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C.E. Ahlgren

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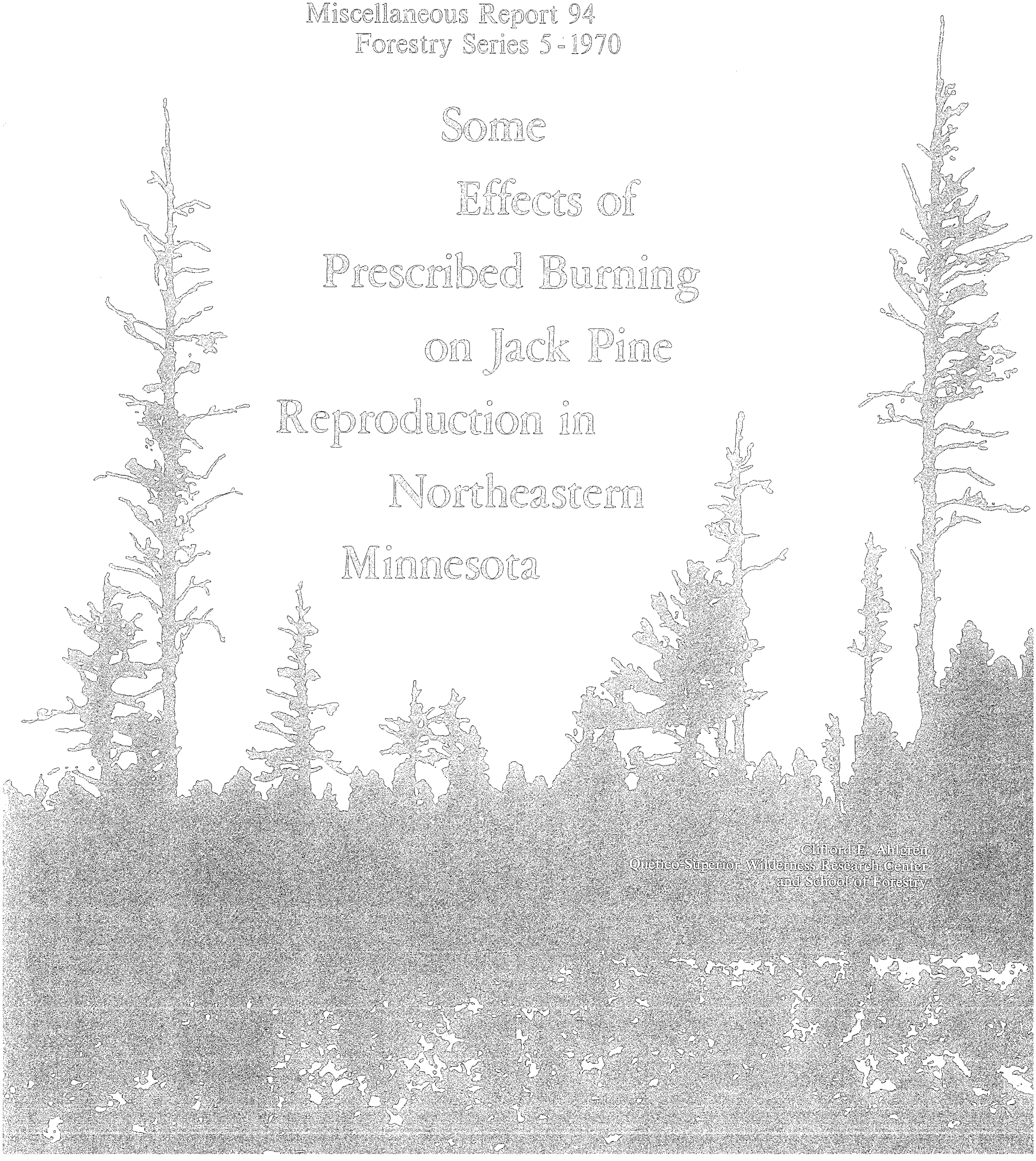

Clifford E. Ahlgren
Quetico-Superior Wilderness Research Center
and School of Forestry

The author is Director, Quetico-Superior Wilderness Research Center, Ely, Minnesota and Research Associate, School of Forestry, University of Minnesota.

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Some Effects of Prescribed Burning on Jack Pine Reproduction in Northeastern Minnesota

Prescribed burning has been used for a number of years in the management of jack pine (*Pinus Banksiana* Lamb.) lands in the United States and Canada. It often is used to reduce fire hazard by eliminating slash. Prescribed burning can be adapted to seedbed or planting site preparation by reducing the humus layer and temporarily reducing competitive vegetation. Under proper conditions, burning with seed trees can be used to fulfill these goals and reforest an area as well. However, the literature on prescribed burning research reports many inconsistencies in results and conclusions.

Reported amounts of seed used in direct seeding of burned areas vary from ¼ to over 3 pounds per acre. Eyre and LeBarron (22) reported seeding a 300-acre tract with 2.5 pounds of seed per acre. Over 15,000 seedlings per acre developed, requiring heavy thinning at 5 years. Roe (34) reported seeding of burned areas with ¼ to 3.1 pounds of seed per acre with varying results. In one case where 3 pounds of seed per acre were used, 9,000-13,000 seedlings per acre developed, while another area seeded with 3.1 pounds per acre resulted in 1,750 seedlings per acre. In Ontario, Cayford (16) reported poor stocking using both spring and fall seeding with 12 ounces of seed per acre. Seeding on snow was judged a failure. Other poor results were attributed to poor destruction of duff and insufficient seed. Because of past results in northeastern Minnesota, jack pine seeding of prescribe-burned lands has been discouraged until recently. Results of recent seedings of prescribed burns vary from heavy overstocking to inadequate stocking where subsequent planting was required (11, 28).

Seed tree burning results have been reported less frequently. As few as 10 trees per acre have been recommended most often (16, 18, 45). Twelve minimum or 20-30 optimum (9), 60 (27), and 75 (43) also have been recommended. Resultant reproduction frequently was not given, or poor results were achieved.

Graber (24) reported that birds caused only minor seed losses on burned hardwood scrub in Maine and that the fungicide arasan also was an effective bird repellent. Significant destruction of seed in seed trees by birds following fire has been reported in Minnesota by Eyre and LeBarron (22), who indicated that although there is less danger of seed consumption by rodents on fresh burns, rodents can consume seed on burned areas within 2 hours following seeding. Heavy seed loss to rodents following burning was reported in Maine (24), where the use of endrin did not significantly reduce the loss. Fire destruction of seed eating rodents has been reported (34, 43).

