SOME IMPLICATIONS OF LARGE-SCALE CLEARCUTTING IN ALBERTA

A LITERATURE REVIEW

by

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INTRODUCTION

The plans for pulpmill establishment and expansion in Alberta and the rapid change to close utilization and mechanized logging has prompted concern over the ecological effects of clearcutting large blocks of timber in the order of hundreds or thousands of acres. This review and interpretation of literature was conducted at the request of the Alberta Department of Lands and Forests and will serve as a basis for research programing as well as forest management planning.

Controversy over clearcutting is gathering momentum in the United States and parts of Canada and is described by Shaw[1] in a report to the United States Congress as "one small facet of the crusade to save the environment". It is essential that Alberta foresters be prepared for greater public interest in renewable resource management and united in their defence of sound forestry practices which are consistent with the needs of the people.

This review considers most of the available information regarding the effects of clearcutting on climate, hydrology, stand establishment and protection from fire, disease and insects. Unfortunately important aspects such as recreation, aesthetics and wildlife management could not be included and should be most important considerations where clearcutting is proposed.

Experience with large clearcuts in Alberta is limited, therefore our conclusions and recommendations are based almost entirely on an interpretation of the literature and our judgment and experience as forest scientists.

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[1] Shaw, Elmer W. 1970. Pro and Con Analysis of Clearcutting as a Forestry Practice in the United States. The Library of Congress, Legislative Reference Service, Washington, D.C.

Validation of these conclusions for local conditions is essential and is the main recommendation emanating from this report.

In summary the following major conclusions were reached:

1. The influence of the forest on most climatic parameters rarely extends more than two or three times the height of the trees in the clearcuts, thus the climatic conditions in the open will remain practically constant with increasing size of the cutover.
2. Sub-climax or climax spruces and firs are extremely difficult and thus expensive to establish outside the influence zone of the stand margin. They require a sheltered environment for early survival and growth. Pioneer species, pines and poplars, can be more easily managed under a clearcut system. Natural regeneration is possible with some site preparation because of the slash-borne cones of pine and the root suckers and wind-borne seeds of poplar.
3. Clearcutting results in increased erosion and sedimentation rates, but the increases can be attributed far more to road and trail construction than to the fact that an opening is created.
4. Beyond a minimum block size of about 25 acres slash fuels on clearcuts are exposed to the full desiccating effects of the environment and capable of supporting rates of spread and intensities comparable to those on much larger areas. When burning conditions preclude crowning in adjacent stands, the final size of a slash fire is likely to be determined by the size of the clearcut. As burning conditions worsen to a point where crowning prevails, fire behavior on relatively small clearcuts with adjacent uncut blocks may well be more intense and erratic than in larger clearcuts.

5. Clearcutting, followed by removal of logging residues, represents the ultimate in sanitation cuts from a disease and insect infestation point of view. Insect populations and disease conditions which are normally associated with mature and over-mature stands, are eliminated. However, monocultures in subsequent reforestation programs provide optimum conditions for outbreaks of insects and diseases which specifically attack seedlings, saplings or immature forests.

ENVIRONMENTAL FACTORS AFFECTED BY CLEARCUTTING

J.M. Powell

Abstract

There is little information concerning possible environmental changes resulting from large clearcuts. Some information is available for small block or strip cuttings. The climate of large clearcuts would probably approach that occurring over bare open areas. The influence of the forest on most climatic parameters rarely extends more than two or three times the height of the trees into clearcuts, thus the climatic conditions in the open will remain practically constant with increasing size of the cutting area, other factors remaining uniform.

A clearcut reflects a greater proportion of solar radiation than a forest, which absorbs 60 to 90 per cent of the total solar energy received. Air and soil temperatures in a clearcut have a larger diurnal amplitude than in a forest. Maximum temperatures are increased and minimum temperatures decreased. Annual average temperatures are higher at all levels in a clearcut than in the forest. Forests reduce depth of frost penetration and delay dates of freezing. Surface temperatures above 50°C are common in the open. There is more evaporation in a clearcut than in the forest, but atmospheric humidity is slightly higher in the forest. Clearcuts eliminate the interception of precipitation so prominent in forests, although some will still be intercepted by the slash of the clearcut. Clearcuts result in increased snow accumulation, higher snow densities and increased snowmelt rates. Wind velocities in open areas are increased considerably and intense turbulence may develop. The formation of nocturnal temperature inversions and frosts are less likely to occur in large clearcuts than in small clearings.

Introduction

A forest has a moderating effect on climate, exerting much of its influence through the crown, which is responsible for the presence of strong sinks and sources of heat and moisture. The forest affects light and solar radiation, air and soil temperature, wind, atmospheric humidity, precipitation, evaporation and transpiration. The various factors of climate are undoubtedly affected by clearcutting, and the degree of this effect is inevitably related to the size of the clearcut. Clearcutting can change the whole pattern of mass transfer and energy balance of the site because the range of values for solar radiation and precipitation reaching the ground, the range of air and soil temperatures, atmospheric humidity, wind velocity and direction, together with interactions of these climatic parameters, may be greatly altered.

Apart from some generalities concerning certain parameters, the microclimate of clearings is not well documented, nor can any universal rules be given relating conditions in the strip-cuttings to dimensions, orientation, soil characteristics, height of adjacent cover, type of trees, etc.(Munn, 1965). There is even less information concerning possible climate changes resulting from large clearcuts, covering several hundred acres. Indications are that the climate of clearcuts would approach that occurring over bare open areas. However, the climatic parameters of clearcuts would be intensified or modified compared with open areas, because clearcutting exposes the forest floor, which is often a heterogenous mass of forest litter, slash and mineral soil. Once away from any effects of the microclimate of the forest stand border, the climate conditions in the open will remain practically constant with increasing size of the cutting area, provided topography, soil and other factors remain uniform.

This review will try to show the major differences in the climate conditions between forest, clearings and clearcuts, and open areas, from the information available, little of which is from reports of Alberta conditions.

Stand Border Climate

The climate of the stand border is a transition climate between that of the forest and that of open country or clearcut area, and the contrasts between the two lead to an exchange of their properties, which differ on the various borders of the stand. For example, at the wind-exposed edge of the forest the characteristics of open country climate mix with the forest climate characteristics, within a distance corresponding to about 5 times the height of the stand, to such an extent that they lose their individual characteristics. The influence of the forest extends farther into the open-country on the lee side than the influence of the open-country extends into the forest on the windward side, although the effect of individual parameters is most variable. On the lee side the influence of any additional water vapor from the forest climate has already lost its effect before 100m but wind does not fully adapt to the new ground surface at the lee side of forests until it has travelled a distance of approximately 50 times the height of the trees (Baumgartner 1967). Kittredge (1962) indicated that the influence of the forest on the interception of precipitation extends more than half but less than $1\frac{1}{2}$ times the height of the trees beyond the edge of the forest. For most factors the influence of the forest rarely extends more than two or three times the height of the trees, and then only for brief periods of time. Along the south border the distance is negligible, along the north border it is not more than twice the height of the trees in winter, and much less in summer. Several studies (see Geiger

1965; Hughes 1949) have shown that air temperatures near the forest edge are a little warmer during the day and a little cooler at night, when compared with stations in the open. This effect increases to a maximum at a distance of 200 to 400 feet from the forest edge, and after than decreases.

Meteorological Factors

Solar radiation

Incident solar radiation under forest canopies is often less than 10 percent of that in adjacent clearcuts (Vézina and Péch 1964) and can be as little as 1 percent of that in the open (Kittredge 1962). Forests absorb 60 to 90 percent of the total solar energy received, the amount absorbed depends primarily on its density and foliage development (Reifsnyder and Lull 1965). Of this amount about one third is used in convection, and nearly all the rest is used in evaporation and transpiration, a small amount being stored temporarily in the forest. The only surface in the natural landscape that has a reflectivity as low as a dense coniferous forest cover (10 to 15 percent) is a wet or dark-colored soil, therefore a clearcut area is likely to reflect a greater proportion of solar radiation. During the growing season, nocturnal radiation from a forested slope should be greater than from bare or grass-covered slopes because radiation is primarily from the treetops, which maintain a higher temperature than bare soil or grass (Reifsnyder and Lull 1965). Hornbeck (1970) showed that the albedo of cleared areas when free from snow was nearly constant at 14% of the solar radiation, but was as high as 83% during periods of snow cover. In contrast the albedo of a hardwood forest ranged from about 14% in the leafless state without snow, to 20% in full leaf and 32% with a snow cover. The albedo and the long-wave radiation components of a small size clearing will not be the same as that of an open field because of edge effects from the forest wall (Munn 1965). Dirmhirn (1953) showed that only at distances closer than 1.5 times the height of the trees were daily amounts of solar radiation reduced below 90 percent of that occurring in the open. The reduction by the canopy of short-wave radiation by 73 to 86 percent is probably the major effect of the forest on any climatic factor, but it depletes long-wave radiation very little (Reifsynder and Lull 1965).

Air and soil temperature

Generally, the influence of most forests is to increase the minimum temperature both in summer and winter, sometimes by as much as 4°C in the monthly mean in summer, and to decrease the maximum temperature (Kittredge 1962). Deforestation in the Wagon Wheel Gap experiment in Colorado (Bates and Henry 1928) was followed by an increase in the maxima, minima and mean air temperatures for every month of the year. The greatest differences in the maxima were seen from September to March, and the smallest in June (0.8°F). The increases in monthly minima were small for all months, being greatest in June and July when they reached 1.1°F. Gregory (1956) found that air and soil temperatures were consistently higher in a large clearcut area than those in the forest during the late spring and summer periods in southeast Alaska. The most noticeable increase occurred in the soil maxima, while air and soil minima were least affected. Cochran (1969) indicated that minimum temperatures (2.5 inches above soil surface) decrease rapidly over a short distance outward from the stand edge. At twice the stand height (120 feet) minimum temperatures were 3.3°F lower. Lützke (1961), in a study of the temperature climate within forest stands and clearings compared to that in an open field, found that annual average temperatures were lower in the stand at all heights than they were in the open field. The differences amounted to 1.14°C at the soil surface, to 0.66° at a height of 2m to 0.34° at the height of the crown. At night time the differences tended to be greater than for a twenty-four hour period. In the warm months the differences were greater than in the cold months, although under calm radiation weather in the winter, forest temperatures were 3 to 4°C lower. More extreme temperature conditions existed in the clearings as compared to the open field. Daily temperature fluctuations in the crown region were more extreme than at comparable height in the open, but near the ground extremes were greater in the open. Aussenac (1970) recorded air temperatures at various levels above bare ground, above herbs and grasses, and in an Abies forest, and found that on nights of high radiation the lowest temperatures were recorded at the soil surface on bare areas, immediately above the surface of the grasses and herbs and at the crown level in the forest. Damage by late frosts is therefore likely to be more severe on cleared areas than on areas with a vegetation cover.

Forest soil temperatures are higher than those of neighbouring open fields in the winter and lower in the summer (Hughes 1949). Soil temperatures in a clearing have a larger diurnal amplitude than in a stand. Forests reduce the depth of frost penetration and delay the dates of freezing. (Keinholz 1940) showed that in Connecticut the maximum depth of freezing was 2.9" in white pine, compared with 10.1" in a ploughed field, and that the date of freezing was delayed 44 days in the pine. According to MacKinney (1929) frozen soil in the forest is kept porous, loose and permeable, when bare soil outside has become solid and impermeable. Heavy exposed clay soils are especially conducive to frost heaving (Roe et al. 1970). The large differences in soil temperature which are attributed to the forest are in the upper 20 to 30 cm. of the soil. Yet after a clearing in the U.S.S.R., it has been reported, the subsoil temperature during the summer increased to equal that in the open to a depth of 3m, and the influence of the forest extended to a depth of 10m. (Kittredge 1962). Kittredge reports other studies showing the maxima at 3 cm. depth in the forest are lower than in the open in every month, with the greatest departure (12.3°C) in July and the smallest in January (1.4°). The monthly minima in the forest at 3 cm. are higher than in the open in every month, with the largest departure in November (+3.3°C). At 15 cm depth the minima in the forest are lower from April to October. The influence of the forest in reducing maximum soil temperatures results partly from the shade of the crowns and partly from the insulation of the forest floor. The shade is usually more effective than the forest litter in reducing the temperatures. The slash and litter debris left in clearcuts would undoubtedly provide some insulation and reduce soil temperatures compared with those that would occur in open areas. Jemison (1934) found in Idaho that mean soil temperatures at 30cm in the soil were 4°C higher in a clearcut in July and August than in the forest and that the mean maxima just under the surface of the duff on the clearcut was 28°C higher than in forest. An absolute maxima of 70°C was recorded just under the duff on the clearcut area, and temperatures at the surface were presumably higher. Averages showed that during July and August on the clearcut area there were 44 days when duff temperature exceeded 120°F, the average period of duration being over 4 hours each day, temperatures lethal to seedlings. In the same period the highest record of duff temperature in the forest stand was 94°F. Jemison's study provides values for other parameters which are of interest (Table 1). Surface soil temperatures above 50°C are common on clearcut areas in the Prairies (Day 1963; Sims, per. comm. 1970) and have also been recorded on slash (Loman 1962)

Table 1. Averages of July and August weather and fuel moisture for three years on three sites at the Priest River Forest Experiment Station (from Jemison, 1934).

Factor measured	Full-timbered area		Half-cut area		Clear-cut area	
	Means	S.E.	Means	S.E.	Means	S.E.
Maximum air temperature, °F	79.3	± 0.6	81.7	± 0.7	84.1	± 0.7
Soil temp. 1-ft. depth, °F	51.4	± 0.1	53.9	± 0.1	59.6	± 0.1
Max. surface duff temp. °F	77.0	± 0.7	91.6	± 1.0	126.9	± 1.3
Rel. humidity, 4:30 p.m. %	35.8	± 1.1	29.0	± 1.1	27.3	± 1.1
Absol. humidity, 4:30 p.m. gm/cu. ft.	3.343	± 0.057	2.886	± 0.057	2.817	± 0.052
Wind movement during day, miles	3.8	± 0.2	18.8	± 0.6	32.6	± 0.7
Evaporation rate, gm[1]	40.0	± 2.0	77.0	± 8.0	163.0	± 11.0
Duff moisture, %	18.8	± 0.9	16.5	± 0.9	8.2	± 0.6
Branchwood moist. 2" diam. %	11.1	± 0.2	9.5	± 0.2	6.4	± 0.2

[1]Average evaporation based on measurements taken every 10 days during 1931 and 1932 only.

Generally heat injury may become serious for most coniferous species when surface temperatures above 50°C are reached for periods of a few minutes up to several hours (Day 1963).

Atmospheric humidity and evaporation

Forest cover influences the water-vapour content of the air by the direct addition of moisture through transpiration, and also by its effect upon evaporation and condensation within the forest. The influence of the forest on the humidity of the air has most often been expressed as relative humidity, however, this is unsatisfactory as relative humidity varies inversely with temperature, and as we have seen above temperatures in forest and open areas are usually different. Kittredge (1962) reviewed various studies measuring humidity by other methods. Jemison (1934) showed that a forest averaged an absolute humidity of 7.69 gm/cu.m. at 4:30 p.m. while that in a clearcut was 6.47 gm/cu.m. Records of saturation deficit and vapor pressures showed that there was an annual cycle of humidity in a forest with a minimum in December and a maximum in August, and that the influence of the forest was greatest in the afternoon. The saturation deficit was lower in the forest than in the open in every month of the year, and the departure of forest from open range from 0.2 millimeter in December to -4.2 millimeters in August.

