Early Establishment of Conifers Following Prescribed Broadcast Burning in Western Larch/Douglas-Fir Forests

RAYMOND C. SHEARER[1]

INTRODUCTION

THE Northern Region and the Intermountain Forest and Range Experiment Station are jointly supporting a series of studies of prescribed fire and their application to forest management. Groups of scientists are investigating the effects of a wide range of fire intensities on forest regeneration, watershed values, wildlife habitat, and atmospheric resources. This publication is one of a series reporting the results of these efforts.

Historically, coniferous forests of the Northern Rockies (and most other forests of the Temperate Zone) have been returned to early stages of succession by fire (Larsen, 1929). This is the inevitable consequence of heavy accumulations of litter and other flammable debris that build up during the life of maturing stands. Because such pioneer tree species as western larch (*Larix occidentalis* Nutt.) and lodgepole pine (*Pinus contorta* Dougl.) require an early successional stage, they usually fail to become established without major disturbance.

[1]/The author is Research Silviculturist, USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah 84401, stationed in Missoula, Montana, at the Forestry Sciences Laboratory, maintained in cooperation with the University of Montana.

Land managers realize that reestablishment of these trees after harvest cutting in western larch/Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) forests requires seedbed preparation. Seedbed preparation is generally accomplished in this forest type by mechanical scarification on slopes less than 30 percent and by prescribed broadcast burning on steeper slopes.

Over the years, fire has been recognized as a potent land management tool but little quantitative data have described how varying intensities of burning affected natural regeneration in this forest type. Therefore, a major silvicultural objective was to determine the effects of varying intensities of prescribed burning on subsequent establishment of conifers on clearcuts. In addition, seed loss, germination, seedling survival, and the length of time these sites remain receptive to natural regeneration were to be studied.

Timing of logging and slashing was controlled as much as possible to provide opportunities for burning slash on all exposures. Burns were conducted in the spring, summer, and autumn over 2 years (1967 and 1968) at Miller Creek and over a similar period (1969 and 1970) at Newman Ridge. These variables provided a wide range of conditions for evaluating natural regeneration success after prescribed broadcast burning.

DESCRIPTION OF STUDY AREAS

Two study areas were selected in the western larch/Douglas-fir forest cover type (Society of American Foresters, 1954) where larch and Douglas-fir predominate. These locations provided contrasting topography, soils, and habitats.

The first area, Miller Creek, is in northwestern Montana (lat. 48°31′N., long. 114°43′W.) in the adjacent Miller Creek and Martin Creek drainages on the Flathead National Forest. Sixty clearcut units (15 on each of the 4 cardinal exposures), each about 4 hectares in size, make up the 256-hectare study area. Engelmann spruce (*Picea engelmannii* Parry) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) are major associates in these cool, moist locations. Lodgepole pine occurs occasionally.

The second study area, Newman Ridge, is about 161 km south-

southwest of the Miller Creek units on the Lolo National Forest. It lies along the main ridge separating Two Mile Creek and Ward Creek near the Montana-Idaho border in western Montana (lat. 47°17′N., long. 115°17′W.). Sixteen clearcut units (4 on each of the 4 cardinal exposures), ranging in size from 8 to 23 hectares, comprise the 210-hectare study area. Ponderosa pine (*Pinus ponderosa* Laws.) is a major associate at lower elevations on the dry, hot slopes, and grand fir (*Abies grandis* (Dougl.) Lind.) and western redcedar (*Thuja plicata* Donn) are major components at the same or higher elevations on the moist, warm slopes. Lodgepole pine is a common associate throughout these stands.

Relief at Miller Creek is moderate, ranging from 10 to 35 percent (average, 24 percent). Occasional pitches on these slopes reach 50 percent. Elevations are from 1,300 to 1,500 meters m.s.l. Locations of cutting units range from those near stream bottoms to those on ridgetops. Clearcuts are arranged in tiers, from one to three span the distance from the toe to the crest of a slope.

In contrast, Newman Ridge forms the divide between two deep canyons with long, steep slopes. The cutting units lie along the upper one-third or one-fourth of these slopes and range from 46 to 64 percent in steepness (average, 55 percent). Some pitches exceed 100 percent. Elevations of the clearcuts vary from 1,300 to 1,600 meters m.s.l.