Good seedbed preparation requires that burning be done during periods of high fire danger and drought index (1, 10, 19, 41). These conditions can exist in spring, summer, or autumn. Burning is done after midday, when winds tend to be more stable. A combination of high fire danger and a drought index of 10 will give good humus reduction (1, 19, 40, 46). Sando (35) reported that in Minnesota between 25-40 good burning days may be expected per year, but special requirements of a particular area may reduce this number. Cooper (17) also emphasized that very few good burning days occur each year and that they must be utilized for good results.

Humus reduction is essential for the preparation of a good seedbed. Williams (46) reported that using headfires and burning with a high fire hazard and a drought index of 3 resulted in inadequate reduction of the humus layer. Adams (1), using strip headfires, achieved good humus reduction when burning with a drought index under 10 and a fire hazard index of not less than 8. Because of slow rate of spread and longer duration of high temperatures, backfires have been recommended for good humus reduction and slash consumption (17, 31).

Soil surface temperatures during prescribed burning on jack pine lands have not been reported extensively. Neal, Wright, and Bollen (33), working in Douglas-fir slash in Oregon, reported temperatures up to 193° F. at 3 inches, up to 633° F. at 1.2 inches, and 1,000° F. and over at soil surface. Duration of these temperatures was not given. Martin and Davis (31) recorded temperatures between 400° F. and 500° F. near the ground during jack pine slash headfires in Michigan. Since the potentiometers recorded at 9-minute intervals, peaks may not have been recorded.

Most prescribed burning studies are reported at the end of one or two postfire growing seasons. Consequently, information on the ultimate fate of the jack pine seedlings and the effect of competitive vegetation is lacking. However, Buckman (14, 15) reported that light fires stimulated growth of hazel (*Corylus cornuta* Marsh.), which is a serious competitor, while intense or repeated fires reduced it. Fire stimulation of vegetative sprouting of aspen (*Populus tremuloides* Michx.) is well known (36).

Inconsistencies related to type of fire technique advised, amount of seed or seed trees, types of damage, and degree of success frequently appear in the literature. If prescribed burning is to be used economically and efficiently, the reasons for these inconsistencies must be understood. As an outgrowth of 20 years of studying the basic ecological effects of forest fire (2, 3, 4, 5, 6, 7, 8) in northeastern Minnesota, the Quetico-Superior Wilderness Research Center, in cooperation with the U.S. Forest Service, conducted several prescribed burns and followed vegetational development for up to 9 years. Since consistent jack pine reproduction results were achieved repeatedly in these studies and followed to the development of well established saplings, an examination of methods used on these tracts will be useful.

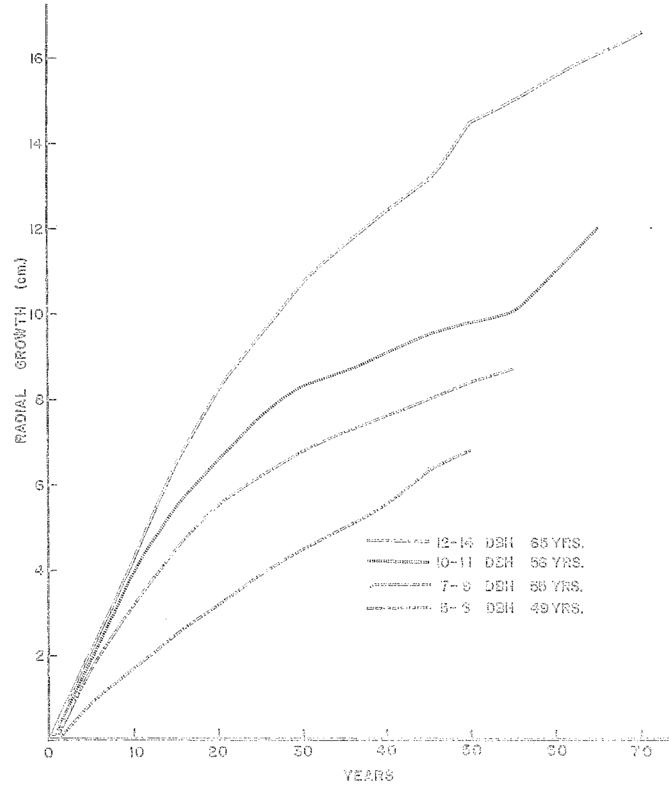

Figure 1. Radial growth in 5-year increments of jack pine of different diameters at breast height (in inches) in mature stand prior to cutting and burning, Bearskin Lake tract.

Methods

Areas Studied

The 10-12-acre study tracts were located on relatively flat land in the Superior National Forest. Soils were loamy sand to a depth of over 4 feet, which was the extent of the pits examined, merging with sand in the lower layers. The organic mantle was 2-3 inches deep. Although the majority of the area had good drainage, the upper loamy sands were moist with a tendency to ball when handled. The area burned over 70 years previously and supported a mature jack pine stand of 30 cords per acre primarily associated with aspen. As would be expected in a mature stand, the oldest trees with the largest diameter had a consistently higher growth rate than the younger trees (figure 1), suggesting that the first jack pine to become established following the past fire dominated the later stand. During the growing season prior to cutting, seed traps yielded 500,000 birch (*Betula papyrifera* Marsh.), 50,000 white spruce (*Picea glauca* (Moench) Voss), 17,000 balsam fir (*Abies balsamea* (L.) Mill.), 15,000 jack pine, 6,000 pin cherry (*Prunus pensylvanica* L.), and 84,000 grass and sedge seeds per acre. Very little seed germinated and became established in the undisturbed areas. The stand contained large quantities of hazel. Dominant herb vegetation included *Aster macrophyllus* L., *Pteridium aquilinum* (L.) Kuhn. var. *latiusculum* (Desv.) Underw., *Oryzopsis asperifolia* Michx., and, less frequently, *Cornus canadensis* L.

At Bearskin Lake, three tracts were delineated: uncut and unburned; cut and unburned; and cut and burned. On the cut tracts, nine seed trees distributed evenly per acre with abundant cone and good form were left standing (figure 2.) At both Grass Lake and Dragon Lake, the study tracts were clear cut and burned. A cyclone seeder was used to seed the tracts with 5-6 ounces of seed per acre mixed with screened sand. Seed, supplied by the U.S. Forest Service, had been treated with arasan and aluminum powder and labeled 89-97 percent viable.

