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NATURAL REGENERATION OF LODGEPOLE PINE IN SOUTH-CENTRAL OREGON

by

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ABSTRACT

A sequence of events is necessary for natural regeneration in the pumice soil region: Adequate seed must be produced and distributed over the area, germination must be favored by warm and moist surface soils, daily surface temperature variation must be moderate, seedlings must survive summer drought, and weather conditions must prevent severe frost heaving the fall after germination and the next spring. This sequence does not always occur within a reasonable time after cutting, and natural regeneration is often delayed. Four possibilities are open to the land manager: (1) declare as noncommercial some severe sites such as lodgepole pine/needlegrass and lodgepole pine/bitterbrush/needlegrass plant communities on flat or basin topography; (2) depend more on a planting program; (3) leave a light slash cover on the surface after shelterwood or narrow strip cutting; and (4) leave a shelterwood on the area after a more thorough slash treatment and be willing to wait much longer than 5 years for natural regeneration. Some problems now exist in obtaining good lodgepole planting stock. Also the slash cover does not guarantee success of natural regeneration and option 3 might turn into option 4.

Keywords: Lodgepole pine, forest regeneration (natural), soil temperature, soil moisture, forest management.

INTRODUCTION

Increased logging of lodgepole pine (*Pinus contorta* Dougl.) in south-central Oregon has emphasized the need for additional information on factors influencing stand regeneration. Abundant lodgepole regeneration along roadsides, under powerlines, and in small openings in natural stands has tended to give foresters the impression that natural regeneration of this species would be easily obtained. However, since the 1950's, lodgepole logs have periodically been in demand, and many of the resulting clearcuts have failed to regenerate. Also, there are many poorly stocked lodgepole stands, a number of old burns which have failed to regenerate, and scattered "pumice deserts" ranging from less than 5 to over 100 acres in size. These "pumice deserts" are a result of very old burns or are areas which have yet to be afforested since pumice deposition.

This note summarizes information gained from two studies pertinent to the regeneration problem in south-central Oregon and from additional observations made in field and laboratory. One of the studies concerned germination and survival of both lodgepole and ponderosa pine (*Pinus ponderosa* Laws), and the other dealt with lodgepole pine only.

THE LODGEPOLE-PONDEROSA STUDY

Ponderosa and lodgepole pine germination and survival were studied in three different areas which differ slightly in severity of night minimum temperatures.

All three areas are on pumice-mantled, level topography. The soils are developing on a Mazama pumice layer about 30 inches thick. Soils under stands of timber and in clearcuts have an A1 horizon 2 inches thick and a 10-inch AC horizon over unweathered pumice which is partially mixed with materials from the buried profile and the weathered A horizons. The A1 horizon is absent in the pumice deserts. Area I is a 5-acre clearcut made in 1948 in a mixed ponderosa-lodgepole stand with an understory of bitterbrush/needlegrass-sedge. The clearcut is located just inside the east boundary of the Pringle Falls Experimental Forest, 7 miles west of Lapine, and now contains lodgepole pine seedlings and saplings of varying density. Part of the area is still open. Area II is a 7.4-acre clearcut made in 1938 in a lodgepole pine stand with a bitterbrush/needlegrass understory. This area is located at the northwestern corner of the Experimental Forest and is only partially regenerated. Area III is an 80-acre pumice desert approximately 5 miles north and one-half mile east of Lapine. The desert is surrounded by a lodgepole pine/bitterbrush/needlegrass plant community.

Methods

Lodgepole and ponderosa pine seeds were sown in 4- by 4-foot screened seed beds in the fall of 1969, 1970, and 1971.[1/] Eight, 6, and 14 beds were planted in each area for the 3 respective years. Seventy-two seeds of each species were placed in each bed resulting in totals of 576, 432, and 1,008 seeds per species sown at each location for the different periods. The screens were made of 1/4-inch mesh hardware cloth to protect the seed from small mammals. Some natural seed may have fallen into the seed beds, particularly in areas I and II, but no attempts were made to take natural seed fall into account.

