PRESCRIBED BURNING IN JACK PINE LOGGING SLASH: A REVIEW

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REPORT O-X-289

CANADIAN FORESTRY SERVICE

DEPARTMENT OF THE ENVIRONMENT

MAY 1979

PREFACE

This report is based to a large extent on a paper[1] submitted
to the Graduate Faculty of Colorado State University in partial fulfill-
ment of the requirements for the degree of Master of Science while
the author was on educational leave from the Canadian Forestry
Service.

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[1] McRae, D.J. 1977. Prescribed burning in the jack pine forest type:
a literature review and discussion. M.Sc. Prof. Pap., Colo. State
Univ., Fort Collins, Colo. 75 p.

ACKNOWLEDGMENT

ABSTRACT

An increase in the use of prescribed fire as a forest management tool is anticipated in Ontario where its use is viewed as a viable method of site preparation for regeneration purposes. Literature available on prescribed burning in the jack pine (*Pinus banksiana* Lamb.) logging slash fuel type is reviewed in order to assess the current state of knowledge. Topics of discussion include fuel hazard reduction, silvicultural, environmental and ecological effects, prescribed burn planning, economics, and fire behavior in jack pine logging slash. A serious lack of quantitative data on prescribed burning in jack pine logging slash was noted. Research required for a complete understanding of prescribed burning in this fuel type is outlined. An area and subject index shows the geographical location of, and subject area investigated by, individual studies reviewed in this report.

RÉSUMÉ

On prévoit un usage accru du brûlage dirigé en tant qu'instrument d'aménagement forestier en Ontario où cette pratique est considérée comme une méthode viable de préparation de la station à des fins de régénération. Pour faire le point des connaissances sur le sujet, l'auteur passe en revue la documentation relative au brûlage dirigé dans le type de combustible représenté par les rémanents de Pin gris (*Pinus banksiana* Lamb.). Les questions débattues embrassent la réduction du danger d'incendie, les implications environnementales et écologiques, la planification du brûlage dirigé, l'économie et le comportement du feu dans les rémanents de Pin gris. Une carence sérieuse de données quantitatives sur le brûlage dirigé dans les rémanents de Pin gris a été notée. La recherche requise pour une complète intelligence du brûlage dirigé dans ce type de combustible est indiquée. Un index des régions et des matières couvertes montre la situation géographique ainsi que le domaine des différentes études passées en revue dans le présent rapport.

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INTRODUCTION

Prescribed burning has been defined by the Canadian Committee on Forest Fire Control (Anon. 1976) as "the burning of forest fuels on a specific area under predetermined conditions so that the fire is confined to that area to fulfill silvicultural, wildlife management, sanitary or hazard reduction requirements." The primary use of prescribed burning in Ontario is for silvicultural purposes, namely site preparation for planting and seeding.

Forest regeneration targets are currently falling well short of the annual cut in the province of Ontario. Dixon (1974) states: "A survey in 1970 indicated that about one-third of cutovers are regenerated naturally, one-third being treated and one-third are being removed from production through lack of regeneration." Heeney (1977) notes that an area of 50,000 ha is removed from production annually in the boreal forest of northern Ontario because of the lack of suitable land for forest regeneration. Timber management personnel are now convinced that the increased use of prescribed fire as a management tool will help to alleviate future regeneration problems.

Jack pine (*Pinus banksiana* Lamb.), a fire adapted species (Fig. 1), ranks second only to black spruce (*Picea mariana* [Mill.] B.S.P.) in terms of economic importance to the forest industry of Ontario when volume cut and stumpage values are considered (Anon. 1976c). This economic value makes it timely to consider the information available on prescribed burning on jack pine logging slash sites. A few papers in the past have reviewed the available literature on prescribed burning in jack pine (Ahlgren 1970, Cayford 1970), but only as one part of the general literature on prescribed burning.

For this review, the literature cited deals specifically with prescribed burning in the jack pine logging slash fuel type. General papers on prescribed burning, and papers on prescribed burning in other slash fuel types, have been referred to only in cases where they deal with points relevant to prescribed burning in jack pine logging slash. This report is divided into several major sections for the convenience of the reader; however, this is an arbitrary division, because the sections are all interrelated. A subject index is provided at the end of the report so that the reader may identify areas of particular interest.

USES OF PRESCRIBED BURNING

Prescribed burning in jack pine slash is undertaken to meet one or more objectives (Dieterich 1964, Foster et al. 1967, Kiil and Chrosciewicz 1970, Van Wagner 1966). Major objectives for prescribed

burning in jack pine slash (Van Wagner 1966) are as follows:

(1) fire hazard reduction

(2) removal of slash for easier planting

(3) preparation of a seedbed

(4) opening of cones in jack pine seed trees.

Prescribed burning may also be used to manipulate and provide maintenance management for wildlife habitat, to increase site productivity, to control insect and disease infestations, and to provide training for fire fighters.

This section of the report deals with the two major objectives that are now fulfilled by prescribed burning in jack pine slash: fire hazard reduction and the silvicultural aspects of site preparation.

Figure 1. A typical jack pine logging slash cutover in Ontario requiring site preparation such as prescribed burning.

Fire Hazard Reduction

Fire hazard, as defined by the Canadian Committee on Forest Fire Control (Anon. 1976a), is "a fuel complex defined by kind, arrangement, volume condition and location that forms a special threat of ignition or of suppression difficulty." In the early 1940s, jack pine slash was not considered a serious fire hazard because fires, though hot, were not thought to spread particularly fast (Eyre and LeBarron 1944). However, later experience indicated that jack pine slash does indeed present a serious fire hazard. Williams (1955) states: "Not only are fires more likely to start in slash areas but once ignited they have greater resistance to control and often do more damage than fires burning in an uncut forest." Beaufait (1959) concludes that jack pine slash is highly combustible. Stocks and Walker (1972) produced quantitative data showing that rates of spread over 18 m per min are common, and over 36 m per min are possible, in jack pine slash.

Prescribed burning in jack pine slash has been found to reduce the fire hazard present before the burn (Anon. 1933, Farrar et al. 1954, Johnson 1955, Williams 1955, 1958, 1960, Adams 1966, Foster et al. 1967, Anon. 1973, Brown 1977). Fire hazards have been reduced by swamper burning (burning the slash as cut), piling and burning, and broadcast burning (Anon. 1933). Broadcast burning produced the greatest reduction in fire hazard. Swamper burning and piling and burning reduced fire hazard to a "normal' level. Williams (1955) found that "...if logging slash is piled and burned, the fire hazard in the area will be approximately one-third of that in slash left unburned and will be comparable to the hazard in the uncut forest." Williams (1958) later determined that the fire hazard in slash could be eliminated even though only 70% of the total area is burned. This is probably related to the breakup of fuel continuity.

Eyre and LeBarron (1944) suggested that slash would disintegrate by the seventh year, and would not constitute a fire hazard at that time. Williams (1955) showed that fire hazard was not drastically reduced until after the ninth year following cutting in unburned slash in Ontario. Other fuel arrangements, such as lopping and scattering, piling, tops left but not burned, etc. represented an even higher fire hazard than undisturbed slash.

Silvicultural Aspects

Most prescribed burns in Ontario are designed to meet silvicultural objectives. This is not surprising since Heeney (1977) emphasizes that, for Ontario, the limiting factor to an immediate increase in the area of regeneration is a lack of treatable or suitable land area. Besides providing excellent site preparation for jack pine regeneration, the economic advantages of prescribed burning make it an obvious choice as a site preparation tool for increasing areas suitable for forest regeneration (Fig. 2).
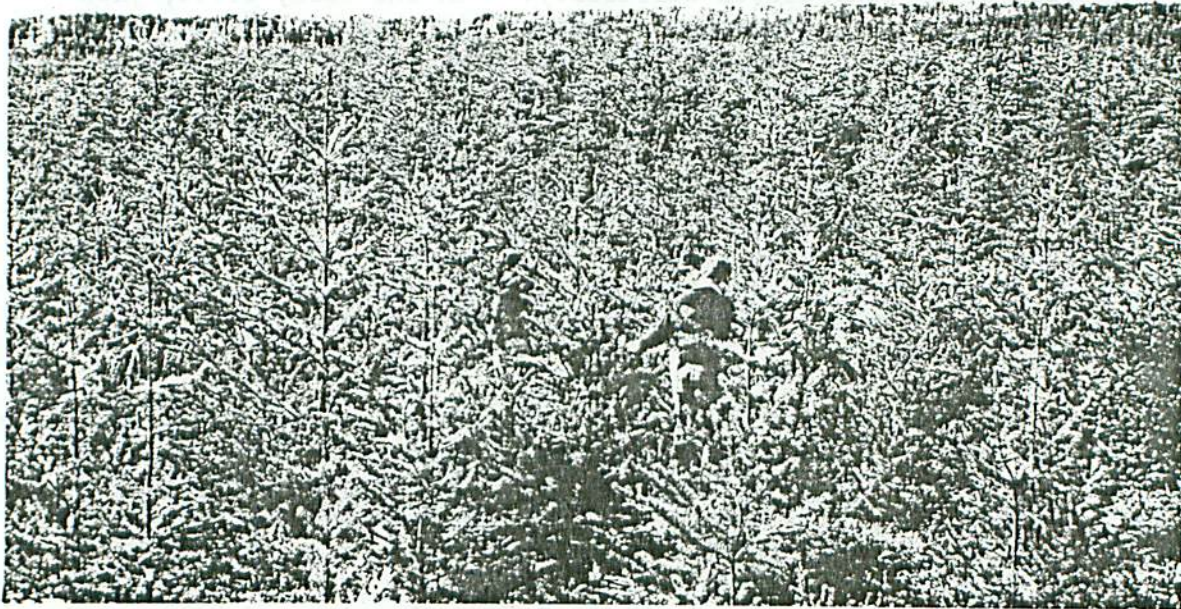
Figure 2. A successful jack pine plantation on a site previously
site-prepared with prescribed fire.

Past studies have shown that jack pine does not reproduce
itself after cutting (LeBarron and Eyre 1938, Rudolf 1946, Atkins
and Farrar 1950, Farrar et al. 1954, Beaufait 1959, Adams 1966,
Cayford et al. 1967, Chrosciewicz 1959, 1967, 1968, Foster et al.
1967). Reasons for reproduction failure in past studies have been
poor seedbeds (Farrar et al. 1954, Adams 1966, Cayford et al. 1967,
Chrosciewicz 1967, 1968), insufficient moisture (Atkins and Farrar
1950), inadequate seed supply (Farrar et al. 1954, Chrosciewicz
1967), insufficient light (Farrar et al. 1954), and excessive
competition (Adams 1966).

(1) Seedbeds. Mineral soil seedbeds have been found to be the best medium for germination and survival of pine seedlings (LeBarron and Eyre 1938, Eyre and LeBarron 1944, Noakes 1946, Farrar et al. 1954, Chrosciewicz 1959, 1967, 1970, 1974, Ahlgren 1959, 1970, Williams 1960, Jameson 1961, Beaufait 1962, Adams 1966, Jarvis 1966). These results indicate that, if prescribed burning is the only site preparation to be undertaken for direct seeding purposes, the objective should be to reduce the duff layer as much as possible. Investigators have found mineral soil best as a seedbed, burned duff second best, and undisturbed duff the poorest (LeBarron 1944, Eyre and LeBarron 1944, Farrar et al. 1954, Chrosciewicz 1959, Jameson 1961, Jarvis 1966, Cayford et al. 1967). Eyre and LeBarron (1944) explain that mineral soil is superior to duff material for germination purposes because of "...(1) its lower wilting coefficient, which makes it easier for seeds to absorb moisture, and (2) the far smaller size of the particles composing it and their greater uniformity, which permits closer contact of the soil and of the moisture it bears with the seeds." Ahlgren (1959) agreed that the steady supply of moisture is what differentiates the two seedbeds. The advantage of mineral soil as a seedbed becomes even more apparent when precipitation is slight (Eyre and LeBarron 1944).

Chrosciewicz (1967) observed that the amount of mineral soil exposure usually varied with such factors as drought conditions at the time of burning, duff type, distribution of individual duff depths, and variation in microrelief of the forest floor itself. Later, Chrosciewicz (1968) stated that "The object of burning for seedbed improvement on clear-cut jack pine sites is not necessarily the total destruction of all surface duff materials present, but rather their reduction to a degree sufficient for prompt reestablishment of favourably stocked pine stands from seed. Field observations indicate that (on moderately dry to fresh sandy upland sites) the best fire produced seedbed conditions are in situations where exposed mineral soil and thin residual duff alternate and both have uniform areal distribution." By means of duff-reduction curves, Chrosciewicz (1968) then demonstrated that the results of burning were predictable as, on the average, the depths of residual duff after burning varied both with the depths of original duff before burning (direct relationships) and with the drought conditions under which the materials were burned (inverse relationships). Cayford (1965) found that mineral soil exposure was dependent on the "intensity" of the burn when there was little difference in the drought index or fire danger index of the old Canadian Forest Fire Danger Tables. The "intensity" could vary depending on the fuel load available since moisture content would be similar for similar drought or fire danger indices. Intensities would naturally be greater on areas with higher fuel loadings. This would expose greater amounts of mineral soil because of greater preheating of duff fuels before ignition as the flame front advanced.