Evaporation in the forest was less than in the open. The largest departure occurred in the growing season and the smallest in the winter (Kittredge 1962). A study in Tennessee showed a minimum departure in January (-20) and a maximum in June (-153) (in Kittredge 1962). Evaporation measured by atmometers in July and August in Idaho (Jemison 1934) indicated that evaporation in a forest was about 25 per cent of that in a clearcut (Table 1).

Precipitation

There has been much controversy as to whether forests increase precipitation on a regional or even local scale. Golding (1970), in a review of this topic concluded that the maximum effect that may reasonably be attributed to the forest is a 5 per cent increase in precipitation, and this only in particular circumstances.

The most apparent effect of clearcutting is the elimination of interception of precipitation by the forest canopy and subsequent evaporation loss of the detained water from tree surfaces. Conifer stands are capable of intercepting nearly 100 percent of low-intensity precipitation. The throughfall increases with intensity and amount of precipitation but it is not unusual for the canopy to intercept more than 10 percent of the incoming precipitation, even during heavy rain (Kittredge 1962). A study in lodgepole pine stands in Colorado (Wilm and Dunford 1948) showed that generally a slightly higher percentage of the snow was intercepted than rain. Measurements in the same locality showed that the slash of cut pine trees also intercepted an appreciable fraction of the summer rainfall, but as the slash disintegrated, the rainfall reaching the soil increased (Goodell 1952).

Clearcuts however, result in increased snow accumulation due not only to reduced interception, but also to wind effects which re-distributes the snow. Higher snow densities occur in the open than in the forests, while snowmelt rates are increased. Anderson (1963) working in clearcut blocks in California of more than 20 acres or strips wider than four times the tree heights found that the average snow accumulation in the clearcut area was 12 inches greater than accumulation in the uncut forest. However, on June 9 when all snow had melted in the open areas, there was still an average of 16 inches of snow water left in the forest. Berndt (1965) reported an increase of snow water equivalent of up to 40 percent in 5, 10 and 20 acre cut blocks compared to an uncut lodgepole pine forest, and the snow melted in the cuts approximately 10 days before that in the forest. The greatest response to clearcutting in blocks was observed on the east aspect. Studies of snowpack ablations have indicated that forest-wind conditions influence snowmelt for long distances to windward and leeward of a clearing edge (Anderson 1970).

Dense canopy forests also have less melt to the leeward than open forests.

Dew and frost are deposited on exposed cold surfaces of plants and soil. Studies in Ohio have indicated that dew and frost constitutes 18 percent of the annual precipitation (Harrold and Dreibelbis 1951), while Lloyd (1961) showed that dew could account for 13 percent of summer precipitation in northern Idaho. In a forest, dew is deposited chiefly on the upper surfaces of the crowns and sometimes amount to 1 mm in a single night, while in the open deposits of 0.1 to 0.4 mm have been recorded (Kittredge 1962). Lloyd (1961) found that no dew was deposited under a closed forest canopy or in small openings, where ratio of diameter to height was about 1 to 2. In the center of large openings, dew deposit was about one-half that in an open meadow. Kittredge (1962) also mentioned that monthly rates of 0.5 to 10 mm of deposited frost were recorded under the crowns and in the openings of pine stands in California in several months.

Wind

Forests reduce wind velocities as compared with those in the open. In the open, the vertical gradient becomes steeper as the distance to the ground decreases. Similar trends are evident as the height above the forest canopy decreases, but below the crown space the velocity may increase again, only to decrease rapidly close to the forest floor. On an annual basis the reduced velocities in a forest are usually between 20 and 50 percent of those in the open (Kittredge 1962). In a clearcut area in Idaho, Kittredge reports an average daily wind speed of 0.6 meters per second, but the velocity in the uncut forest was only 0.1 m/sec. In the Wagon Wheel Gap Experiment wind velocity after deforestation averaged 3.3 mph as against 1 mph. before (Hughes 1949). In a clearcut area wind velocities near the surface would be reduced compared with an open area because of the greater roughness of the surface. Wind velocities, like temperatures, show a diurnal cycle with highest velocities about the time of maximum heating and may result in considerable turbulence. Intense turbulence may develop in clearings from other causes. In particular, aerodynamic downwash on the upwind side of the clearing may produce a mean surface wind direction that is the reverse of the geostrophic direction (Munn 1965). If strong winds blow in a direction parallel to a strip clearing winds may be channelled causing higher velocities in the clearing than may occur over open country, or if a clearing is at a slight angle to the geostrophic wind direction, there will be a tendency for the surface winds in a strip clearing to be deflected and to blow parallel to its lengthwise direction (Munn 1965). Reduced wind speeds in small clearings as compared to what is found in open country favour the formation of nocturnal inversions, and calm periods favour frost formation in such areas.

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SILVICULTURAL IMPLICATIONS OF LARGE BLOCK CLEARCUTTING IN ALBERTA

by

F. Endean, H.J. Johnson and J.C. Lees

"Too often the forester thinks of the method of cutting as acting directly instead of through its effect on basic physical conditions." Pearson (1928).

Abstract

This review of research into the silvicultural problems associated with large block clearcuts has revealed two important considerations: first, that the silvics of the tree species, spruces and pines, are well known; and second, that while the economics of the situation may force the forest manager into the clearcutting of ever increasing areas, there is a marked paucity of research and development trials related to size of clearcut. Existing trials are too often dependent on the current standards of merchantability and utilization. We are forced therefore to make predictions about the silvics of a situation which is not yet the norm but towards which cutting practice is now turned. These predictions are made with justification on the basis of silvicultural and ecological studies, many of which are referred to in this review.

They are:

(1) The clearcut area is hotter and drier than the stand margin environment. Vegetation encroachment is complete in about four seasons but the severe conditions in the clearcut which affect conifer seedlings may also inhibit growth of vegetation competition to advantage.

(2) Most of our regeneration problems are with spruce. In sub-climax and climax stands there are clear limitations to size of clearcut area since the "stand margin" environment should be preserved and planting techniques for spruce are not sufficiently well developed. Beyond this zone of influence, establishment of spruce becomes increasingly expensive.

(3) If pioneer species are satisfactory for timber production there is little evidence in the literature to suggest that beyond a 2 to 3 times tree height strip width, there are any effects which would limit the size of clearcut. Logging methods can be devised which will preserve existing advance growth without increase in cost or productivity. Natural regeneration will not constitute 100 percent of the restocking, but could be augmented by artificial regeneration. The decision as to whether clearcutting is applied with these species rests on aesthetics and watershed considerations.

Introduction

This review of literature covers the period 1940 to the present and was in large part obtained from Forestry Abstracts. Where possible papers were obtained and studied and this is indicated in the list of references.

Clearcutting results only where there is a high degree of utilization of all species occupying the site. Harvesting pine stands or mixed conifer stands is more likely to result in the denuded areas associated with large block clearcutting than cutting in stands with a hardwood component. Therefore, individual effects of clearcutting (microclimatic changes, soil effects, erosion and run-off etc.) documented in recent literature should not be ascribed to the kind of partial cutting in B18 mixedwood stands (Rowe 1959) with which we are currently familiar in Alberta.

Clearcutting eliminates the stand and thus there are no silvicultural considerations left but the regeneration of a new stand and how the altered environment will affect this process. Because of the different requirements of pine and spruce (pioneer vs. sub-climax species) and the fact that each can grow in pure or mixed stands, it is well to examine the implications of block clearcutting separately for these two species and between the two major ecological subdivisions in the province i.e. the foothills/subalpine and mixedwood regions (Rowe 1959).

Smithers (1964) stressed the influence which increasing mechanization will have on silvicultural practices. He points out that the silviculturist cannot assess the impact of large block clearcuts with fully mechanical harvesting, site preparation and regeneration, since it simply had not been done at that time on even a trial scale. Theoretically, the cost reduction of efficient logging systems should be sufficient to support site preparation, planting and tending costs.

Presently there is a trend towards:

1. Year round operation,
2. Larger clearcut areas,
3. Better utilization of small dimension material,
4. More complete removal of material, and thus nutrients from the site.

Smithers listed the following increased costs of mechanized logging:

1. Damage to advance growth necessitating replacement,

Figure 1. Climax spruce-fir stand.

Figure 2. Pioneer lodgepole pine stand.

2. Slash disposal,

3. Artificial regeneration,

4. Possible site deterioration necessitating amelioration.

He argued that the cost of protecting advance growth would be high. The literature reviewed suggests that this is not necessarily so.

Some of the effects of clearcutting on the microclimate and soil are well documented although results are largely confined to areas of less than 50 acres. In general terms these are:

(i) Abrupt increase in incident light which encourages proliferation of ground vegetation and which at high altitudes (8,000 ft.) can be damaging to foliage,

(ii) Increase in sunlight reaching soil surface layers,

(iii) Increase in surface soil temperatures depending upon colour and texture often to levels lethal for germinating seedlings and also contributing to drying effects,

(iv) Increase in soil temperatures below the surface by as much as 5°C.

(v) Increase in wind speeds and turbulence,

(vi) Reduction in atmospheric humidity,

(vii) Reduction of minimum temperatures and frequently an increase in maxima,

(viii) Increased incidence of frost,

(ix) Penetration of frost more deeply into soil layers, increase in frost heaving and soil detachment,

(x) More rapid snow melt,

(xi) More violent impact of rainfall and, until vegetation establishes more surface run off,

(xii) Frequent increase in soil moisture and occasional water logging.

(xiii) Accelerated oxidation and breakdown of organic layers.

Most of these changes especially those affecting the surface soil moisture regime are detrimental to germination and seedling establishment.

Clearcutting in Climax and Sub-climax Stands

White spruce may be used to represent the mean characteristics of Canadian spruces with the exception of Sitka Spruce (Sutton 1969). In the mixedwood type it grows in mixtures, often with merchantable pines but more frequently with unmerchantable hardwoods, spruce and firs. In the High Foothills Section of the Province merchantable mixed stands of spruce and fir are not uncommon. These climax stands provide good utilization opportunities for clearcutting but because of the characteristic accumulation of organic material or "deep duff" may be difficult and expensive to reforest.

Experience has shown that extensive cutting of the more common mixed spruce stands must be accompanied by a proportional amount of site improvement for regeneration because of the proliferation of root suckering from poplars and vegetative regrowth (Lees 1970). Without site preparation repeated cutting of spruce will result in conversion to a pioneer species.

General

From 1940 to 1947 there are conflicting and unsupported published opinions concerning the manner in which mature spruce should be logged. Long (1946) favored clearcutting of mature spruce in Quebec and suggested that natural regeneration would be adequate. Melekhov (1944) discussed extensive clearcuts in Northern Russia which followed forestry mechanization in the thirties.

He observed that generally clearcutting of spruce resulted in vast tracts of birch forest. Spruce only occurred as a pioneer species where seed source was available and the soil was "light, well-drained and well-cleaned". A report of the U.S. Forest Service (Koch 1942) points out that selective or partial cutting removing the best trees in even-aged stands is the wrong principle to apply in any even-aged forest type. Robertson (1945) recommended clearcutting for even-aged mature stands in spruce/fir and white birch, spruce, fir types but stipulated that ample reproduction must be assured and that no serious damage to adjoining stands nor soil erosion should result. The diameter limit modification of the selection system was recommended for over-mature uneven-aged stands of any type. Chapman (1944) emphasized the dangers in selective cutting and indicates the place for clearcutting in sustained yield management, particularly in the mature and over-mature even-aged stands of North America. In Northern Norway experience over a period of forty years (Collet, 1942) has indicated that clear felling of spruce and pine followed immediately by planting has been successful. The results indicate the advantage of this method over selection systems under conditions of relatively humid and cold forest soils. It should be remembered however that artificial regeneration systems in Scandinavian countries are considerably more intensive than anything practised in Canada.

Long (1946) summarized the factors affecting the regeneration of spruce in Eastern Canada.

1. Lack of a source of seed,
2. Clearcutting in poor seed years,
3. Destruction of seed by insects, birds and rodents,
4. Drought,

5. Competition from ground vegetation,

6. Destruction of seedlings by fungi,

7. Poor seed beds.

Holt (1955) showed the spruce regeneration problem to exist as late as 1955, "the practical problem which remains largely unsolved in Canada is how to manipulate our forest stands so as to produce conditions which are known to favour regeneration" .... "In fact, after cutting, almost the only white spruce stands which are found are those where white spruce was present as advanced growth...". Between 1947 and 1953 there are many unsubstantiated statements with regard to methods of cutting spruce. Most of them favour strip and selection cutting and oppose large clearcuts.

Pogue (1946) after examining cutover white spruce areas in central British Columbia stated that adequate restocking was found to be the result of a well distributed residual stand rather than any other factor or group of factors. Long (1947) and Lexen (1949) advocated strip cutting for the natural regeneration of pulpwood species in Eastern Canada and lodgepole pine in Colorado.

These references indicate the degree of confusion which exists in the literature of this period largely arising from the lack of factual evidence. They give no firm basis for any conclusions on clearcutting as a system of management for white spruce.

In Alberta, De Grace (1950), established 26, .32 acre plots at 26 sites from Crowsnest to Nordegg in different types of white spruce cutover, and assessed regeneration after logging. Natural regeneration was poorest in the clearcut areas and could not be regarded as adequate. He recommended selective logging as giving uniformly better results. Crossley (1955) recognized that in general old cutover spruce stands were not regenerating adequately and quotes Candy's survey (1951) to this effect.

Proceedings of the 1959 Annual Meeting of the Canadian Institute of Forestry at Prince George B.C. indicate a concern for spruce regeneration following "clearcutting" as then practiced. In fact, however, logging in spruce was generally conducted according to a merchantable diameter limit and among mixed stands where other unmerchantable coniferous species were left standing together with scattered hardwoods. Regeneration of spruce alone was then acceptable to the B.C. Forest Service and there was concern over the utility of "leave strips", seed tree blocks and single residual seed trees, Silburn (1960) and Bonner (1960), Johnson (1960). Johnson (1960) further examined clearcutting in spruce and reported that without cultural treatments to secure regeneration, clearcutting could be termed only "low order forestry".

Effects on seed bed conditions

The effect of clearcutting in raising maximum soil temperatures, perhaps to levels lethal to conifer seedlings, is described by Gregory (1956), Cochran (1969), and Hallin (1968). Extremes of temperature, light and soil moisture are shown to moderate after two growing seasons on clearcut blocks. Day and Duffy 1963 show that in the subalpine region of Southern Alberta, (Rowe 1959) mean natural stocking of spruce, fir and pine after clearcutting was 21, 36 and 6 percent respectively and that more than half the area sampled was less than 40% stocked. They found that spruce were better represented on cool north and east slopes and on the moister, better protected environments of each site and suggest that spruce was the most sensitive to heating and drying of the exposed soil surface. Day (1964) showed that drought was more acute in open cutover than beneath partial stand cover and maximum drought periods of 3-4 weeks were measured, accompanied by high surface temperatures. His conclusions from these initial studies were that after clearcutting in the Subalpine region, heating and drought of the soil surface may cause natural seedling mortality and regeneration failure. Day (1963) quotes Daubenmire (1943) who showed that Engelmann spruce and Alpine fir were considerably less resistant to heat and drought than Ponderosa pine. Day showed that mid summer heating of the upper layers of the soil in clearcut areas, and the low relative humidities and temperatures achieved at this time are probably serious causes of seedling mortality. Shading significantly reduced seedling mortality on all seed bed types tested and under shade, drought was the main cause of mortality. This latter conclusion is supported by Ronco (1970) working with Engelmann spruce and Soos (1970) with white spruce.

