulation depends on temperature, moisture, precipitation, aspect, elevation, soil type, evapotranspiration and related site factors. Fires directly or indirectly contribute to the recycling of the organic matter in an ecosystem but only in exceptional circumstances is the reduction of the duff layer likely to be detrimental to site productivity (Lutz, 1956). In areas of permafrost, removal of part of the organic mantle increases the depth of the active layer, and may enhance growth of the incoming vegetation (Viereck, 1973).

Table 1 reflects the depth and oven-dry weight of representative forest floor layers in lodgepole pine, aspen, and white and black spruce stands in Alberta. For the four stands sampled, depth and weight of the forest floor ranged from 5.5 to 22.3 cm and from 49 to 124 tonnes/ha, respectively. These figures include significant amounts of mineral soil in the H layers, but the values for the L and F layers are believed to be indicative of fuel loadings in these forest stands. Differences in fuel loading and arrangement contribute to wide fluctuations in the amount of fuel consumed by a fire but fire behavior is strongly affected by the moisture content of the surface layer of the forest floor.

Depending on yearly and seasonal drying regimes, the vertical moisture profile through deep forest floor layers such as those commonly found in northern regions may vary considerably and thereby complicate the pattern of fuel consumption. For the lodgepole pine duff samples in Table 2, the oven-dry weight and the water-holding capacity of the surface 5 cm amount to about 24 and 46 tonnes/ha (equivalent to 0.46 cm of rain), respectively. By contrast, the corresponding figures in the next lower 5-cm layer are 56 and 110 tonnes/ha (equivalent to 1.10 cm of rain). Thus, a typical 10-cm deep duff layer under a lodgepole pine stand can be expected to store up to about 1.5 cm of rainfall, with one-third of that amount in the top half of the layer. By comparison, an 11-cm deep duff layer under a white spruce stand is capable of storing

Table 1. Average depth and oven-dry weight of L, F and H layers under forest stands in Alberta

Forest floor layer	White Spruce		Black Spruce		Aspen		Lodgepole Pine: Dry Sites		Lodgepole Pine: Moist Sites	
	Depth in cm	Weight in tonnes/ha	Depth in cm	Weight in tonnes/ha	Depth in cm	Weight in tonnes/ha	Depth in cm	Weight in tonnes/ha	Depth in cm	Weight in tonnes/ha
L	2.8	12.2	3.9	23.0	2.8	6.8	2.5	10.9	3.6	8.5
F	6.6	62.9	18.2	97.1	6.7	87.8	2.8	37.1	4.9	46.5
H	1.6	29.8	0.2	3.6	0.3	5.8	0.04	1.1	1.2	23.4
TOTAL	11.0	104.9	22.3	123.7	9.8	100.4	5.5	49.1	9.7	78.4

Basis:

White spruce	240	0.092 sq m plots
Black spruce	72	"
Aspen	72	"
Lodgepole pine (dry)	308	"
(wet)	240	"

Samples were collected in stands covering a wide range of sites, ages and densities.

Note: Weights are not corrected for mineral content.

Table 2. Oven-dry weight and moisture-holding capacity of the forest floor under lodgepole pine and white spruce stands in Alberta.

Depth below surface of forest floor in cm	Lodgepole Pine			White Spruce		
	Wt. in tonnes/ha	Wt. of water in tonnes/ha (at saturation)	Water equivalent in cm	Wt. in tonnes/ha	Wt. of water in tonnes/ha (at saturation)	Water equivalent in cm
0 - 2.5	8.1	14.1	0.14	11.0	22.0	0.22
2.5 - 5.0	16.1	32.7	0.33	14.6	31.7	0.32
5.1 - 7.5	22.4	45.2	0.45	18.1	43.9	0.44
7.6 - 10.0	34.0	64.4	0.64	21.0	53.6	0.54
10.1 - 12.5	-	-	-	27.6	64.3	0.64
TOTAL	80.6	156.4	1.56	92.3	215.5	2.16

Basis: Five 0.092 sq m forest-floor samples were taken from each stand type. Moisture-holding capacity was determined in laboratory. The data in Table 2 are indicative of duff weight and water-holding capacity in these stands but independent of fuel weight data in Table 1.

about 1.8 cm of rainfall.