R. C. McConnell's field notes describe soils at Miller Creek as well drained, sandy and gravelly loam from the Wallace (Belt) Formation. They lie within the Brown Podzolic Great Soil Group (Spodosol soil order) and are derived from glacial till (3 to 8 meters in thickness) of argillite, siltite, and quartzite. Except where glacial till is absent, these soils belong to the Sherlock Series and are described as coarse, loamy, skeletal, and ashy. The ashy "Bir" layer ranges to 41 cm in thickness. The soils on the clearcuts were overlain (before prescribed burning) by a mor-type layer of litter and duff that averaged 5 to 10 cm in depth.

Newman Ridge soils are underlain by colluvium and weathered bedrock, but do not have the high percent of rock typical of glacial till. The soils which are loamy, are in the Craddock Series. The ashy Bir ranges to 53 cm in thickness.

Habitat-type maps were originally prepared for both study areas using the method developed by the Daubenmires (1968). Maps were later revised to agree with preliminary habitat work for Montana that was done in 1974 by Robert D. Pfister and associates. Preliminary classifications have been developed and tested, and publications presenting classification systems for Idaho and Montana are being prepared. The major portion of the Miller Creek study area is classified as an *Abies lasiocarpa/Clintonia uniflora* habitat type. Most stream bottoms are in the *Thuja plicata/Clintonia uniflora* habitat type. Three distinct phases of the *Abies lasiocarpa/Clintonia uniflora* habitat type were identified: the *Menziesia ferruginea* phase primarily on the higher middle to upper north- and east-facing slopes; the *Xerophyllum tenax* phase on the south- and dry, west-facing slopes; and the *Clintonia uniflora* phase on most other sites.

Newman Ridge, in contrast, has four distinct habitat types identified on the study areas: *Abies grandis/Clintonia uniflora* on concave east-, northwest-, and protected south-facing slopes; *Abies grandis/Xerophyllum tenax* on west-facing slopes off of ridgetops; *Thuja plicata/Clintonia uniflora—Menziesia ferruginea* on concave north- and northeast-facing slopes; and *Pseudotsuga menziesii/Xerophyllum tenax—Vaccinium globulare* on upper south-facing slopes.

METHODS

The 60 cutting units at Miller Creek were roughly square (201 meters a side) and included a central measurement plot (1 hectare in size) surrounded by an isolation zone (50 meters in width). The 16 cutting units at Newman Ridge permitted the placement of three 1-hectare measurement plots on each unit with surrounding isolation strips. Nearly all measurements referred to in this paper were taken within these 1-hectare measurement areas.

Effects of prescribed burning on soil water, soil temperature, and mortality of nonconiferous roots were studied at Miller Creek (Shearer 1975) and at Newman Ridge. The percent of water lost from the upper 4 inches of soil during burning was estimated gravimetrically from six samples collected before and six samples collected after certain prescribed fires. The preburn and postburn samples were taken about 1 foot apart at the following depths: 0 to 13, 13 to 25, 25 to 57, and 57 to 102 mm. During prescribed burning, the amount of soil heating within the upper 10 to 15 cm of soil was approximated by using temperature-sensitive materials, tempils[2] or tempilaq (Tempil Division, Big Three Industries, Inc., South Plainfield, N.J.). Six to 12 melting points (45° to 538° C) were used at each of 25 to 36 point sampled within a clearcut (Shearer 1975). Within the upper 10 cm of soil, root mortality of nonconiferous vegetation was measured before and after burning near the points where soil water samples were taken. A vital stain, orthotolidine, was used to identify living roots.

The condition of the seedbed after burning was estimated on 32 clearcuts at Miller Creek and on 7 clearcuts at Newman Ridge. At Miller Creek, seedbed categories were (1) logs, (2) rock, (3) unburned, (4) rotton wood, (5) mineral soil, (6) scorched duff, and (7) burned mineral soil. The percent of each seedbed type on 34 to 86 circular plots, 3.92 m^2 in size, was estimated. At Newman Ridge, the percent of seedbed in four categories was estimated on 25 to 36 square plots, 37.16 m^2 in size. Seedbed was categorized (1) scarified by logging, (2) unburned duff less than 13 mm in depth, (3) unburned duff more than 13 mm in depth, and (4) surface covered by logs, stumps, or rock outcrops. Seedbed classification provided another basis for ranking the effectiveness of the prescribed fires in reducing duff and litter and in preparing seedbed.