Germination in the laboratory before seeding was 78 percent for the lodgepole pine and 25 percent for the ponderosa pine seeds used in the 1969 and 1970 sowings; for the 1971 sowing, germination was 55 and 80 percent, respectively, for lodgepole and ponderosa pine. All seed were collected on the Experimental Forest. Germination (emergence) and mortality were observed at intervals ranging from 3 days to 2 weeks each year; and in August 1972, some seed that did not germinate from the 1971 sowing were retrieved from the beds and examined. The apparently sound seed were subjected to a germination test in the laboratory.

Results

Percent germination in the field was:

Year and area		*Lodgepole pine*	*Ponderosa pine*
1970	I	1.2	0.2
	II	.6	0
	III	1.2	0
1971	I	45.5	3.5
	II	36.4	2.3
	III	4.4	0
1972	I	.7	.8
	II	2.4	.6
	III	2.2	2.2

Most of the viable seed failed to germinate in 1970 and 1972. In 1971, germination of both species was lowest on the desert (area III) where no ponderosa pine germinated, and ponderosa pine germination was much lower than lodgepole germination in the other two areas.

[1/] These experiments are split plot designs allowing objective testing of the following null hypotheses where sufficient numbers of seedlings are involved: (1) location caused no difference in germination or survival, (2) location affected both species alike, and (3) there is no species by location interaction.

A total of 70 lodgepole and 101 ponderosa seed were removed from the seed beds in August 1972, and some of the seed did not appear to be sound (table 1). Most of the seed not classed as apparently sound were cracked, and the contents were shriveled. Some of these seed were just slightly cracked, and the endosperm appeared to be sound. After dissecting the endosperm we could see that the radicle had begun to develop and then stopped. In a few cases, a withered radicle protruding about one-eighth of an inch from the seedcoat was present. Since the seed lots contained less than 2 percent cracked seed, damage to the seed must have occurred after sowing.

Table 1.--*Number of seed removed in August 1972 from beds sown in the fall of 1971*

Area	Total seed removal		Apparently sound seed	
	Lodgepole	Ponderosa	Lodgepole	Ponderosa
I	22	33	19	10
II	26	28	19	4
III	22	40	18	22

The apparently sound seed were then planted in A1 horizon soil material in the greenhouse under a 15-hour photoperiod where day-night air temperatures were 75-55° F. The soil was kept moist. Germination of the seed taken from different areas was:

Area	*Lodgepole pine (Percent)*	*Ponderosa pine (Percent)*
I	15.8	0
II	10.5	0
III	72.2	33.3

Although the sample size was small, the decrease in soundness and in ability to germinate after seeding appeared greater for ponderosa pine than for lodgepole pine seed in the first few months after sowing.

During the spring and summer of 1971, no germinants were observed in the eight beds which had been sown in 1969.

Mortality after germination.--While lodgepole pine seed is germinating, cold night temperatures can cause some mortality. Mortality of ponderosa seedlings is probably greater during this period because ponderosa is not as tolerant to night minimum temperatures below 20° F.

as lodgepole pine seedlings,[2/] but some lodgepole pine mortality is possible. During the period between May 12 and May 30, 1972, a total of 15 ponderosa pine and seven lodgepole pine seedlings in the screened seed beds apparently died from exposure to low night temperature. Temperatures in standard weather shelters (4½ feet from the soil surface) reached a minimum of 18° F. during this period.

Drought and heat injury during the summer and frost heaving at other seasons have been widely and consistently observed as causes of lodgepole pine seedling mortality. However, during some years, losses due to any one of these factors can be low. For example, the number and percent mortality attributed to drought and heat during 1971 were 14 (7.3 percent), 6 (3.9 percent), and 4 (2.2 percent) for areas I, II, and III, respectively.

Frost heaving can occur during the germination period, resulting in mortality of seedlings just a few days old. This happened occasionally, and the new seedlings were replanted and usually survived. Older seedlings are often frost heaved in the fall and early spring before new germinants appear. Many seedlings were lost in the screened seed beds between September 1971 and the following spring (table 2). Although it is impossible to account for all mortality between these examinations, presence of large numbers of seedlings with roots attached lying on the surface in the spring indicated that frost heaving caused most of the losses.