Fire spreading along the surface of the forest floor generally kills all lesser vegetation including grasses, herbs, shrubs and tree seedlings. In northern coniferous forests, the quantity of lesser vegetation is usually less than 3 tonnes/ha and is likely to regenerate from undamaged underground stems and roots within a single growing season. A light surface fire with a frontal intensity of about 100 kcal/(s·m) of fire front can be expected to consume anywhere from 5 to 15 tonnes/ha of organic matter, depending on fuel type, arrangement, moisture content and weather conditions. Thin-barked trees may be killed but such fires often leave appreciable amounts of fine material on site. In British Columbia, light surface fires with energy transfer rates of less than 100 kcal/(s·m) killed practically all advance regeneration and an average of 31% of mature trees on three lodgepole pine sites (Lawson, 1973).

By contrast, widespread killing and substantial reduction of the tree crop occurs with fire intensities in excess of about 6,000 kcal/(s·m) of fire front. A conflagration-type fire, involving tree crowns and spreading at rates up to 7 km/hr over several hours, may consume up to 25 tonnes/ha, or more, of above-ground dead and live standing woody material, including bark, dead woody material, all foliage and finer branches (Table 3). While nearby all live trees are killed, the dead trees and unburned branches continue to provide partial shade to the forest floor for several decades as well as enhancing the available mineral nutrient status of the site. In eastern pine stands, duff consumption was shown to increase with decreasing moisture content, with an estimated 26 tonnes/ha being consumed at Duff Moisture Code 80, equivalent to about 20 drying days without precipitation (Van Wagner, 1972). Given a total biomass of 190 tonnes/ha in a 70-year-old lodgepole pine stand, total fuel consumption by an intense crown fire may exceed 50 tonnes/ha, or about 26% of the biomass on the site.

Only the most intense forest fires will provide for more than spotty mineral soil exposure. Mineral soil exposure in excess of 50% of the surface area of the forest floor is often associated with relatively shallow organic layers of less than 5 to 6 cm on well-drained sites. On such sites, a combination of seed release from fire-opened cones and a near-continuous exposure of mineral soil may produce an extremely dense 14-year-old stand of 1,500,000 lodgepole pine seedlings per hectare. More commonly, the removal of more than 50% of forest floor by weight and the exposure of patches of mineral soil will, for example, produce a typical, well-stocked lodgepole pine stand of fire origin (Table 3). On moister sites with deep accumulations of organic material such as moss and humus, fires may occasionally consume fuel to a depth of 20 cm or more but even here, the average depth of burn will not exceed 15 cm. On such sites, slow smouldering may continue for hours or even days, further reducing the amount of organic material.

Soil and water are an integral part of the forest landscape and key elements in forest productivity. As shown in Table 2, undisturbed forest soils accept and store significant amounts of water and the relatively thick organic soil mantle in northern forests contributes to the stability of soil by reducing soil loss and erosion. A reduction of the surface area of the forest canopy will increase the amount of water reaching the forest floor but the fire-reduced humus layer has a lower capacity for water storage than the undisturbed forest floor. The reduction in the amount of water transpired and intercepted by the standing dead trees contributes to increased water yield and streamflow (Stone, 1973) and, depending on site conditions, fire intensity and frequency, and type and periodicity of post-fire precipitation, may have the potential to degrade water quality (Rice, et al., 1972). Increases in snow water equivalents of up to 40% in 2-to 8-hectare clearcut blocks, compared to an uncut lodgepole pine forest, have been documented (Berndt, 1965).