Seed production at Newman Ridge was estimated from the number of sound seeds found in eight seed traps placed within the timber surrounding each of 7 clearcuts. Seed dispersal within 8 clearcut blocks was estimated from the number of sound seeds collected from 14 to 36 systematically spaced seed traps within each opening. Traps, 0.39 m^2 in size, were used to sample this seedfall.

Establishment of coniferous regeneration was studied on clearcuts facing each of the cardinal directions. At Miller Creek, 39 clearcuts

[2]/The use of trade or firm names in this publication is solely for the convenience of the reader. Such use does not constitute an official endorsement by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

were examined and from 28 to 86 circular quadrats, 3.9 m^2 in area, were established on each unit, one every 20.1 meters on a grid enclosed entirely within the burned area. At Newman Ridge, the 8 clearcuts had from 110 to 177 circular quadrats, 3.9 m^2 in area, established within each unit. These were established on burned seedbed with no duff remaining, mechanically scarified seedbed, or burned seedbed with more than 13 mm of unburned duff.

Germination, mortality, and survival of the major conifer species were studied on a series of quadrats, each 3.9 m^2 in area, on various types of seedbed. Seeds of the major tree species represented on each area were sown on the respective quadrats in mid-October from 1967-70 at Miller Creek and from 1969-71 at Newman Ridge. Sown seed was not protected in 1967, but was covered thereafter with window screen from the time of sowing until germination was nearly complete. Weekly counts were made of germination, mortality, and survival.

To help approximate temperatures, ranging from 45° to 73° C, at the soil-air interface, tempils were inserted halfway in the soil on some seeded plots. These were examined at each remeasurement.

Soil water was measured gravimetrically at monthly intervals on some seeded plots to help verify losses attributed to drought. Samples were taken at 0 to 13, 13 to 25, 25 to 102, and 102 to 203 mm levels.

RESULTS

Early establishment of coniferous regeneration following prescribed broadcast burning of clearcuts was influenced by the interaction of several factors. The most important of these were (1) seedbed condition, (2) seed supply, and (3) environmental characteristics affecting seedling survival.

SEEDBED CONDITION

Clearcutting these mature stands added considerable slash, cull, and other unmerchantable wood material to the forest floor. Duff accumulation averaged about 50 percent deeper and slash volume slightly more at Miller Creek than at Newman Ridge (Table 1). Be-

Table 1. Average slash volume and duff depth before prescribed burning, average duff depth after prescribed burning, and average duff reduction by study location and aspect on some clearcut units.

Location	Aspect	Slash volume[1]	Duff Depth		Duff
			Before burning	After burning	reduction
		(kg/m²)	cm		(percent)
Miller Creek	North	534	6.6	3.6	46
	East	488	7.1	2.7	63
	South	537	6.0	2.6	60
	West	473	5.7	3.3	40
Newman Ridge	North	472	4.2	0.8	80
	East	433	4.3	1.2	71
	South	443	3.9	0.9	77
	West	502	4.1	1.0	75

[1]Beaufait and others, 1975.

cause of the depth of the duff and slash and the competition of the vegetation on most clearcut units, it was evident that natural regeneration of such seral species as lodgepole pine or larch would be severely limited or excluded without site preparation (prescribed broadcast burning).

Prescribed broadcast burning of logging slash from May through October on four exposures (north, east, south, and west) resulted in a wide range of seedbed conditions (Table 2). The amount of duff reduction was largely a function of duff water content at the time of burning (Beaufait and others, 1975). When the lower half of the duff was dry (less than 50 percent ovendry weight), all or almost all duff was burned (Shearer, 1975). However, when the water content of the lower half of the duff was greater than 100 percent, usually less than half of the duff burned. As shown in Table 1, the percent duff reduction on some exposures was much greater at Newman Ridge than at Miller Creek. Reduction in duff thickness ranged from 11 to nearly 100 percent at Miller Creek and from 65 to 90 percent at Newman Ridge.