Table 2.--*Number of live seedlings present in screened seed beds in early fall 1971 and spring 1972*

Area	September 1971		Spring 1972	
	Lodgepole	Ponderosa	Lodgepole	Ponderosa
I	182	12	32	4
II	147	10	16	1
III	15	0	1	0

[2/] Carl Martin Berntsen. Relative low temperature tolerance of lodgepole and ponderosa pine seedlings. (Unpublished Ph.D. thesis on file at Oreg. State Univ., Corvallis.) 158 p., 1967.

THE LODGEPOLE STUDY

This study explored the possibility of improving germination and survival by modifying the environment at the soil surface.

Observations indicate that certain soil surface treatments favor germination and survival. A powerline and pipeline right-of-way west of Chemult is covered, for the most part, by dense natural regeneration. This strip was highly scarified and probably compacted. The felled timber was piled and burned. The strip is 5 to 6 chains wide, runs north-south, and transects flats, depressions, slopes, and both north and south aspects. Scarification may have buried the seed so that moist soil favored germination. Surface temperatures may have been modified by soil surface treatments thus favoring both germination and survival. Or, perhaps the seed bed was prepared in one of those unusual years when natural conditions were favorable for both germination and survival. Bordering the powerline are a number of small clearcuts 3 to 10 acres in size, mostly on flat topography, and broadcast burned. These areas remained inadequately stocked 7 years after cutting. The soil is developing on parent material deposited by the glowing avalanche from ancient Mount Mazama and has a 2-inch A1 horizon above a 10-inch AC horizon over parent material several feet thick.

Methods

Three small unregenerated clearcuts made 6 years earlier in a lodgepole stand with a bitterbrush/needlegrass understory were chosen for the study. These clearcuts are located 2 miles north and one-half mile west of Chemult, Oregon.

Strips 144 feet long and 16 feet wide were staked out and given the following treatments: (1) control, (2) scarified, (3) rolled with a pneumatic roller, and (4) scarified and rolled with a pneumatic roller. Strips were laid out in groups of four, and the groups were replicated a total of four times.

Scarification of the clearcut was accomplished with brush blade mounted on a crawler tractor. The soil was disturbed to remove the grasses and forbs. Care was taken to remove as little soil as possible. Pneumatic rolling was an attempt to compact the surface soil, increase thermal conductivity and heat capacity, and thus reduce surface temperature variations. The strips were scarified or rolled or both in late October, and seed were sown on November 10, 1971. Seed source was the Davis Flat area about 9 miles east of the study area and 250 feet higher in elevation. Laboratory germination of the seed was 86 percent. There were 66,200 seeds per pound, and the sowing rate was 1½ pounds per acre (99,300 seeds per acre or 2.3 viable seed per square foot).

In addition to broadcast sowing the strips, we laid out an additional strip with each replication and spot seeded it. Spots 2 by 2 feet square were prepared with a McLeod tool and a rake. Five-tenths gram of lodgepole seed (73 seeds) were scattered on each spot. Spacing of the spots in each strip was approximately 5 by 8 feet center to center resulting in a sowing rate of 79,500 seeds per acre.

A rodent census taken in October showed that sufficient numbers of deer mice as well as chipmunks and golden-mantled ground squirrels were present to warrant baiting under guidelines then in use by the Forest Service. The area was baited once by hand with 1080-treated wheat on November 10. Bait, method of placement, and amount followed prescriptions then current in the 1968 USDA Forest Service Animal Damage Control Handbook, 2609.22 of Region 6.

After we sowed the seed, we divided each strip into four rectangles 16 feet wide and 36 feet long. Two of the four rectangles on each strip were randomly chosen to receive a light slash cover.[3/] Lodgepole saplings up to 10 feet in height were cut and laid on the soil. Branches of adjacent saplings touched each other but did not overlap.

The following spring 10 rectangular plots 1 by 3 feet in size were randomly located in each quarter of each broadcast-sown strip, and these initially located plots were checked once a week for seedlings. In the strips that were spot seeded, 10 seed spots in each quarter were randomly selected for observation.