The amount of duff consumed during a fire depends primarily on its moisture content. Using the Duff Moisture Code (DMC) of the Canadian Forest Fire Weather Index Tables (CFFWIT), one can make a reasonable prediction of duff consumption (Van Wagner 1972). The higher the moisture content of the duff layer, the less duff removal and resultant mineral soil exposure may be expected.

Chrosciewicz (1971) states that a substantial reduction in the depth of duff is required for natural or artificial seeding but only a moderate reduction is necessary for direct planting. This reflects the ability of a tree planter to get the seedling roots he is planting into mineral soil in the planting process. Ahlgren (1970) felt a postburn duff depth of less than 2.5 cm would provide a good seedbed for seeding and allow jack pine seedling roots to penetrate to mineral soil. Chrosciewicz (1974) shows a curvilinear (inverse) relationship between jack pine frequency distribution (number of seedlings at a particular postburn humus depth divided by total seedlings for all postburn humus depths) and the duff depth two years after seeding (duff depth being more or less representative of the type of seedbed produced). In this relationship, he found that most seedlings were growing on exposed mineral soil (33%) and on thin residual duff (27%) not exceeding 0.5 cm. As the depth of duff further increased, the seedlings became fewer in number until the levels of extremely low frequency (21%) were reached for depths approaching 9.0 cm. Consequently, he rated his seedbeds as shown in Table 1. These seedbed ratings are applicable primarily to moderately dry and fresh sandy upland sites.

Table 1. Rating of fire-produced seedbeds (after Chrosciewicz 1974).

Average postburn duff depth (cm)	Relative quality of fire-produced seedbeds
<0.5	very high
0.5 - 1.3	high
1.3 - 3.8	moderate
<3.8	low

(2) Shade requirements. Shade has been found to favor germination and survival of jack pine seedlings after burning (Farrar et al. 1954, Ahlgren 1959, Beaufait 1959, 1960a, 1962). Eyre and LeBarron (1944) found shading to be beneficial in that it reduced temperatures and consequently seedling transpiration rate. The beneficial effect of reducing drought conditions has been verified by other investigators (Farrar et al. 1954, Walker and Dobbs 1968). Partial shade necessary for good germination and early growth

is provided by vigorous herb and shrub growth during the first few years after fire (Ahlgren 1959).

Once the seedling is established shading is less desirable (Eyre and LeBarron 1944, LeBarron 1944, Ahlgren 1959, Beaufait 1959, 1962). Beaufait (1959) found that shading was required until cortical collapse, which occurred within one month after germination in a greenhouse regulated to correspond with actual field conditions. Ahlgren (1959) found that older seedlings received the direct sunlight necessary for their growth in the openings created by fire once they rose above the herb-shrub layer.

(3) Seedling mortality. Jack pine seedling mortality following establishment on a burn site may be caused by several factors. Survival during the first two years varies most strikingly with the soil surface type; it is best on mineral soil, and poorest on undisturbed duff (Eyre and LeBarron 1944, LeBarron 1944).

Mortality has been induced by heat in a modified microclimate created by burning (Eyre and LeBarron 1944, Beaufait 1960a). Beaufait observed that greater mortality occurred in late July and August because of heat intensity. According to Eyre and LeBarron, "...high surface temperatures cause heavy losses among the young seedlings, especially if the plants do not have shade during part of the day or the surface soil becomes dry and is not cooled by evaporation." Ahlgren (1970, 1974) showed that heat did not result in appreciable seedling mortality on burned areas. He suggested that jack pine seedlings seem relatively heat tolerant.

Moisture deficiency is commonly referred to as a factor causing seedling mortality (Beaufait 1960a). According to Sims (1968), "...exposed and blackened surfaces of these areas are hot and droughty and may not maintain sufficient surface moisture for satisfactory germination, thus resulting in poor direct seeding results." Ahlgren (1970) took an opposite view, stating that "...surface soil moisture reduction on the burned tracts, while statistically significant, apparently was not critical to the germination and growth of jack pine except in the drought year." Walker and Dobbs (1968) found that drought after germination was related to high seedling mortality. Observations by different investigators (Jameson 1961, Cayford 1963, Walker and Dobbs 1968) have indicated that mortality was related to site: generally, the drier the site the higher the mortality.

Ahlgren (1959) and Sims (1968) both suggest the possibility that ash may contain high concentrations of substances toxic to seedlings. Ahlgren (1959) states that "...apparently under some conditions, high concentrations of ash release amounts of salt into

solution in the soil sufficient to cause plasmolysis and death of root hairs and young roots, thus killing or retarding growth of seedlings." Sims (1968), through experimentation, found no toxic or inhibitory substance in burned duff which would inhibit germination.

.It has been suggested that mortality of seedlings is caused by vegetative competition (Ahlgren 1959, Sims and Bruce 1969, Chrosciewicz 1970). Ahlgren suggests the possibility that mortality may also be due to the fact that some seedlings germinate too late in the summer to develop hardiness before the onset of winter. Beaufait (1960a) states that "seedlings should be at least a month old before the autumn freeze." He feels that spring seeding and subsequent seed germination have to occur late enough in the season to prevent frost kill, but early enough to take advantage of spring moisture found on the site.

(4) Seed tree regeneration. Seeds found in cones on slash lying near the ground are destroyed during prescribed burning (Eyre 1938, LeBarron and Eyre 1938, Noakes 1946, Farrar et al. 1954, Johnson 1955, Chrosciewicz 1959, Beaufait 1959, 1960a), and therefore cannot be depended upon as a seed supply. The exception occurs where fire tends to run through green or fresh slash rapidly, and many serotinous cones may survive (Ahlgren 1959). In situations of this type, poor stocking will occur simply because the fire does not reach the intensity necessary to burn off the duff layer and expose the underlying mineral soil. The objectives for prescribed burning in areas to be regenerated by the seed tree method should be (1) to open the cones in the seed trees for seed dispersal, and (2) to provide a suitable seedbed for seed germination.

Seed trees are the only successful means of providing seeds for natural regeneration since cones high in the crowns are not consumed during burning. They should be selected before initial logging (Beaufait 1962, Cayford 1965) so as to be phenotypically desirable trees (Beaufait 1962). Selected trees must have adequate cone supplies and seed yields per cone, be windfirm, and be of superior quality (Williams 1958, Ahlgren 1959, 1970, Beaufait 1960b, 1962). The number of seed trees used has ranged from 25 to 265 trees per ha (Table 2).

Beaufait (1962) found that seeds may disperse from a seed tree to a distance of up to several times the cone height above the ground, given average subsequent wind velocities. Jameson (1961) observed that stocking decreased with increasing distance from a 35-year-old stand adjacent to a piled and burned area.

A prerequisite of seed tree regeneration is an understanding of the opening process in jack pine cones. Beaufait (1962) states:

Table 2. Seed fall from seed trees located on prescribed burns conducted for natural regeneration.

No. of seed trees per ha	Total seeds	Viable seeds per ha	Seedlings produced	Reference
222	–	–	–	Adams 1966
25 (30.5 cm DBH)	–	–	–	Ahlgren 1959
47–59	–	–	–	Beaufait 1960a
59	447,260	–	–	Beaufait 1962
47	219,923	–	–	Beaufait 1962
198	–	–	11,367	Cayford 1963
49 (dominant trees plus 371 with a DBH of 2.5–7.6 cm)	–	–	3,954	Cayford 1963
22	259,460	74,132	–	Cayford 1965
15–30 (85-year-old trees)	–	–	–	Chrosciewicz 1959
262 (7.5–14 cm DBH)	568,342	381,407	–	Dobbs 1967
185 (70-year-old trees)	–	–	–	Jameson 1961
25	214,981	138,873	–	Cayford 1966 Walker 1966
25	–	–	–	Williams 1958

"Jack pine cones may be opened in 20 seconds when exposed to temperatures of 400°F [204°C]. It requires nearly twice that length of time to open cones at 300°F [149°C] and an average of 80 seconds to open them at 200°F [93°C]." Beaufait (1960b) determined that the interval between cone opening and ignition lies within a range of temperatures between 93 and 705°C, depending upon the time the cone has been exposed. Cones open after exposure to temperatures ranging from 49 to 60°C during a fire (Eyre 1938, Cayford 1963). A complete loss of seed viability was observed when cones ignited. Beaufait (1960b) concludes that seed viability is not markedly affected by prescribed burning for seeds found in cones on seed trees. Seeds of jack pine continue to be shed for at least three years after burning (Beaufait 1959, Ahlgren 1959, 1970, Chrosciewicz 1970).

(5) Direct seeding. Direct seeding has met with success when proper seedbeds have been established and moisture requirements have been met for jack pine germination and growth (Ahlgren 1970; Chrosciewicz 1970; Johnson 1974). Johnson (ibid.) observed that covering seeds in spot seeding a burned site provided better conditions for germination and survival than did broadcast seeding. Areas spot seeded have had a higher stocking than areas broadcast seeded in other studies (Cayford 1966). Cayford observed better stocking for fall spot seeding, and no difference between spring and fall broadcast seeding.

Johnson (1974) preferred disking the prescribed burn since disking usually exposed even greater amounts of mineral soil than did other types of site preparation. Johnson concluded that, for broadcast seeding, a combination of prescribed burning and disking was preferable to either disking or prescribed burning alone. Success was determined by the number of seedlings per hectare as a result of such site preparation. Sims (1971) found that scarification after prescribed burning helped to provide adequate regeneration.

Following a successful series of burning and seeding treatments Chrosciewicz (1970) stated: "A comparison of scarified and unscarified burns indicated that [preburn] scarification was unnecessary for the burning and seeding treatments to be effective. Scarification substantially increased the number of trees where it occurred, but this had little, if any, effect on the third year stocking by 0.001 acre [4 m^2] quadrats. Moreover, the dominant trees were somewhat taller and grew better where scarification was not the influencing factor."

There appear to be two satisfactory methods of preparing mineral soil seedbeds for direct seeding: (1) burning under correct fire weather conditions to expose mineral soil, and (2) burning under low or moderate fire weather conditions to remove part of the duff, and removing the remaining duff mechanically to expose mineral soil.

The determination of the amount of seed required for broadcast seeding depends on many factors including seed viability, quality of fire-produced seedbeds, soil material present, and anticipated rodent loss of seed and seedlings (Ahlgren 1970, Chrosciewicz 1971). For example, the amount of seed necessary for adequate stocking increases as depth of duff on the fire-produced seedbed increases. Chrosciewicz (1970) observed that, to serve the desired number of seedlings per hectare at more or less uniform spacing, the intensity of seeding must be inversely adjusted in relation to the quality of postburn seedbed conditions as defined by the average depth of residual duff and the exposure and texture of mineral soil materials. He felt that, provided the seed is at least 70% viable and it is treated with bird- and rodent-repelling chemicals, this type of adjustment would probably range from about 70 to 700 g of seed per hectare. Ahlgren (1970) found that 385 g of viable seed per ha gave a well distributed stand when seeding was done in the fall in areas of low mouse activity. Riley (1975) states that, generally, 50,000 viable seeds per ha (close to 100 g) are necessary for adequate stocking.

(6) Planting. The survival of spring-planted jack pine seedlings is observed to be better than that of fall-planted seedlings on prescribed burns (Cayford 1966, Walker 1966, 1967, 1969, Walker and Dobbs 1968). The reliability of some of the data on planting was questionable because of severe drought conditions during the study period, and the planting of seedlings was too deep in some of the study areas (Walker 1967).

Walker's (1969) preliminary observations indicated that delayed planting after burning gave somewhat better results but adverse drought conditions eliminated the advantage during the second growing season. Planting was delayed so that it might be observed if vegetation development and leaching action of nutrients on the site would moderate the environment and enhance regeneration results.

Chrosciewicz (1971) felt that for direct planting the duff depth needed to be reduced only moderately during a prescribed burn. Planters can easily place the planted seedling roots in direct contact with mineral soil through duff of a moderate depth. This observation is true only on sites where hardwood species, including deciduous shrubs, are absent and will not resprout and compete with planted seedlings. A deep burn into the humus is necessary in those areas where competing or resprouting woody vegetation is a problem. The deeper burn ensures a more complete destruction of the root system to prevent resprouting. Sims and Bruce (1969) observed that a second burn would be necessary after a single "light burn" on sites supporting a high proportion of hardwoods, to reduce resprouting in site preparation for planting.

(7) Competition. For jack pine seedlings, prescribed burning reduces competition from other vegetation to varying degrees (Dieterich 1964, Adams 1966, Foster et al. 1967, Chrosciewicz 1970, Anon. 1975, Brown 1977). According to Dieterich (1964), site preparation of any type "...rarely eliminates all the competing vegetation for any extended length of time." Prescribed burning reduces light and root competition for up to three years in certain parts of Ontario (Brown 1977). Brown (ibid.) feels that, on soil with a productive capacity, prescribed burning is necessary to reduce severe competition typically associated with this site type.

Ahlgren (1959), commenting on seedling survival and growth, stated: "Poor seedling survival and growth were associated with heavy growth of certain herbs--for example, *Pteridium aquilinum* (L.) Kuhn, *Calamagrostis canadensis* (Michx.) Nutt., *Carex adusta* Boott, and *Epilobium angustifolium* L. Where such herb growth was found, those jack pines which did survive were light colored and stunted." Sims and Bruce (1969) observed mortality of planted jack pine seedlings after prescribed burning as a result of competition from *Populus tremuloides*, *Rubus* sp., *Rosa* sp., *Gaultheria* sp., and various other herbs and grasses. Chrosciewicz (1970) found that competition was more severe within a multispecies vegetation cover type (*Comptonia* sp., *Pteridium* sp., *Vaccinium* sp., and *Epilobium* sp.) than within a monospecies cover type (*Vaccinium*).