Prescribed broadcast burning of logging slash caused only minor changes in measured soil water and soil heating, except during fires of high intensity when the water content of both duff and soil was low. When duff was wet and soil water was at or near field capacity

Table 2. Mean seedbed conditions on 32 clearcuts by aspect, Miller Creek, 1974.

Condition	North	East	South	West
	percent			
Burnt mineral soil	55	75	76	57
Mineral soil	4	11	7	4
Unburned duff	4	1	5	13
Scorched duff	73	41	43	57
Rotten wood	47	34	25	35
Logs	16	52	42	53
Rock	6	19	20	18
Plot unburned	0	0	0	10

(usually in spring or occasionally in years of prolonged summer or fall rains), fires caused slight soil heating and no decrease in soil water. As the duff dried, prescribed fires burned a greater proportion of the duff causing more water loss from and heating of the surface soil. Water loss was usually confined to the surface 1 to 2.5 cm during these periods. However, when both fuels and soils contained little moisture, water loss was noted as deep as 10 cm in the soil.

The maximum soil temperature associated with these burns decreased rapidly below the soil surface (Fig. 1). The relation of maximum soil temperature to depth in soil and to duff reduction was expressed mathematically using techniques of Jensen and Homeyer (1970 and 1971) and Jensen (1973). The most intense burns (averaging 82 percent duff reduction) heated the soil to 160° C at the surface, 91° C at 1 cm, and 51° C at 3 cm, with no heating occurring at the 5-cm depth where temperatures remained at or below the minimum 47° C recorded, on the average. Less intense burns (averaging 61 percent duff reduction) caused the soil surface to reach 112° C, but at depths of 1 and 3 cm, temperatures reached 73° C and 49° C, respectively, from the minimum recorded of 47° C. Under the least intense burns (averaging 23 percent duff reduction), the soil surface reached 61° C, and that at 1 cm reached 52° C. Soils at 3 cm and deeper were not affected by the fire and remained at or below the minimum recorded, 47° C. The maximum temperatures within the upper 4 cm usually were reached between 1 and 2 hours after ignition depending on depth. Soil color indicated that these burns apparently caused little change in soil characteristics.

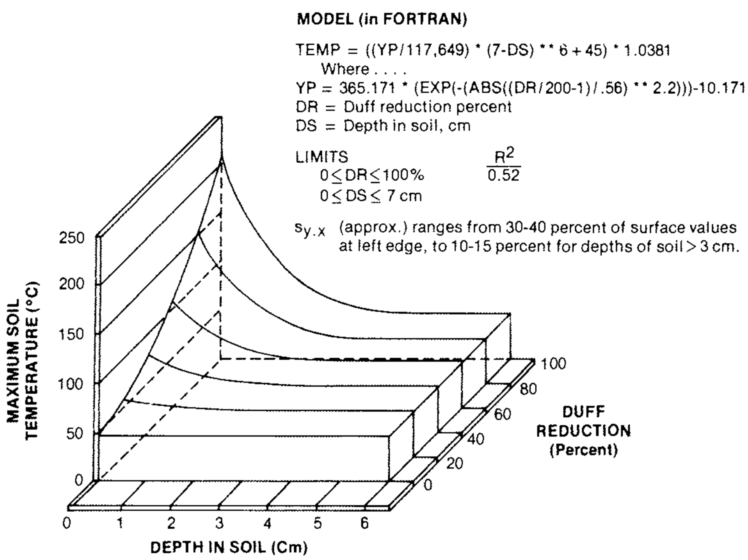

Fig. 1. Maximum soil temperature reached at given depths of soil by duff reduction level, Miller Creek and Newman Ridge.

Root mortality attributed to heating by prescribed burning was usually limited to the surface 2.5 cm of soil. Spring burning under wet conditions caused little or no root mortality at any depth. The same was true for early summer or wet summer burning conditions; only scattered root mortality was found and it was mostly confined to the upper 2.5 cm of soil. Prescribed burning under the driest summer conditions resulted in the greatest root mortality, sometimes to 10 cm in depth of the drier exposures.