Results

Of the 80 plots examined for each soil surface condition, the number of plots where seedlings had germinated by June 1 was:

	Open	*Slash covered*
Control	0	8
Rolled	0	20
Scarified	3	12
Scarified and rolled	11	43

3/ The design of this experiment is a split plot with four treatments (seedspotting was not analyzed in conjunction with the other four treatments because different amounts of seed were sown on an area basis) and four replications. Orthogonal degrees of freedom were also designed before installation to test the following hypotheses: (1) germination and survival is as good on the control as the average of the rest of the treatments, (2) rolling is as good as the average of scarifying and scarifying plus rolling, and (3) rolling a scarified area is no better than merely scarifying it.

The number of plots where seed germinated was significantly greater under slash cover, and tests of orthogonal individual degrees of freedom showed that the scarified and rolled treatment resulted in a significantly greater number of plots with seedlings than scarification alone.

Seedlings germinated on 46 seed spots beneath slash and on only 12 seed spots in the open, further indication of the beneficial influence of a light slash cover on germination.

The slash apparently keeps the surface soil from drying out as rapidly, thus prolonging the duration of the period when temperature and moisture are optimum for germination.

More seedlings were lost beneath the slash cover during the 3-week period after germination started because many more seedlings germinated beneath slash. However, when mortality is expressed as percent of germinants, slash resulted in a reduction in percent mortality for treatments where germination occurred both in the open and beneath slash (table 3). Percent germination of viable seed was

Table 3.--*Mortality of lodgepole seedlings for the Chemult study between the start of germination in the second week of May and June 1, 1972*[1/]

Treatment	Uncovered soil		Slash covered soil	
	Number of seedlings	Percent[2/]	Number of seedlings	Percent[2/]
Control	(3/)	(3/)	1	8.3
Rolled	(3/)	(3/)	22	56.4
Scarified	15	100	9	39.0
Scarified-rolled	14	66.7	72	28.4
Spot seeded	29	60.5	47	6.8

1/ Each number of seedlings represents the total number lost from 80 3-square-foot plots or 80 seed spots.

2/ Total number of germinants from 80 3-square-foot plots or 80 seed spots divided into the number of seedlings lost times 100.

3/ No germinants.

greater beneath slash and the survival of seedlings through the summer appeared to be greater beneath slash (table 4) for all treatments except the control where no seedlings survived. The absence of survival in the uncovered portion of each treatment and the very low survival under slash in three of the five treatments prohibit establishment of a firm statistical conclusion that slash definitely increased survival in this study. On the other hand, not one seedling was found in the open on any treatment at the end of the summer.

Penetrometer measurements showed that pneumatic rolling did not compact the surface soil as was planned because on the day of treatment the soil was too dry and was covered with about 2 inches of powder snow. Rolling did smooth the surface after scarification. Smoothing the surface probably reduced evaporation and prevented the soil from drying as rapidly as the scarified treatment.

Average maximum temperatures per week at the soil-air interface, determined by weekly examination of thermotubes and tempil pellets[4/] placed on the control strips on all four replications, were over 145° F. for the open areas and over 132° F. for the slash covered areas during the May 15 to September 5 period. Maximum temperatures during this time were over 160° F. in the open and 140° F. under the slash.

4/ Use of brand names does not imply endorsement by the U.S. Department of Agriculture.

Table 4.--*Total germination and survival of viable lodgepole pine seed on October 1, by treatment and by soil surface condition*

Treatment	Open soil[1/]		Slash covered soil			
	Germinants	Germination of viable seed	Germinants	Germination of viable seed	Trees surviving (per acre basis)	
	Number	*Percent*	*Number*	*Percent*	*Percent*	*Number*
Control[2/]	0	0	12	2.2	0	0
Rolled[2/]	0	0	32	5.8	12.5	726
Scarified[2/]	15	2.6	23	4.2	8.7	363
Scarified-rolled[2/]	22	4.0	253	46.0	1.6	726
Spot seeded[3/]	48	1.0	691	13.8	2.9	272

1/ No trees survived.

2/ Each number represents a total of 80 3-square-foot plots containing the sum of 552 viable seeds.

3/ Each number represents a total for 80 spots containing the sum of 5,022 viable seeds.