In burned-over watersheds, any such increase in snow accumulation and early snow-melt tend to further increase peak

Table 3. Estimated fuel consumption in a representative lodgepole pine stand in Alberta

Stand Component	Pre-fire fuel quantities	Fuel consumption by Light surface fire (about 100 kcal/(s· m)	Fuel consumption by Intense crown fire (about 6,000 kcal/(s· m)
	Tonnes/ha		
Needles	11.3	0.0	11.3
Branches	13.8	0.1	5.5
Live stems - wood	83.9	0.0	1.1
- bark	9.3	0.4	3.1
Standing snags	11.0	0.5	4.4
Lesser vegetation	1.2	1.0	1.2
Litter (incl. moss & needles)	7.2	5.0	7.2
Dead woody material on forest floor (i.e. twigs & logs)	7.7	4.0	6.0
F & H Layer	45.4	0.0	12.0
Total	190.8	11.0	51.8

Lodgepole pine stand: 2,224 stems/ha
Height: 17.1 m
Age: 70 yrs

spring runoff and subsequent water yield. Removal of part of the organic soil mantle and, in particular, exposure of the mineral soil by fire, may result in mass movement of soils or increase the hazard of surface erosion. However, mixing, gauging and compaction of the mineral soil is extremely rare. Of the three main contributors to surface erosion - exposure of soil surface, deep disturbance of the soil, and compaction (Stone, 1973) - exposure of the soil surface by an extremely hot fire is likely to be the most deleterious effect. Nevertheless, sediment volumes of the order of 1,300 tonnes/sq km in the first year after logging in California (Anderson, 1962) will not occur following wildfire.

Fire-caused openings in the stand canopy reduce the moderating effect of the forest on climate, thereby increasing the wind flow, the rate of evaporation, solar radiation reaching the forest floor, soil and air temperatures, and throughfall of precipitation (Johnson et al., 1971). Since the influence of the forest on most climatic parameters rarely extends beyond more than a few times the height of the trees into burned areas, climatic conditions in the burn are likely to change but little with increasing size of burn. On an annual basis, wind velocities in a forest are usually between 20 and 50% of those in the open (Kittredge, 1972), with corresponding values for burned-over forest likely to be intermediate between these two extremes. In northern Saskatchewan, midday summer soil temperatures in burned-over forest exceeded those in mature forests by 2.3 to 7.9°C, depending on age of burn and forest type (Scotter, 1971).

Significant accumulations of organic matter are likely to inhibit productivity and the general vigor of animal and plant life (Youngberg and Davey, 1968). Oxidation by burning releases the minerals found in plant materials and, through its effect on insolation, speeds up the decomposition process. Many of these nutrients will be deposited as ashes on the forest floor, thereby reducing soil acidity. Nitrogen, being non-mineral in origin, can escape into the atmosphere but fire, through its salutary effect on fungal and bacterial activity, may enhance the conversion of atmospheric and other unavailable forms of nitrogen for use by plants. Some fires kill all trees but do not consume the foliage; in those instances, significant amounts of nutrients return to the forest floor as part of litter fall following the fire. While the precise nature of nutrient cycling by fire is not well documented, it seems that the northern forest has adapted to, and benefits from periodic wildfire to sustain its productivity. However, repeated severe burns within the natural fire rotation of a boreal forest stand may seriously deplete nutrient reserves (Ahlgren and Alhgren, 1960).

As shown by Tamm (1969), tree crowns of pine and spruce often make up about one-third of the dry weight of the above-ground stand, but contain two-thirds of the nutrient store. Other studies (Baskerville, 1965; Kiil, 1968; Weetman and Harland, 1968) suggest a wide variation in the proportional weight of tree crowns, ranging from about 20% in mature stands to in excess of 60% in younger stands. An intense fire in a young conifer stand will therefore deposit or destroy a proportionately greater amount of the nutrient stored in the fine, combustible material compared to an older stand where a considerable portion of the nutrient supply is locked up in the heavier stems or the deep humus layer on the mineral soil. In a young Douglas fir stand in British Columbia, Cole et al. (1967) estimate that foliage contains 31.9 and 43.9% respectively of the total amounts of nitrogen and phosphorous in this second-growth ecosystem.