However, Chrosciewicz (1970) observed: "The fact that most of the pine regeneration increased with time, in spite of the developing vegetation, indicated that the competition after all was not too serious or detrimental". Ahlgren (1970) noted similar results, and stated that "possibly the presence of these herbs contributed to an environment conducive to early seedling growth." This indicates that the generally held view that all vegetation is competitive with seedling growth may not hold true all the time. Forest managers could possibly allow certain vegetation to grow on burn sites to enhance the survival chances of young jack pine, especially since shading benefits germination of jack pine seeds and early growth of the seedling. Walker and Dobbs (1968) initiated a study to discover if it was beneficial to delay regeneration attempts following prescribed burns, so that vegetation development and leaching action would moderate the environment sufficiently to enhance regeneration results. Initial results (Walker 1969) showed promise in delaying regeneration.

(8) Disease. Prescribed burning may be used to eliminate diseased timber stands (Beaufait 1959, Chrosciewicz 1971, Alexander and Hawksworth 1975, Brown 1977). Prescribed burning can also contribute to the control of damping-off (Beaufait 1959), of Gremmeniella canker (*Gremmeniella abietina* [Lagerb.] Morelet) (Brown 1977), and of dwarf mistletoe (*Arceuthobium americanum* Nutt. ex Engelm.) (Alexander and Hawksworth 1975).

ENVIRONMENTAL EFFECTS

Environmental effects are defined as the physical or chemical changes (non-living) that occur to the environment as a result of prescribed burning. Environmental effects include changes in soil, microclimate, water quality and air quality. Only soil and microclimate have been studied in connection with prescribed burning of jack pine in the past.

Soil

(1) <u>Organic matter</u>. Organic matter is the result of decaying plant tissue and animal bodies, and animal action. The importance of the organic matter in the soil is best described by Buckman and Brady (1969): "Organic matter influences physical and chemical properties of soils far out of proportion to the small quantities present. It commonly accounts for at least half the cation-exchange capacity of soils and is responsible perhaps more than any other single factor for the stability of soil aggregates." These authors also state that organic matter supplies energy- and body-building constituents for the microorganisms found in the soil. Organic matter may be divided into: (1) unincorporated organic matter found in the L, F, and H horizons, and (2) incorporated organic matter found in the mineral soil.

Unincorporated organic matter makes up the duff layer. The Canadian Committee on Forest Fire Control (Anon. 1976a) defines the duff layer as "a mat of partially decomposed organic matter immediately above the mineral soil, consisting primarily of fallen foliage, heraceous vegetation and decaying wood." Organic material above the mineral soil in this definition would include the L, H, and F horizons of the soil. The removal of the duff layer is critical for silvicultural objectives designed to create mineral soil seedbeds for direct seeding.

A correlation between average duff depths after burning and fire weather conditions was developed by Chrosciewicz (1968), who created a series of duff depth-reduction curves for moderately dry to fresh sandy upland sites found in Ontario. Taking into consideration the depths of original duff before burning, these curves predicted the depths of residual duff after burning in an inverse relationship to the indexed drought conditions (Anon. 1957) at the time of burning. Chrosciewicz (1978) produced two straight line duff depth-reduction curves for fresh and moderately moist sites in central Saskatchewan. The straight line curves predict the duff depth remaining after burning using the Canadian Forest Fire Weather Index Tables (CFFWIT) (Anon. 1978) and average preburn duff depth. Van Wagner (1966) found that moisture content was the factor controlling the amount of duff consumed during the burn. He placed more emphasis on moisture content than on fire behavior for duff consumption. Van Wagner (1972) states

that duff consumption can be predicted through use of the Duff Moisture
Code (DMC) of the Canadian Forest Fire Weather Index (CFFWI) System.
Williams (1960) chose an arbitrary value of 20% moisture content or
less as the range within which humus will burn best.

Sims (1976) observed an increase in weight of the H horizon
in two out of three prescribed burns done in Manitoba and concluded
that "The addition of charcoal and charred particles of slash and
vegetation resulted in a 200 percent increase in the weight of the
H layer after burning." He admits that the addition of charcoal and
charred particles does not constitute humus (duff) but these were
classified as humus in the study since they could not be easily sep-
arated from the humus in the post-burn collection.

Sims (1976) explains that the reduction of organic matter in
surface soils after burning is the result of loss from ignition and
leaching. He states: "Severe fires can cause subsurface tempera-
tures sufficiently high to destroy incorporated organic matter,
particularly in well-drained soil." Reduction of organic matter in
the A horizon was greatest when subsurface temperatures were highest.
Reduction of incorporated organic matter in the Bt horizon was observed
during the spring after burning. A combination of improved temperatures
and increased microorganisms (see microclimate and soil organisms) is
cited as the cause of reduction by the breakdown and utilization of
organic matter in the burn area. By autumn of the second growing
season, organic matter content had increased. This increase was
attributed to the addition of organic matter from dying feeder roots
in this zone, and deposition in the Bt horizon of organic matter
leached from surface soil horizons.

(2) Moisture. Soil moisture is important because the soil
water: (1) must satisfy the evapo-transpiration
requirements of growing plants, and (2) must act as a solvent to
transport dissolved nutrients to plant roots (Buckman and Brady 1969).

Relative evaporation losses were found to be only 10%
greater on cut and burned areas than on cut and unburned areas
(Beaufait 1959). These results, Beaufait states, show "...that
burning is little different from no site treatment with slash re-
moved in its effect on the microclimate to which seedlings are
exposed." Ahlgren (1963) found that soil moisture was less than 10%
different on burned areas than on unburned areas for two growing
seasons after fire. The moisture content of burned soils decreases
much more rapidly than that of scarified soils over prolonged rain-
less periods (Anon. 1973, Sims 1976). Ahlgren (1970), in comparing
a burned and unburned site, observed drier surface soil (0-3 cm) on
the burned site, but a greater moisture content in the transition
between humus and mineral soil (3-6 cm) for the burned site.

Buckman and Brady (1969) define permanent wilting point as "the moisture content of soil, on an oven-dry basis, at which plants (specifically sunflower plants) wilt and fail to recover their turgidity when placed in dark humid atmosphere." Preliminary observations showed no changes in the permanent wilting point after burning (Sims and Bruce 1966). Later work by Sims (1976) showed that burned seedbeds reached the permanent wilting point on days 9 and 23 at 3.8 and 7.6 cm depths, respectively, during a 30-day rain-free period. Soils under scarified seedbeds were found to remain above the permanent wilting point during this same period.

Field capacity, a measure of the amount of moisture in the soil, is another factor to be considered. Buckman and Brady (1969) define field capacity as "the percentage of water remaining in a soil 2 or 3 days after having been saturated and after free drainage has practically ceased." Field capacity has been found to be unchanged by prescribed burning (Sims and Bruce 1966).

Percolation is a term used to describe the downward movement of free water into the soil. This action frees the surface soil of superfluous moisture and may also deplete soil nutrients by leaching (Buchman and Brady 1969), which would be detrimental to such objectives as forest regeneration in cases of soil nutrient depletion. Sims (1965) stated: "Burning had very little effect on percolation of water into mineral soil...". Infiltration time was found to be on the average only 0.58 minutes greater on burned than on unburned soil in Manitoba. Burned soil with ash and other residues undisturbed was observed to have an infiltration time of only one minute longer than that of unburned soil.

Sims and Bruce (1966) found that Manitoba infiltration time increased from 7.2 minutes on the preburn mineral soil to 8.1 minutes on postburn mineral soil. Similar increases in infiltration time were observed between preburn litter and postburn litter (ash and humus) where the preburn infiltration time of 4.4 minutes increased to 7.5 minutes after burning. Findings by Bruce (1967) showed that infiltration time decreased flow from 7.2 minutes for preburn mineral soil to 5.9 minutes for postburn mineral soil. The preburn litter infiltration time was 4.4 minutes. This increased to 4.8 minutes on postburn litter (ash and humus).

Later work by Sims (1976) showed that percolation rates were not significantly changed by burning, since there was no appreciable change in texture and pore volume of the mineral soil horizon after burning. Percolation appears to be little changed after prescribed burning on the soils tested so far.

(3) pH. pH is a measure of the acidity of the soil. Buckman and Brady (1969) state: "The soil pH may influence nutrient absorption and plant growth in two ways: (1) through the direct effect of the hydrogen ion; or (2) indirectly through its influence on nutrient availability and the presence of toxic ions." This statement points out the importance of knowing what prescribed burning does to the pH of the soil, and how the new pH affects soil properties.

Changes in the pH of the soil after prescribed burning have not been consistent. LeBarron (1944) found that the pH of the surface material did not change after burning. Later works have indicated that an increase in pH is to be expected (Sims and Bruce 1966, Bruce 1967, Ahlgren 1970) in the surface soil layer (A horizon), although Bruce observed a decrease in soil pH on some burn sites.

The B soil horizon is less affected by prescribed burning. Changes in the pH have been found to be delayed in the B horizon (Ahlgren 1970). The pH has been found to increase from one month to 6 years after burning (Sims and Bruce 1966, Ahlgren 1970), although decreases in soil pH have been observed at some burn sites (Bruce 1967, Sims 1972).

These results indicate that pH is more easily altered in the A horizon than in the B horizon. Intensity of fire would appear to have an indirect effect on pH because its effect is not as great in deeper soil as in surface soil. The direct effects appear to be changes in the OH ions near the surface from the fire. The increase of OH ions is first noticed in the A horizon. Leaching of OH ions later changes the pH of the lower B horizon. Sims (1972) suggests that increased acidity, particularly in areas with sandy soils of low buffering capacity, may be due to increased organic acids which are, in turn, caused by increased microbial populations following burning (see *Soil Organisms* on page 25).

(4) Nutrients. Nutrient increases have been observed after prescribed burning (Ahlgren 1959, 1963, 1970, Beaufait 1960a, Sims 1972, 1975, Anon. 1973). The destruction of nutrients (except for nitrogen) by fire is more than offset by additions from slash and vegetation destroyed during burning (Sims 1975). The increased nutrient level in the soil has been cited as a major reason for increased lush growth of early postfire vegetation (Beaufait 1960a, Ahlgren 1970). Sims (1972) presents a detailed account of the effect of burning and time on the concentration of different soil chemicals at different soil horizons for Manitoba. He concludes that the effect of adding nutrients to mineral soil was not long lasting.

Ahlgren (1959) found that increased concentration of nutrients was not noticeable after 5 years. Later studies by Ahlgren (1970) indicate that only phosphate is reduced to preburn conditions after 6 years. Ahlgren found that nutrient increases were more gradual at deeper levels than at shallower levels in the soil. This was due primarily to the leaching of nutrients in the 0-3 cm level. Sims (1975) states that "burning will not provide increased soil nutrient levels over a period long enough to be of significant benefit to jack pine regeneration."

Microclimate

Air temperature studies on areas after they have undergone prescribed burning have shown that warmer seedbed temperatures are prevalent (Shirley 1932, LeBarron 1944, Eyre and LeBarron 1944, Beaufait 1960a, Ahlgren 1963, Sims and Bruce 1966, Bruce 1967, Ahlgren 1963, 1970, 1974, Sims 1976). The type of seedbed produced after the burn greatly influences the maximum temperatures that can be expected. Burned litter seedbeds have higher maximum temperatures than burned ash-humus seedbeds which, in turn, have higher maximum temperatures than mineral soil (LeBarron 1944, Bruce 1967, Sims 1976). Temperatures of 49°C and over have occurred on mineral soil seedbeds in Manitoba for 6 out of 17 weeks, on burned ash-humus seedbeds for 12 weeks, and on burned litter seedbeds for 16 weeks (Bruce 1967). Ahlgren (1970, 1974) states: "Soil temperature on the burned tract exceeded 140°C [60°C] for 2 hours for up to 3 consecutive days and 122°F [50°C] for 2 hours for up to 8 consecutive days in June and July of the first two postfire growing seasons." Sims' (1976) results show that the duration on a daily basis of temperatures over 49°C depends once again on seedbed type: it is greatest for burned litter, and least for mineral soil. Sims felt that 49°C represented the lethal temperature for cells of jack pine.

The microclimate on burned areas has been compared with that on unburned areas. Temperatures in the latter were similarly high but of shorter duration for the soil surface (Ahlgren 1970). Ahlgren (1974) found that maximum temperatures averaged 2.0°C higher, and minimum temperatures averaged 3.0°C lower during June, July, and August for 7 years after burning. After 8 years, no differences in maximum and minimum temperatures were evident between burned and unburned areas. In one case, Ahlgren (1970) observed higher temperatures on an unburned area for one month shortly after burning.

In Manitoba, average maximum temperatures for the period from June to September have ranged from 46 to 57°C for burned litter, from 44 to 53°C for burned ash-humus, and from 44 to 48°C for mineral soil (Sims and Bruce 1966, Bruce 1967). Extreme temperatures for the same period ranged from 66 to 76°C for mineral soil. Sims' (1976) study

produced similar results: maximum temperatures on a daily basis for a few selected days showed the same temperature trends with the same type of seedbed.