In all cases, logging was done in the autumn, when all merchantable timber was removed and cull trees and snags were felled. To minimize disturbance of organic mantle for experimental purposes, pole skidding with horses was the method used. Slash was evenly scattered to an average depth of 3 feet. Burning was completed the summer after cutting on all tracts except the Dragon Lake tract, where, because of lack of suitable weather, burning was delayed 2 years. Observations on a wildfire study tract in the Keeley Creek natural area are given for comparison of natural seeding from burned standing timber with prescribed burning methods. The Keeley Creek tract had a volume of 149 square feet basal area per acre with an average diameter at breast height (d.b.h.) of 10 inches.

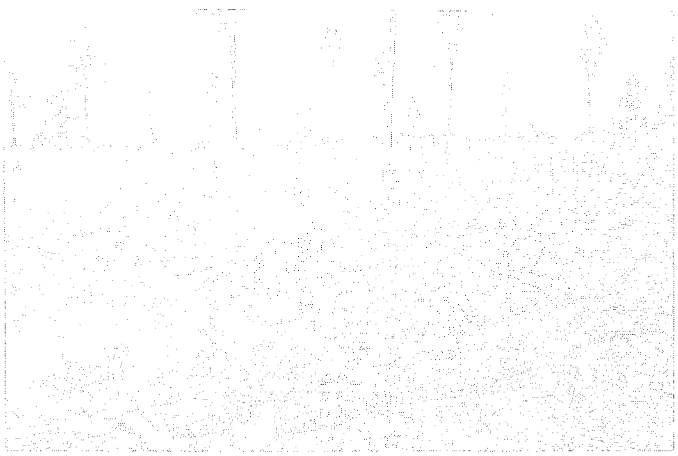

Figure 2. Bearskin Lake tract cut, with slash evenly scattered, nine seed trees per acre.

Ecological Data

A vegetational study was made to determine the major postfire changes in herb and shrub populations in relation to tree reproduction. On each tract, 30 permanent stations were established 30 meters apart. At each station, vegetational data were gathered from concentric 10 and 100 square meter circular plots. From the 10 square meter plots, a list of dominant herbs and shrubs and the percentage cover and height were obtained. Other more detailed vegetational studies in the area will be reported elsewhere. Tree reproduction was recorded by age. Records were made the year before burning, annually the first 5 years following burning, and are continuing at 5-year intervals. Depth of organic mantle was determined before and after burning. Preburn data included d.b.h. of the mature stand and, on the Bearskin Lake tracts, increment borings of 75 trees of the mature stand to determine growth rates.

Determination of Seed Tree Yield

To establish the number of seed trees needed, the number of viable seed per tree was determined. On the Bearskin Lake tract in mid-August, 22 trees that were 7-13 inches in diameter were felled and all cones were gathered. For each diameter class, cones were sorted into three groups: 1-year-old cones (many not mature): entire cone light bronze, located near branch tips; 2-4-year-old cones: dull bronze, found in the outer crown; and 5-year and older cones: dark grey, found well back from the outer crown. Seed was extracted in a standard seed extractory, after which each cone lot was re-examined and hand extracted to obtain all possible seed. In this way, more seed was obtained than would be by usual mass extraction. This was especially true of the 5-year and older cones, many of which did not open sufficiently to release seed in the extractory. Quantities were determined and germination tests run on 200 seeds of each lot for 30 days in sand flats.

Soil Moisture Content

Soil moisture was determined on the Bearskin Lake tracts before burning and periodically for 3 years after burning. Thirty 100-cubic centimeter (cc.) soil cores, 6.5 x 30 centimeters (cm.), one sampling the surface 3 cm. of soil, and another sampling the 3-6 cm. transition between humus and mineral soil, were taken from each of the study tracts. Moisture holding capacity also was determined (44).

Soil Fertility Factors

Soil samples were obtained for chemical analysis prior to burning and during the first, second, and sixth postfire growing seasons. A composite of 10 100-cc. cores was gathered from the first 10 odd-numbered plots in each tract. A representative composite was obtained from the first 3 cm. (level 1), a second from the 3-6 cm. transition between organic mantle and mineral soil (level 2), and a third from 25 cm. into the mineral soil (level 3). Soil reaction, dispersible silt and clay, organic matter, total nitrogen, available phosphorus and potassium, and exchangeable calcium and magnesium analyses were done by S. A. Wilde and associates at the University of Wisconsin (26, 44).

Preparation for Burning

At three locations on the Bearskin Lake tract, alumel-chromel thermocouples were placed at ground surface, between organic mantle and mineral soil, and 3 feet and 40 feet above ground on seed trees before burning. Records were obtained from a 12-point high temperature recorder buried near the thermocouples. Tempil tablets with melting points ranging from 300° to 1700° F. were placed on asbestos plates at each of the 30 plot centers.

Precautionary methods included a 10 foot wide mineral soil break exposed around each tract to be burned. Tracts selected were near water sources. Two portable gasoline driven water pumps adapted to 2-inch canvas hose were used to provide water for fire control around boundaries. Four men with back pumps were available for patrol.

Burning Procedure

Under favorable conditions, which are discussed later, burning was done in early or mid-summer (table 1), when vegetation was most active, in order to obtain greatest retardation of competitive species such as hazel. All fires were ignited in the afternoon when winds were relatively stable and estimated at less than 10 miles per hour.

A backfire was started on the lee side of the tract and gradually burned into the wind in a horseshoe shaped pattern. In a few cases where the main fireline became sluggish, a small strip fire was ignited a short distance in front to keep the main fireline moving. When the fireline had burned to within approximately 100 feet of the

Tabel 1. Prescribe-burned tracts, related information

Area	Date of burning	Time started	Air temperature	Relative humidity	Burning duration	Method of seeding
Bearskin Lake	June 6, 1961	5:00 p.m.	71° F.	21 percent	5 hours	Seed tree
Grass Lake	July 8, 1963	12:30 p.m.	72° F.	40 percent	5 hours	Clear cut, seeded
Dragon Lake	May 29, 1967	1:45 p.m.	74° F.	33 percent	5 hours	Clear cut, seeded

end of the tract, a head fire was ignited at this point and burned with the wind to meet the main line.