The conditions investigated by Day in Southern Alberta are more extreme than those found in the foothills or the mixedwood regions but there is no doubt that the same principles prevail.

Timmer and Weetman (1969) working in upland black spruce concluded that large exposed clearings showed consistently higher (2°-14°C) surface temperatures and caused extreme surface maxima. This may lead to temperatures lethal to tree seedlings (49-50°C). Yet at night, temperatures in clearcuts drop below frost damage levels. Such extreme day temperatures result in increased evaporation and other water losses.

There is general agreement that young conifer seedlings die when exposed to temperatures of 120°-130°F. (Such temperatures are common in the Prairies Region - Sims per. comm.). Jemison (1934) quoted Toumey and Neethling in finding stem lesions on nursery stock after temperatures of 122°F of two hours duration. This is confirmed by Baker (1929) who sets lethal temperatures in the range 124°-131°F. He points out that this limit is for very young seedlings and that resistance increases with age and stem hardening. Jemison (1934) gave average results over a period of three years for Priest River, Idaho and showed great differences in humidity and duff surface temperatures between cut, half cut and clear cut areas. In the latter, surface duff temperatures were 120°F for 4 hours on 44 days, 130°F for 3 hours on 26 days. Phelps (1948) found surface temperatures of between 120°F-130°F on clearcut areas in Manitoba and Saskatchewan and suggests 7-21 days of drought as critical for white spruce survival.

Vaartaja (1954) states that extremes of temperature can be considered as a characteristic of clearcut forest sites. Quoting from his own unpublished work he showed that high evaporation rates are not lethal to established Scots Pine seedlings provided moisture supply is good but that these conditions are damaging to young seedlings and germinating seed. He is supported by Arnborg (1947) who holds that the limiting factor for success in natural regeneration is not a temperature suitable for germination but moisture.

Eis (1967) working in Central British Columbia would appear to contradict this in stating that white spruce seedling survival was better on dry sites than on moist. He does stress however that drought was the principal cause of mortality on all sites and it would appear that the better performance found on dry sites was a function of freedom from vegetative competition.

The deleterious effects of clearcutting on surface run-off, soil erosion and stream flow patterns may moderate as soon as exposed mineral soil is revegetated, (Reinhart 1964). Even on mechanically disturbed seedbeds this may be as soon as 4 growing season (Lees 1970). There is some evidence to suggest, (Benzie 1963) that vegetation encroachment on wetter sites may be more rapid under shelterwood than on clearcut blocks beyond the zone of stand margin influence.

Because of the many factors detrimental to successful establishment of natural spruce regeneration, Sutton (1969) concluded, "spruce has thus gained prominence in artificial regeneration". This is a reflection of the difficulty of maintaining a sub-climax species under a clearcutting system. Natural regeneration of other species in the mixture, e.g. *Abies balsamea* and *Abies lasiocarpa* may yet be acceptable. The possible contribution of advance growth of spruce to restocking has not yet been investigated. Current logging practices tend to destroy much advance growth only to be followed by expensive treatments to reestablish seedlings. This is an aspect of extensive logging in spruce stands which is currently being considered by the Alberta Forest Service and which deserves increased research support. Russian foresters reported that volume production under specialized felling patterns is not less than standard procedure once the crews are trained (Izvekov, 1960). MacDonald *et al*. (1969) compared production in Ponderosa pine logging and reached a similar conclusion for test operations in California. There should be no hesitation by the silviculturist in prescribing special felling patterns to protect advance growth if no loss of logging production results.

Some of the observations of R.R. Alexander from his work in Engelmann Spruce and alpine fir in Colorado are pertinent to the study of strip clear-cutting practices in the Alberta foothills. In 1956, he first reported that growth of trees in the narrow leave strips did not improve after cutting. There was a marked loss of existing regeneration but Alexander considered that improved felling patterns could minimize this damage. In 1967 he further commented that when advance growth, protected by the improved logging methods of 1960 was added to natural regeneration there was adequate regeneration on strips up to 7 chains wide. Both species, spruce and fir, exceeded 35% milliacre stocking. In 1968 he reported windfall in the leave strips and identifies strip alignment as the major contributing factor. This series of papers from the Rocky Mountain Forest and Range Experiment Station should be followed and contact with Alexander and his co-workers by Alberta forest managers would be worthwhile.

In a summary paper, Roe et al. (1970) concluded that effective seed dispersal ceased 10 chains from the stand margin in a good seed year but was less effective over shorter distances in a lighter seed year. Slow snow melt helped to maintain soil moisture for seed germination. Mineral soil seedbeds were required and survival and growth were dependent on moist sheltered microsites. Many seeds germinated on duff but did not survive the first growing season. They recommended:

1. Preserving advance growth through efficient logging patterns with minimum equipment movement for maximum production.
2. Clearcutting by groups, patches and strips or uniform shelterwood with minimum time between cuts.
3. Strip width limit of 10 chains and clearcut limit of 40 acres on favourable aspects for natural regeneration.
4. Cutting boundaries should be located in stands of sound trees and should be irregular to prevent wind funnelling. Cut boundaries in immature stands are preferable.
5. Planting should be carried out immediately after logging.
6. The same amount of site preparation, slash disposal and scarification is necessary for transplants as for natural seedlings.
7. Hand planting is recommended so that advantage can be taken of "safe" microsites.

8. Direct seeding is not recommended.

Long (1946) adds the final cautionary note on clearcutting in terms of seed dispersal. "Through clearcutting one of the best guarantees of regeneration (that of continuing seed supply) is destroyed".

Working with larger than average Norway spruce seed, Kos (1947) found that there is a critical wind velocity of 1.8m/sec. (4 mph) below which seed falls to the ground and above which it rises. He stated that the average seed would have a lower critical velocity than this and advocated irregular stand structure by leaving dense groups of trees. Maclean (1959) sets three chain widths for cut strips as the maximum for satisfactory seed dispersal in spruce. Information quoted by Geiger (1950) supports this, showing that only 17% of the total seed yield from a Norway spruce stand reaches a distance of 37 m. (40 yrds) from the edge of the stand and suggests that most of this would be the lighter (less desirable) seed.

Conclusion

Young seedlings of spruce require a cool, moist, sheltered environment for establishment and satisfactory early growth. Of all our species in Alberta spruces are the most sensitive to high seed bed temperature, moisture deficit by drying, vegetative competition and high light intensity. Clearcutting modifies the environment of the seedling in a direction which is the reverse of these establishment requirements and removes the seed source. These factors have different emphasis depending upon the ecological region being considered. In the foothills/subalpine regions rapid moisture depletion, high soil surface temperatures prolonged periods of drought, high levels of radiation and low relative humidity are features of the growing season, all adverse to spruce requirements. In the mixedwood region summer precipitation is greater and better distributed and periods of moisture deficit less frequent although aggrevated by heavy soil texture. Evaporation is lower and radiation not a problem. Such conditions are more conducive to spruce regeneration and this is well recognized. On the other hand they also encourage rapid recolonization of the ground and woody vegetation which by its mechanical and physiological competition constitutes the major hazard to spruce regeneration in this region.

The implications of these facts in spruce management are clear, if regeneration from seed is to be expected, small cutting blocks not more than 40 acres which preserve the "stand margin" type of environment are necessary. If the stand is removed by clearcutting in large blocks and artificial seeding applied, conditions of shelter must be simulated by artificial means. Attempts at this with high windrows or furrows have been made. So far spruce seeding has proved to be at best an unreliable method. It is acknowledged that there are many instances of success in the province in both ecological regions but it is agreed that these instances are due to particularly favourable circumstances at the time of treatment which are often not recognized and rarely capable of prediction which is required for a reliable technique. In this report we have only considered environmental problems of spruce establishment. The destruction of seed by rodents, Radvanyi (1970) also remains a problem.

This leads us inevitably to planting as the last possible method of regeneration following clearcutting. Here there is greater flexibility in the size and hardiness of material used and its ability to overcome disadvantages of the altered environment.

So far in the foothills/subalpine region the degree of success with bare root stock is not encouraging, Soos (1970). The quality of this stock is poor and size inadequate. The production of better stock and proof of adequate field performance is still regarded as a problem requiring further research! Results with container seedlings in this region have been erratic (Dixon and Johnson 1969, Soos 1970) and generally unsatisfactory. This technique is regarded as a problem requiring further research by both Industry and the Provincial Forest Service.

Results in the mixedwood region are better but far from the standard required for a proven technique.

This leads us to the conclusion that in the absence of proven techniques for spruce regeneration even in terms of presently approved stocking levels of 40%, the application of large block clearcuts on spruce sites is insupportable and that the current system of narrow 40 acre strips should be maintained for the present.

There is considerable evidence in European work to show that with good ground preparation techniques, large, hardy stock and careful planting, spruce can be regenerated satisfactorily on large clearcuts. There are however significant differences in climate and in the intensity of silviculture applied.

Clearcutting in Pioneer Stands

General

There is a clear indication that the high degree of merchantability of lodgepole pine stands in the foothills/subalpine forests and increasing mechanization will create a demand for management by large clearcuts.

Stands of merchantable pure pine are not a significant part of the Mixedwood forest and this problem does not exist in that region. There is no large scale utilization of our most widespread pioneer species Aspen/Poplar yet but this is purely a question of time and demand. When this time arrives no problems of regeneration in large clearcuts are forseen because of their ability to regenerate from root suckers.

Discussions in this section then centers around the lodgepole pine stands of the foothills/subalpine region on the east slopes. Here the regeneration requirements of the species and the sites occupied are very different from those of spruce. Lodgepole pine occupies the drier, freely drained, more exposed sites with generally shallow organic layers and a light to stony texture. The seedlings are well adapted to this environment (Day & Duffy 1963). They are more susceptible to stem girdling by heat than Douglas fir or Ponderosa pine (Day 1963) but their heat resistance through transpiration is better than Douglas fir or Spruce (Day 1963 quoting Roesev 1932). The serotinous cone characteristic of lodgepole pine demands extreme conditions for seed release and its intolerance of shade and sensitivity to root competition from over wood though not to ground vegetation (Ackerman 1957) places it as a species of open areas such as clearcuts. Lodgepole pine seed germinates best under wide diurnal temperature fluctuations up to 30°F (Smithers 1961 quoting Bates 1924). Since lodgepole pine regenerates well from slash borne cones, and because of its heavier seed, marginal seed source is of relatively small importance (Smithers 1961 quoting Ackerman 1955).

Smithers (loc. cit) maintains that conditions in Alberta are not limiting to pine and draws attention to its readiness to regenerate profusely on exposed sites produced by wildfire, its ability to withstand competition up to the level of 5,000 stems per acre and tendency to overstocking on moist well-drained soils. All these features are undoubtedly those of a vigorous hardy pioneer well suited to open clear cut conditions.

Smithers quotes Blythe (1954) and Bloomberg (1952) who state that partial cutting in lodgepole pine does not produce satisfactory restocking and suggests that it is better suited to clearcutting. He quotes Tackle (1953) on harvesting methods in the Northwestern States as concluding that clearcutting is best suited to the management of this species.

Strip clearcutting in pine with successful natural and artificial regeneration has been repeatedly demonstrated in Alberta. (Ackerman 1955, 1957 1963, Crossley 1952, 1955, 1956, Johnson 1968). More recent results with planting leave a great deal to be desired but are generally better than with spruce (Soos 1970). Frequently survival is dependent on a number of environmental factors which are effected by size of clearcut. Cochran (1969) points to low temperatures as a possible cause of seedling mortality on relatively small (7.4 acres) clearcut blocks. Other factors, he considers, include heat/drought complexes, frost heaving and low soil temperatures during the growing season. On plain topography, Cochran recommends limiting strip width to twice stand height to prevent frost damage. Beyond about four times stand height, the influence of the stand margin disappears and the size of clearcut has no further influence on seedling growth per se although it influences other factors such as soil moisture andvegetation competition. On undulating or sloping topography, however, the clearcut environment is hot during the day, with high insolation, and cold at night. Full light and increased soil surface temperatures encourage suckering of herbaceous species and the extension of rhizomes. Vegetation competition is severe. Even when conifer seedlings suffer from the heat/drought effects perennating rootstocks of lesser vegetation deeper in the soil are protected and thus able to compete more successfully.

Conclusions

There is sufficient evidence to show that lodgepole pine can be readily managed on a clearcut basis on the east slopes although seeding techniques are not wholly reliable and planting techniques require considerable but foreseeable improvement.

There is no evidence to suggest that extremely large clearcuts will produce any change in performance of the species. The decision on this aspect of management rests then on aesthetic and watershed considerations. While the existence of large tracts of even aged pine arising from catastrophic destruction of previous crops is an ecological fact and part of our present land scape it would be foolish to pretend that this is an ecologically static situation which we are automatically justified in maintaining by clearcutting without further thought.

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PROBABLE HYDROLOGICAL EFFECTS OF CLEARCUTTING LARGE BLOCKS IN ALBERTA

by

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ABSTRACT

Clearcutting coniferous forests or the creation of large openings in these forests generally result in a measurable increase in one or more of the following: snow accumulation, snowmelt rate, and water yield. The increase in water yield, and the delivery time depend on both the percent of watershed cut and the pattern of cut. Clearcutting results in increased erosion and sedimentation rates, but these increases can be attributed more to road and skid trail construction than to the fact that an opening is created. Other side effects produced by clearcutting include: increased flood hazard, changes in water temperature, depletion of the water's dissolved oxygen, and changes in ground water levels. Carefully planned and controlled clearcutting could be compatible with good watershed management provided roads and skid trails are not constructed on steep slopes.

Consideration must be given to present and future water requirements when planning clearcut sizes and cutting patterns. Steps should be taken to evaluate the effects on water yield, quality and regime of any harvesting or silvicultural system before it is applied to large areas in Alberta.

INTRODUCTION

An examination of the relevant literature shows that no research has been carried out on the hydrological effects of clearcutting areas of the order of thousands of acres. Some research has been done on the hydrological effects of wildfire or insect infestation which have killed vegetation on areas of greater size. For example, in the White River Basin of Colorado, 487,000 acres, insects killed 144,600 acres of lodgepole pine and Engelmann spruce. Love (1955) examined the effect upon streamflow and found that the annual flow of the White River increased by 2.3 inches (or 22 percent) over the 5 years following insect attack. Davis (1959) stated that through changes induced in microclimate and vegetation, fire has major effects on the interception, evaporation, transpiration, storage, and movement of water in forest stands and soils. Destruction of forest cover on even relatively small areas of less than a thousand acres may, with unstable conditions and high intensity rainfall, permit serious flood damage. These statements could well apply to the present case if the words "clearcutting large blocks" were substituted for the word "fire".

Water and land-use are intimately related and nowhere is this more apparent than in forest-water interactions. Anderson (1970) and Jeffrey (1964a) have described the many ways in which trees modify the land phase of the hydrologic cycle during and following inputs of precipitation. If large areas of forest land are clearcut, the most noticeable change will be that of microclimate.

Of Alberta's 163.4 million acres of land, 105.7 million acres are covered with forest (Underhill 1962). Some of the key forested, water-producing areas of Alberta, such as the headwaters of the Athabasca and

Saskatchewan Rivers, are located in Banff and Jasper National Parks. The headwater regions can produce between 1000 and 3000 acre-feet of annual runoff per square mile. However, because it is very unlikely that these areas will be heavily logged, they will not be further discussed.