Using a dense lodgepole pine stand in Alberta (Kiil, 1968) and nutrient element tables (Young and Carpenter, 1967), rough calculations suggest that an intense forest fire will release about 400, 65 and 100 kg/ha of nitrogen, phosphorous and potassium, respectively from the standing tree crop and the organic material on the forest floor. These figures represent about one-half of the nutrients in the above-ground portions of the tree crop but only a small fraction of the substantial quantities locked in the humus and soil layers. In a black spruce stand in Quebec, Roberge et al. (1968) found 890 kg N/ha in a 20-cm deep humus layer on a well-drained site.

While substantiating data are not available, it is expected that leaching and runoff of mineral nutrients is highest in steep terrain with a minimum of residual humus following a hot and deep-burning wildfire. The general absence of overland flow in relatively flat northern areas prevents nutrient loss into streams through erosion. Where underground seepage or streamflow contribute to an increase in nutrients in lakes, eutrophication, with an attendant increase in plant density and winterkill of fish owing to oxygen depletion, may occur (Ball, 1950). In terrestrial plant communities, the initial increases in nutrient concentrations are depleted in 1 to 2 years (Smith, 1970) but residual effects may continue for as long as 20 to 30 years. Considerable evidence is now available to suggest that productivity can be higher in early than in late stages of ecosystem development (Rowe, 1973).

The accumulated impact of previous fires is discernible in the varied age class distributions and irregular boundaries of forest types. This random pattern is nature's own method of retarding fire propagation, for even the larger wildfires eventually run into fuels of lower flammability or recently-burned areas with scarcity of fuels. By consuming most of the fine fuels on the forest floor as well as in tree crowns, a wildfire reduces the flammability of the immediate post-fire plant community. The usually rapid development of lesser vegetation provides shade and further reduces fire hazard in summer, although the presence of large quantities of cured vegetative material may contribute to fast-spreading surface fires in spring and autumn. Development of conifer seedlings and a renewed buildup of the duff layer, combined with the presence of dead stems, bark and branches from the previous fire, represent an increasingly flammable fuel complex. Many of the major conflagrations burn in heavy accumulations of dry fuels in decadent stands, especially following insect and disease infestations, blowdown and harvesting. The increasingly greater fuel loads and higher ratios of dead vs live vegetative material with age suggest a corresponding increase in fire potential, peak flammability occurring with a biomass and fuel moisture distributions most conductive to ignition and propagation of crown fires.

Smoke is often the most visible part of a wildfire and its persistent presence is usually considered to be offensive to the senses. When a fire burns for several days or weeks, smoke haze may be a nuisance over a large area, reducing visibility near the ground surface and in the atmosphere. According to results of studies carried out in Australia, woodsmoke does not appear to contain harmful concentrations of gas or particulate matter such as carbon monoxide, sulphur dioxide or oxides of nitrogen (Vines et al., 1973). Similarly, ash in the smoke cloud in most cases amounted to a few per cent of the total ash produced and deposited on the forest floor.

Bulldozers and chemical retardants dropped from airtankers are commonly used to assist fire-fighters contain and suppress wildfires. Lotspeich et al., (1970) report that the melting of permafrost, caused by removing the organic layer in building firelines, is a major contributing factor to erosion. Annually in Canada, an estimated 17 million litres of chemical fire retardants, primarily ammonium sulphate and diammonium phosphate, are dropped in support of fire control operations (Grigel et al., 1974). Nitrogen concentrations in a range of 50 to 75 kg spread unevenly over a drop area of one-fifth of a hectare can be expected, but this level of fertilizer generally produces beneficial effects on site productivity, except when the whole load enters a stream or a lake. In the latter instance, it may affect the survival of freshwater fish (Van Meter and Hardy, 1971).