Slash cover also offers some protection from drought. Depth to visible wetting fronts are greater in the open than under slash as shown by the following results from the Chemult study:

	Depth to visible wetting front (inches)	
Date	*Open soil*	*Slash covered soil*
May 30	1.5	0.8
June 5	1.4	.5
June 26	1.6	.7
July 5	2.4	1.2
July 10	3.0	1.9
July 17	3.5	2.5
July 31	2.9	1.8
August 7	2.9	1.9
August 14	3.7	2.3
August 28	2.5	1.9

Each point represents an average of one measurement taken on each of the four replications on the control strip.

The vast majority of seedling losses in the Chemult study were attributed to drought or heat or both. The lowest temperature after the start of germination in a weather shelter 4.5 feet above the surface was 18° F. on May 24. Insufficient numbers of seedlings survived for examination of mortality during fall frost heaving. In the summer 1971 when conditions were favorable for germination and survival in the study using the screened seed beds, subsequent frost heaving destroyed the seedlings. In the spring and summer 1972, conditions were poor for germination and survival in both studies.

DISCUSSION

A sequence of events is necessary for establishment of lodgepole seedlings in south-central Oregon. Adequate seed must be produced and distributed over the area, and germination must be favored by warm, moist surface soils; after germination, soil and weather conditions must minimize frost heaving, soil-air interface temperature variation must be moderate, seedlings must survive summer drought, and soil and weather conditions must limit severe frost heaving in the fall and following spring.

Other factors such as small mammal and bird damage, vegetation competition, insect and disease attacks, and hail impact at times further complicate the sequence. I will discuss each item and where possible suggest ways to modify the environment to increase probability of seedling establishment.

Seed production.--In the uncut stand, Dahms (1963) found the fall of sound seeds to range from 14,000 to over 500,000 per acre per year over a 4-year period. For 2 of those years, seed fall was 178,200 and 230,400 sound seed per acre. For the 1960-62 period of Dahms' study, "number of seeds decreased from 272,300 per acre within the timber to 17,200 seed at 66 feet from the timbered edge, to 2,450 seeds at 198 feet, and to only 540 seeds per acre at a distance of 462 feet." Pine squirrels (*Tamiasciurus* spp.) harvest large quantities of lodgepole cones but the seriousness of this has yet to be investigated. Lodgepole cones in south-central Oregon are not serotinous, and the bulk of the seed is shed by November 1 and, in some cases, by early October (Dahms 1963).

After seed fall, rodents such as deer mice (*Peromyscus* spp.), golden-mantled ground squirrels (*Citellus lateralis*), and chipmunks (*Eutamias* spp.), as well as birds and fungi, destroy some of the seed. No studies have been conducted to determine the importance of seed depredation. Some of the lodgepole seed are cached by rodents and later germinate.

Seed germination.--As the study using the screened seed beds shows, the presence of viable seed in the field does not guarantee germination. In the spring of 1970 and 1972 when germination was very low, minimum night temperatures averaged 27.2° and 24.5° F. for the May 3 to May 19 period. In 1971 when lodgepole seed germination was considerably greater, the average night minimum temperature was 31.5° F. for the May 3 to May 19 period. Average daytime highs for this period were 64° (1970), 61.7° (1971), and 62.3° F. (1972). The soil surface of the ponderosa and lodgepole areas was also wetter during this period in 1971 than in 1970 or 1972. It is possible that low temperatures in the spring, combined with dry surface soils once temperatures become warmer, inhibit germination. Fraser (1968) stated that "natural, simultaneous occurrence of optimum moisture and temperature for germination of a given species is less frequent and of shorter duration than we might suppose."

In some preliminary experiments to determine the effects of temperature and soil water on germination of lodgepole and ponderosa pine seed, 20 seeds of each species were planted in each of 22 soil moisture cells (Cochran 1972) containing A1 horizon material where water contents could be maintained at optimum for germination. Further, 100 seeds of each species were planted in A1 horizon soil material in plastic trays 12 by 8 inches wide and 6 inches deep.