An area which is receiving increasing attention because of its potential for supplying pulpwood to proposed and existing pulp mills is approximately bounded on the east by a line running north-south through Whitecourt. An east-west line passing through Grande Prairie marks the approximate northern limit of the area, while the southern boundary is approximated by the Brazeau River. The western boundary of this area is formed by the British Columbia border and the eastern limit of Jasper National Park. It is presumed that the area described will be the one most likely to feel the impact of extensive logging operations. Annual runoff from this area ranges from less than 100 acre-feet to more than 1000 acre-feet per square mile, but for most of the area, it is between 100 and 400 acre-feet. Underhill's Figure 17 (1962) reproduced here as Figure 1 shows the annual runoff for the entire Province of Alberta.

Much of the research into forest-water interactions has been conducted in the United States and, to a lesser extent, in Europe. Underhill reviewed much of the older (prior to 1961) literature pertaining to the subject and included abstracts of 87 papers in his report (Underhill, 1962). From these and from more recent reports certain general conclusions can be drawn regarding the possible hydrological effects of clearcutting large blocks of timber, even though most of the results are based on treatment of, at the most, only a few hundred acres, with the clearcut areas being smaller still.

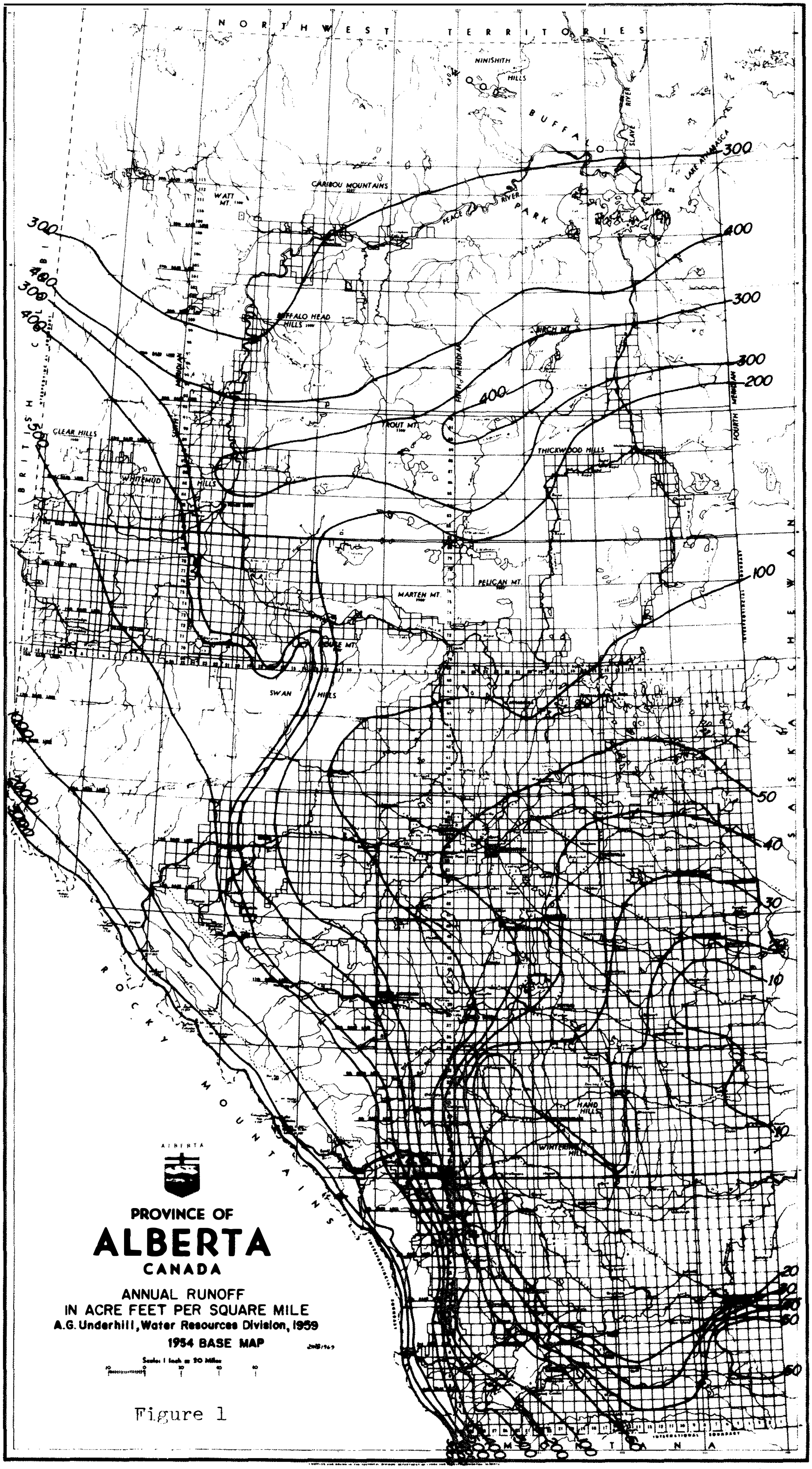
NORTHWEST TERRITORIES
BRITISH COLUMBIA
SASKATCHEWAN
MONTANA
ROCKY MOUNTAINS
CARIBOU MOUNTAINS
BUFFALO HEAD HILLS
CLEAR HILLS
WHITEMUD HILLS
TROUT MT.
THICKWOOD HILLS
PELICAN MT.
MARTEN MT.
SWAN HILLS
BIRCH MT.
HAND HILLS
LAKE ATHABASCA
PEACE RIVER
BUFFALO PARK
PROVINCE OF
ALBERTA
CANADA
ANNUAL RUNOFF
IN ACRE FEET PER SQUARE MILE
A.G. Underhill, Water Resources Division, 1959
1954 BASE MAP
300
400
300
200
100
50
40
30
20
10

Figure 1

Jeffrey's (1968) appraisal of watershed management problems in Interior British Columbia, serves as an excellent summary of hydrologic problems that can arise from forest harvesting, related operations, and other land-uses. The following sections describe how similar problems could arise in Alberta.

Water Yield, Streamflow Regime, and Flood Hazard

The most apparent effect of clearcutting is the elimination of interception of precipitation by the canopy and subsequent evaporation loss of the detained water from tree surfaces. Snow accumulation, in particular, will be affected by clearcutting. This is due to reduced interception and to aerodynamic properties imparted to an area through clearcutting. Wind patterns after cutting are such that differential snow drifting occurs which is most noticeable at the boundary of the clearcut area and the remaining forest.

Hibbert (1967) has reviewed the results of 39 studies of the effect of altering forest cover on water yield in different parts of the world. Most of the studies were conducted in the United States. Part of his Table 1 is reproduced here because it contains data pertaining to water yield studies conducted in western United States -- where conditions most nearly approach those of western Alberta. Hibbert concluded that the results of individual treatments vary widely. He found that forest reduction increases water yield and that reforestation decreases water yield. First-year response to complete forest reduction varies from 1.34 inches (or 22 percent of mean annual streamflow) to more than 17.7 inches (80 percent) of increased streamflow. A practical upper limit of yield increase appears to be about 0.18 inches (0.8

TABLE I. Location, Description, and Results of Water-yield Experiments, with References (After Hibbert, 1967).

Catchment	Area (acres)	Vegetation and soils	Mean annual precip. (inches)	Mean annual stream-flow (inches)	Description of treatment (percentage refers to portion of area treated unless otherwise stated)	Water yield increases by years following treatment 1st	2nd	3rd	4th	5th	References
						-------- (inches)				-----------	
H.J. Andrews, Oreg.											
1	237	Coniferous. Volcanic tuffs and breccias, clay loams, shallow to deep.	94	54	1962-3, 40% commercial clearcut.	small increase in low flow					Rothacher (1965)
					1963-4, 40% additional commercial clearcut.	small increase in low flow					
3	250		94	53	1959, 8% area cleared for road construction.	small increase in low flow					
					1962-3, 25% clearcut and burned.	small increase in low flow					
Sierra Ancha. Ariz. North Fork, Workman Creek	248	Ponderosa pine. Quartzite, clay loam up to 16 ft. deep.	32 (some snow)	3.39	1953, 1% cut (riparian vegetation only), sprouts controlled.	nonsignificant					Rich et al. (1961)
					1958, 32% cleared (moist site), grass seeded.	0.51 *15%	2.01 59%	0.59 17%	1.89 56%	1.18 35%	U.S. Forest Service (1964)
South Fork Workman Creek	318		32	3.42	1953-5, 30% basal area cut by selective log.	nonsignificant					
					1956, 6% basal area cut by thinning.	nonsignificant					
					1957, 9% basal area reduced by burning.	nonsignificant					
Fraser Colo. Fool Creek	714	Lodgepole pine, spruce-fir. Granite, sandy loam, less than 8 ft. deep.	30 (75% snow)	11.13	1954-7, 40% commercially clearcut in strips, regrowth.	3.39 30%	2.09 19%	3.11 28%	3.82 34%	2.09 19%	Goodell (1958) Martinelli (1964)
Wagon Wheel Gap, Colo.	200	84% forested (aspen and mixed conifers). Augite, quartzite, rocky clay loam.	21.1 (50% snow)	6.18	1919, 100% clearcut, some removal, slash burned, regrowth.	1.34 22%	1.85 30%	0.98 16%	0.87 14%	0.51 8%	Bates and Henry (1928) Reinhart et al. (1963)
Meeker, Colo. White River	486,787	Engelmann spruce.		10.4	1941-6, insects killed up to 80% of timber on 30% of area.	2.28 (average for 5 years) 22%					Love (1955)
Southwestern Washington Naselle River	35,199	Douglas-fir, western hemlock. Silty-clay loam and stony loam, 7 ft. deep.	130	105.9	1916 to 1954, 64% area logged at rate of 2% per year, regrowth.	no detectable change					Martin and Tinney (1962)

*Increases in water yield as percentage of mean annual streamflow.

percent) per year for each percent reduction in forest cover, but most treatments produce less than half this amount. There is some evidence that streamflow response is proportional to reduction in forest cover. More recently (Rothacher, 1970), data from a completely clearcut, 237-acre watershed in a high precipitation area of the Oregon Cascades showed an increase in annual water yield of 18 inches (32 percent)--a value exceeding the theoretical maximum yield of 17.7 inches cited by Hibbert (1967).

In this paper streamflow regime refers to the discharge-time relationship of a given stream or river. A plot of this relationship is referred to as a "hydrograph". Because it is important to provide increases in water yield both when and where it is required, studies on timing of flows have usually been carried out concomitantly with those on water yield. If the entire increase in water yield is released during a short time period in spring, flood and sedimentation hazard increases. By prolonging the time in which the increase in yield reaches the stream channel, it is possible to reduce these hazards and at the same time provide downstream water users with extra water supplies at a time when they are most needed -- in summer.

The vegetation in parts of western Alberta is similar to that of the spruce-fir region of the western United States. However, in Alberta this vegetation type occurs at lower elevations than it does in the United States. It includes lodgepole pine as well as spruce and fir. The combination of short growing season and relatively low year-round temperatures causes the spruce-fir complex to have a growth rate slower than that of any vegetation type which receives an adequate moisture supply (Colman, 1953). It follows, therefore, than any constructive vegetation change will be difficult and slow. Results obtained from studies in areas encompassing this vegetation type in western

States such as Colorado and Wyoming will probably have some applicability in certain parts of western Alberta.

Perhaps the best known experiment designed to determine the influence of timber harvesting on snow accumulation and the subsequent snowmelt on streamflow is the Fool Creek Study. The Fool Creek watershed is part of the Fraser Experimental Forest, Colorado. Here, annual precipitation, two-thirds of which falls as snow, varies from 15 to 30 inches with an average of 24 inches (Love, 1960). Forests in this area are composed of lodgepole pine, Engelmann spruce, and subalpine fir.

Prior to treatment, merchantable forest covered 550 acres of the 714-acre watershed, with 55 percent occurring in the lodgepole pine type and 45 percent in the spruce-fir type. Pre-treatment records of the discharge by Fool Creek and by a nearby stream (East St. Louis Creek) were obtained during the period 1943 to 1954. These data provided the basis for a regression equation by which the discharge of Fool Creek can be accurately predicted from the recorded discharge of East St. Louis Creek. Streamflow of Fool Creek averaged 11.11 inches before cutting (Goodell, 1958).

Fifty percent of the merchantable timber was cut in a pattern of alternate cut and uncut strips. Four widths of strips were used: 1, 2, 3, and 6 chains. Annual runoff has averaged 3.4 inches per year higher during the 13 years since cutting. Most of this increase has occurred in the spring -- in fact a slight decrease in late season runoff is noted but not proveable. There is no indication that the effect has decreased with time.

Experiments elsewhere have shown fairly rapid loss of treatment effects, with streamflow returning to near pre-treatment levels in 15 to 20 years. The apparent reasons for the longevity of the effect at Fool Creek are the slow growth of new vegetation and the strong influence that the leave strips of old-growth timber have on windflow and snow accumulation. Plot experiments show that these snow accumulation effects can last at least 30 years (U.S. Forest Service, 1969).

Another study (Wilm and Dunford, 1948) was conducted in mature lodgepole pine on the same Experimental Forest. Twenty 5-acre plots were arranged in four randomized blocks and 16 of them were cut over by selective cutting methods. Snow disappeared from all plots at approximately the same time. However, melting was more rapid on the cutover plots, as the larger amounts of snow which they contained melted in about the same time as the lesser amounts in the uncut areas. Water available for streamflow on uncut plots amounted to 10.34 inches, or about 42 percent of total annual precipitation (24.5 inches). In contrast, the heavily cut-over plots yielded 13.52 inches, an increase of 31 percent in the quantity available for streamflow.

In the Big Horn Mountains in Wyoming, clearcutting mature lodgepole pine in blocks of 5, 10, and 20 acres increased peak snow accumulation over that of uncut stands (Berndt, 1965). The peak snowpack water equivalent of the blocks averaged about 2.5 inches or 40 percent greater than that of the uncut forest. However, snow persisted in the uncut stands approximately 10 days longer than in the cutover areas.

Anderson (1963) in developing techniques for managing California's forests for water, defined clearcutting as cutting blocks of more than 20 acres or strips wider than four times the tree heights. Experimenting at the Central Sierra Snow Laboratory, he found that the long term average snow accumulation in the clearcut areas was 12 inches greater than accumulation in the uncut forest.

However, snowmelt was more rapid in the open areas. On June 9, when all snow had melted in the open areas, there was still 16 inches of snow water left in the forest. Anderson used these results to develop a special sequence of strip cutting called the wall-and-step method. It is designed to obtain both greater snow accumulation and to reduce snow melt rates. This results in more water being made available as streamflow and a greater quantity of this water being made available in summer instead of spring.

In general, regardless of the species involved, clearcutting coniferous forests or the creation of large openings in these forests result in a measurable increase in one or more of the following: snow accumulation, snowmelt rates, and water yield. This is true of black spruce in Northern Minnesota (Bay, 1958), red pine in northern Lower Michigan (Hansen, 1969), pure red fir, lodgepole pine, admixture of the two, and stands of mixed conifers in the Central Sierra Nevada, California (Anderson, 1967), mountain hemlock, noble and Shasta firs in the Oregon Cascades (Rothacher, 1965), and ponderosa pine in central Oregon (Berndt and Swank, 1970).

Snowmelt can also be affected by the presence of slash. Anderson and Gleason (1960) found 4.2 inches of water left in the snowpack on May 4, 1959 where slash had been piled and burned, compared with 0.5 inches of snowpack on slash-covered areas. This can be attributed to solar radiation penetrating the snow and being absorbed by the slash thus increasing the melting rate.