The blackened soil surface of the burned litter seedbeds (as a result of charred material) appears to be the major reason for the greater temperatures found on this seedbed. The black surface is able to absorb more solar energy than are seedbeds of other types. Burned litter seedbeds have a greater temperature fluctuation as a result of lower heat capacity and conductivity (Sims 1976). Burned litter seedbeds reach higher temperatures more frequently on days with intermittent cloud cover than do burned ash-humus or mineral soil seedbeds (Sims 1976).

Shirley (1932) observed that temperatures at a depth of approximately 20 cm in the soil (horizon not stated) were warmer on cut and burned plots than on cut and unburned plots but the differences were not statistically significant.

Ahlgren (1963) observed lower relative humidity on the ground in burned areas than in unburned areas for the first growing season. Relative humidity during the second growing season was similar in the two areas because the appearance of herbaceous vegetation modified the drier microclimate of the unvegetated area.

ECOLOGICAL EFFECTS

This section deals with the interaction of living organisms with their environment. Here the main interest is in assessing the effects of prescribed burning on living matter found on the site. For simplification, this section has been divided into vegetation, wildlife, and soil organisms.

Vegetation

The study of the relationships between fire and vegetation has posed numerous questions about fire ecology. The fire ecologist views the effects of fire on vegetation mainly in terms of species composition, total biomass (kg/m^2), density, frequency, average cover percentage and average height.

Ahlgren (1963) believes that, for the growth of any plant community, there are at least six interacting factors: (1) the surrounding biotic community, (2) type of reproduction (vegetative or seed), (3) nutrients, (4) moisutre, (5) temperature, and (6) light. These six factors must be considered in evaluating the postburn vegetation.

Table 3 (after Ahlgren 1970) shows that the percent plant cover of many species is reduced after prescribed burning. This has been verified by other workers (Beaufait 1959, Sims and Bruce 1966). On occasion, the frequency of some species such as *Carex* is actually increased by prescribed burning (Ahlgren 1970, Sims 1972). Recording of preburn and postburn percent plant cover has been minimal but a few papers do contain records (Sims and Bruce 1966, Bruce 1967, 1968, Ahlgren 1970, Sims 1972, Noble et al. 1977). Ahlgren (1966) recorded the frequency of preburn and postburn vegetation. Chrosciewicz (1970) found that third-year plant cover varies inversely with the reduction of raw-humus depth and the corresponding exposures of mineral soil after burning.

Table 3. Average cover percent before and after prescribed burning in jack pine logging slash (adapted from Ahlgren 1970).

Species	Average cover percent			
	Preburn	Postburn		
		Year 1	Year 2	Year 5
Alnus crispa	13	1	1	2
Aster macrophyllus	82	43	53	40
Carex sp.	0	2	87	54
Comptonia peregrina	1	1	1	18
Corylus cornuta	52	6	7	8
Diervilla lonicera	1	2	2	–
Oryzopsis asperifolia	3	3	5	10
Pteridium aquilinum	40	35	35	34
Vaccinium angustofilium	5	3	4	8

Herbaceous vegetation after the burn is often seed-producing (Ahlgren 1959, 1963, 1970, Chrosciewicz 1970). Ahlgren (1970) found that species such as *Geranium bicknellii*, *Epilobium angustifolium*, and *Polygonum cilinode* were the major seed-producing, postburn species in Minnesota, while Chrosciewicz (1970) found that *Epilobium angustifolium* was the major species in this category in Ontario. Ahlgren (1970) found that seed-reproducing species disappeared 3 to 5 years after burning.

Seeds of many species found on the ground before burning are killed as a result of high temperatures (ranging from 149° to 482°C) during prescribed burning (Ahlgren 1963). In fact, the lethal

temperature at which seeds are killed depends on length of exposure to heat. Beaufait (1960b) found that at 371°C it took only 10-15 seconds for significant seed viability decreases in jack pine and at 538°C only 0-5 seconds. This combined effect of temperature and time on prescribed burns indicates that seeds of seed-reproducing species must be transported to the burned area from adjacent areas in some manner.

Herbaceous vegetation may reappear after the aerial portions of the vegetation are destroyed by fire since their roots and rhizomes may survive in the duff or mineral soil layers. A fire of higher intensity (e.g., a summer fire associated with a long drying period) may eliminate virtually all roots and rhizomes because of greater depth of burn into the duff layer. A spring burn would allow more of the roots and rhizomes to survive because depth of burn into the duff would be less. Chrosciewicz (1970) found *Comptonia peregrina*, *Pteridium aquilinum*, and *Vaccinium* sp., to be the major species resprouting after fire in Ontario (Fig. 3).

Figure 3. Vegetational response one year after a prescribed summer burn in jack pine logging slash.

It is difficult to determine which factors affect vegetation growth on the site. The effect of prescribed fire on vegetation growth may be indirect, while other factors are direct. Ahlgren (1970) observed an initial reduction in cover of *Comptonia peregrina* and *Vaccinium angustifolium* after prescribed burning, but an increase over that of the preburn condition 5 years after burning. Since unburned cut areas showed similar increases, Ahlgren suggests that the increase is due to clearing rather than directly to fire.

Another problem in analyzing vegetation responses is the difficulty in sorting them because of the influence of moisture. A dry year following the burn will show quite different results than a wet year. Such variation in moisture from year to year prevents reliable comparison of results. In analyzing vegetation responses, it is important to note the time of year at which the prescribed burn was ignited. A spring burn and a summer burn can result in entirely different vegetation regrowth on the same site. A summer burn associated with a longer drying period would burn deeper into the duff layer than a spring fire and conceivably remove most root and rhizome systems of preburn plants.

Prescribed burning encourages sprouting of trees and shrubs (Farrar et al. 1954, Beaufait 1960a, Ahlgren 1970, Anon. 1973). *Populus tremuloides* (Ahlgren 1960, 1970, Beaufait 1960a, Sims and Bruce 1969), *Quercus rubra*, *Acer* sp., and *Prunus* sp. (Beaufait 1960a) have been found to sprout profusely after burning. Birch (*Betula* sp.) sprouting dies out, and few birch remain 5 years after burning (Ahlgren 1970). By the end of the fifth year after burning, trembling aspen was found to be present in about the same proportion as before the fire (Ahlgren 1970). Where mechanical site preparation is the sole treatment, trembling aspen sprouting is much more widely distributed after treatment than on a similar site that has undergone prescribed burning. Ahlgren (1970) states: "While aspen sprouting may be stimulated by fire, this sprouting generally was confined to the region containing rhizomes of the parent stand. In nearby areas where mechanical means of exposing mineral soil have been used aspen sprouting is very vigorous and widely distributed. The heavy equipment for these operations cut aspen rhizomes and contributes to their wider distribution."

Table 4 is a synthesis of available information to illustrate how prescirbed burning affects different species of vegetation. The table includes those species which are eliminated by prescribed burning, those which appear both before and after burning (stable), and those which appear only after burning. The table is meant only as a general observation of possible effects of prescribed burning on the different vegetational species. For a complete understanding of how prescribed burning affects the different species much more detailed information than is available from past studies would be needed.

Table 4. Synthesis of vegetation responses one year after prescribed burning.

Species eliminated	References*
Anemone quinquefolia	f
Aquilegia canadensis	c
Betula papyrifera	g
Calliergon schreberi	f
Chimaphila umbellata	c,f
Cladonia rangiferina	c,f
Dicranum sp.	c
Equisetum arvense	c,f
Lathyrus ochroleucus	f
Melampyrum lineare	f
Oryzopsis sp.	a,f
Polygala paucifolia	a
Rubus idaeus	a
Salix sp.	c
Streptopus roseus	a+,b+

Species remaining on site	References*
Alnus crispa	a,g
Amelanchier sp.	a,b,d,e
Amelanchier alnifolia	a,c,d,f,g
Anemone cylindricum	c,d
Anemone patens	c,d,g
Anemone quinquefolia	c,d
Antennaria canadensis	c,d,e,f
Apocynum androsaemifolium	a,c,d,e
Aralia nudicaulis	a,b
Arctostaphylos uva-ursi	c,d,e,f
Aster microphyllus	a,b
Betula papyrifera	a,g
Calamagrostis canadensis	a
Campanula rotundifolia	c,d
Carex sp.	b,c,d,e
Ceanothus americanus	b,e
Clintonia borealis	a,b
Compositate sp.	b,c,e,f
Cornus canadensis	a,b
Corylus cornuta	a,b,g
Diervilla lonicera	a,b,g
Dryopteris thelypteris	a

Species remaining stable	References*
Epilobium angustifolium	a,b,c
Equisetum hyemale	d
Fragaria vesca	a,b
Fragaria virginiana	c,d,e,f
Galium boreale	c,d,e
Gaultheria hispidula	a
Gaultheria procumbens	c,d,f
Geranium bicknellii	c
Grasses: sp.	c,d,f
Andropogon gerardi	e,f
Koeleria cristata	f
Stipa spartea	e
Heuchera richardsonii	c,d
Lathyrus ochroleucus	b,c
Lilium philadelphicum	c
Linnaea borealis	a,c
Lithospermum canescens	c,d,e
Lycopodium obscurum	a
Maianthemum canadense	a,b,c,d,f
Monarda fistulosa	e
Oryzopsis asperifolia	a
Petasites sagittatus	d
Picea mariana	a
Pinus banksiana	a,b
Potentilla tridentata	c,d,f
Polygala paucifolia	b
Populus tremuloides	a,b,e,g
Prunus pensylvanica	b,d,g
Prunus pumila	c,d
Prunus virginiana	c,d,e,g
Pteridium aquilinum	b,e
Pyrola sp.	c,f
Pyrus americana	a
Ribes glandulosum	a
Rosa acicularis	a,c,d,e,f,g
Rubus sp.	a,b,d,g
Salix sp.	c,d,e,g
Solanum nigrum	c
Spiraea alba	c,d
Symphoricarpos albus	c,d,e,f,g
Thalictrum venulosum	d
Trientalis borealis	a,c,d
Vaccinium angustifolium	a,b,c,d,e,f
Viola sp.	a,c,d,f

New species	References*
Anaphalis margaritacea	a
Anemone cylindricum	c
Anemone quinquefolia	a
Apocynum androsaemifolium	f
Aralia hispida	a
Aster ciliolatus	a
Campanula rotundifolia	f
Carex sp.	a,b,f
Comptonia peregrina	a
Corydalis sempervirens	a
Epilobium angustifolium	a,c
Equisetum hyemale	c
Geranium bicknellii	a,b,e,f
Heuchera richardsonii	f
Lilium philidelphicum	f
Linnae borealis	c
Lithospermum canescens	f
Lonicera canadensis	a
Marchantia polymorpha	a
Moldavica parviflora	e
Petasites sagittatus	c
Polygala senega	c
Polygonum cilinode	a
Prunus pensylvanica	b
Prunus pumila	g
Salix sp.	f
Silene antirrhina	e
Solanum nigrum	f
Spiraea alba	f,g
Thalictrum venulosum	c
Vicia sp.	f

* References:

a. Ahlgren, 1960
b. Ahlgren, 1966
c. Bruce, 1967
d. Bruce, 1968
e. Sims, 1972
f. Sims and Bruce, 1966
g. Sims and Bruce, 1969
+ This response is probably due mainly to increased light.

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Wildlife

The effects of prescribed burning on animal populations have been studied by several investigators. Ahlgren (1966) suggests that availability of food is the primary factor in population fluctuations, and states: "...changes in cover were not always associated with changes in mouse populations."

Deer mouse (*Peromyscus maniculatus*) populations have been observed to increase after prescribed burning (Ahlgren 1963, 1966, 1970, Bruce 1967, 1969, Sims and Buckner 1973). Ahlgren (1966) observed a reduction in the deer mouse population during the second postfire year, with a recovery during the third postfire year. Ahlgren relates this reduction to food supply, concluding: "Deer mice subsist largely on a diet of seeds. They invaded both burned areas immediately after fire. Jack pine seeds shed by trees or broadcast, miscellaneous seeds in the organic soil layer, and insects from the slash were available as an abundant food supply. These food sources were reduced the second year and the number of mice present in the area also decreased. By the third year, recovering vegetation, especially cranesbill, was producing seed and the population again increased."

An increase in the deer mouse population has been found to occur at the expense of other small mammal populations on postburn areas (Bruce 1968). Deer mice increase quickly since they require only permanent nesting sites which are readily available under roots, large areas of unburned fuel and rocks (Sims and Buckner 1973). Sims and Buckner (ibid.) observed that on larger burns (97 hectares) young deer mice travelled farther than subadults and adults. This fact may be of interest on larger prescribed burns.

Redback vole (*Clethrionomys gapperi*) numbers have been observed to remain low for at least two growing seasons after burning, at which time they begin to increase (Ahlgren 1966, Bruce 1968, Sims and Buckner 1973). This decrease reflects the vole's varied diet which includes seeds and fruits, as well as succulent plant parts which are absent after burning. The recovery of vegetation on the postburn site capable of producing seeds and fruits that constitute part of the vole's diet signals the recovery of the redback populations on the burned area in the third year after burning (Ahlgren 1966).

Populations of the meadow vole (*Microtus pennsylvanicus*) and the common shrew (*Sorex cinereus*) are low after prescribed burning (Sims and Buckner 1973). Bruce (1968) found that it took up to four years for meadow voles and at least three years for the common shrew to reappear on the postburn site. Sims and Buckner (1973) found that meadow vole populations increased to their preburn levels during the second year after burning. Delay in recovery may be caused by lack of mulch used for cover on surface runways; this mulch evidently reappears by the second year after burning (Sims and Buckner 1973).