Although prescribed burning was frequently effective in reducing the duff layer, the sprouting potential of many competing species was not decreased greatly. Only the Miller Creek wildfire in 1967 noticeably reduced the recovery potential of vegetation from rhizomes or root sprouts, and this occurred only on a few dry, south- and west-facing units. Sprouting of herbs and shrubs and leaf elongation of partly burned beargrass (*Xerophyllum tenax* (Pursh) Nutt.) was common within a few weeks after prescribed burning on other clearcuts.

The differences in recovery of vegetation is pronounced; Newman Ridge has much more uniform vegetative coverage than Miller Creek. In 1974, most Miller Creek clearcuts had some exposed mineral soil with moderate amounts of competing vegetation, but Newman Ridge clearcuts had dense competing vegetation and little exposed mineral soil.

In addition to resprouting of understory vegetation, considerable fireweed (*Epilobium angustifolium* L.) seed germinated on most units and ceanothus (*Ceanothus velutinus* Dougl.) seed germinated on severely burned south- and west-facing slopes at both Miller Creek and Newman Ridge. Ceanothus now dominates these severely burned sites, but tree seedlings are beginning to penetrate the canopy.

Prescribed broadcast burning in the summer or fall provided seedbed that was far more receptive to seedling establishment than unburned forest floor or seedbed on which the duff was only slightly reduced. Two south-facing units were burned May 18, 1968. Because the duff was nearly saturated (about 200 percent) by water, only flash fuels burned and the duff surface was reduced by an average of only 14 percent—in some places, it was only scorched. Subsequent natural regeneration was no better (19 seedlings per hectare, 4 percent stocked) than on a nearby unburned clearcut on a south-facing slope (Table 3). In contrast, the south-facing clearcut immediately above these was burned August 5, 1967, and the duff layer was almost eliminated. Natural regeneration was sufficient (480 seedlings per hectare, 44 percent stocked) to reforest the area (Table 3).

Table 3. Number of seedlings per hectare and stocking on three prescribed burned and on nearly unburned clearcuts, Miller Creek, spring 1974.

Aspect	Seedbed	Seed walls	Seedling total	Stocking[1]
		(number)	(number per hectare)	(percent)
North	Burned	1	603	59
	Unburned	2	80	17
East	Burned	2	1,014	72
	Unburned	2	37	9
South	Burned	2	468	44
	Unburned	3	14	3

[1]Based on percent of circular plots, 3.92 m^2 in area, on which at least one conifer seedling was counted.

At Miller Creek, three unburned clearcuts were examined for regeneration 7 years after harvest. Even though considerable seed fell on these areas, seedling establishment and stocking were sparse (Table 3). On the average, established seedlings were growing more slowly and had poorer vigor than seedlings of the same age on burned seedbeds. Moisture stress and shade from competing vegetation undoubtedly caused much seedling mortality and decreased the vitality of the survivors. The more shade-tolerant tree seedlings grew slowly because they were overtopped by other vegetation, and the more shade-intolerant species were in poor condition. (Newman Ridge had no unburned clearcuts for comparison.)

However, on the same aspects, the nearest burned clearcut to each of these unburned units showed significantly greater regeneration and stocking percents (Table 3). The burned clearcuts on the north- and east-facing slopes were immediately above the unburned units, and the burned clearcut on the south-facing slope was about 0.8 km southwest of the unburned comparison. The north-facing clearcut was burned August 31, 1968, and the duff layer was reduced about 40 percent. An average of 4 cm (0 to 11 cm) of unburned duff remained. The east-facing clearcut was burned August 7, 1968, and about 60 percent of the duff was removed. An average of 2.5 cm (0 to 8 cm) of unburned duff remained. Most of the duff was burned on the south-facing slope August 5, 1967. An average of 0.2 cm (0 to 0.6 cm) of duff remained unburned.