Seed Dispersal

On the seed tree tract, actual seed dispersal from seed trees was determined by using 90 1-foot square seed traps placed 30 meters apart throughout the tract the year prior to cutting and the first 3 postfire years. Contents of the traps were collected at the end of each growing season.

Rainfall and Temperature

On four study tracts, continuous recording 7-day instruments were used to measure rainfall (figure 3). Air and soil temperature and humidity also were recorded and will be reported in more detail in a separate paper.

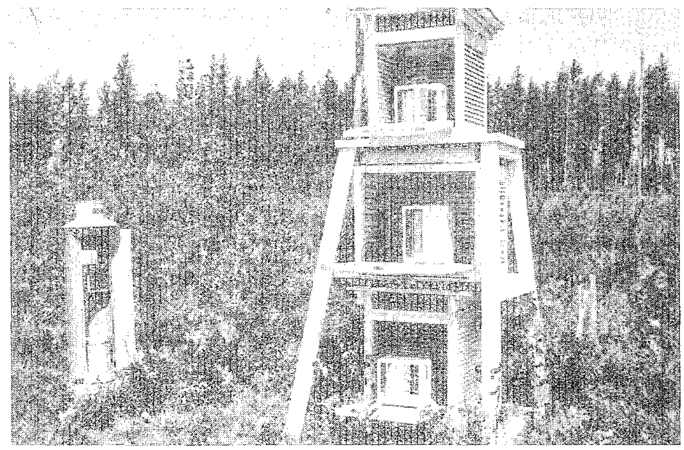

Figure 3. Weather recording instruments included: (1) top and bottom boxes, thermohygrographs recording temperature and humidity simultaneously, (2) center box, three-point thermograph recording temperature at ground surface, between humus and mineral soil, and 2 inches into mineral soil, and (3) at left, Hellmann rainfall recorder. All are 7-day recording instruments purchased from Wilh. Lambrecht's, Göttingen, Germany.

Results and Discussion

Determination of Necessary Seed Trees

Cone and seed production of 11-13 inch d.b.h. trees was much higher than that of smaller trees (table 2). Where available, trees with the larger diameter would be more productive as seed trees. Although there was no relationship between seed viability and tree diameter, there was a relationship betwen age of cone and seed viability (table 2). More reproduction came from 2-4-year-old cones, since they produced seed of higher viability and made up a greater portion of cones on a tree. These results are similar to those reported by Beaufait in Michigan (9), who also reported a decrease in viability with increased age of cones. LeBarron (29) and Eyre and LeBarron (22) reported higher germination percentages, but they worked with mass extracted seed. In both of those studies, 1- and 2-year-old seed was combined, so slightly higher germination values for younger seed were obtained than in this study, in which cones were gathered in mid-August, when many 1st year cones still were immature.

Average number of seed per tree was determined from the seed yields given in table 2. Seven-nine seed trees per acre were calculated to be required (table 3). These trees were selected and left standing on the Bearskin Lake tract.

Sufficient seed to stock the tract was shed during the 3 years after burning (table 4). The number of seed per seed trap was consistent throughout the tract, indi-

Table 2. Cone and seed yield by tree diameter at breast height (d.b.h.) and cone age*

	Cones per tree by tree size (d.b.h., inches)							
	7	8	9	10	11	12	13	Germination by cone age
Age, years								
1	1	21	19	29	64	42	91	9
2-4	174	396	615	545	1,023	784	1,295	68
5+	86	166	289	242	728	643	703	48
Total cones per tree	261	583	923	816	1,815	1,469	2,089	..
Total seed per tree	3,500	4,512	17,850	18,850	38,450	35,150	34,800	..
Total germination, percent ..	63	41	56	54	57	57	51	54 (average)

* Cones were obtained from trees felled within the Bearskin Lake tract prior to burning.

Table 3. Determination of number of seed trees necessary for Bearskin Lake tract seed tree burn

Average seed per tree	21,873
Viability, percent	54
Viable seed per tree	11,811
Predicted pregermination loss, percent	95
Germinants per tree	590
Predicted postgermination loss, percent*	57
Number of established seedlings per tree	254
Number of established seedlings desired per acre	2,000-3,000
Number of seed trees required per acre	7-9

* Figure obtained from seedling survival data on Keeley Creek wildfire tract.

cating a uniform seed distribution. Immediately after fire, 33 percent of the seed tree crowns were completely scorched, 52 percent were partially scorched, and 15 percent remained green. In the scorched crowns, the majority of the 1-4-year-old cones and some older cones had opened.

Martin and Davis (31) have indicated that headfires are necessary to obtain sufficient heat to open cones in seed trees, although such headfires seldom prepare an adequate seedbed. In this study, however, backfire technique was used and satisfactory cone opening and seed shed, as well as good seedbed preparation, were achieved.

Differences in reports of number of seed trees required per acre undoubtedly are related to differences in size of seed trees and number of cones present, which vary considerably among stands. If cone availability is low, the number of seed trees required represents considerable economic loss. Clear cutting and some other seed source must be considered in such cases.

Determination of Seed Required for Broadcast Seeding

A pregermination loss of 85 percent was anticipated in the direct seeding operation. With 8,188 seeds per ounce (39), the calculated requirement for direct seeding was 5½ ounces of viable seed per acre. On the Grass Lake tract, seeding done immediately after fire coincided with high population and activity of deer mice (*Peromyscus maniculatus gracilis*). Much seed was destroyed (6) and very little germination was found. The area was reseeded in autumn just prior to snowfall, when mouse activity was lower. From this fall seeding, calculated amount of seed resulted in a well distributed stand.

In determining the amount of seed necessary for direct seeding, high viability seed must be used. For the Grass Lake tract, samples of seed tested after sowing had high viability, confirming the U.S. Forest Service viability figure on the seed lot. On the Dragon Lake tract, a sample of the seed lot tested at seeding time had less than 20 percent viability. Resultant germination was very poor and reseeding was necessary.

These examples of seed loss to small mammals and use of low viability seed may indicate why some direct seeding fails and why large amounts of seed sometimes are needed.

Sources of Seed Loss

Much seed is lost prior to germination with either seed tree or direct seeding techniques. In determining seed required, a loss of 95 percent was estimated for seed trees (table 3) and 85 percent for direct seeding. The difference was due primarily to large losses of seed in seed trees to birds. The U.S. Forest Service estimates 90 percent loss of seed in aerial seeding of rock-raked jack pine areas (28).