Data on chipmunks (*Eutamius minimus*) for one prescribed burn show an increase in the population after the burn, followed by a reduction during the second postfire year (Ahlgren 1966). The chipmunk population increased again in the third postburn year, probably for the same reason as the redback vole population increased, i.e., because of an increase in fruit-bearing and seed-bearing vegetation used as a food supply. Bruce (1967, 1969) found an opposite trend, recording low numbers of chipmunks after prescribed burning.

The nutritional quality of vegetation in a study done on moose (*Alces alces andersonii*) populations was found to be greater on areas having an "intenser" burn and sufficient available soil moisture for vegetation growth after burning (Peek et al. 1976). The integration of fire as a tool in future wildlife management plans, especially for moose management, is stressed by Peek et al. (ibid.).

Increases in bird populations have been observed after prescribed burning (Ahlgren 1970). An increase in seed-eating bird species in the crowns of seed trees occurs soon after the burn. These include species of pine siskin (*Spinus pinus*), robin (*Turdus migratorius*), blue jay (*Cyanocitta cristata*), common flicker (*Colaptes auratus*), wood pewee (*Myiochanes virens*), rose-breasted grosbeak (*Hedymeles ludovicianus*), and blue-headed vireo (*Vireo solitarius*). During the first summer after burning, there was an increase in species that feed largely on insects found on burned tree trunks. These species included hairy woodpecker (*Dryobates villosus*), downy woodpecker (*Dryobates pubescens*), red-breasted nuthatch (*Sitta canadensis*), robin, and dark-eyed junco (*Junco hyemalis*).

Buckman (1964) describes a 200 ha prescribed burn with seed trees. He states: "The dual purpose of the burn was to create sapling thickets of jack pine, the habitat necessary for the Kirtland's warbler (*Dendroica kirtlandii*), and to provide stands for later timber production." A number of sources refer to the same use of prescribed burning to preserve the habitat of the Kirtland's warbler (Mayfield 1960, Millar 1963, Wagner 1971). Millar states: "...the critical requirement of the species appears to be the presence of living pine branch thickets near the ground." Millar's other requirements for this species are large homogeneous blocks of pine at least 32.4 ha in size, "...varying from five to fifteen feet in height and occurring in a patchy condition of dense stands interspersed with a near-equal area of small openings." Wagner states that the Kirtland's warbler requires a minimum breeding territory of 16.2 ha in jack pine ranging from 1.8 to 4.6 m in height.

Soil Organisms

The only studies conducted on soil organisms have been done by Ahlgren and Ahlgren (1965) in Minnesota, and later mentioned by I.F. Ahlgren (1974). These studies in the soil organisms looked mainly at bacteria, actinomycetes, and fungi found in the soil.

(1) Bacteria. A population decline in bacteria in the upper 2.5 cm of soil was observed by Ahlgren and Ahlgren (1965). A greater decline was noticed on more severely burned areas. I.F. Ahlgren (1974) states: "In most areas where moisture is a limiting factor, these population declines are temporary, lasting only until the first postfire rainfall." Increases in bacterial numbers of three or four times over preburn numbers were observed after the first rainfall following burning (Ahlgren and Ahlgren 1965). I.F. Ahlgren (1974) states: "The sharp first year increase may be related to availability of ash minerals dissolved into the soil by rain."

Increases in the bacterial population at 5.1 to 7.6 cm below the surface were not observed until the first year after burning. I.F. Ahlgren (1974) states: "Since the increase was not detected the first year, it is believed to be related to the gradual leaching of ash minerals to lower soil layers."

(2) Actinomycetes. Results of Ahlgren and Ahlgren (1965) showed that the actinomycete population in the upper 2.5 cm of soil fluctuated above and below the actinomycete population in the cut and unburned area. Actinomycete numbers were observed to increase significantly after burning at the 7.6 cm depth. I.F. Ahlgren (1974) states: "In the lower soil levels, actinomycetes may be stimulated to increase in later years, possibly because of the downward leaching of ash minerals." Because of the results of the 1965 study, Ahlgren (ibid.) suggests "...that the actinomycetes are more resistant to heat than bacteria and are less affected by moisture changes."

(3) Fungi. I.F. Ahlgren (1974), commenting on the effect of prescribed burning on soil fungi, states: "No postfire decrease in fungi in the upper soil layer was detected in quantitative platings from northern Minnesota jack pine burns. After the first rain, however, the fungi on the burned areas increased, and the increase continued during the first postfire growing season. In later years, the burned and unburned soil population were similar."

No significant increases were observed for fungi at a 3 cm soil depth (Ahlgren and Ahlgren 1965).

(4) Other soil organisms. I.F. Ahlgren (1974) found "...fewer
beetles on burned than unburned land
the first 3 months after prescribed burning in Minnesota jack pine
stands." To date, studies on the effect of prescribed burning on
other soil organisms have not been conducted in jack pine logging slash.

PRESCRIBED BURN PLANNING

Prescribed Burn Plan

Planning is the key to the success of any prescribed burn. The
prescribed burn plan is compiled from information on intended objectives
of the burn and on the ecology of jack pine, from the experience of the
individual planner, and from additional general information available
in the literature on prescribed burning.

A good prescribed burn plan may be composed of as many as 17
individual sections (Barrows 1976). Each section must be considered
separately if the objectives of the burn are to be achieved in an
organized and professional manner. These sections are outlined in
Table 5.

A number of guides are available for planning a prescribed
burn (Beaufait 1966, Allen et al. 1968, Kiil 1969, Anon. 1969, Sando
and Dobbs 1970, Mobley et al. 1973, Brown and Davis 1973, Anon. 1975,
Anon. 1976c, Fischer 1978). While these guidelines do not relate
specifically to the jack pine forest type, the principles on which
they are based can be adapted readily to local conditions. The fol-
lowing subsections discuss different parts of the preburn planning
process, with specific reference to jack pine logging slash. They
are not intended to be a rigid prescription for planning new burns
since each burn is unique in its requirements. Rather, they are
intended to give some idea of the planning procedures that have been
used in the past for prescribed burns.

(1) Prescription. One of the major requirements of planning
for prescribed burns is the preparation of
a prescription. A prescribed burn prescription specifically states
the range of values for different fire weather parameters and fuel
conditions to realize the objectives of the burn. Williams (1958)
states that "a prescribed burn is a control burn set under predeter-
mined burning conditions to obtain a specific result. Thus the
prescription for a burn intended for hazard reduction on a cutover
area may differ greatly from that for seedbed preparation on the same
area." Chrosciewicz (1970) observed that one of the basic requirements
in the use of burning for silvicultural purposes is the selection of
a suitable drought condition best fitting the desired reduction of

duff depth. These statements reflect the need for a prescription in determining the burning conditions necessary to achieve the objectives of the prescribed burn.

The number of weather factors to be considered in the prescription (Table 5) may seem unusually large. Fortunately, many are inputs in the Canadian Forest Fire Weather Index Tables (Van Wagner 1974, Anon. 1978). Thus, instead of prescribing factors such as temperature, relative humidity, precipitation, and wind speed, the method in Ontario is to prescribe the different codes and indices of the Canadian Forest Fire Weather Index Tables (CFFWIT) required to achieve the objectives of the burn. The Fire Behavior Index (FBI) (Stocks and Walker 1972) used for prescribing the different CFFWIT codes and indices needed to reach burn objectives provides a very easy and reliable method of preparing the prescription for a burn. Past studies have relied mainly on the old Canadian Forest Fire Danger Tables (Beall 1948, Anon. 1956, 1957).

Using the old Canadian Forest Fire Danger Tables, Williams (1958) found that a high hazard index was necessary for hazard reduction in jack pine slash while a high drought index was required for exposing bare mineral soil. Prescriptions used by Adams (1966) specified that the drought index and fire danger index of the old Canadian Forest Fire Danger Tables would have to be at least 10 and 8, respectively, for satisfactory results in removing the humus layer.

Williams (1960) found a relationship between the drought index of the old Canadian Forest Fire Danger Tables and duff moisture content. This relationship is given by month in a table where he assumed that the duff layer would be non-combustible at moisture contents above 20%. Hence, the prescription for a prescribed burn in jack pine slash should consider this arbitrary value of 20% as the maximum moisture content possible for adequate duff disposal on sites being prepared for seeding.

Williams (1958) and Van Wagner (1966) suggest morning and evening burns, when the relative humidity is higher, to reduce fire intensity and facilitate control.

(2) Prefire preparation on site. Prefire preparation on the preburn site usually involves the establishment of fire lines to contain the prescribed burn. Low intensity prescribed burns usually do not require fire lines because water lines are sufficient to hold them. In special cases, additional preparation, such as the use of herbicides to kill brush on the preburn site, is necessary.

Firelines may be prepared by hand (Stocks and Walker 1972), by plow (Williams 1955), or by bulldozer. The use of a bulldozer well in

Table 5. Sections to be covered by the prescribed burn plan.

_____

1. Determination of fire objectives.

2. Prefire inventory of ecosystem and fuels.

3. Prefire analysis (type of fire required).

4. Preparation of map.

5. Description of type of fire desired to meet objectives (fire behavior information on type of fire required).

6. Preparation of prescription:

Date expected	Date expected
Time of day	Time of day
Canadian Forest Fire Weather Index	Precipitation
FFMC	Temperature – humidity range
DMC	Wind direction
DC	Wind velocity
ISI	Atmospheric stability
BUI	Fuel condition
FWI	Fuel moisture
Wind direction	Weather forecast
Wind velocity	
Atmospheric stability	
Weather forecast	

7. Testing of prescription using fire models (Fire Behavior Index, climatological analysis).

8. Specification of preburn prepartion on site (e.g., fire line construction).

9. Specification of on-site measurements and analysis (fire behavior analysis).

10. Specification of weather forecast and analysis plan (how to use it).

11. Preparation of burning plan (type of firing technique to be used).

12. Preparation of control plan (control organization involved).

13. Specification of equipment and facilities required.

14. Establishment of fire organization.

15. Specification of decision making (who authorizes ignition of burn).

16. Public relations.

17. Postfire inventory and analysis of ecosystem and fuels.

advance of the anticipated prescribed burn date is the most common method; lines prepared in this way vary from 1.8 to 7.3 m in width (Williams 1958, Chrosciewicz 1959, 1967, Beaufait 1962, Cayford 1965, Adams 1966, Van Wagner 1966, Dobbs 1967, Foster et al. 1967, Stocks and Walker 1972).

There is no rule of thumb for fire line width, although Albini (1976) notes that a rough estimate may be calculated from expected flame length. The fire line width should be proportional to the expected flame length since flame length is proportional to frontal fire intensity. The more intense the fire expected, the wider the fire line should be. Residual trees or snags in the prescribed burn area are usually cut or bulldozed over when they are within 30-35 m of the fire line (Adams 1966, Foster et al. 1967, Dobbs 1967). Chrosciewicz (1959) states that fire lines should have straight edges, be completely exposed to bare mineral soil and have no accumulations of heavy slash close to them.

(3) Weather forecast and analysis plan. Fire weather forecasts received by fire control agencies generally cover a large region and are not specific enough for prescribed burning purposes. A special spot weather forecast is necessary for any prescribed burn (Williams 1958, Chrosciewicz 1959, Adams 1966). This type of forecast should originate at the nearest meteorological centre and should attempt to predict the weather situation over the prescribed burn area.

Special spot weather forecasts can be obtained on a daily basis as favorable weather appears, and burning is more probable (Adams 1966). On the day of the prescribed burn, the fire control crew and equipment are assembled if the special spot weather forecast indicates favorable wind, relative humidity and no precipitation chance for the day. If, on the day of the planned prescribed burn, the special spot weather forecast indicates unfavorable weather, the prescribed burn should be cancelled, because it could become hazardous and result in control problems. Furthermore, the objectives of the prescribed burn will not be realized if the prescription is not followed.

(4) Burning techniques. The most popular burning technique, when slash is not piled, is that of the strip-head fire (Williams 1958, Cayford 1965, Adams 1966, Dobbs 1967). Fire intensity can be regulated by adjusting the width of the strips burned. The strips will be narrower when the Fire Weather Index (FWI) is high to facilitate better fire control.

Strip-head fires have been easily controlled with strips 20 m (Adams 1966) to 121 m (Williams 1958, Adams 1966) wide. Adams (ibid.)

states: "Each new headfire [each strip] was ignited only after the
previous one had covered the prescribed strip and was reduced greatly
in intensity." Adams (ibid.) initially fired the downwind edge of the
prescribed burn for a distance of 20 m into the wind using a backfire
before starting any strip burns. Later, he used a series of narrow
headfires approximately 3 m wide to burn out a protective strip 20-30 m
wide, thereby reducing the building time for the downwind edge of the
control line.

In cases where the prescribed burn is expected to have a
poor rate of spread because of poor horizontal fuel continuity, high
humidity, or low winds, perimeter ignition and area ignition techniques
are used (Williams 1958, Chrosciewicz 1959, Cayford 1965, Adams 1966)
in the hope that their air draft will aid fire spread. Head fires on
the windward side only, to burn the entire prescribed area, are
generally for research purposes alone, and would not be used opera-
tionally.