On the basis of the foregoing results, it is reasonable to assume that if large blocks of timber, whether it be spruce-fir or lodgepole pine, are cut in Alberta, an increase in snow accumulation and subsequent increase in water yield can be anticipated. Although it is difficult to predict the magnitude of this increased water yield, it is probable that most of the increase will occur during spring runoff when it is not needed. No satisfactory solution to this problem of earlier snowmelt has yet been found (Dunford, 1966).

No convincing evidence has been presented showing that large clearcuts per se will result in higher instantaneous peak flows from either snowmelt or rain. Rothacher and Glazebrook (1968) report that the influence of sustained yield harvest in the high rainfall west coast forests on either amount of precipitation or peak-flow can be considered insignificant.

There is a flood hazard associated with clearcutting large blocks in Alberta that should not be discounted. Most of the rivers in western United States flow southwards while those of Alberta drain eastwards or northwards. The implication of this is that in the United States downstream regions experience ice breakup before snowmelt in the upstream headwaters, and there is a relatively steady supply of water at the downstream end of the river as snowmelt proceeds from south to north. Conversely, in Alberta, snow in the headwaters regions is likely to melt before channels are free of ice in the downstream reaches further north. The northward and/or eastward-flowing rivers already show high flood potential. It is reasonable to assume that this situation will be aggravated if large areas of block clearcuts are created in headwater regions of streams in Alberta.

No data are available on the hydrological effects of any size clearcuts in Alberta, although a study is underway on Marmot Creek Basin to determine the effects of small blocks. Tri-Creeks basin will provide similar data for a larger clearcut area. The development of the Marmot Creek programme has been discussed elsewhere (Jeffrey, 1964b, 1965). No cutting has been carried out to date on this forested watershed which drains into the Kananaskis River system, but present plans provide for road construction during summer 1971 and for commencement of harvesting during summer 1973. The principal evaluation parameter for treatment is to be sediment and chemical water quality. The secondary objective is to evaluate water yield and/or regime change as a result of harvest. Road construction and logging will be controlled and an array of clearcut blocks 10 - 40 acres in size is contemplated. Hydrometeorological data have been compiled into five volumes and the most recent (Water Survey of Canada, 1969) contains an up-to-date bibliography of much of the work that has been done so far on Marmot Creek Basin. References on some other experimental watersheds in Alberta are also given.

The Tri-Creeks programme will give similar data for the lodgepole pine area within the Northwest Pulp and Power Company Lease. Present plans are for one watershed to be cut as now practiced -- 40 to 100 acre clearcut blocks with buffer strips adjacent to the streams, and as a test for future establishment -- continuous clearcutting of an entire watershed. As in Marmot, roads will be built and then sediment contribution evaluated prior to and separate from the actual harvest. No firm time-table for this operation exists to date.

Neither Marmot nor Tri-Creeks will yield conclusive data for management application. Both will tend to strengthen the statement that "clearcutting causes an increase in water yield".

Erosion, Sedimentation, and Mass Wasting

Erosion and deterioration of site quality could be important considerations, particularly where mountain or foothill watersheds are clearcut.

Vegetation has an ameliorating effect on erosion -- even on natural geological erosion. The mineral soil beneath a forest stand is usually covered with a litter-humus layer consisting of organic matter in various stages of decomposition. This material has the capacity to retain large amounts of water, it facilitates infiltration, and absorbs the impact of raindrops. It also acts as a good thermal insulator, particularly in conjunction with snow. This property is valuable because it can control the formation of concrete frost which reduces soil permeability and tends to cause or to increase surface runoff. Ideal conditions for soil erosion may exist during the spring melt period when frost melting at the surface causes the surface soil to be saturated above the remaining frozen impermeable layer. Should heavy spring rains fall on soils in this condition, sheet erosion will likely occur (Hale, 1950).

During two winters in six areas in the Northeast United States, ranging from central Maine to northern Pennsylvania, frost penetrated to an average depth of 5.0 inches in open lands and to an average of 2.5 inches in forest lands. Concrete frost, which is characterized by many very thin ice lenses, small crystals and an extremely dense structure, was observed over twice as often in open land as in forest lands, averaging 72 and 31 percent of observations respectively. Mean frost accumulation in inch-days in the forest was about one-sixth that in the open: 74 inch-days compared to 412 inch-days (Pierce et al, 1958).

When the organic material covering the soil is removed from large areas, splash and scour erosion processes damage the land in at least four important ways. They carve gullies (Figures 2 and 3), remove sheets of surface soil (Figure 4), remove organic matter and other soil nutrients even without significant net loss from the surface of the land, and they puddle

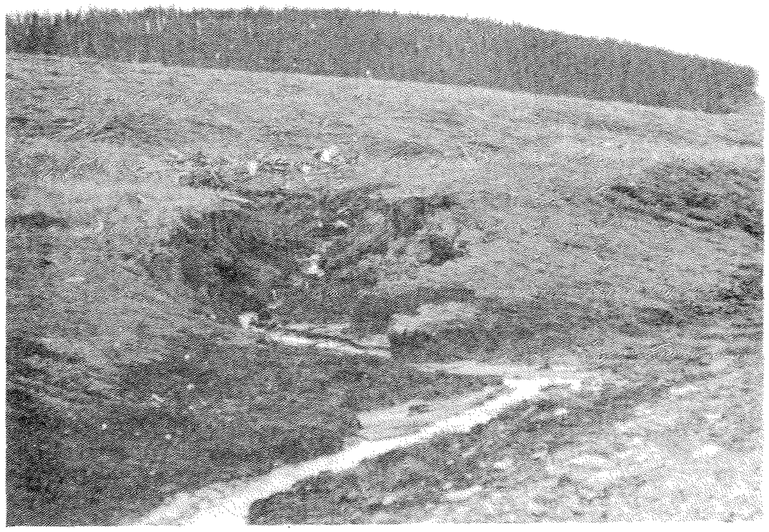

Figure 2 Gully erosion on logged area.

Figure 3. Gully erosion on improperly constructed logging road.

Figure 4. Sheet and rill erosion on a roadcut.

soils, making them droughty and reducing productivity (Ellison, 1950). Puddle erosion is caused by the breakdown of soil structure, washing of fine materials into soil pore spaces and compaction by raindrops. This process effectively seals surface cracks and pores and tends to "waterproof" the land. It may also seal deep sections of the profile, as well as the surface, on many soil types. The result is a less pervious soil, decreased intake of rainfall, curtailment of yields to groundwater, and increased overland flow. The mechanics of raindrop erosion have been described by Ellison (1944). If overland flow occurs soil particles will be carried into stream channels. This type of erosion is known as sheet erosion and is a function of intensity, quality and distribution of rainfall, soil type, relief, and vegetation cover (Leaf, 1966). Another form of erosion is channel erosion and the sediment derived from this is known as bed-material load. The quantity of bed-material load in a stream at any time depends on the hydraulic characteristics of the flow. A study by Leaf (1966) of annual sediment yields from one carefully logged and two undisturbed watersheds in the Fraser Experimental Forest, Colorado, showed that a major portion of the total sediment load was composed of bed-material load derived from streambank erosion and channel degradation. When discharge is increased as a result of wide-spread logging operations, then the chances of increased channel erosion and subsequent sedimentation in streams become greater.

The consequences of increased sediment in streams are well known. For example, Dendy (1968) reviewing the literature on reservoir sedimentation stated that there is a wide variation in sedimentation rates in smaller reservoirs. He concluded that, if present siltation rates continue, about 20 percent of the small reservoirs in the United States will be half filled with sediment and, in many instances, their utility seriously impaired in about 30 years.

Erosion material alters the environment of fish in a number of different ways and is generally recognized as harmful to fish population. One of the most important effects is the blanketing of spawning beds with heavy silt which causes mortality to the buried eggs and fry by retarding the free circulation of dissolved oxygen to them. Other changes include: (a) creation of unfavourable stream bottom conditions by the retention of organic material and other substances, (b) alteration of temperature change rates, and (c) screening out light. Silt has been found to limit the food supply (James, 1956). The same author cites an experiment where application of silt-laden water, for short periods, to gravel containing fertilized salmon eggs reduced the yield of fry from an average of 16.2 percent for the unsilted control to 1.16 percent for the silted gravel beds.

There is a great wealth of information available regarding the effects of logging and associated road construction on sediment yields in streams. It is generally agreed that improper road construction (Figure 5), is largely responsible for increased sediment yields (Figure 6). Anderson (1954), using regression analysis of sediment records for 29 streams in western Oregon found that if timber cutting were increased from the annual cut of 0.6 percent to 1.5 percent, sediment content would be expected to increase by 18 percent due to cutting alone. Likewise, if the total area occupied by roads were increased from 0.1 percent to 0.5 percent sediment content of the 29 streams would increase 260 percent. Anderson (1954) concluded that future logging and road development together would increase sediment discharge by 3 times. Dyrness (1967a), stated that the factors contributing most to increased soil erosion following logging are exposure of bare mineral soil and surface soil compaction from mechanical disturbance. In a logging experiment at Fernow

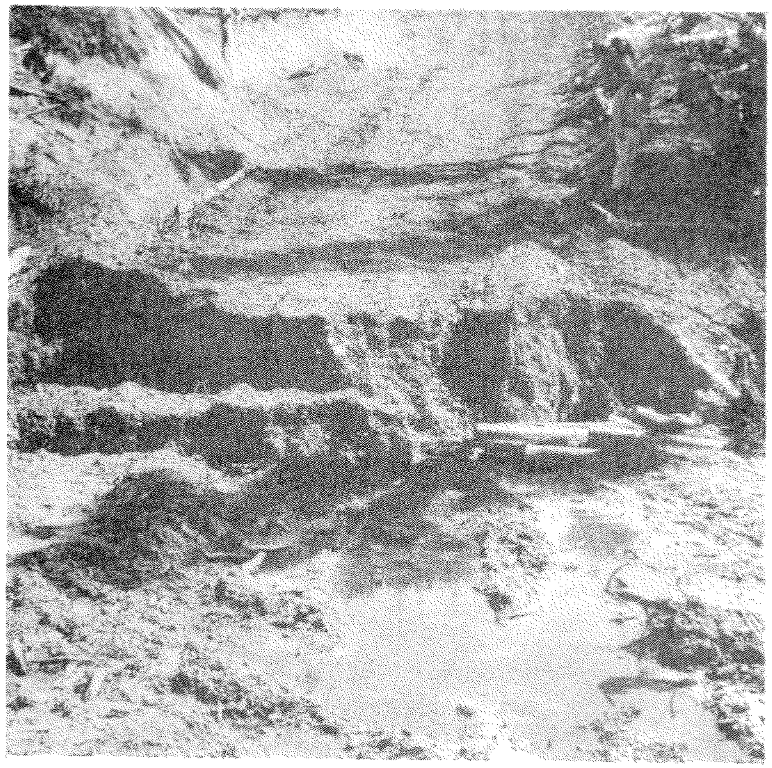

Figure 5. Washout resulting from improperly constructed road.

Figure 6. Sediment flowing downslope from a logging road.

Experimental Forest in West Virginia (Reinhart and Eschner, 1962), poorly located and constructed roads eroded to such an extent that maximum stream sediment went as high as 56,000 p.p.m. On the other hand, carefully planned and constructed skidroads contributed only negligible amounts. This study also showed that the impact on water quality was greatest during and immediately after logging and that recovery of vegetation substantially decreased erosion within a year. A case is also cited by Dyrness (1967a) where tractor logging in Washington resulted in a 93 percent decrease in skidroad soil permeability rate and 35 percent decrease in soil permeability rate of the remainder of the cutover area. In the H.J. Andrews Experimental Forest in the Cascade Range of Oregon (Fredriksen, 1965), runoff from the rainstorms which occurred when roads were nearing completion carried sediment of maximum concentration of 1780 p.p.m. or 250 times that found in an adjacent, undisturbed watershed. However, two months later the sediment concentrations were only slightly more than twice the corresponding concentration before construction.

Logging debris may obstruct flowing water and divert it against channel banks causing erosion and channel scouring. This waste material accumulates when logs are dragged across stream channels and when trees are felled into them (Dunford, 1962). The overall effect of logging and improper road construction on streams is a pronounced alteration of hydraulic characteristics; stream velocities are increased, pools are destroyed, and channel bottoms become alternately scoured or loaded with an unsorted mass of silt, debris, and rock. Such changes are particularly harmful in fishing streams.

Mass wasting is a process involving the bulk transfer of masses of rock debris down slopes under the direct influence of gravity and is usually aided by the presence of water, but the water is not in such an amount as to be considered a transporting medium (Thornbury, 1969). The definition includes landslides, debris avalanches, earthflows, mudflows, sheet floods and slope wash. From personal observation this process is highly evident in Alberta, and it must be considered in areas where any type of harvesting is contemplated in mountainous or hilly country, particularly if logging camps or other dwellings are to be located in such areas.

Although mass wasting is primarily geologically controlled, the importance of trees in reducing this mass wasting hazard should not be ruled out. Some of the ways in which the presence or absence of trees and road construction influence mass wasting processes have been listed by Bishop and Stevens (1964). Timber weight removal may result in reduced shear strength immediately under the tree root systems. Gradual deterioration of root systems following harvest will cause loss of continuity in the network of tree roots with subsequent loss of anchorage. The time lag in slide activity after logging supports this view. Patric and Swanston (1968) concluded that tree roots serve a dual hydrologic function: (a) they add greatly to soil stability on steep forest land, and (b) their channels facilitate saturated flow within the soil. Swanston (1969) claims that man's activity will aggravate naturally unstable slope conditions and that the practical problem faced by land managers is the decision to accept the consequences of logging very steep slopes, or to control the effects of these activities in order to minimize the occurrence of mass movements. To reduce hazard of mass wasting on unstable slopes, strips of timber could be maintained parallel to and including the unstable areas, with a wide enough lateral spread to reduce windthrow hazard. An analysis of 47 mass movements in the Cascade Range, Oregon (Dyrness, 1967b) showed that about 72 percent of them occurred in connection with roads and 17 percent in logged areas.

The fact that detrimental effects of logging and road construction need not materialize if careful planning and recommended harvesting and road construction practices are followed, is borne out in a study by Leaf (1970). Roads were constructed and timber harvested in a careful manner to minimize soil disturbance on a watershed in the Fraser Experimental Forest, Colorado. Annual sediment yield averaged 200 lb. per acre immediately following road construction in 1950-52, and logging in 1954-56. In the period 1958-66 sediment yield averaged only 43 lb. per acre, despite an estimated 25 percent increase in annual runoff caused by the harvest, compared with yields of 11 and 21 lb. per acre respectively on two undisturbed watersheds. Much information is available on practices designed to minimize erosion from roads and logging areas (Dunford, 1962; Geale, 1966; Kochenderfer, 1970; Packer, 1967; Packer and Christensen, 1964, and Pearce, undated).

Chemical and Thermal Water Quality

Studies in Oregon and Alaska indicate that removal of streamside vegetation during clearcut logging operations results in significant changes in water temperature. Brown and Krygier (1967) measured stream temperatures on a 174-acre clearcut watershed in Oregon's Coast Range and found that cutting regularly increased the daily change in temperature by 14°F. for the period August 1-15. Similar studies conducted on a 2-year-old clearcut area in Oregon's Cascade Range showed that the temperature of water passing through this area on a clear day in May increased 16°F. during midday hours. These results apply particularly to small stream systems with low summer flows and large surface area in relation to water volume. Such streams in this part of Oregon provide a major portion of spawning beds for salmon, steelhead, and trout. The authors point out that the biological activity in the stream is effected by water temperatures. For example biochemical activity, including enzyme activity will increase with increasing temperature.