As previously indicated, trapping studies on the Bearskin Lake seed tree burned tract and on the Grass Lake seeded tract indicated that immediately after fire during the summer months the population of seed eating deer mice was noticeably higher than on the unburned tracts (6). Birds also were a factor in seed loss on the seed tree burned tract (4). For several days after burning, flocks of 40-50 pine siskins (*Spinus pinus pinus*) were observed feeding in the crowns of seed trees. Other birds observed in the area at the same time included robin (*Turdus migratorius migratorius*), blue jay (*Cyanocitta cristata cristata*), flicker (*Colaptes auratus luteus*), wood pewee (*Myiochanes virens*), rose-breased grosbeak (*Hedymeles ludovicianus*), and blue-headed vireo (*Vireo solitarius*). Bird activity on the burned tracts appeared to be greater than on the cut and uncut tracts throughout the first postfire summer. In late July, birds seen regularly in some numbers included hairy woodpecker (*Dryobates villosus villosus*), downy woodpecker (*D. varius varius*), red-breasted nuthatch (*Sitta canadenis*), robin, and slate-colored junco (*Junco hyemalis hyemalis*). These observations indicate the continued presence of seed eating species and the invasion of species that feed largely on insects on burned tree trunks.

Table 4. Seed shed by seed trees and seedlings produced on Bearskin Lake seed tree burn tract*

	1961	1962	1963	1964	1965	1969
Cumulative seed trap yield of whole seed per acre	26,824	38,799	79,035	....	....	....
Viability, percent	17	17	17	....	....	....
Predicted number of seedlings per acre	4,560	6,596	13,436	....	....	....
Actual seedling count per acre	608	1,580	1,377	1,134	1,985	1,580
Percentage loss	86.7	76	90	....	....	....

* Counts of seed and seedlings are cumulative. Germination potential was based on yearly tests of 100 seeds.

Table 5. Jack pine germination and seedling survival on 30 10-square meter plots of each study tract for 5 years following prescribed burning and wildfire

		Bearskin Lake seed tree burn tract				
Postfire years	1	2	3	4	5	Total
First year germinants	24	74	13	1	30	142
Older seedlings	..	13	70	62	62	...
Total seedlings	24	87	83	63	92	92
Survival, percent*	..	54	80	75	98	65†
		Grass Lake burn tract, hand seeded				
First year germinants	60	97	14	0	0	171
Older seedlings	..	49	145	145	140	...
Total seedlings	60	146	159	145	140	140
Survival, percent*	..	82	99	91	96	82†
		Keeley Creek wildfire tract				
First year germinants	588	356	44	8	0	996
Older seedlings	..	253	406	432	385	...
Total seedlings	588	609	450	440	385	385
Survival, percent*	..	43	67	96	88	39†

* Survival percentage was computed from the number of total seedlings of the preceding year and the older seedlings of the current year.

† Total survival was computed from the sum of all first year germinations and final total seedlings.

Table 6. Stocking, reproduction, and growth of jack pine on seed tree and seeded prescribed burns and on tract burned by wildfire

			Bearskin Lake seed tree burn tract				
Postfire year	1	2	3	4	5	9	10
Stocking, percent*	47	87	83	83	97	93	..
Average seedlings per acre	608	1,580	1,377	1,134	1,985	1,580	..
Average height, feet	0.1	0.1	0.2	0.4	0.5	3.0	..
			Bearskin Lake cut unburned tract				
Postfire year	1	2	3	4	5	9	10
Stocking, percent	0	..	10	..	20	18	..
Average seedlings per acre	0	..	40	..	243	174	..
Average height, feet	0	..	0.2	..	0.5	2.7	..
			Grass Lake burn tract, hand seeded				
Postfire year	1	2	3	4	5	9	10
Stocking, percent	80	97	100	100	100	..	..
Average seedlings per acre	810	1,984	2,146	1,944	1,912	..	..
Average height, feet	0.2	0.2	0.4	0.7	0.8	..	..
			Keeley Creek wildfire tract				
Postfire year	1	2	3	4	5	9	10
Stocking, percent	100	97	100	100	97	..	100
Average seedlings per acre	7,209	4,212	6,075	5,854	5,224	..	4,374
Average height, feet	0.1	0.1	0.2	0.4	0.7	..	4.1

* Percentage of 30 plots with one or more seedlings.

Jack Pine Reproduction

Most jack pine that germinated became established the first 2 years after fire on all burned tracts (table 5). The highest mortality occurred during the first and second growing seasons and the first winter. On the seed tree burned tract, an unexplained increase in 1 year seedlings occurred the 5th year. Mortality of these seedlings was high.

By the end of the 2nd year, stocking on all burned tracts was over 80 percent (table 6). Similarly, the average number of seedlings per acre was within the range expected. Number of seedlings per acre the 5th year was similar on both seed tree and seeded burned tracts. On the seed tree burn, both stocking and number of trees per acre still were satisfactory after 9 years, although some mortality could be noted between the 5th and 9th years (table 6 and figure 4). Overstocking and crowding resulted on the tract burned by wildfire where the overstory burned. Only preliminary results were available for the Dragon Lake tract; they are not included in table 6. At the end of 5 years, average height of established jack pine seedlings was 6 inches or over on all burned tracts. Average height at 9-10 years was 3-4 feet. Deer browse was quite severe the first 5 years.

On the cut unburned tract, stocking and number of seedlings per acre were low. Germination occurred only where skid trails exposed mineral soil.

Jack pine reproduction was influenced by intensity of burn, humus reduction, moisture relationships, soil fertility, postfire soil temperatures, prevalent disease, and associated plant and animal life. These influences were investigated in relation to reproduction.

Factors Affecting Jack Pine Reproduction

Temperature During Burning. A summary of temperatures during the burning of the Bearskin Lake tract re-

Figure 4. Nine-year-old jack pine reproduction on Bearskin Lake seed tree burn tract.