In areas of heavy slash where summer burning is considered
dangerous for site preparation prior to seeding, a double burn is
recommended (Williams 1960, Van Wagner 1966). A double burn is a
hazard reduction burn followed by a seedbed preparation burn. The
hazard burn may be carried out in the spring to reduce the fuel
loading, while a later burn in the summer destroys the remaining fuel
loading, including the duff layer. Van Wagner (1966) warns that
double burning is not feasible where seed is derived from seed trees
since the second fire would consume the seeds released by the first
fire.

Skillful application of back and head fires during prescribed
burning is necessary because "...the rate of burning must be reasonably
rapid to utilize the right drought conditions" (Chrosciewicz 1967).
Chrosciewicz continues: "If burning progresses too slowly in relation
to the size of a given area, adverse changes in such conditions [weather
and fuel moisture] may occur, and consequently some of the objectives
may not be fully realized." Burning operations must be scheduled
only when they can be carried out safely and efficiently.

(5) Personnel and equipment. Since most of the literature is
research-oriented, no reliable
rule of thumb is possible for determining the manpower and equipment
needed. Most reports describe specific cases (Williams 1955, 1958,
Chrosciewicz 1959, 1967, Cayford 1965, Adams 1966, Van Wagner 1966,
Dobbs 1967).

MacLeod (1958) states that most prescribed burns will have an
excessive number of suppression facilities when an inexperienced fire
boss is in control. MacLeod, having observed such a fire boss
gaining experience, states: "...after getting over the shock of

seeing the first few acres burn and after learning how easily
the fire can be controlled at the prepared or natural firebreaks, the
relief may be such that they are almost embarrassed at their former
fears." However, it is better to have too many suppression facilities
than not enough.

Experience with prescribed burning has led to the establishment
of a number of useful practices. Adams (1966) stated: "All personnel
were provided with sketch maps of the area being burned for orientation
purposes. These maps outlined fire breaks, roads, and reference points
(trees outside the fireguards numbered with tree-marking paint)." The
orientation of personnel prevents confusion when personnel are being
stationed or equipment placed during the prescribed burn. Williams
(1958) notes: "To avoid confusion in dense smoke it is advisable to
give explicit instructions to the fire fighters before the area is
ignited. It should also be borne in mind that heavy smoke has an
unnerving effect on inexperienced personnel." Chrosciewicz (1959, 1967)
stresses the importance of pretesting fire fighting equipment in advance
of burning. Pretesting involves not only in-shop inspection, but also
testing in the field (Fig. 4).

Figure 4. Prescribed burning personnel using drip torch tested prior
to fire to ignite specified ignition points on a prescribed
burn.

FIRE BEHAVIOR

Importance

The behavior and effects of fire are important factors in the prescribed burning process. Fire and land managers require a satisfactory understanding of fire behavior principles in order to accomplish prescribed burning objectives (Fig. 5).
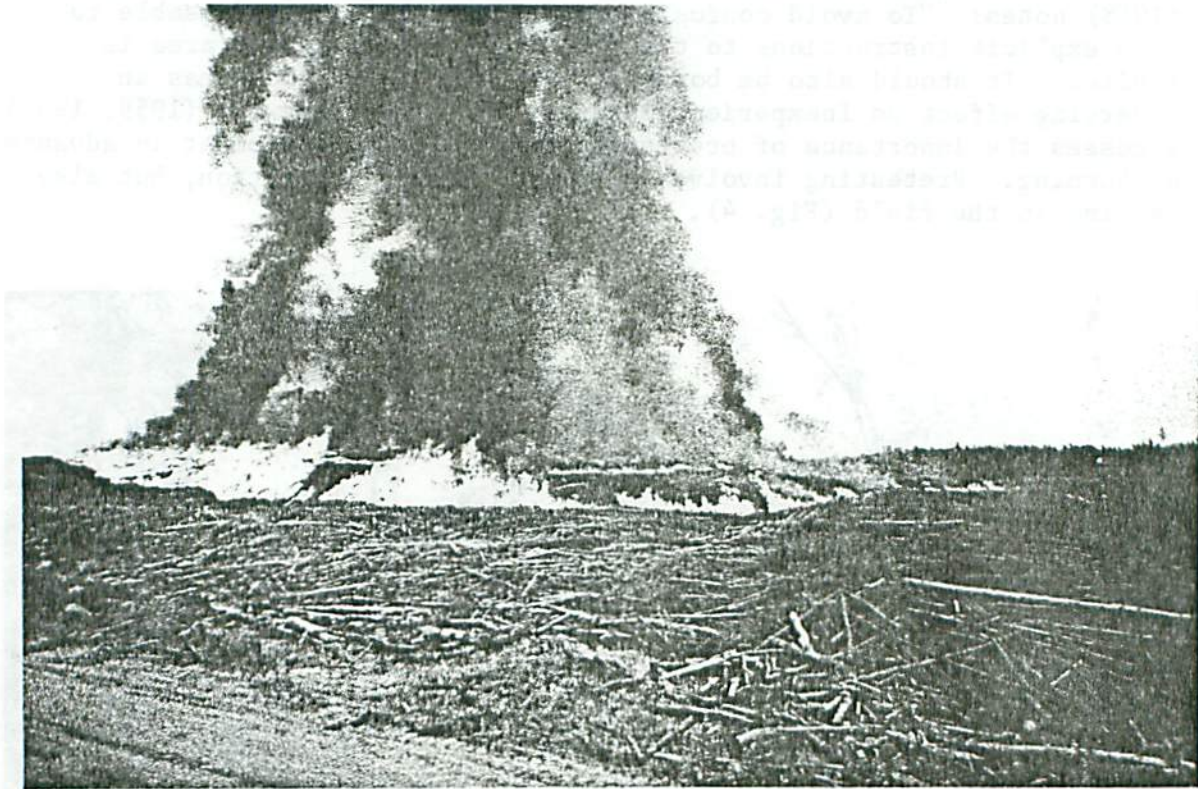

Figure 5. Knowledge of fire behavior is essential when one uses techniques such as centre firing ignition patterns at prescribed burns.

The fire manager needs a good understanding of fire behavior in planning ignition procedures and in containing the fire in the desired area. The land manager is concerned with fire behavior as it affects seedbed condition, soil properties, vegetation, and wildlife. Together, the fire manager and land manager must decide on the fire behavior characteristics that will fulfill the objectives of the prescribed burn.

Table 6. Range of possible slash consumption in jack pine slash.

Slash consumption range		Number of burns	Reference
Lowest	Highest		
(kg/m^2)			
0.94	4.26	24	Stocks and Walker 1972
1.61	2.59	3	Van Wagner 1966

Ground fuels (the duff layer) with original fuel weight load-
ings of 4.51 to 11.37 kg/m^2 had duff consumptions of .86 to 4.36 kg/m^2
(Stocks and Walker 1972). Depth of burn is a fire behavior parameter
that serves as a gauge not only for computing duff consumption but also
for determining the success of a prescribed burn from the silvicultural
standpoint, where removal of the duff is necessary for seeding. Table 7
shows the range of depth of burn obtained on a few prescribed burns in
jack pine logging slash.

Table 7. Ranges of preburn duff depths and depth of burns on prescribed
burns conducted in jack pine slash.

Preburn duff depth range		Depth of burn range		Reference
low	high	low	high	
(cm)		(cm)		
3.05	3.56	1.02	2.03	Adams 1966
5.08	6.86	1.52	5.08	Chrosciewicz 1967
4.78	10.92	0.89	4.01	Stocks and Walker 1972
-	-	0.64	1.27	Williams 1958

Fire Behavior Characteristics

The rate of spread of a prescribed burn is an important consid-
eration in terms of fire control. The range of fire spread in jack pine
slash has been quite variable in the past (see Table 8).

The importance of fire behavior may be more clearly visualized in Figure 6. The application of fire to a specific area produces certain environmental and ecological effects which are strongly influenced by fire behavior parameters. Environmental changes have an important effect on ecological changes in an area while the reverse is not as evident.
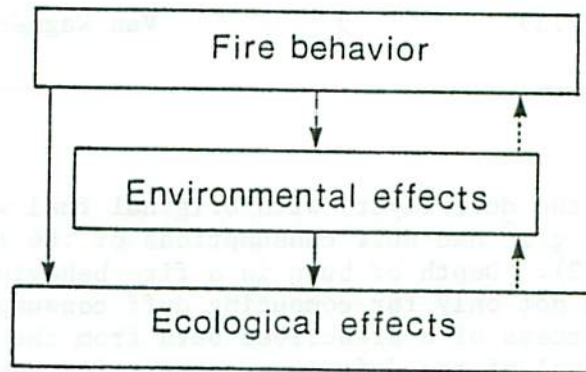
Figure 6. Relationships between fire behavior, environmental effects and ecological effects.

Fuel Complex

Fire behavior is dependent on the fire environment triangle, which consists of weather, topography, and fuel. Prescribed fire involves both ground and surface fuels. Ground fuels (the duff layer) include the L, F, and H horizons, and may include also some forms of living or dead vegetation such as punky wood and root systems. Surface fuels are composed primarily of downed woody slash material (branch-wood, foliage) and living or dead vegetation such as grasses and forbs. At times, aerial fuels consisting of residual conifers and birches left behind by logging operations may become involved in torching.

Slash consumption is a useful indicator of fire hazard reduction and a necessary parameter in calculating total heat release. Few investigators have measured slash consumption after prescribed burning. Table 6 gives an indication of the results that might be expected in the range of possible slash consumption in jack pine slash. Stocks and Walker (1972) reported an original slash fuel weight loading of 3.66 to 11.84 kg/m^2 while Van Wagner (1966) reported an average loading of 3.33 kg/m^2. Nelson and Irving (1966) found that fuel oil application of 562 and 1124 ℓ/ha did not significantly increase fuel consumption or percentage of area burned.

Table 8. Range of rate of spread on prescribed burns conducted in jack
pine logging slash.

| No. of burns | Type of fire | Rate of spread (m/min) | | Reference |
		Lowest	Highest	
5	headfire	1.95	9.08	Cayford 1965
5	backfire	0.55	1.95	Cayford 1965
24	headfire	2.09	37.67	Stocks and Walker 1972
3	headfire	0.00	16.76	Van Wagner 1966
2	headfire	0.61	1.22	Van Wagner 1966
2	backfire	1.01	2.01	Williams 1958

Frontal fire intensity, synonymous with Byram's fireline
intensity (Byram 1959), is also an important parameter in terms of
fire control. Frontal fire intensity (kW/m), the product of the
available heat of combustion, slash fuel consumed, and rate of spread,
is the amount of heat in kilowatts per second for each metre of fire
edge. Firebrand spotting from the fire may begin at a frontal fire
intensity of 2000 kW/m and get progressively worse as the frontal fire
intensity increases. Frontal fire intensities in the past have
ranged from 2421 to 13837 kW/m for Van Wagner (1966) and from 1235 to
59118 kW/m for Stocks and Walker (1972). The variation in frontal
fire intensities in jack pine slash fires is shown in Figure 7.

Flame heights on some prescribed burns have ranged from 1.83
to 15.24 m (Cayford 1965, Van Wagner 1966).