Another study conducted in Oregon by Levno and Rothacher (1967) showed that when 55 percent of the study watershed was patch clearcut and timber was felled along all major stream channels, mean monthly water temperature increased by 7° to 12°F. from April through August. This was, in some measure, due to scouring by flood in 1964.

Working in selected areas of southeast Alaska, Meehan (1970) found that water temperature increases following clearcutting do not approach lethal limits for fish populations. He suggested that some rise in water temperature might increase the primary productivity of the stream, enhancing the feeding opportunities and growth of resident fish. Changes in seasonal and diurnal water temperatures also need to be considered. For example, warmer daytime water temperatures in winter could be beneficial to fish, but colder winter nighttime water temperatures could be harmful. The total effect must be determined.

Logging large areas of forest can result in accumulation of slash and small-wood debris in streams. The presence of excessive amounts of organic material of this kind leads to removal of the water's dissolved oxygen through bacterial decomposition of slash and other logging debris (Cope, 1966; Prince, 1967).

Groundwater and Drainage

In flat-lying areas where the water table is close to the surface there is a possibility that, when large areas are clearcut, the water table will rise with subsequent ponding of water. This may lead to problems of drainage and forest regeneration. Muskeg, which fits into the foregoing category, is common in Alberta and often supports large areas of black spruce -- a desirable pulping species. Bay (1967) cites several workers who have reported a rise in the water table when timber stands are thinned or completely removed. In a study carried out on drained peatland where the ground water level was close to the soil surface, in North Europe, Heikurainen (1967) found that clearcutting a birch stand caused the water level to rise as much as $15\frac{1}{2}$ inches. In Denmark, Holstener-Jorgensen (1967) found that the water table became considerably higher during the growing season after a beech stand growing on the soil with high ground water level had been clearcut. The deepest water table was raised by 79 inches. Another study conducted in the Coastal Plain of North Carolina (Trousdell and Hoover, 1955), showed that when a 200-foot strip was clearcut, the water table, which had been falling rapidly prior to cutting ceased to recede. Following rainfall, the water table rose 8.8 feet during one month, while the water table under a selection cut stand rose only 0.4 feet. This was a complete reversal of the situation existing before cutting. The authors concluded that heavy cutting on poorly drained soils could create soil moisture conditions unfavourable for seedling establishment. However, it might be possible to construct drainage ditches in order to overcome this problem (Stanek, 1968).

CONCLUSIONS

The foregoing review shows that clearcutting forested areas, that is, the creation of openings larger than 20 acres, or with any dimension greater than 4 times the height of the remaining timber, results in a measurable increase in one or more of the following: snow accumulation, snowmelt rates, and water yield. In some instances, water yield increases in excess of 50 percent of the mean annual streamflow have been recorded. The absolute maximum increase in water yield so far recorded amounts to over 18 inches -- in the Oregon Cascades. This represents a 32 percent increase in mean annual streamflow. A practical upper limit of yield increase appears to be about 0.18 inches per year for each percent reduction in forest cover, (or 0.8 percent of mean annual streamflow) but most treatments produce less than half this amount. For spruce-fir and lodgepole pine forests, the average annual increase in water yield following timber harvest is 26 percent.

Clearcutting accelerates soil and streambank erosion and increases stream sediment. Soil erosion results from the puddling of soil, through raindrop impact, which renders the soil less permeable and facilitates overland flow. Increases in streambank erosion and channel degradation can be caused by increased flows following clearcutting. It has been shown that improper road construction contributes far more sediment to streams than does logging alone. Sediment in streams has adverse effects on fish habitat and on downstream structures. Logging on steep slopes increases the hazard of mass-wasting processes such as landslides, debris avalanches, earthflows, mudflows, sheet floods and slope wash.

Of the many studies carried out on the effects of forest harvesting on water yield, most have shown that water yield will increase, but few have demonstrated how this increase can be provided to downstream users during times when flows are normally low. The work that has been done on improving timing of flows, particularly in snow zones, indicate that some degree of shading is required e.g. Anderson's wall-and-step method. Retention of the snowpack in this way is not compatible with clearcutting large blocks. In general, clearcutting leads to a prolonged peak in the annual hydrograph, with some forward shift in its temporal position.

There are other ways in which clearcutting affects the environment. Increased flows resulting from clearcutting can lead to increased flood hazard. Significant changes in water temperature follow removal of streamside vegetation, maximum temperatures becoming higher and the minimum temperatures lower. This affects biological activity and fish populations in streams. Bacterial decomposition of logging residues in streams depletes the water's dissolved oxygen. In some cases groundwater has been reported to rise following forest harvesting operations.

It can be concluded that the net increase in water yield and its delivery time depend on both the percent of watershed cut and the pattern of cut. Erosion and sedimentation are governed by road and trail construction activity rather than by the area cleared.

Some consideration must be given to water requirements both now and in the future. If water is needed in the summer, for example, we should try to encourage on-site retention i.e. plan clearcut boundaries near the tops of ridges to accumulate snow under the canopy and along the edges.

The effects of clearcutting lodgepole pine will last for 30 or more years. Therefore, consideration must be given to water requirements for the year 2000. Cuts should be planned now to meet those goals because the proportion of the timber leases affecting runoff will be large by then.

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FIRE HAZARD FROM LARGE BLOCK CLEARCUTTING IN ALBERTA

by

A.D. Kiil

ABSTRACT

In Alberta, from 5 to 25 tons of logging debris per acre less than 4 inches in diameter are left behind on the over 50,000 acres of forested land that are harvested annually. It is generally recognized that this fuel type represents a special fire control problem but there is much concern about the effectiveness of conventional methods to reduce the hazard to an acceptable level. A review of pertinent literature was carried out to provide a basis for comparing the fire hazard in clearcuts and uncut stands and to interpret the findings in terms of the effect of size of clearcut on fire behavior.

Fire hazard in large clearcut blocks is assessed in terms of risk (ignition probability), rate of spread and fire intensity (resistance to control). Fire expectancy is highest during active logging but decreases to a level comparable to that in uncut areas once logging is completed. Logging debris becomes highly flammable within a few weeks after felling and supports fast-spreading and relatively intense fires when fire spread in standing timber is unlikely or of low intensity. When crowning conditions prevail, fire behavior in boreal forest cover types such as pines and spruces is likely to be more erratic than that in slash. Beyond a minimum block size of about 25 acres, most of the slash fuels thereon are exposed to the full dessicating effects of the environment and capable of supporting rates of spread and intensities comparable to those on much larger areas.

The need for, and effectiveness of, special slash hazard reduction methods must be evaluated in terms of the values to be protected and the capability of the fire control agency to keep fire losses to an acceptable level. This would necessarily entail consideration of land values, fire control objectives, climate, and the overall pattern of fuels in the area or region.

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INTRODUCTION

Clearcutting changes the amount, distribution and condition of flammable fuels and exposes these fuels to the dessicating effects of the environment. In Alberta, the resultant logging slash amounts to more than 15 tons per acre and represents a near-continuous mass of fuel. A significant portion of the 50,000 acres logged annually is in the form of alternate clearcut-uncut strips but a few large clearcut blocks in excess of several hundred acres have resulted from felling of overmature timber or from harvesting of timber between adjacent clearcut strips. Extensive areas of clearcut-uncut strips represent a special fire control problem which needs to be examined in terms of risk and fire hazard. The purpose of this report is to review relevant literature on fire hazard in slash and to interpret the findings in terms of fire behavior and fire control operations.

Any assessment of fire hazard in logging slash must be based on risk (ignition probability), the fuel complex and the effect of meteorological factors on fuel flammability and fire behavior. While this review deals primarily with risk, rate of spread and fire behavior on clearcuts, it is important to point out that this by itself does not indicate whether the hazard is acceptable or unacceptable in terms of the policy and capability of the fire control agency. It may well be that indirect factors such as values to be protected, climate, accessibility, detection, initial attack and hazard in adjacent areas, rather than the fire hazard on a clearcut block *per se*, dictate the final decision on what is an acceptable level of fire hazard in clearcuts.

FUEL CHARACTERISTICS

Fuel and weather are the main components of fire hazard; clearcutting affects both. Large quantities of fuel are suddently placed near the ground where burning conditions are favourable (Fahnestock 1968, Figure 1). The quantity, size, and vertical and horizontal distribution of fuels varies considerably between regions and forest types (Fahnestock 1960; Chandler 1960; Kurucz 1969) and can be predicted from simple measurements of stem and crown parameters. For Alberta, slash and duff quantities for four major forest cover types are given below (Kiil 1967, 1968a).

Species	Slash diameter			Duff
	< ½"	½-2"	2-4"	
All weights in oven-dry tons/acre				
Lodgepole pine	8	3	7	25
White spruce	10	5	5	40
Black spruce	7	3	6	50+
Aspen	3	4	5	35

In addition to the logging debris less than 4 inches in diameter, varying amounts of larger material may be left on the ground. In mature lodgepole pine stands, this material is usually less than 10 tons per acre but it frequently exceeds 25 tons per acre in overmature spruce-fir stands. The amount of duff depends partly on the fire history of the previous stand, moisture status of the site, and the age of the stand.

Following felling, the logging residue becomes exposed to the full drying and wetting effects of the atmosphere and is susceptible to wide fluctuations in moisture content (Fahnestock 1960; Simard 1968; Kiil 1968b). The moisture content of freshly cut slash is generally between 60 and 150 per cent, depending on species, tree component, age, and time of felling (Van Wagner 1967; Kiil 1968b). For spruce and pine in Alberta, the moisture content of foliage increases from about 75 per cent in spring and fall to 105 per cent during the growing season. Moisture content of branchwood, the unmerchantable portion of the stem and dead branchwood averages 70, 120 and 15 per cent, respectively.

The initial drying of slash involves a change from the living to the dead state. In the Intermountain West, the moisture content of needles and twigs of untreated slash dropped to 11 per cent in six weeks and 8 per cent in two months (Fahnestock 1960). By contrast, needles and twigs on lopped branches dropped to 10 per cent in two weeks and to 6.5 per cent in 18 days. Similar trends were measured in Alberta but less severe drying conditions prolonged the time required for these fuels to reach a highly flammable level. The striking difference in the rate of moisture loss between lopped and untreated slash is attributed to the availability of water from the untreated unmerchantable bole which serves as a water reservoir. Having reached equilibrium moisture content levels, slash fuels can only gain moisture from rain, dew, or other forms of precipitation. Variation in temperature, relative humidity, solar radiation, wind and fuel size and condition produce lag effects so that fine fuels may be minutes and heavy fuels may be months or even years behind current weather conditions. (Schroeder and Buck 1970).

In clearcuts, the moisture content of duff can range from less than 10 per cent to over 400 per cent of ovendry weight. The ability of duff to lose and retain moisture depends on its depth, bulk density, the relative depths of the L, F and H layers, and the type and continuity of the overlying slash fuel bed. Maximum moisture content of pine duff seldom exceeds 300 per cent (Van Wagner 1968) whereas the corresponding value for deep spruce-fir duff can exceed 450 per cent (Kiil 1970). While some precipitation is intercepted by the slash, the proportion reaching the duff is probably substantially higher than in stands. Evaporational water losses from the duff surface in the clearcut exceed those from the stand (Jemison 1934) but total evapotranspiration from the stand may exceed that from the clearcut (Kiil 1970. The latter possibility is attributed to the presence of a large proportion of roots in the duff layer near the ground surface. Following extended periods of drought, the moisture content of duff in the stand may therefore be lower than that in clearcuts.

In addition to quantity, size, moisture content of slash fuels, the dropping of foliage, extent of fuel decay, increased fuel compaction, reduction in surface area-volume ratios of fuel particles and density of lesser vegetation affect fire hazard. Spruce needles drop to the ground during the first two months following felling whereas pine and fir foliage stays on twigs and branches for at least two summers (Kiil 1968b). As the needles drop off twigs and branches, the surface area exposed for active combustion is reduced by more than 50 per cent (Muraro 1966).

In Alberta, slash decay and compaction are relatively slow (Loman 1959). It takes five years for untreated slash to be packed down to 50 per cent of its original depth of about 1.0 to 1.5 feet. Slash treatment methods such as scarifying and lopping and scattering both increase compaction but scarification is particularly effective in crushing and packing down the fuel components. Bark disintegrates and peels from branches and logs during the first 5 years after felling and results in case-hardening. This reduces the penetration of moisture into the fuel and retards deterioration by decay.

FIRE HAZARD FROM CLEARCUTTING

Risk

In Alberta, about 60 per cent of all forest fires are man-caused, the remaining 40 per cent lightning-caused (Alberta Dep. of Lands and Forests 1968). For the seven-year period 1957-1963, the average size of lightning-caused fires was 230 acres compared to 107 acres for man-caused fires (Kiil 1965). A separate analysis of 985 fires indicated that logging slash was the main fuel type 3, 9 and 3 per cent of the time in spring, summer and fall, respectively (Kiil and Quintilio 1969).

No data are available on the relative proportion of lightning and man-caused fires in slash but dry snags are particularly susceptible to lightning fires (Kourtz 1968). Studies of nearly 12,000 fires in the northern Rocky Mountains have shown that nearly 50 per cent of the lightning fires start in dead snags, green tree tops, or in tree moss (Barrows 1951). While clear-cutting may not reduce the number of snags per unit area compared to uncut timber, the snags in clearcuts are likely to be drier and thus more susceptible to ignition. Evidence about man-caused slash fires is conflicting (Koch _et al_. 1927; Munger and Westveld 1931) but all sources conclude that the greatest risk is on current logging operations. In Oregon, this risk is from 5 to 59 times as great on the logging operation as on the cut-over land away from it. In the same area 0.6% of the area with untreated slash burned compared to 0.2% of the virgin forest.

On the basis of the above and related information, it appears that risk from lightning does not change appreciably with clearcutting. Fire expectancy from human causes is highest during active logging. In Alberta, the ratio of slash to all fires is highest in summer but the greatest number of slash fires occurs in the spring.

Rate of Fire Spread

Rate of spread of slash fires is influenced primarily by wind, relative humidity, air temperatures, fuel moisture, weight, size, vertical and horizontal continuity and species of slash (Fahnestock 1960; Fahnestock and Dieterich 1962; Rothermel and Anderson 1966; McArthur 1967; Canadian Forestry Service 1970). The rate of spread appears to be proportional to the 1.5 power to the square of the wind speed (Fons 1946). For Australian grasslands, McArthur (1960) showed that an increase in wind from 10 to 20 mph resulted in doubling in the rate of spread. While no references are available, it is possible that an upper limit of fire spread exists with an as yet undetermined maximum wind speed. Average wind speeds of up to 40 mph do not appear to limit fire spread in timber or slash.

Wind is instrumental in carrying fire brands 5 to 10 miles ahead of the fire front (McArthur 1967). These firebrands are carried by air currents in the convection column or by prevailing winds ahead of the fire front. Theory and experience suggest that fire-brands are carried further in front of wildfires in timber than in slash. Loose bark on dry snags appear to be chiefly responsible for spotting ahead of the main slash-fire front.

Rate of spread increases with decreasing fuel moisture (Fahnestock 1960) but it is not clear if this increase is linear (Curry and Fons 1938) or exponential (McArthur 1967). For laboratory fires, rate of spread decreases by 4 or 5 per cent for each one per cent rise in moisture content.

Critical burning conditions in slash occur when fine fuel moisture drops to less than 7 or 8 per cent. With the exception of the loose litter layer, slow-burning duff contributes very little to rate of fire spread in slash but it may contribute significantly to the development of convection columns.