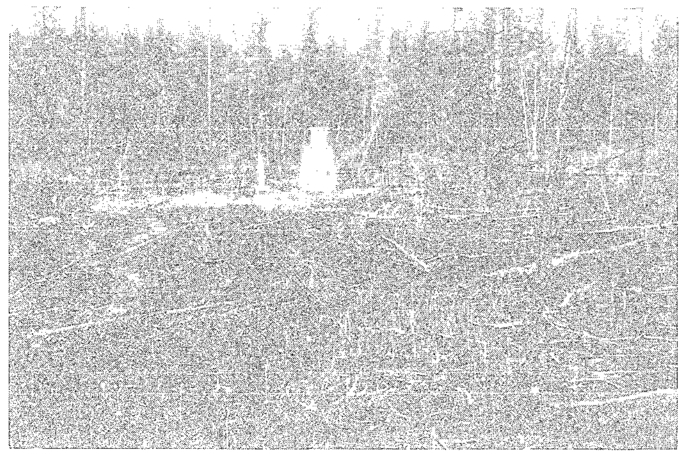

Figure 5. Bearskin Lake tract 2 weeks after fire, showing slash and shrub competition.

corded from thermocouples is given in table 7. Maximum surface temperatures elsewhere on the tract as determined with Tempil tablets ranged from 300° to 900° F. Surface temperatures were lower on the portion of the tract burned in late afternoon and early evening when humidity began to increase. On the two tracts burned earlier in the afternoon when humidity remained low, maximum temperatures ranged from 300° to 1500° F.

During each prescribed burn, the fire moved at an average rate of 4-4½ feet per minute. Total burning time was 5 hours. With the exception of large lopped tree trunks, most slash was consumed. Brush was destroyed to the root collar (figure 5).

Humus Reduction. On the Bearskin Lake burned tract, the organic mantle was reduced from 2-3 inches before burning to an average depth of 1 inch, including ash. Destruction of the organic mantle was greater on the portion of the tract burned earlier in the day, so seedbed conditions were not entirely uniform. On the Grass Lake and Dragon Lake tracts, seedbed conditions were more uniform because humus was reduced to less than 1 inch and in some places mineral soil was exposed. Since there was no slash for a lingering fire on the Keeley Creek wildfire tract, only loose dry litter burned, leaving humus 2 inches deep.

Table 7. Duration of temperatures during prescribed burning on the Bearskin Lake seed tree burn tract*

Temperature, degrees F.†	Between mineral soil and humus	At soil surface	Three feet above ground	Forty feet above ground
122	105	72	19	7
212	74	50	9	3
392	20	25	7	..
572	14	17	5	..
752	..	13	4	..
932	..	9	3	..
1,112	..	4	2	..
1,292	..	1	1	..
1,472	..	1	1	..
1,562	..	..	1	..

* Records were continuous at 14-second intervals and are reported here in minutes.
† Determined with 12 alumel-chromel thermocouples attached to a 12 point high temperature recorder.

Since humus generally was reduced to 1 inch or less on all prescribe-burned tracts, a good seedbed that would allow for jack pine seedling root penetration to mineral soil was produced. The satisfactory reproduction obtained on these tracts indicated that it was not necessary to remove the humus layer completely. A thin layer of residual humus may act as a protective mantle, slowing runoff and blowoff of ash and allowing for leaching of ash nutrients into the soil, as well as providing a more porous surface for moisture penetration. A layer of ash alone has been reported to form a more or less waterproof barrier on some western soils (33). The fire had to be sufficiently hot and of long enough duration to achieve humus reduction. Slash had been evenly scattered to insure adequate fuel. Before ignition, the slash was uniformly dry and humus was dry to a depth of within 1 inch of mineral soil. Following a light rain of ½ inch or less, 2-3 days of humidity below 40 percent and warm temperatures usually were necessary before conditions favorable for burning were created. The backfire techniques used on all three tracts under these conditions resulted in good humus reduction. A fast-moving headfire probably would not have accomplished this.

Moisture Relationships. Prior to burning, soil moisture contents of the surface soil (level 1) and the transition between humus and mineral soil (level 2) on all tracts were similar (table 8). During the first postfire growing season, surface soil on the burned tract was drier than on the cut or uncut unburned tracts. However, in the transition between humus and mineral soil, moisture content was greater on the burned tract than on the unburned tracts. This difference has been observed on other burned areas (7) and may be related to a combination of increased evaporation and increased capillarity of the compacted burned surface prior to establishment of protective insulating vegetation. During this 1st postfire year (1961), rainfall was insignificant, except for a short

Table 8. Moisture content of soil on Bearskin Lake prescribe-burned tract

	Burned		Cut, unburned		Uncut, unburned	
	Level 1*	Level 2†	Level 1	Level 2	Level 1	Level 2
Preburn	39	25	41	21	43	23
Postfire, 1961						
June	35	26	41	22	44	26
July	26	28	33	23	28	20
August	32	33	40	30	39	24
Average	31	29	38	25	37	23
Postfire, 1962						
June	45	26	43	27	46	26
July	27	22	37	20	49	22
August	30	25	40	19	45	25
Average	34	24	40	22	47	24
Postfire, 1963						
June	26	26	..	..	40	25
July	53	26	..	..	44	28
August	33	22	..	..	48	21
Average	37	25	..	..	44	25

* Level 1: first 3 centimeters deep.

† Level 2: transition between mineral soil and humus, 3-6 centimeters deep.

period of heavy rain in July (table 9). During the second and third postfire growing seasons, when normal rainfall occurred, moisture content of the surface on the burned tract also was lower than on the unburned tracts, but the moisture contents of the lower levels were quite similar. The differences were statistically significant at the 1-percent level as determined by a t-test. Moisture holding capacity also was reduced on the burned tract.

First year germination was less on the seed tree burned tract than on the seeded tract (table 5). Second year germinations were very similar. The drought conditions of 1961, when 1st year germinations occurred on the seed tree burned tract, may have impeded germination that year.

In relating soil moisture and rainfall to jack pine reproduction, jack pine seed germination and subsequent survival must be considered separately. More germination occurred the 2nd postfire year than the 1st on both prescribe-burned tracts. However, on the wildfire tract, where the humus was not burned as severely and there was more moisture, greatest germination occurred the 1st year (table 5). On this tract, a fully stocked forest burned. First postfire season seed trap yields of viable seed were nine times greater than on the seed tree burn. First year germination also was proportionately higher. Survival of germinants, however, was only 39 percent, compared with 65-82 percent for the prescribe-burned tracts. This difference indicates the importance of seedbed preparation in the establishment of seedlings following germination.