Occasionally, closure of a forested area may be required to assist that fire control organization contain and suppress a wildfire, with the result that recreationists and visitors from other areas may be prevented from pursuing their interests. The persistent presence of woodsmoke during an unexpected fire and the appearance of a recent burn detract from the aesthetic qualities of a burned area. However, viewed on a broader scale involving a mix of successional types and stages, both short- and long-term fire effects may well enhance the recreational attributes and scenic attractions of a region. The generally gradual and irregular interface between burned and unburned forest contrasts sharply with the very abrupt border between a clearcut and unutilized forest, with the former perhaps representing a more pleasing appearance. By contrast, the intentional burning of logging slash may well intensify the stark appearance of a square or rectangular-shaped block.

PRESCRIBED FIRE EFFECTS

Burning of logging debris has been practiced throughout the world; today, about 60,000 hectares of cutover lands are burned in Canada, with over 90% of that taking place in British Columbia. The application of prescribed burning and its effects on logged areas are relatively well documented (Van Wagner, 1966; Chrosciewicz, 1967; Muraro, 1971) but increased utilization of the tree crop and greater mechanization including scarification may be reducing the need for slashburning in aid of hazard reduction and seedbed preparation. Intensive forest management will certainly contribute to fuel management, early discovery of fires and better access, but it will not eliminate the wildfire problem; in fact, fire incidence may increase over present levels in extensively managed forests. In unutilized northern forests, fuel management by prescribed fire is not usually feasible owing to the low fire resistance of many tree species and the high potential for crowing when effective burns are possible. Regardless of local vegetation types and their susceptibility to fire propagation and damage, fuel management must be viewed in relation to all land management objectives (Brackebusch, 1973).

In northern and western conifer forests, prescribed burning is used primarily for reduction of logging slash, plant competition and humus before direct seeding, planting and scarifying, or in anticipation of natural seeding in partially cut stands, or in connection with seed tree systems (Kiil and Chrosciewicz, 1970). Hazard reduction burns are carried out when slash is dry enough to support a running fire without high risk to adjacent areas. Since many northern tree species respond favourably to the influence of fire, managed fire is also used to prepare seedbeds for successful artificial and natural regeneration of lodgepole pine, western larch, aspen and other species. Other applications of prescribed fire include improvement of wildlife habitat, pest control, brush control, control of stand density and perpetuation of natural ecosystems (Fahnestock, 1973).

Slash-fuel loadings following clearfelling may range from about 25 tons/ha in even-aged pine stands to in excess of 500 tons/ha in overmature, decadent spruce-fir stands. Depending on the moisture status of these dead fuels and weather conditions at the time of burning, a slash fire may consume as much as 150 tonnes/ha of slash fuels and 25 tonnes/ha of the forest floor. More commonly, a moderate-intensity burn (500 to 1,000 kcal/(s·m) following a pulpwood operation can be expected to consume 30 tonnes/ha of slask and 20 tonnes/ha of forest floor, equivalent to about one-half of the total fuel load on the site. While the slash-fuel loading will have a pronounced effect on fire intensity, the variation does not appear to have a commensurate effect on the amount of humus consumed. A layer of 10 cm of humus is usually sufficient to protect the underlying mineral soil from possible damage from temperatures in excess of 800° C several inches above the surface of the forest floor. Unless the pre-burn humus layer is less than 10 cm thick, even a relatively severe burn is unlikely to reduce it by more than 50% by weight or to provide for more than spotty exposure of mineral soil.

Generally, the environmental effects of prescribed burning tend to aggravate those brought about by harvesting. Any such effects may be beneficial or detrimental, depending on management objectives and sensitivity of the site. Nearly all prescribed burns reduce the fire hazard to an acceptable level, allow ground space for planting, enhance planting crew efficiency by reducing the physical barrier presented by the slash fuelbed, release nutrients for immediate use by incoming vegetation and eliminate at least the litter layer of the forest floor. The removal of all live vegetation by fire further accentuates the effects of harvesting on the microclimate and soils. While seeds in serotinous pine cones are destroyed, pioneer pines are well adapted to the drier more exposed sites with a thin organic layer (Johnson et al., 1971), provided appropriate seeding or planting techniques are used. By contrast, young seedlings of spruce require a cool and sheltered environment for establishment and early growth, a condition not obtainable by prescribed burning.