Fahnestock (1960) found that an increase in fuel quantity from 10 to 20 tons per acre resulted in nearly double the original rate of fire spread. In addition to fuel quantity, surface area-volume ratios and compaction of different fuel components affect rate of spread. For example, fire spread through five-year-old spruce and pine slash is about one-third of the rate in fresh slash with needles on twigs and branches. Rate of spread can also be reduced by the application of partial slash-disposal methods such as scarifying, prescribed burning (Figure 2), lopping and scattering and packing down with a bulldozer.

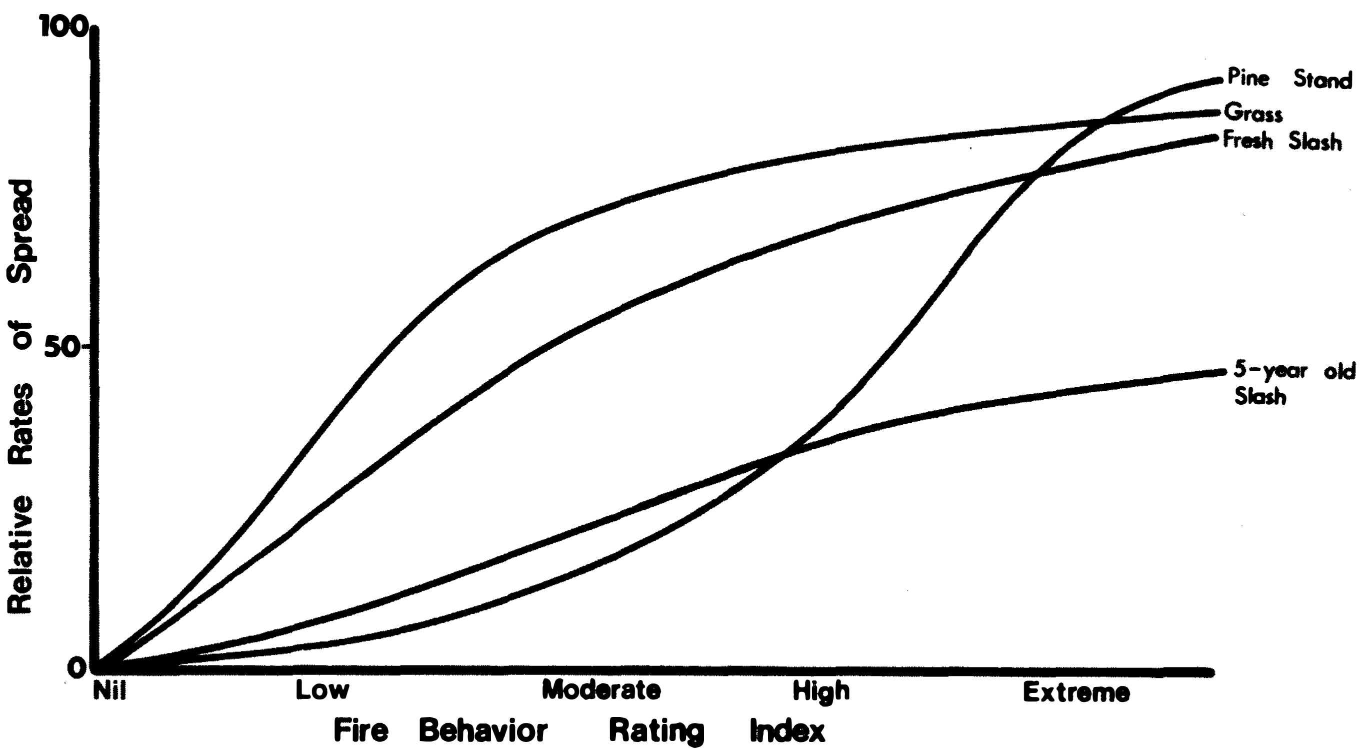
Rate of spread is also influenced to a lesser degree by fuel and air temperatures, amount and condition of lesser vegetation on the site, quantity, distribution and moisture content of heavy logs and duff, and particularly slope. In the northern Rocky Mountain forests, an increase in slope from 5 to 60 per cent resulted in a three-fold increase in rate of spread (Barrows 1951).

The exposure of logging slash to the full dessicating effects of the atmosphere creates favourable conditions for rapid rates of fire spread. There is no doubt that fire spread is faster in slash than through surface fuels in uncut timber when Fire Behavior Rating Indices (Canadian Forestry Service 1970) are low to moderately high. The reverse appears to be true, however, when extensive crowning occurs in coniferous stands such as lodgepole pine and black spruce. Maximum rates of spread in standing timber exceed 4 mph or 5.3 chains/min over several hours (Chandler, et al. 1963; McArthur 1967; Kiil and Grigel 1969) whereas corresponding values for slash are usually less

Figure 1. Typical fuelbed of spruce-fir slash in west-central Alberta.

Figure 2. Aerial view of a prescribed burn in spruce-fir slash.

than 2 mph or 2.7 chains/min. Such extreme rates of spread do not occur every year but they are nevertheless responsible for a large proportion of the total damage by wildfires over several years. The following illustration will serve to indicate relative rates of spread values in uncut timber and slash for a range of burning conditions. It is based on a synthesis of relevant information and believed to be indicative of gross trends and relationships.

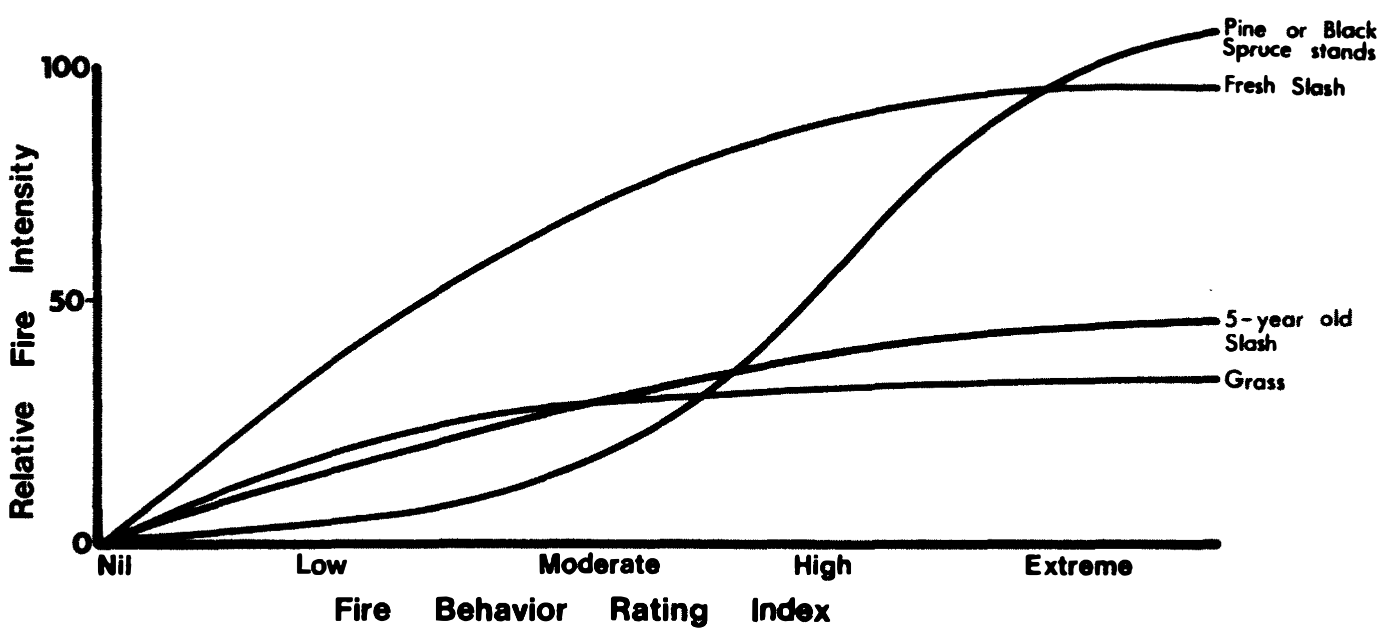


The effect of size of clearcut on rate of fire spread is important primarily during low to high burning conditions when the surrounding stand is likely to retard fire spread. When crowning conditions prevail, slash fires will spread into the surrounding stand and may take on an exaggerated horizontal and vertical structure. A clearcut over 25 acres in size appears to be sufficiently large to be affected by radiation, temperature, relative humidity and wind levels similar to those in larger openings or fields. The above reasoning is based in part on the view factor of differential area at centre of forest opening to sky above (Reifsnyder and Lull 1965).

Fire Intensity

During low to high Fire Behavior Rating Indices, fuel consumption in slash and standing timber appears to range from 0.5 to 1.0 and 0.2 to 0.5 pounds per square foot, respectively. (Van Wagner 1968; Quintilio 1970). When burning conditions are extreme, wildfires in standing timber may release energy at a rate in excess of 20,000 Btu./sec/ft of fire front. Corresponding maximum intensities for slash fires exceed 15,000 Btu./sec/ft of fire front.

Of the three components in the fire intensity formula, rate of spread has a range of 100-fold plus and contributes most to the variation in intensity. The weight of fuel consumed covers a range from about 0.05 to 2.0 pounds per square foot. The third item, heat of combustion, varies little and can be considered constant. A schematic example of fire intensities in selected Alberta fuel complexes over a full range of burning conditions is given below:



In the Intermountain West, Fahnestock (1960) found that fire intensity (as indicated by maximum heat radiation) increases three-fold with an increase in slash weight from 20.0 tons to 32.5 tons per acre. Furthermore, fire intensity declines more rapidly in the year after cutting than does the rate of spread. The reduction was found to be about 60 per cent for species that retain their needles and more than 80 per cent for the others.

Other Considerations

Rate of spread tells the fire manager where the fire will be at a specified time and thus helps him to determine the approach to containing the fire. Fire intensity, although it incorporates rate of spread, tells him what the fire is like and something of the difficulty of extinguishment and subsequent mop-up operations. Once a clearcut exceeds a minimum size of about 25 acres, most of the fuels thereon are exposed to the full dessicating effects of the atmosphere and capable of supporting rates of spread and intensities comparable to clearcuts in excess of thousands of acres. Thus the real advantage of small clearcuts is not in terms of reduced fire intensities but rather the presence of standing timber which may retard fire spread when burning conditions preclude crowning. Once the crowning threshold level is reached, the presence of alternating clearcut-uncut strips is likely to result in more erratic fire behavior than would occur in large slash blocks. Increased wind turbulance in such situations is likely to result in more erratic spotting ahead of the main fire front.

RECOMMENDATIONS

An assessment of fire hazard in clearcuts of different sizes entails:

A. 1. Comparison of fire behavior in clearcuts and uncut stands in a range of burning conditions.

2. Consideration of land management objectives.

3. Evaluation of policy and operational capability of the fire control agency. It is a fact that clearcut areas have heavy concentrations of flammable fuels which support relatively high-intensity fires when burning conditions in adjacent stands preclude continuous fire spread. During extreme burning conditions, however, available data suggest that fires in standing timber are more erratic and more difficult to control than those in clearcuts. Besides an assessment of the factors affecting fire behavior in a clearcut per se, the final decision on what is an acceptable level of slash-fire hazard must also be based on consideration of the capabilities of the fire control agency, land values, pattern of cut-uncut blocks and cost and effectiveness of alternative approaches. In view of these considerations, it is recommended that:

   a. Aspects of risk and fire behavior (rate of spread, fire intensity, spotting) which determine the difficulty of control in clearcuts and uncut stands are evaluated over a range of burning conditions.

   b. On the basis of this information and consideration of its fire control objectives and capability, the fire control agency should decide on an acceptable level of slash-fire hazard. This could be expressed in terms of fire behavior rating indices for major fuel types.

   c. Rate each slash area according to a quantitative rating scheme. The scheme could be based on all known fuel, weather and fire management considerations.

These considerations point to the need for a clear definition of fire control objectives in terms of the values to be protected and the ability of the fire control agency to keep fire losses to an acceptable level. The problem of slash hazard is therefore inextricably tied to the capabilities of the fire control agency to provide adequate protection. The cost and effectiveness of slash hazard reduction (prescribed burning, scarifying, systems of fuelbreaks) should be compared with benefits from extra protection and improvements in the capabilities of the fire control agency.

B. 1. In considering the effect of size of clearcut on fire hazard, the following points are relevant:

a. Most meteorological and fuel factors affecting fire behavior do not change appreciably once a clearcut exceeds about 25 acres. Wind velocity increases with size of clearcut whereas wind turbulence increases with decreasing alternate clearcut-uncut strips.

b. When burning conditions preclude crowning in adjacent stands, size of clearcut will limit fire size and reduce the suppression effort.

c. When crowning conditions prevail, fire behavior is likely to be more erratic in alternate clearcut-uncut strips than in large clearcuts.

d. In Alberta, fire incidence is slightly higher in slash than in uncut stands but a lower proportion of slash fires exceed 100 acres. The latter trend is attributed primarily to fast initial attack facilitated by generally easy access to slash areas and to the relatively small size of most clearcuts which may limit final fire size when burning conditions in adjacent uncut stands preclude fire spread.

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THE EFFECT OF CLEARCUTTING ON INFECTION AND DEVELOPMENT OF DISEASE IN REGENERATION IN ALBERTA

by

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ABSTRACT

Large block clearcutting eliminates all forest diseases associated with mature and overmature forests. Heartwood stains in lodgepole pine, stem decays in pine and white spruce, and dwarf mistletoe infections in lodgepole pine are of little economic importance in young stands up to rotation age. Fungal diseases causing damping off, root rots, stem and foliage rusts, and bark cankers, will more likely cause serious mortality in artificial than in natural regeneration of monocultures of pine or spruce following large block clearcutting. Recommendations for the control of fungal diseases in regeneration include regular surveys for disease symptoms, followed by sanitation practices, with special attention to artificial regeneration adjacent to residual stands of mature forests.

INTRODUCTION

Little information is available concerning disease development in large artificially regenerated lodgepole pine or white spruce forests in western Canada. Experience in the southeastern United States, Europe and Asia indicates that diseases which are endemic and cause only minor losses in immature naturally regenerated forests, may cause serious losses in immature artificially regenerated forests. It is therefore indicated that a distinction must be made in large block clear cuts between artificially regenerated monocultures of lodgepole pine and white spruce, and monocultures which regenerated naturally after large block clear cutting. To date, information in Alberta concerning forest diseases in regeneration and in immature pine and spruce has been obtained exclusively from unmanaged forests. Attempts to extrapolate existing information to conditions that will prevail in artificially regenerated forests is therefore speculative, but in general the severity of losses due to epidemics may be expected to equal or exceed those observed in unmanaged forests.

It is assumed that in large block clearcutting all standing trees are removed, including those which are unmerchantable. Diseases associated with mature and overmature forests such as heartwood stains in pine and decays in pine and spruce are therefore not included in this review. Similarly, dwarf mistletoe on lodgepole pine will not be discussed, since a complete clear cut removes all sources of mistletoe infection. Seedling mortality due to drought, frost heaving or other adverse site conditions created by large block clear cutting are discussed elsewhere in this report by Endean et al.

Several fungal diseases of seedlings and saplings which are present at endemic levels in unmanaged forests in Alberta, are known to be severe in localized areas of natural regeneration (1). Comandra blister rust is an example

Stem rusts and foliage rusts

The invasion of indian paint brush (*Castilleja* spp.) and lousewort (*Pedicularis* spp.) into clear cut areas seeded or planted with lodgepole pine, increases the chances for development of stalactiforme stem rust caused by *Cronartium coleosporioides*. The presence of these two herbaceous alternate hosts assures a rapid spread and intensification of stalactiforme stem rust. Disease symptoms are elongate diamond-shaped stem cankers. Rodents frequently remove the infected bark and underlying cambium. Vigorous, fast growing lodgepole pine seedlings 2 to 4 years old are particularly susceptible to infection (Hiratsuka, pr. com.). In localized areas, up to 80% of natural regeneration has been observed to be infected (4, 17).