Headfire Versus Backfire

One of the major controversies concerning fire behavior
during prescribed burning concerns the question of the use of the
headfire versus the backfire. For fuel reduction, Chrosciewicz (1967)
found no difference between the two types of fire in jack pine slash
when burning slash, vegetation, or duff. On the other hand, Ahlgren
(1970), Beaufait (1962), and Cayford (1965) found duff reduction and
the establishment of mineral soil seedbed more successful with backfires
than with headfires. Beaufait (1959) explains: "...a backing fire is
hotter, slower, and consumes a greater portion of the available fuel
than does a headfire." Martin and Davis (1960) elaborate: "...the
slower rate of spread and longer temperature duration facilitates the
drying of moist litter and duff, thus causing the [back] fire to burn
closer to mineral soil."
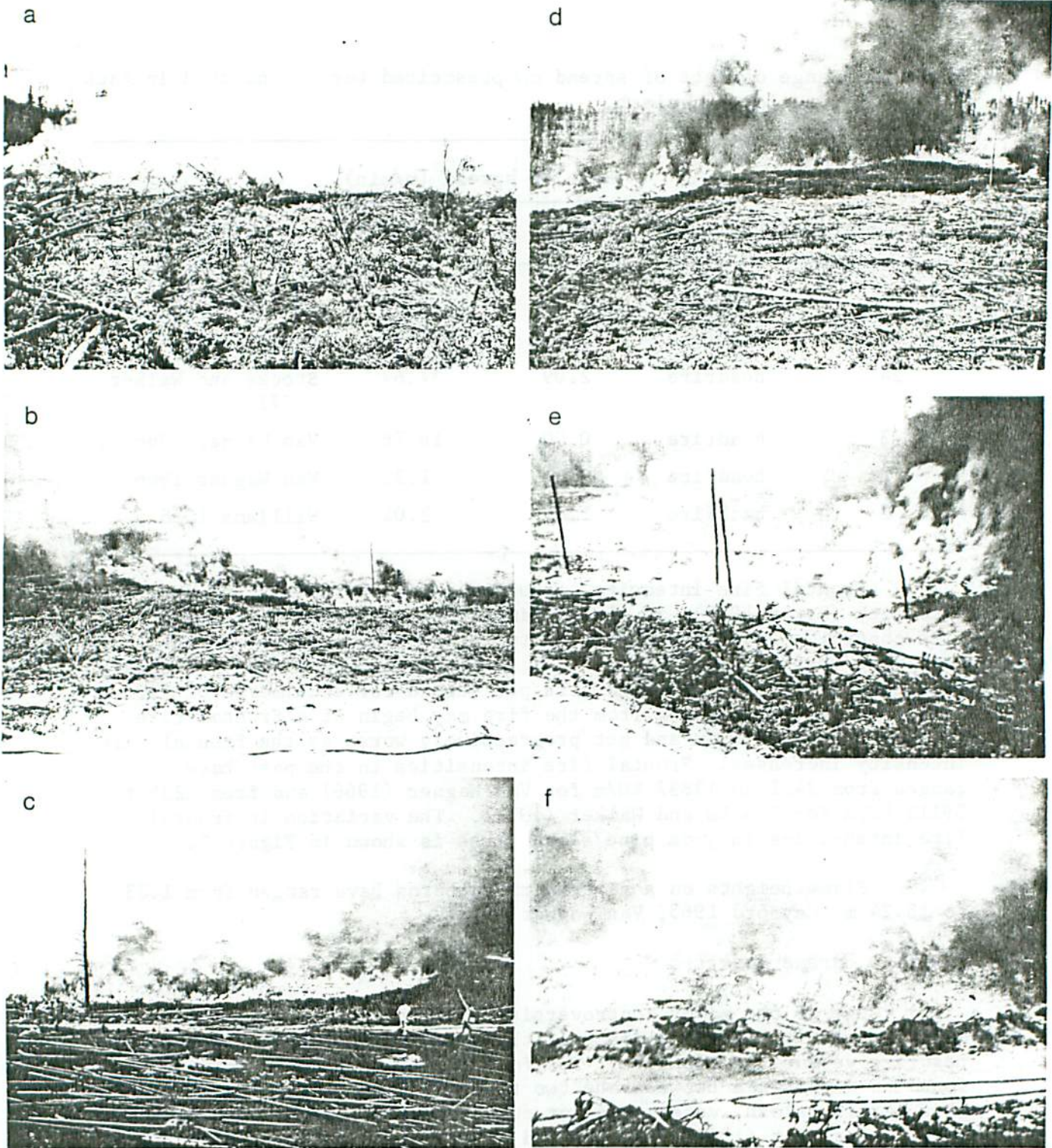
Figure 7. Visual appearance of prescribed burns in jack pine logging
          slash. Measured frontal fire intensities (kW/m) were
          (a) 1235, (b) 4867, (c) 14100, (d) 29203, (e) 43621,
          (f) 59118 (Stocks and Walker 1972).

The relative merits of headfire and backfire in seed tree regeneration are also disputed. Martin and Davis (1960) felt that a headfire should be employed in conjunction with natural regeneration by seed trees on the site, since a backfire would seldom develop the temperatures necessary to open the serotinous jack pine cones. Ahlgren (1970) found that backfires provided satisfactory heat for cone opening on seed trees. For each seed tree site the prescribed burn planner must attempt to predict the effect of fire on the seed trees. This prediction will take into account available fuel, fuel distribution and wind conditions.

Studies by Martin and Davis (1960), Beaufait (1960a), and Ahlgren (1970) have all shown that temperature decreases with height above the ground during the burn. The rate of this decrease is greater when a fire burns with a light breeze than when the atmosphere is still (Martin and Davis 1960).

Martin and Davis (1960), observing the characteristics of some headfires and backfires, found that headfire temperatures rose rapidly to a peak and declined quickly after the fire front had passed. Backfire temperatures rose and fell more gradually and peaked at lower temperatures for longer periods of time. They noted that "the temperature curve at the 4-foot level peaks earlier than the curve at the 1-foot level for a headfire, whereas the reverse is true for a backfire. This is to be expected, as the wind will incline the flames and convection currents, causing the higher levels to be heated first."

The final decision to use a headfire or a backfire for any prescribed burn must take into account the safety and economics of each type of fire (Chrosciewicz 1967, Ahlgren 1970). Backfires with their slower rate of spread and lower intensities are a safer method of burning. Headfires with a faster rate of spread allow for speedier completion of the burn (Ahlgren 1970).

Fire Behavior Index

Stocks and Walker (1972) found several relationships between fire behavior in jack pine slash in Ontario and fire weather conditions as expressed by the Canadian Forest Fire Weather Index Tables (CFFWIT) (Van Wagner 1974, Anon. 1978). These relationships, based on headfires, were used by Stocks and Walker (1972) to develop a Fire Behavior Index (formerly call the Burning Index) for the jack pine logging slash fuel intensity, rate of spread, depth of burn, and fuel consumption using their relationships as expressed through the CFFWIT. Stocks (1972) predicts depth of burn, rate of spread, and percent slash consumption (Tables 9–11) for operational use.

Table 9. Association between Buildup Index (BUI) and depth of burn (D/B) in duff found under jack pine slash (adapted from Stocks and Walker 1972).

BUI	0-5	6-10	11-16	17-21	22-26	27-32	33-37	38-42	43-56	57-66	67-77	78-88	89-100	100+
(cm)	0.8	1.0	1.3	1.5	1.8	2.1	2.3	2.5	3.1	3.6	4.1	4.6	5.1	5.1+

Table 10. Association between Buildup Index (BUI) and percentage of total slash consumed (SC) i.e., the amount of slash consumed expressed as percentage of the total slash available before burning (adapted from Stocks and Walker 1972).

BUI	0-10	11-19	20-26	27-35	36-43	44-51	52-59	60-67	68-75	76-83	84-91	91-100	100+
% SC	20	25	30	35	40	45	50	55	60	65	70	75	75+

Table 11. Association between Initial Spread Index (ISI) and expected equilibrium linear rate of spread (R/S) of jack pine slash fire (adapted from Stocks and Walker 1972).

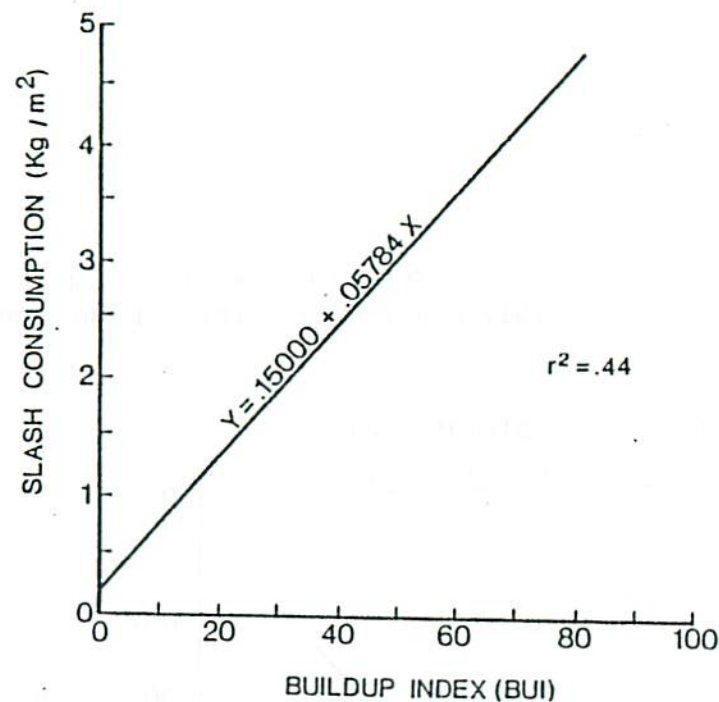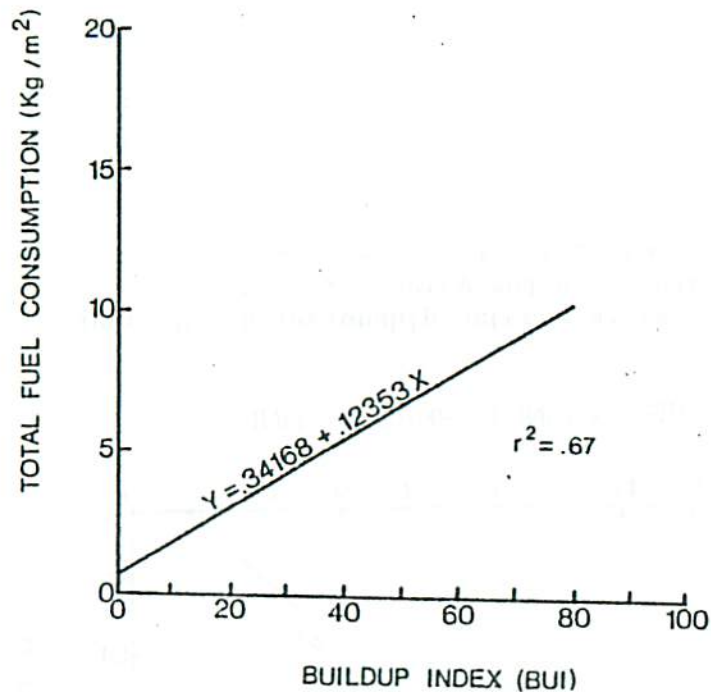| ISI	0	1	2	3	4	5-6	7-8	9-10	11-12	13-14	15-16	17-18	19-20	21-24	25-28	28+
R/S (m/ min)	0	1.2	2.7	4.0	5.2	7.3	10.1	12.8	15.24	18.0	20.7	23.5	26.2	30.2	35.4	35.4+
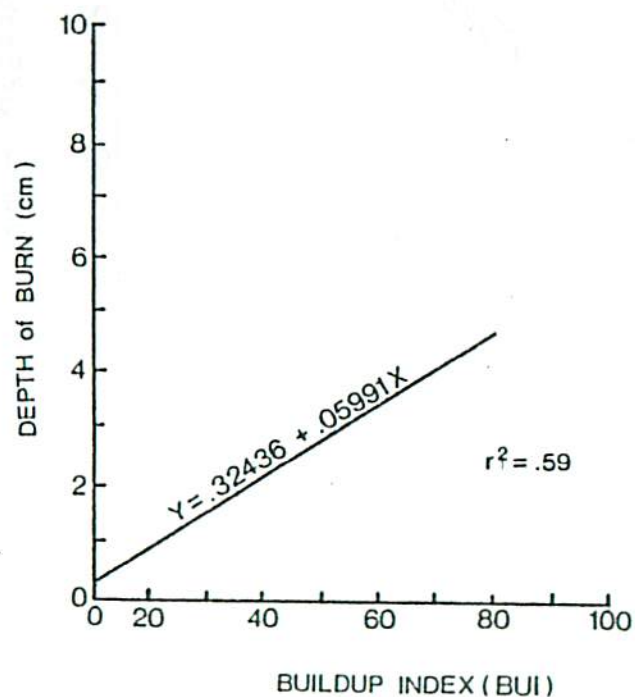
Figure 8. Relationship between different fuel consumption parameters (total fuel consumption, slash consumption, and depth of burn) and Buildup Index (BUI) for jack pine logging slash (adapted from Stocks and Walker 1972).
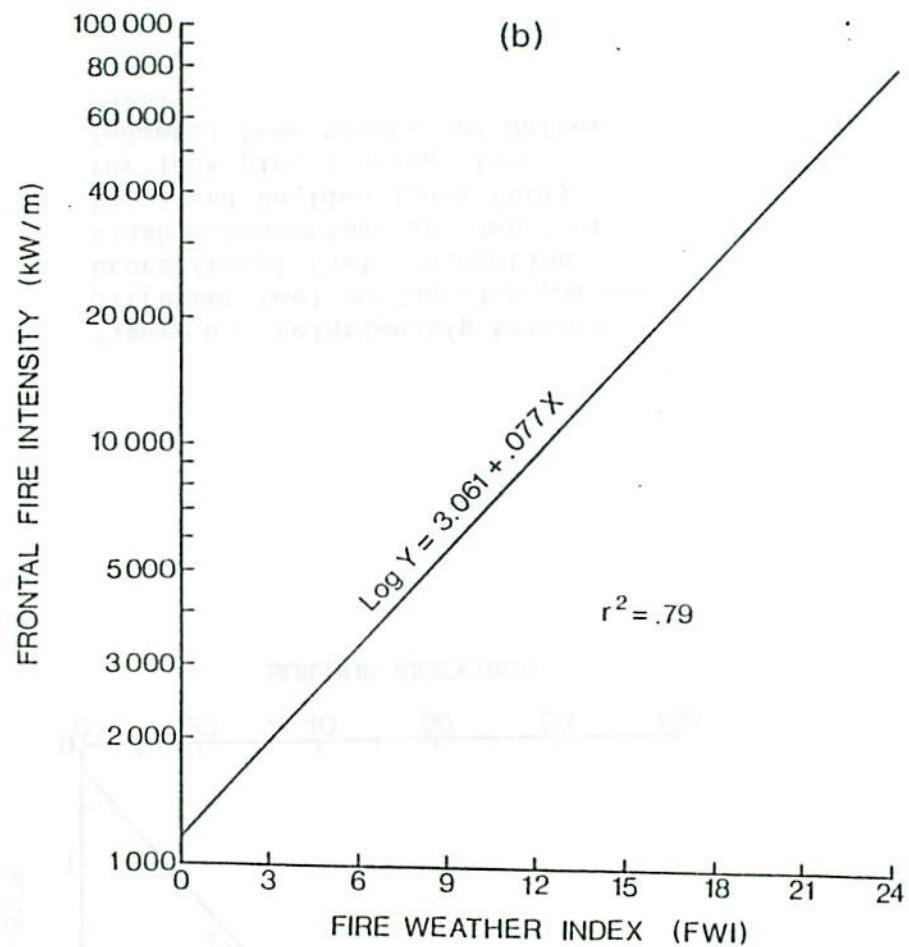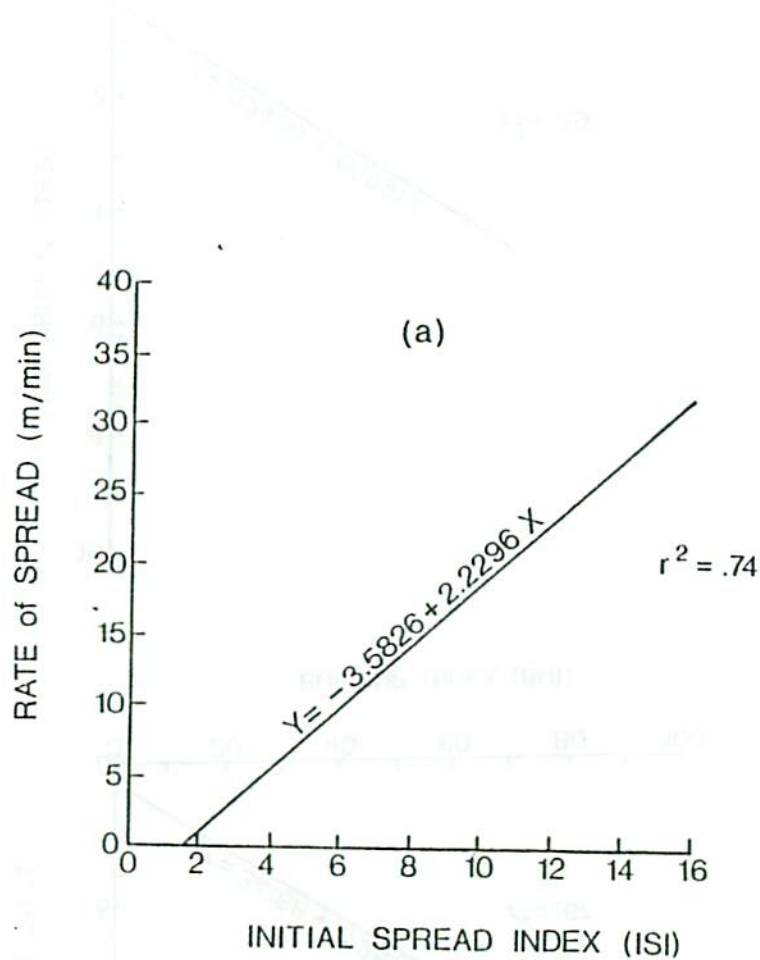
Figure 9. Relationship between a) rate of spread and Initial Spread Index (ISI), and b) frontal fire intensity and Fire Weather Index (FWI) for jack pine logging slash (adapted from Stocks and Walker 1972).