Six of the cells and three trays were placed in each of three growth chambers. In each of the growth chambers one tray was watered 5 days a week, the second tray was watered 3 days a week, and the third tray was watered every 3 days. Photoperiod in each growth chamber was 15 hours, but the day-night temperatures were 70°-34°, 60°-34°, and 50°-34° F., respectively. No germination had occurred after 59 days in the 50°-34° F. chamber. In the 60°-34° F. chamber, a total of 15 lodgepole and two ponderosa seeds had germinated in the cells where moisture content was optimum. No germination occurred in the trays. In the 70°-34° F. chamber no germination took place in the driest tray. In the tray watered 5 days a week, 13 ponderosa and 53 lodgepole seed germinated, and in the tray watered 3 days a week nine ponderosa and 29 lodgepole germinated. A total of 61 ponderosa and 90 lodgepole seeds germinated in the six cells.

In the greenhouse during the same period where day-night temperatures averaged 75°-55° F., germination of 20 seeds per species in four cells was 80 percent for ponderosa pine and 55 percent for lodgepole pine. The results in the growth chambers were not subjected to statistical analysis because of probable additional variables besides temperature regime. However, these preliminary observations support the hypothesis that both temperature and moisture are important factors controlling seed germination in the field.

The low germination in the pumice desert in 1971 is attributed to the fact that this area became bare of snow earlier in the spring and had dried out at the surface much more than the other two areas when temperatures warmed to permit germination.

Low night temperatures during germination.--Although some mortality due to low temperatures at night was observed in the screened seed beds, the small numbers of seedlings involved do not permit evaluation of the relative importance of this factor. In growth chamber experiments, Cochran and Berntsen[5/] found lodgepole mortality occurred when temperatures at night dropped below 20° F. at the plant level but mortality was not complete until temperatures dropped to 11° F.

Frost heaving.--Frost heaving, as observed in the first study reported here, has been widely and consistently observed as a cause of seedling mortality in the pumice soil region.

Frost heaving is most pronounced when the soil is wet to the surface, is initially free of frost, and when air temperatures drop below freezing at night after being above freezing during the day. At night when water freezes in a thin layer of surface soil, additional water moves upward in the profile in response to the water potential gradient created by freezing. This water then freezes and forms ice crystals. The upper ends of these ice crystals are attached to the frozen soil layer and lower ends are in contact with water in the

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5/ P. H. Cochran and Carl M. Berntsen. Tolerance of lodgepole and ponderosa pine seedlings to low night temperatures. For. Sci. (In press.)

unfrozen soil. As water freezes these ice crystals of segregated water elongate forcing the frozen soil layer next to the surface upward. Plants with bases solidly encased in the frozen layer are displaced upward; and when the surface layer thaws and the ice columns melt, these plants are left on the surface with a portion of the root system exposed or destroyed (Schramm 1958, Portz 1967).

Enough precipitation usually occurs in October and November to moisten the soil surface, and the pumice soils are always very wet throughout the profile after snowmelt in the spring. The wet soils in combination with the same factors which cause high frequency of radiation frosts (high altitude, relatively dry airmass, clear nights, and the thermal properties of pumice soils) also cause severe frost heaving.

High soil surface temperatures and drought.--Surface temperatures in the open on control strips in the study near Chemult exceeded 160° F., and no seedlings survived. It is difficult to separate the influence of high soil surface temperature and drought in the field because both factors are influenced by the same weather conditions. High insolation increases evaporation rates, increases the internal water stresses in the plant, and dries the soil. Dry surface soils have lower thermal conductivities and volumetric heat capacities than similar wet soils; consequently, surface temperature variation becomes more extreme. The thermal properties of pumice soils cause wide surface temperature variations even when the soil is wet; and as a result, seedlings on these soils are subjected to both lower and higher temperatures than if grown on a more dense mineral soil under the same meteorological conditions (Cochran 1969b).

Other factors.--Hail, ants, and small mammals cause small amounts of lodgepole seedling mortality. Other insects and disease probably contribute to mortality also. The relative importance of these factors has not been determined. Vegetation competition for soil moisture, particularly from sedges and fescue, increases the probability of losses to drought.