The invasion of bastard toadflax (*Comandra* spp. and *Geocaulon* spp.) provides a potential source of inoculum of comandra blister rust, (*Cronartium comandrae*) which causes stem rust on lodgepole pine. In Alberta, in localized areas, 23% of natural regeneration of lodgepole pine has been found infected, 44% of which had been killed by comandra blister rust (15). In plantations, the published figures for infection and mortality by this disease on other pine species are considerably higher (7, 16).

Western gall rust of lodgepole pine is caused by *Endocronartium harknessii*. This rust disease does not require an alternate host but infects from pine to pine. The development of single or multiple galls on the stems of young trees make them susceptible to windbreak in exposed areas. Growth reduction is frequently pronounced.

The invasion of Labrador tea (*Ledum groenlandicum*) into clear cut areas seeded or planted with white spruce may result in the development of *Chrysomyxa ledi* or *Chrysomyxa ledicola* on the foliage of white spruce seedlings.

of a fungal disease that may be beneficial as a natural thinning agent in overstocked young pine stands (14) but can cause very high mortality in pine plantations (16). Specific examples of fungal diseases which may cause severe mortality in artificial regeneration in the Upper (B19c) and Lower (B19a) Foothills areas of Alberta are the following:

The invasion of fire weed (*Epilobium angustifolium*) may result in the development of *Pucciniastrum epilobii* on the foliage of *Abies lasiocarpa* seedlings.

Stem cankers of immature trees

Atropellis canker on lodgepole pine causes serious utilization problems. Heavy resin flow results in inadequate debarking, and wood discoloration may add to bleaching costs in the pulp industry. Research on the biology of Atropellis canker has been carried out almost exclusively in Alberta, by Hopkins (8, 9, 10, 11, 12, 13.). Atropellis canker incidence of over 70% has been reported in areas as large as 125 square miles in the Upper Foothills area of Alberta (6). Young regeneration appears to be highly resistant to this disease. A decrease in resistance usually occurs soon after the trees become 15 years old (13), although a few resistant older trees have been observed in highly infected areas (10). Infection sources will be eliminated by large block clear cutting, provided all trees, including unmerchantable trees are felled. It is recommended that sources of infection within the residual forests marginal to clear cut blocks be eliminated by sanitation cuttings.

Damping off diseases in seedlings

Damping off diseases are caused by a number of fungi that live saprophytically in the upper layers of the soil. These fungi are found in two major groups: Phycomycetes and Fungi Imperfecti. No economically acceptable, practical control methods are known which will eliminate damping off diseases in forest conditions. However, chemical treatments combined with careful manipulation of the soil, seem to successfully control damping off diseases in Prairie nurseries and greenhouses (18-26). Damping off fungi may continue their activities as root rots in 2- to 3-year old seedlings. In large block clear cuts, the variety of exposures, sites, soil types and moisture levels will favour a variety of species of damping off fungi. In areas of severe seedling mortality due to damping off, it may be economical to plant 4- to 5-year old seedlings.

Root rots of immature trees

The shoestring root rot (*Armillaria mellea*) can cause severe mortality of lodgepole pine regeneration in Alberta (2, 3, 5). This fungus is widespread at endemic levels, but may reach epidemic levels in extensive areas. Areas of high incidence of shoestring root rot coincide with the presence of decaying aspen stumps (2). Mortality of *Armillaria* infected pines seems to be most severe in suppressed trees which had also been subjected to heavy browsing. It appears that *Armillaria* root rot invades suppressed non-vigorous young pines in overstocked regeneration (3) and may therefore be considered to function as a natural thinning agent. However, seeding or planting of pine in clear cut areas should be avoided in aspen sites.

Recommendations

1. Within clear cut blocks, cut all merchantable residuals to eliminate potential carriers of infection sources.
2. Remove logging residues by burning, to eliminate the non-living substrate required for the development of fruiting bodies of many fungal diseases.
3. Train regeneration survey crews to recognize and appraise forest disease conditions, and organize annual disease surveys in all large clear cut areas.
4. Budget for sanitation practices in immature second growth forests, and in residual stands that are marginal to clear cut areas.

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INSECT PROBLEMS ASSOCIATED WITH LARGE BLOCK CLEARCUTTINGS IN ALBERTA

by

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SUMMARY

This review interprets and summarizes the available literature on potentially important insect problems associated with large clearcut areas (i.e., areas in excess of 50 acres) in Alberta, and makes recommendations for silvicultural control. Three broad forest habitat types in clearcuts are considered, namely pine, spruce and spruce-fir. The insects considered include those which attack seedlings, saplings and immature forests of pine, spruce and fir following artificial reforestation. These are terminal weevils, spruce bud midge, a root-collar weevil and spruce budworm. Large clearcuts in pure pine are recommended for control of the root-collar weevil but for the other pest species, large clearcuts provide no apparent advantages over small clearcuts. Forest practices which do not favor monocultures of spruce or pine on clearcut sites should be encouraged where possible to minimize insect losses.

INTRODUCTION

The practice of cutting timber in large block clearcuttings has an immediate devastating effect upon insect populations since the food source is eliminated and the habitat destroyed or altered. In Alberta, such stands are generally mature to overmature, and may represent various stages in forest succession, depending upon the species, site and general location.

For example, the pioneer species, lodgepole pine, predominates throughout the Lower and Upper Foothill Sections while white spruce and trembling aspen types are characteristic of the Mixedwood Section and late-successional stands of pine-spruce, spruce-fir and fir-spruce are commonly represented in the Subalpine Forest Region. The insect problems in these mature stands may be quite different from those in regeneration following clearcutting, and therefore the potential impact of insects on tree mortality and growth losses in regeneration must be interpreted in the light of a "clearcut environment" in addition to tree species, stand structure and geographical location.

A problem arising in clearcut blocks with post-cutting treatments is that a monoculture of pine or spruce regeneration is usually encouraged in an even-aged condition, either by natural or artificial means. Such stands provide an optimum food source and breeding conditions for several potential insect pests. The insects considered most important as pests in regeneration in Alberta are discussed below.

1. Two species of terminal weevils (Pissodes spp.) are common and attack the axial stems of trees, causing reduced height growth, permanent crooking of stems and in severe cases, "stag-headed" crowns.

(a) Lodgepole terminal weevil (Pissodes terminalis Hopping). This weevil attacks lodgepole and jack pines and is most common throughout central and western Alberta (1,17,19). Attacks are most commonly confined to the leaders of vigorous pine reproduction; incidence of attacks on true laterals is rare (9,17). Maximum damage occurs on open-grown trees 4 to 25 feet high. Damage is confined to the current year's elongating leader and there is a good chance of a single lateral branch assuming leadership after damage. Repeated attacks can occur, however, thus reducing the odds for recovery.

No accurate estimates of height losses from weevil damage were found in the literature. The incidence of attack has generally been highest in stands of uniform age and height class, and in stands of several acres in extent. Extensive acreages of reproduction, such as on burned or clearcut sites would thus tend to promote a build up of weevil populations.

As examples of damage which can occur, two plot areas of jack pine in Saskatchewan each had 23% incidence of infested leaders, and damage appeared to be greater along stand peripheries than within (9). In the Kamloops and Prince George Forest Districts, 40% (on about 320 acres) and 50% (on about 60 acres) top kill respectively, resulted from infestations in 1967 (1, 1968).

(b) White pine weevil (*Pissodes strobi* Peck). (Now considered synonymous with Engelmann spruce weevil and Sitka spruce weevil (16)). In Alberta this weevil attacks Engelmann, white and black spruces and occurs throughout the spruce forested areas. Its attacks are confined to the preceding year's leader of spruce regeneration, mostly 3 to 30 ft. tall (18, 23). As a result, height loss and distorted stems are more severe than in the case of *P. terminalis*. Trees may be attacked repeatedly as new leaders take over. Open growing trees are preferred and damage in shaded stands is negligible (10,11,14,15,20).

Few stands within the province have thus far been reported with damage sufficiently severe as to be rendered non-commercial (1,18). However, the hazards of this insect appear to be potentially greater than *P. terminalis*. For example, planting of Sitka spruce in Washington, Oregon and coastal B.C. has been curtailed in some cases and seriously questioned in others (14,15).

One weeviled Sitka spruce plantation established in 1931-32 in coastal B.C. averaged 18 ft. in height compared with over 50 ft. for unattacked trees. Elsewhere in B.C., attack intensity has risen in all districts during the past four years; i.e., the percentage of sampled stems attacked in 1969 ranged from 6.0 in the Kamloops Forest District to 33.5 in the Prince George District. The percentage of locations examined in which weevils were found varied from 51 in the Prince George District to 100 in the Kamloops District (1, 1969).

As in the case of *P. terminalis*, the degree of uniformity in tree age and height, the size of stands and the degree of shading are important stand characteristics to be considered in silvicultural control (10,11,15,20,23).

2. Spruce bud midge (*Rhabdophaga swainei* Felt)

This insect is a small fly which occurs generally throughout the province, especially in central and west-central Alberta (1, 1967). Its hosts are white, black and Engelmann spruces. It attacks and kills terminal buds of main branches and stems, particularly on open-ground trees up to 15 ft. or more in height (8). The midge may also be common on regeneration with an overstory (7).

On 1 to 6 ft. high trees sampled near Lesser Slave Lake the incidence of leader bud mortality was 15.7% on black spruce and 38.3% on white spruce. A study of attacks on leader terminal buds on white spruce regeneration suggested that height growth was reduced about 25% during the first year after attack, and that normal growth was resumed in the second year after attack when a lateral branch assumed dominance (7). Leader buds may be attacked in successive years, resulting in distorted stems as well as height losses. Information available suggests that even-aged stands of extensive areas are likely to enhance population build-up of the midge.

3. A root-collar weevil (*Hylobius warreni* Wood)

This large weevil occurs generally throughout the forested areas of Alberta, except the southwestern portion south of Calgary. Highest populations exist in the lodgepole pine stands in the Lower and Upper Foothills Sections between Grande Prairie and Calgary. Its hosts also include jack pine and white spruce (4,5,22).

Larvae of the root weevil feed in the root-collar zone of trees 6 years old to mature, causing open wounds and resinosis (4,21). Trees may be killed by girdling, suffer growth losses from repeated attacks and degrees of partial girdling, or the wounds may serve as entry points for root and stem diseases. Tree mortality from girdling is most common in stands less than 30 years old. Mortality may reach 10% in naturally regenerated stands, but in most cases it is less than 5%. Its damage impact has not been adequately assessed in artificially regenerated stands in Alberta, but pine plantations (exotic and native species) have tended to be attacked more heavily (up to 63% tree mortality) than natural regeneration in eastern Canada (4).

Within lodgepole pine stands the order of attack preference from most to least preferred, is from dominant, co-dominant, intermediate to suppressed trees. Highest populations occur on high quality pine sites in the Lower Foothills and habitat conditions tend to become less favorable for the weevil with increasing elevation (4,5,6).

Clearcutting lodgepole pine reduces larval populations by an estimated 67% but the remaining larvae can complete their development on the cut stumps 1 and 2 years after tree removal (4). Adults are long-lived (up to 5 years), flightless and disperse by crawling. Therefore, large clearcut blocks appear to be beneficial for control, providing that all advanced pine and spruce regeneration is removed at the time of cutting to eliminate the "reservoir" populations. Control efforts should be aimed at reducing build-up and spread of the weevil in newly established regeneration. Clearcutting in large blocks, followed by complete scarification treatment is likely to provide adequate control of the weevil.

4. Spruce budworm (Choristoneura fumiferana (Clemens))

The spruce budworm is considered the most destructive defoliator in North America, and in Alberta outbreaks have occurred mainly in the northern half of the province where white spruce is the primary host (1, 12, 13). Tree mortality and extensive top-killing are apparent in many of the mature and over-mature spruce stands along major drainages, such as the Wabasca, Chinchaga and Peace Rivers. While the larvae of this insect feed on trees in all age classes the behavior and survival of populations is probably least understood in regeneration. Regeneration and saplings growing under a mature forest canopy are usually severely deformed or killed, mostly by larvae which disperse from the canopy overhead.

In the Maritimes it was generally agreed that an accumulation of mature balsam fir was necessary for a spruce budworm outbreak, and cutting practices were recommended accordingly (12). In Minnesota, stand age, site index, staminate flowering and basal area were not significantly related to defoliation, top killing and tree mortality (3). Rather, balsam fir mortality was more reliably predicted by three stand characteristics: (a) percentage basal area in spruce, (b) percentage basal area in non-host species and (c) total balsam fir basal area. It was shown in a pilot study in spruce-fir stands in Minnesota that, as cutting intensity increased, defoliation by the budworm decreased; commercial clearcutting reduced defoliation most (2).

This evidence suggests that clearcutting the mature spruce stands infested by the budworm in northern Alberta may offer the best means of silvicultural control. However, the insect problems which may develop in the spruce regeneration following cutting remain unknown.

5. In addition to the above major potential pests the following insects are briefly mentioned since each has been recorded in damaging numbers from time to time and generally in localized areas. There is insufficient information at present to predict their behavior in extensive areas of regeneration of a uniform age class. They are listed below approximately by order of importance as judged by frequency of occurrence and damage potential (1).

Yellow-headed spruce sawfly (*Pikonema alaskensis*) - attacks spruce throughout spruce-growing areas.

Black-headed budworm (*Acleris variana*) - attacks spruce and is common throughout northern and western Alberta.

Aphids (*Adelges cooleyi* and *Pineus pinifoliae*) - attack spruce and pine and are common in central and western Alberta.

Spruce spider mite (*Oligonychus ununguis*) - has occurred in large numbers on spruce plantings in central Alberta.

Pine needle scale (*Phenacapsis pinifoliae*) - has caused moderate to severe damage in regeneration pine in southwestern Alberta.

Pitch nodule makers (*Petrova* spp.) - occasionally cause pine branch and tree top mortality in western Alberta.

Grass hoppers - (*Acrididae*) - have been reported in central and western Alberta destroying newly planted white spruce and lodgepole pine seedlings.

RECOMMENDATIONS

1. Train regeneration survey crews to recognize and appraise forest insect conditions and conduct surveys periodically in existing clearcut areas supporting pure pine or spruce.

2. In pine habitats, large clearcut areas are recommended for partial control of H. warreni, but for control of P. terminalis, large clearcuts offer no advantage over small clearcuts. An intermixture of other tree species with the pine regeneration, such as aspen, would reduce losses by both insect species.

3. In H. warreni - infested stands which are to be clearcut, all advanced pine and spruce regeneration and unmerchantable residuals should be removed to eliminate sources of reinfestation. Sanitation practices are encouraged.

4. In spruce budworm damaged forests in northern Alberta clearcutting appears to offer the best means of silvicultural control but the size of cut areas should be kept small to minimize subsequent insect damage in the regeneration. In spruce habitats outside the range of the budworm the shelterwood system provides the best opportunity for silvicultural control of Pissodes strobi and Rhabdophaga swainei. Alternatively, a cover crop of aspen to provide partial shade for the spruce regeneration would also reduce the chance of attacks by P. strobi and R. swainei.

5. Some existing large clearcut areas of pine and spruce should be prepared for long-term (i.e. 15-30 yrs.) appraisals of insect effects in relation to stocking, species composition, stand age and structure.

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