Stocks and Walker's (1972) report on producing a Fire Behavior Index (FBI) for the jack pine logging slash fuel type has aided the prescribed burn planner in choosing correct indices or codes of the CFFWIT to meet prescribed burning objectives. The FBI correlates various fire parameters with fire weather as expressed through the CFFWIT and its component indices and codes in terms of actual values. Frontal fire intensity, rate of spread, and fuel consumption parameters (total fuel consumption, slash consumption, depth of burn) were found to be related to the Fire Weather Index (FWI), Initial Spread Index (ISI) and Buildup Index (BUI), respectively (Fig. 8 and 9). One serious drawback is that preburn fuel loadings are not considered in this relationship. In using the FBI for preparing the prescribed burn prescription, one must first determine the range in fire behavior parameters (rate of spread, fuel consumption, etc.) necessary to meet the silvicultural and control objectives of the prescribed burn. Then one can calculate the specific code values necessary for obtaining these burning parameters from the FBI tables for the prescription. Martell (1977) has developed an interactive computer program called SLASH to predict fire behavior using the FBI developed by Stocks and Walker (1972).

Van Wagner (1966) suggested that the rate of spread in jack pine logging slash is decreased by at least half after the jack pine foliage drops. It is important to keep this observation in mind when one is working with Stocks and Walker's (1972) relationships, which were developed when the majority of needles were still on the slash.

In future, prescribed burning will require correlation of different fire behavior parameters with specific fire effects. This correlation will allow prescribed burn planning for very specific results. Input of desired fire effects into the prescribed burn planning stage will permit the calculation of figures for the fire behavior parameters necessary to meet the objectives of the burn (Fig. 10).
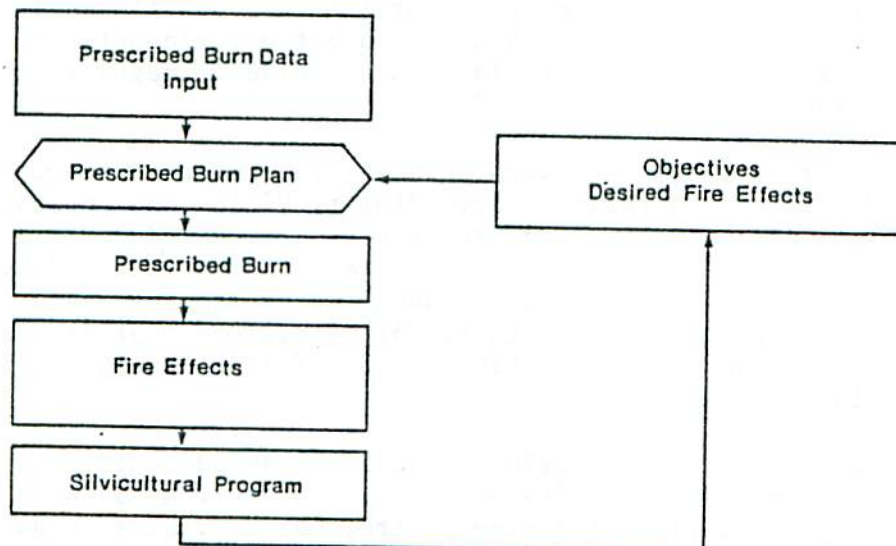

Fig. 10. Flow chart of prescribed burning for silvicultural purposes.

ECONOMICS

Prescribed burning has been found to be more economical than machines for site preparation (Chrosciewicz 1967, 1970, 1971, Foster et al. 1967, Brown 1977). O'Donnell (1976) has given cost figures for different site preparation methods for the Timmins district of Ontario (Table 12). These data show that prescribed burning is cheaper than any other site preparation method, even on small areas.

Table 12.   Cost comparison of different site preparation methods in Ontario (adapted from O'Donnell 1976).

Method	Cost/ha	Area (ha)
Shark fin barrels	$45.00	75
Young Teeth	$50.25-$51.25	–
Straight blade and angled blade	$94.00	178
Anchor chains	$26.70	–
Prescribed burning	$10.28-$12.38	8

The cost per hectare of prescribed burning decreases as the size of the area to be burned increases (Chrosciewicz 1959, Beaufait 1962, Dieterich 1964, Adams 1966, Foster et al. 1967, Kiil and Chrosciewicz 1970). Prescribed burning is cheaper if planning is completed prior to timber sales. Prelogging preparation will involve locating and laying out timber sales to take advantage of existing roads, trails, and other features as natural firebreaks (Adams 1966, Foster et al. 1967). Prelogging should reduce the ratio between length of fire line and area by laying timber sales in regular compact blocks (Adams 1966, Foster et al. 1967).

The advantages of prescribed burning are evident after its initial use for site preparation. According to Vézina and Robitaille (1970) the elimination of slash by prescribed burning reduced plantation costs by 25% in Quebec. Brown (1977) felt that prescribed burning by reducing competition on the site, reduces later tending costs for seedlings. Alexander and Hawksworth (1975) maintained that prescribed burning provides a cheap and effective method of eliminating dwarf mistletoe in logged over areas.

Kiil and Chrosciewicz (1970) discuss the added costs of suppression and damage if the fire gets away. Dieterich (1964) admits that there is a risk of losing a fire, but "...there is as

great a risk in terms of overall economic values if the site is lost to brush and inferior tree species following a successful logging operation." A well planned and executed prescribed burn has a backup control plan in case the fire should escape the prescribed burn area. This serves to minimize economic losses from an escaped fire.

CONCLUSIONS

Prescribed burning is becoming a very important land management tool. It can be used to effect desired changes in soil properties, microclimate, vegetation, and wildlife present on the burn area as well as for traditional silvicultural purposes and fuel hazard reduction. Although it is already being used in many parts of Ontario, a stepped-up program of prescribed burning across the province could go a long way toward alleviating forest regeneration problems.

It is necessary at this time to state that only recently has the need for quantitative as opposed to qualitative fire behavior relationships been recognized so that correlation with environmental effects, ecological effects, fire hazard reduction and silvicultural effects may be predicted. It is not sufficient to state that good silvicultural regeneration was due to a "hot" burn. In the past, papers on prescribed burning in the jack pine forest type have generally not stated or measured the fire behavior characteristics of the burn, and as a result no correlations between fire effects and fire behavior have been obtained. In effect, these papers have contributed little to the art and science of prescribed burning. It is important to realize that there is a need for quantitative information on fire behavior-fire effect relationships. The collection of fuel and fire behavior data in a standardized format would facilitate this understanding by permitting comparison of burns and enabling forest managers and fire managers to benefit from the experience of others.

One must keep an open mind when evaluating responses after prescribed burning. Some responses may appear to be related directly to burning, but in fact are responses to other types of stimulations. Vegetation growth after prescribed burning has in some cases resulted from the opening of the stand and has not been directly related to fire effects.

For a complete understanding of how prescribed burning affects the different plant species one would need much more detailed information than has been gathered by past researchers. Data on fire behavior characteristics of the prescribed burn, preburn site conditions, and preburn vegetational species composition would be required.

The two most common objectives of prescribed burning are fuel hazard reduction and site preparation. Prescribed burning has been found to be an excellent means of fuel hazard reduction. Areas do not need to be completely burned since fuel hazard is greatly reduced by breaking up the continuity of the fuel beds. In many cases, though, it is just as easy and more economical to burn the entire area. Silvicultural application of prescribed burning for jack pine regeneration has been found to be successful if certain conditions are met. The survival of jack pine seedlings on the burn site depends mainly on adequate exposure of mineral soil in the case of direct seeding and natural regeneration, and an adequate supply of moisture. Prescribed burning has been found to be cheaper than different scarification methods used for site preparation.

Delaying artificial regeneration to allow vegetational development to moderate environmental factors appears to enhance regeneration results. Certain plant species found after burning offer minimal competition to jack pine seedlings, and it may be possible to allow vegetational development to modify the harsher environment found after prescribed burning. This delay increases shading from solar insolation, thereby reducing moisture loss from the soil. The increased shade also benefits jack pine seed germination.

Prescribed burning is both an art and a science. A specialist with a broad background in fire behavior and forest management should work in conjunction with the fire boss to meet the objectives of the prescribed burn.

This report reviews the literature on prescribed burning over vast areas within Canada and the United States. Ahlgren (1963) summarizes the problem this represents: "In most cases, we cannot generalize from the ecological changes wrought by fire in one region and expect the same results in another region." In an attempt to overcome this problem the present report provides an area index that lists the geographic areas in which the studies referred to have been conducted. In addition there is a subject index to enable the reader to locate a particular subject quickly.

RESEARCH NEEDS

The amount of quantitative information available on prescribed burning in the jack pine forest type is small compared to the number of studies completed over the years. Very little is available for operational use on the relationship between fire behavior characteristics and the effects of fire on fuel hazard reduction, or on the environmental effects, ecological effects, and silvicultural uses of fire. This lack of information is a problem to which fire researchers must address themselves.

Research in the use of prescribed fire should attempt to answer the following questions.

1. Can the Fire Behavior Index be further developed and improved for jack pine logging slash?

2. Can soil property changes caused by prescribed fire be documented to the extent that soil changes can be predicted?

3. What responses can be expected from vegetation and wildlife on the site after a prescribed burn has been conducted?

4. On what sites is prescribed burning a feasible site treatment technique?

5. How soon and how long after prescribed burning is the site receptive to artificial regeneration?

6. Can vegetative competition to jack pine regeneration be reduced by prescribed fire (if indeed postburn vegetation is competitive)?

7. Can vegetation moderate environmental factors after prescribed burning to enhance regeneration results?

8. How are prescribed burn costs affected in terms of (i) harvest methods employed, (ii) fuel loadings, and (iii) size of prescribed burns?

9. What is the optimum prescribed burn size (hectares) in terms of cost?

AREA INDEX

The many publications referred to in this paper have been indexed according to the area in which the studies they document were conducted. There are six geographical areas and one general category representing general publications not associated with specific geographic location.

Area	Reference Number
General	10,11,12,14,15,16,18,19,20,21,22,24,25, 30,31,36,37,38,42,43,51,55,57,58,64,65, 68,73,96,98.
Manitoba	1,33,34,35,39,40,41,48,61,62,81,83,84,85, 86,87,88,89,90,91,99,100,101,102.
Michigan	13,26,27,28,29,63,70,71,72,80,82.
Minnesota	2,3,4,5,6,7,8,9,54,66,67,74,76,78,82.
Ontario	23,32,44,45,46,47,48,49,52,56,59,69,75,76, 77,79,92,93,94,95,103,104,105.
Quebec	97.
Saskatchewan	17,48,50,53,60,81,91.

SUBJECT INDEX

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