The size and vigour of plants on burned clearcuts often exceeds that on unburned clearcuts but, on thin and desiccated layers of humus at least, this trend has been observed to reverse after nine growing seasons (Uggla, 1967). Here again, many fire-related effects determine productivity of any given site. The depth of the humus, site moisture status, and the distribution and composition of post-burn vegetation are likely to be important determinants of growth rates. On steep slopes and coarse shallow soils, an intense prescribed burn may reduce productivity owing to major erosion. On cool moist sites with a thick layer of organic material, the number of days with soil temperatures between 6 and 8^{o} C is significantly greater in a burned clearcut than either in an unburned clearcut or in standing timber (Lesko, 1971). It is likely that the higher temperatures have a salutary effect on water and mineral uptake and rate of seedling growth. Rhizina root rot, caused by the fungus *Rhizina undulata*, has been observed on burned sites in British Columbia, but associated mortality of seedlings disappears in the third year following burning (Baranyay, 1972).

Air and soil temperatures in clearcuts are consistently higher than those in the forest during the late spring and summer in southeast Alaska (Gregory, 1956). Jemison (1934) recorded litter temperatures in excess of 49^{o} C on 44 days in Idaho, with absolute maxima of 70^{o}C just under the forest floor surface in clearcuts. The reduction of logging debris and the blackening of the forest floor surface by prescribed fire accentuates any temperature and related environmental effects of harvesting. Clearcutting, followed by burning, eliminates interception of precipitation by the forest canopy but it may increase evaporation by 400% over that in a forest. Concurrent increases in impact of precipitation on soil compaction, runoff and erosion last until new vegetation is again capable of intercepting some of the precipitation. Infiltration rates have been reduced by 20 to 60% of the unburned condition, but detectable increases in water yield seem closely related to the proportion of a basin clearcut, with 20% of a basin disturbed appearing to be a "threshold value" (Jeffrey, 1968, 1970). If burning is done adjacent to stream channels, some deterioration of water quality can be expected, although clearcutting did not adversely affect salmon spawning habitat in southeast Alaska (Meehan et al., 1969). Burning should not induce sufficient water repellancy into soils to be of any concern (DeByle, 1973).

In recent years, much attention has been focused on the pollution of the atmosphere by unsightly smoke from prescribed burns, particularly during weather inversions when smoke may linger in valleys for several days. However, aside from the obvious loss in visibility, burning of logging debris does not appear to contribute excessive amounts of noxious gases and particulate matter into the atmosphere (Vines et al., 1971). While the practitioners of prescribed burning recognize and accept the certainty that some fires will spread beyond the intended boundaries, such excursions are nevertheless largely responsible for the often adverse reaction to the visual and on-site effects of prescribed fires, particularly in heavily populated areas. As a consequence, more emphasis must be placed on realistic fire prescriptions to ensure that net benefits accrue and that the desires of the public are satisfied (Fahnestock, 1973).

SUMMARY AND CONCLUSIONS

This paper discusses the historical and current significance of wildfires and prescribed fire in Canada, with particular emphasis on northern coniferous forests. The role of fire is discussed in terms of a natural ecosystem process having significant direct and indirect effects on species succession and diversity, accumulation of organic matter, nutrient status and cycling, wildlife habitats, potential for natural disturbances such as blowdown and insect epidemics, chemical soil properties, water quality and quantity, atmospheric pollution and aesthetical considerations. The fire ecology principles governing these processes are briefly reviewed to provide a perspective for assessing effects of wildfires and prescribed burns following harvesting.