Table 9. Monthly and seasonal rainfall in inches, Bearskin Lake prescribe-burned tract

Year	June	July	August	Total
1960	1.54	3.53	1.13	6.20
1961	0.61	4.63	0.75	5.99
1962	4.96	6.34	3.18	14.48
1963	2.67	5.01	3.16	10.84
1964	4.94	2.78	2.04	9.76
1965	3.95	3.55	2.72	10.22
1966	2.91	2.98	3.49	9.38
1967	4.78	5.60	2.86	13.24
Average	3.29	4.30	2.42	10.01

Lowest survival of germinants on the prescribe-burned tracts was recorded following the 1961 drought. When sufficient rainfall occurred during other years, there was good seedling survival on the burned tracts, even though surface moisture was lower than on the unburned tracts. Therefore, surface soil moisture reduction on the burned tracts, while statistically significant, apparently was not cirtical to the germination and growth of jack pine except in the drought year. In Oregon, burning reduced ability of the surface soil to absorb moisture and reduced moisture content from 25 percent on unburned lands to 10-16 percent on burned land (33). Oregon soils, both burned and unburned, were much drier than those reported here, where moisture content of the unburned layer ranged from 26 to 49 percent and on the burned lands from 12 to 53 percent.

Soil Fertility. Ash contributed to the fertility of the seedbed on the burned areas, as shown in the soil analyses (figure 6). In soil level 1, ash increased pH and content of nutrients. The amount and duration of this increase varied. After 6 years, only phosphate had been reduced to an amount below that of the preburn stand. The changes were more gradual in level 2, the transition between organic and mineral soil. This sudden release of soluble mineral salts to the soil via ash and subsequent rainfall frequently has been reported to improve soil fertility following burning (7). The addition of nitrogen to the soil has been reported (20) to improve drought resistance in plants and therefore may have contributed to the survival of jack pine and other plants on the drier soil surface.

Postfire Soil Surface Temperatures. Soil surface temperature on the burned tract exceeded 140° F. for 2 hours for up to 3 consecutive days and 122° F. for 2

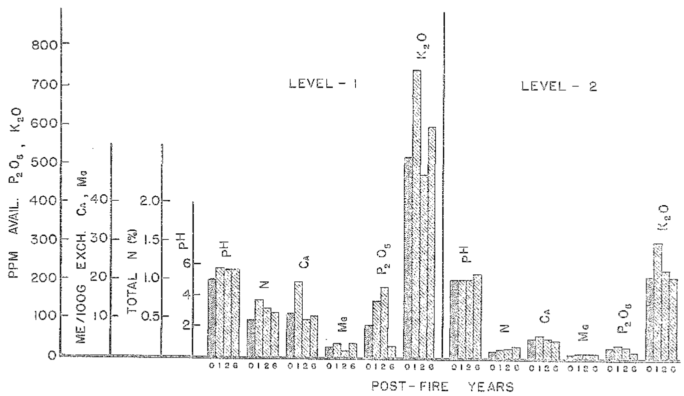

Figure 6. Analyses of soil from the Bearskin Lake burn tract before burning (dark bar) and after burning (light bars). Level 1 represents the first 3 centimeters from the surface. Level 2 represents the next 3 centimeters, the transition between organic matter and mineral soil.

hours for up to 8 consecutive days in June and July of the first two postfire growing seasons. On the unburned control tract, maximum temperatures were similar or slightly higher but for shorter durations, usually less than ½ hour. Soil surface temperatures of 122°-140° F. for 2 hours or more on burned lands have been reported to kill tree seedlings (12, 22, 25, 29, 32, 37, 38). The good germination and survival obtained here (table 5) indicate that high temperatures did not result in appreciable seedling mortality on these burned tracts. Many of the other papers reporting high temperature seedling damage deal with other tree species, and it is possible that there is a species difference in heat tolerance.

Sources of Seedling Damage. Deer browsing can be a factor in jack pine seedling survival. The most severe browsing occurred on the Bearskin Lake tract between the 4th and 5th years after fire when there were no logged areas nearby. Extensive nearby logging operations were begun during the 5th year and browse damage decreased. Deer browsing was less noticeable on seeded tracts where extensive logging occurred in the immediate vicinity. Brown (13) found that deer mice fed on newly merging seedlings as well as on seed.

Heavy infection of needle rust (*Coleosporium solidaginis* (Schw.) Thum.) was observed on jack pine seedlings during the early years of growth. Effect of the rust was temporary and did not cause permanent damage on the Bearskin Lake tract, where it is no longer evident.

Associated Vegetation

Herbs

Preburn ground cover on most tracts was dominated by *Aster* and *Pteridium*. This condition was not appreciably changed by burning (table 10). Percentage cover of these species was reduced following fire. *Cornus* was most frequently the third dominant on the unburned land. After burning, it was supplanted by *Carex* or *Oryzopsis*. In many cases, ground cover temporarily included transitory seed-reproducing, fire-following species such as *Geranium Bicknellii* Britt., *Epilobium angustifolium* L., and *Polygonum cilinode* Michx., which began to disappear 3-5 years later. Changes were not as great on the unburned tract.

Ground cover was dominated by herbaceous plants during the first and second postfire growing seasons (figure 7). Since it was during these 2 years that most jack pine germination occurred, jack pine seedlings evidently were able to grow in association with these plants. Possibly the presence of these herbs contributed to an environment conducive to early tree seedling growth, since Brown (13) has reported stimulation of jack pine germination in water extracts of some dominant species as well as in field studies when jack pine was sown in association with them.

Shrubs

Except for the Keeley Creek area, the tracts were heavily covered with hazel 5-6 feet high before burning (table 10). For at least 5 years after burning, hazel was very much reduced in height and cover. On the unburned cut tract, hazel reduction was not as great (figure 8). Where present, alder (*Alnus crispa* (Ait.) Pursh) also was reduced. *Comptonia peregrina* (L.) Coult. and *Vaccinium angustifolium* Ait. usually were temporarily reduced but increased to levels above the preburn condition 5 years after burning. Similar response was noted for these latter species on the unburned cut tract, indicating that the increase was primarily a response to clearing rather than to fire.

Hazel recovery on the burned tracts was much slower than on the cut unburned tract. The backfire, which burned part of the humus, created soil surface temperatures up to 1500° F., which apparently severely damaged

Figure 7. Herb and shrub growth two growing seasons after burning, Bearskin Lake burn tract.