Probability for seedling establishment.--To further consider the sequence of events necessary for natural establishment of lodgepole pine, a preliminary model is proposed. The model could predict probability of natural establishment of lodgepole pine after fire or cutting in the pumice soil region in similar plant communities and at the same elevations as the two field studies.

Suppose seed is available 3 out of every 4 years, conditions favorable for germination exist 1 of every 2 years, low temperatures cause mortality only once every 10 years, seedlings can survive the summer drought and high surface temperatures once every 2 years, and that frost heaving causes significant mortality 1 of every 2 years.

Assuming each of the above factors operates independently and that all other factors such as seed and seedling depredation and vegetative competition are not limiting, the probability of seedling establishment for any given year is 3/4 x 1/2 x 9/10 x 1/2 x 1/2 = 27/320 or approximately once every 12 years. Stated in another way, there is only 25-percent probability of establishing lodgepole pine from seed under these hypothetical conditions in any given 3-year period without consideration of other factors which further decrease probability of establishment. Actually, the probability may be much lower than 25 percent, and this model needs testing with data collected over a long time period from each important plant community at several elevations. Also, the model may need modification because all the factors may not be independent, the occurrence of seed crops may not have the same probability each year, and other factors may need to be incorporated.

The actual conditions influencing establishment vary with elevation and with plant communities. At higher elevations, snow remains on the ground longer and the soil surface remains moist longer during the growing season. Germination is later and seedlings are subjected to shorter periods where low temperatures and frost heaving can cause mortality.

Volland[6/] has done an excellent job describing some of the plant communities in the pumice soil region having lodgepole as a component and presenting problems associated with their management. These plant communities such as lodgepole/needlegrass or lodgepole/bitterbrush/needlegrass are easily recognized and often are indicative of areas where temperature extremes and frost heaving will be problems. Some of these communities--lodgepole/needlegrass or lodgepole/bitterbrush/needlegrass--can be extremely difficult to regenerate and perhaps should be considered as noncommercial when found in frost pockets.

Improving chances for seedling establishment.--Proper planting of site-adapted lodgepole stock capable of growing well would circumvent many of the factors that cause seed and seedling mortality including frost heaving. Schramm (1958) found that planted conifers were not very susceptible to frost heaving because wind blowing against the foliage displaced soil from the base of the stems and the stems did not become solidly encased in a frozen surface layer. Frost heaving has not been serious in plantations in the pumice soil region. Unfortunately, good planting stock has not always been available, and there are questions about the proper size of planting stock. If planting is not possible, the land manager should be concerned about modifying surface temperature extremes, preventing the soil surface from drying during the germination period, and modifying conditions which promote drought and severe frost heaving to encourage natural reproduction.

[6/] L. A. Volland. USDA Forest Service R6-2210-71. 1971.

At present, only one management practice capable of causing these modifications seems feasible--leaving a light slash cover over the soil surface after logging. A light slash cover is defined as sufficient material lying on the surface so a well-stocked stand would result if only seedlings which germinated beneath this slash survived. Harvest cuts should be either narrow strips less than two tree heights wide if clearcut (Cochran 1969a) or a shelterwood leaving standing trees with good crowns at a spacing not to exceed one-half tree height.

For the latitude 42°30' on June 21 the percent of the area shaded sometime between 1100 and 1500 hours is only about 22.8 percent for a spacing equivalent to one tree height, 25 percent for a spacing equivalent to 0.75 tree height, and 55 percent for a spacing equivalent to one-half tree height. Further, spacing must not exceed one tree height to provide any protection from radiative cooling at night (Moen 1968). However, leave trees will not always offer adequate protection from frost heaving. Heaving takes place at temperatures just below freezing, and no amount of overstory cover will prevent occurrence of these temperatures near the soil surface in the pumice soil region on many nights in the fall and spring.

Beneficial effects of slash.--Slash modifies temperature extremes at the soil surface, prevents the surface from drying rapidly, and offers some protection from frost heaving. A consideration of the energy balance at the earth's surface is helpful in understanding how slash is beneficial to seedling establishment.