Wildfire impinges on natural vegetation at almost any stage of development, thereby playing a key role in shaping the total vegetation mosaic. Its effects depend on a wide variety of factors, but the existing vegetation usually provides protection to the site and a source of rapid revegetation with species previously present. Similarly, fire-killed trees and unburned "stringers" continue to provide partial shade, thereby preventing the exposure of the site to the full desiccating effects of the atmosphere. By contrast, prescribed burning is usually applied after site disturbance by mechanical logging and depletion of the source of regeneration. This physical treatment of the site, followed by prescribed burning, creates harsher site conditions than after wildfire and weakens the recovery of both site and vegetation. Thus, wildfire effects represent an intermediate condition between an undisturbed forest and a clearcut, with prescribed burning likely to aggravate any adverse effects of mechanical harvesting. Important variations and exceptions to this generalization occur; hence, regional and local factors must be identified and quantified.

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DISCUSSION - EFFECTS ON ECOSYSTEMS AND SILVICULTURE

The importance of nutrient losses from the site as an effect of whole-tree logging was questioned, as was the importance of nitrogen as a limiting factor in relation to some other elements such as potassium.

Kerruish (Australia) stated that loss of any organic material on light sandy soil types was harmful. He stated that there has been a very noticeable falloff in site productivity in the *P. radiata* plantations with second rotations. It is thought to be the result of a biological soil condition related to the soil organic matter rather than strictly a nutritional problem.

In Sweden, nitrogen deficiency does not appear to be a major problem. In eastern Canada, nitrogen was claimed (Weetman, Canada) to be the number one factor limiting growth.

With regard to inputs of nitrogen during the second rotation period and taking into account the reserve of nutrients which are stored in the humus layer, the situation does not look bad. Much research remains to be done in this field.

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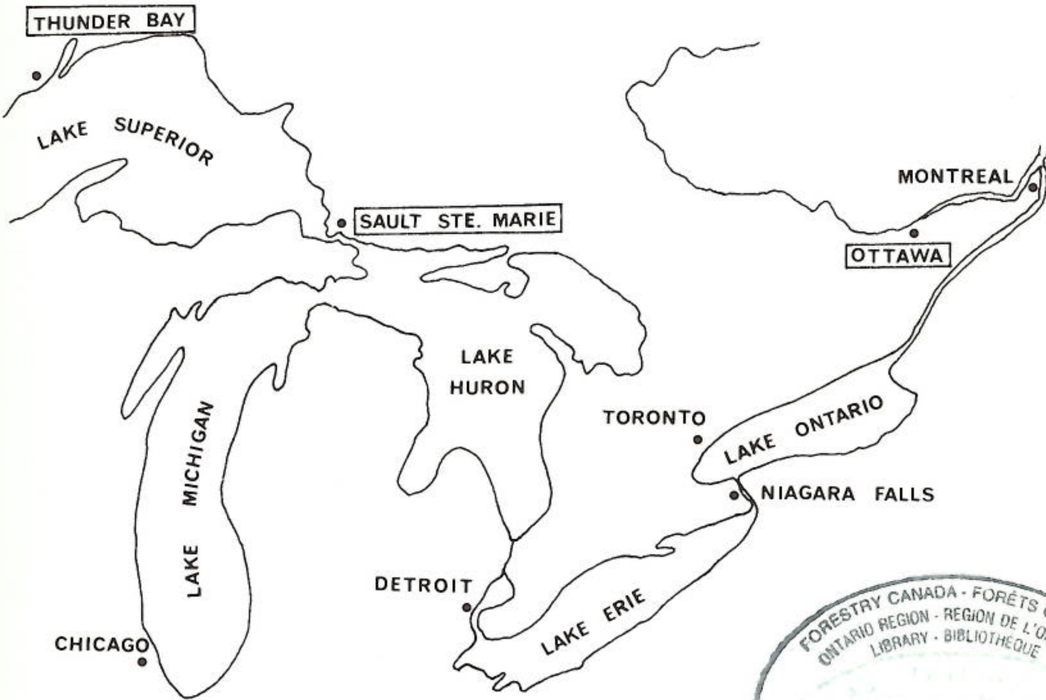

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