Table 10. Dominant herb and shrub species on study tracts

Species	Preburn: Average cover, percent	Preburn: Average height, feet	Postfire: Average cover, percent — Year 1	Year 2	Year 5	Postfire: Average height, feet
Bearskin Lake seed tree burn tract						
Aster macrophyllus	80	0.6	58	79	22	0.4
Pteridium aquilinum	51	3.1	43	53	33	1.8
Oryzopsis asperifolia	2	0.7	1	2	10	0.8
Corylus cornuta	53	5.6	3	3	10	1.2
Vaccinium angustifolium	3	0.8	1	1	13	0.7
Comptonia peregrina	1	1.2	1	1	18	1.5
Bearskin Lake cut unburned tract						
Aster macrophyllus	81	0.6	76	83	32	0.4
Pteridium aquilinum	34	2.7	4	13	16	1.9
Oryzopsis asperifolia	3	0.6	3	13	21	0.9
Corylus cornuta	55	5.4	31	20	14	3.0
Vaccinium angustifolium	3	1.2	2	6	11	0.8
Amelanchier sp.	3	4.9	2	2	4	2.5
Grass Lake burn tract, hand seeded						
Aster macrophyllus	83	0.8	3	27	57	0.6
Pteridium aquilinum	34	2.2	14	35	35	1.6
Carex spp.	..	..	2	87	54	1.1
Corylus cornuta	49	6.4	1	1	5	1.2
Vaccinium angustifolium	4	1.2	1	1	2	0.6
Alnus crispa	13	6.0	1	1	2	1.9
Dragon Lake burn tract, hand seeded						
Aster macrophyllus	83	0.6	67	53	..	0.4
Pteridium aquilinum	36	2.5	47	17	..	1.1
Oryzopsis asperifolia	4	0.5	4	7	..	0.6
Corylus cornuta	48	5.1	14	18	..	1.5
Vaccinium angustifolium	9	1.1	6	11	..	0.6
Diervilla Lonicera	1	1.1	2	2	..	0.9
Keeley Creek wildlife tract						
Aster macrophyllus	..	..	4	5	5	0.4
Carex spp.	..	..	1	9	16	1.8
Epilobium angustifolium	..	..	0	1	29	2.7
Comptonia peregrina	..	..	0	1	5	1.4
Vaccinium angustifolium	..	..	1	1	8	0.5
Diervilla Lonicera	..	..	1	1	2	1.1

the root collar of hazel and retarded sprouting for several years. During this time, jack pine seedlings became well established and were beginning to rise above the recovering shrub layer.

Other Tree Species

On the burned tracts, dense aspen sprouting occurred and grew in association with jack pine. Average height at 5 years was 4-5 feet. By the end of 5 years, growth of aspen indicated that it would be present in the recovering forest in about the same proportion as before the fire. While aspen sprouting may be stimulated by fire, this sprouting generally was confined to the region containing rhizomes of the parent stand. In nearby areas where mechanical means of exposing mineral soil have been used, aspen sprouting is very vigorous and widely distributed. The heavy equipment necessary for these operations cuts aspen rhizomes and contributes to their wider distribution.

Birch was a minor part of the preburn stand. Its recovery by stump sprouting was poor, and 5 years after burning very few birch remained.

Conclusions

The prescribed burning of three tracts reported here resulted in good slash removal, humus reduction, shrub retardation, and establishment of a new jack pine stand.

Figure 3. Vigorous shrub recovery on the cut unburned tract, Bearskin Lake.

We think that similar methods would give consistent results in other jack pine forests under similar conditions.

The understocking and overstocking results of direct seeding reported in the past may be related to poor seedbed preparation, time of seeding, and viability of seed. When seeding was done in late fall after small mammal activity had subsided, seed germination occurred in the spring before small mammal populations again reached high levels. In calculating the amount of seed necessary, current viability had to be established and taken into account. Five to 8 ounces of seed per acre well distributed with a good spreader gave satisfactory results when seeded on a burned humus layer 1 inch or less thick in late fall.

Use of seed trees as an alternative to seeding gave equally good results. The seeding potential of seed trees must be accurately assessed in determining the number of trees to be used. In addition, the burning process must be sufficiently hot to open cones.

Regardless of which method of seeding is used, seed of sufficient quantity should be put on the tract very soon after burning, since the earliest germination generally dominates the mature stand and later germinants are suppressed.

Most workers agree on the importance of dry humus and dry, well distributed fuel. Fuel can be most efficiently and economically obtained if prescribed burning is planned with the timber sale (21). Low humidity and stable, low winds are necessary on the day of burning. Various drought index-fire hazard formulas have been suggested. On the tracts reported here, a simple, on the ground determination was sufficient: Slash was dry; and humus, including under slash, was dry to within 1 inch of mineral soil. Burning was done after midday, when the relative humidity was below 40 percent and winds were stable at less than 10 miles per hour.

There is general agreement that the danger of spot fires or losing control can be handled with proper precautions and burning techniques (23). While danger should be minimized, proper firebreaks and a trained burning crew can control a well designed fire, especially if the backfire technique is used, burning into the wind instead of with it.

Both headfires and backfires have been recommended by various investigators. Headfires are of value in rapid splash disposal and for opening seed tree cones. Because of the rapid fire movement, burning with a headfire usually is less expensive, although danger of losing control is high and poor humus reduction generally results. Where humus reduction for seedbed preparation was desired, backfires gave consistently good results. Backfires are easier to control, although the burning time is considerably extended. In this study, cone opening of seed trees was achieved with backfire.

Shrub competition is a serious deterrent to forest regeneration. In this study, the backfire technique used retarded shrub competition for several years following fire, allowing trees to become established and rise above the shrub layer (figure 4). Aspen was not reduced by fire, but 9-year results indicated that it would occupy approximately the same position in the new stand as it did in the precut unburned forest.

Success of burning is not evident for at least 2-3 years after fire, since survival of germinants depends upon a number of factors, including a good seedbed, adequate rainfall, seed supply, rodents, and rate of recovery of competitive species.

No attempt has been made here to assess the cost of prescribed burning. Experimental burning of these small tracts with proper documentation for research purposes would not give an accurate picture of costs on a management basis (21). Recent figures from the U.S. Forest Service (28) on the Superior National Forest indicate that site preparation by prescribed burning costs one-third the average of all site preparation methods and one-sixth that of rock raking.

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