The net radiation flux density, *Rn* (cal./$cm.^2$-min.), of the earth's surface is equal to the amount of short and longwave radiation striking the earth minus the amount of short and longwave radiation leaving the earth. *Rn* can be expressed by:

$$Rn = R_1 + S\ (1-a)$$

where R_1 is the net longwave radiation, S is the shortwave radiation and a is the albedo or reflectivity. The term $S\ (1-a)$ expresses the solar energy available for evapotranspiration, sensible heat (the heat that changes the air temperature), soil heat, vegetative storage, and photosynthesis.

The albedos of pumice soil surfaces are high (23 percent), but the albedo of the lodgepole forest is much lower (9 percent).[7/] Adding a light slash cover to a bare pumice soil decreases the albedo and increases the $S\ (1-a)$ term. Some of the extra energy available near the surface is used in heating the slash. The slash shades the surface during the day thereby lowering maximum temperature at the soil-air interface and reducing evaporation from the shaded surface. At night

[7/] Harold Richard Holbo. The energy budget of pumice desert. (Unpublished Ph.D. thesis on file at Oreg. State Univ., Corvallis.) 136 p., 1972.

the covered soil surface exchanges longwave radiation with the slash as well as with the surrounding vegetation and the water vapor, carbon dioxide, and ozone in the atmosphere. Therefore, not as much radiation is lost to the sky from the covered soil, and the soil surface stays warmer beneath the slash at night than in the open.

The warmer soil surface beneath the slash protects the seedling from injury from low temperature and frost heaving. The protection from frost heaving has been noted in the field on several occasions and was very evident in the fall of 1969. In strip clearcuts above 5,200 feet on the Chemult District of the Winema National Forest, lodgepole seedlings were unusually abundant in the spring of 1968. Although considerable mortality occurred during the summer, apparently from drought, large numbers of seedlings were present in September. However, fall frost heaving was severe, and the vast majority of the seedlings present the following spring were beneath slash.

The longwave radiation exchange between the soil surface and the slash prevents the water in a thin layer of soil from freezing to form a solid ice-soil layer which is then pushed upward as ice crystals from beneath. Field observations indicate that ice crystals do form beneath the slash cover but they form right at the soil-air interface and then elongate upward into the air and seedlings are not heaved. When the weather becomes colder, the freezing layer penetrates deep into the soil and no frost heaving takes place in the open or beneath the slash.

It may be argued that the presence of slash increases danger from wildfire and that seedlings established with the aid of the slash protection stand a good chance of being destroyed by fire later. Timber management and fire control personnel must determine the amount of slash necessary for seedling establishment and the smount which would create an unacceptable fire hazard.

Slash cover does not guarantee seedling establishment. The number of seedlings present under slash in the Chemult study (table 4) may be inadequate if subsequent mortality is high. Further, the amount of cover from slash sharply decreases because of needle loss after 2 to 3 years while competing vegetation increases, so probability of seedling establishment from seed fall during years following treatment is reduced. When a shelterwood is left on the area, natural regeneration will probably be obtained; however, foresters will have to accept a regeneration period of longer than 5 years.

CONCLUSIONS

Natural regeneration of lodgepole pine in some areas within the pumice soil region may take decades because at least five factors have to operate in sequence to allow seedling establishment. Planting good site-adapted lodgepole stock would circumvent many of the factors, including frost heaving, that hinder establishment from seed. At present, there are problems in obtaining this stock associated with seed collection and nursery mortality. Also, there is a question about the best age to outplant. The problems are being worked out, and foresters can expect more lodgepole planting stock to be available in the future.

For the present, one possible way to improve the probability of obtaining natural regeneration in a reasonable length of time is to leave a light slash cover on the soil surface even when a shelterwood or narrow strip cut is applied. However, this practice does not guarantee seedling establishment, and the slash cover will be of little help if good seed years are more than 3 years apart. Where thorough slash disposal is performed or when regeneration is not obtained soon after cutting even where some slash is left untreated, foresters will have to accept a regeneration period longer than 5 years.

An additional option open to the land manager is to declare certain lodgepole stands noncommercial. These stands would be those associated with understory vegetation which indicates that temperature extremes, frost heaving, or vegetative competition would limit natural regeneration.

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