SEED SUPPLY

Seed production is a key factor in the success of natural regeneration. Both the Miller Creek and Newman Ridge study areas had generally good (>40,000 sound seed per hectare) seed crops in 1971 and 1974 and poor (<20,000 sound seeds per hectare) crops in 1969, 1970, 1972, and 1973. In 1967 and 1968, fair (20,000 to 40,000 sound seeds per hectare) and poor crops were produced at Miller Creek. (Seed crops at Newman Ridge were not estimated.) A heavy frost in late May 1971 substantially decreased the potential western larch crop, but other tree species were less affected. Hereafter, only the abundant 1971 seed crop will be discussed because most of the seed available for natural regeneration through 1974 was produced then.

Seed dissemination began in mid-September at Miller Creek and about 3 weeks later at Newman Ridge. In 1971, the number of sound seeds was generally low and varied considerably between the cutting units (Table 4). Seed that fell before October 21 averaged 38 percent sound, but seed that fell later averaged only 16 percent sound. Western larch and grand fir had the least sound seed, averaging 15 percent. Engelmann spruce and ponderosa pine had the most sound seed, averaging 52 percent.

Most of the natural regeneration on the burned clearcuts at Miller Creek and Newman Ridge originated from seed produced in 1971. The good 1971 cone crop provided seed that was dispersed throughout all cutting units. Even a large opening at Newman Ridge (created when a fire in 1969 killed most trees separating several clearcuts) had seed disseminated throughout. Some seed was as much as 305 meters from the nearest seed source. Seed from the fair cone crop produced in 1967 at Miller Creek partially regenerated the clearcuts that were burned that year. Regeneration counts, completed in May 1974 on 14 Miller Creek clearcuts burned in 1967, showed that 15 percent of the seedlings came from the fair 1967 seed crop, 81 per-

Table 4. Percent sound seed and number of sound seeds per hectare dispersed by timber species at Newman Ridge and Miller Creek in 1971[1].

			Miller Creek		Newman Ridge	
Species	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
	------ percent -------		--------- thousands per hectare ---------			
Western larch	16	7	38	23	17	9
Douglas-fir	38	15	40	34	46	38
Engelmann spruce	49	10	40	0	1	2
Grand fir	14	13	[2]—	[2]—	8	9
Ponderosa pine	55	22	[2]—	[2]—	9	13
Subalpine fir	31	4	9	7	[3]—	[3]—
All species	25	12	127	18	82	57

[1]Miller Creek, two clearcuts; Newman Ridge, eight clearcuts.
[2]No grand fir or ponderosa pine at Miller Creek.
[3]Less than 500 subalpine fir seeds.

cent from the good 1971 seed crop, and 4 percent came from poor 1968, 1969, and 1970 seed crops.

Three blocks of uncut trees, most of which were killed by wildfire in late August 1967, disseminated considerable seed from cones produced that year. Conifers counted on these areas the fall of 1973 showed that 89 percent of the natural regeneration came from the 1967 seed crop, 7 percent from the 1971 seed crop, and 4 percent from the 1968, 1969, and 1970 seed crops. In another block of uncut trees, of which more than half survived the 1967 wildfire, 50 percent of the conifers came from the 1967 seed crop, 44 percent from the 1971 seed crop, and 6 percent from the 1968, 1969, and 1970 seed crops.

In 1971, residual timber produced an average of 127,200 sound seeds per hectare at Miller Creek (Table 4). In contrast, about two-thirds as many sound seeds were produced at Newman Ridge. The number of seeds each species produced was extremely variable (Table 4), usually reflecting the composition of the mature stand. An average 24,000 (range 12,000 to 48,000) sound seeds per hectare fell into the large clearcuts at Newman Ridge and 92,000 (range 35,000 to 153,000) sound seeds per hectare into the smaller clearcuts at Miller Creek. Only 12 and 29 percent as much seed fell in the openings at Newman Ridge and Miller Creek as fell on adjacent forest. A lower percentage of seed fell in the clearcuts at Newman Ridge because the openings were larger than at Miller Creek.

GERMINATION AND MORTALITY

The effects of some environmental factors on seeds and seedlings were observed on specific plots where seeds were sown. Germination of western larch seed began before the snow completely melted, and Engelmann spruce seed began to germinate 2 or 3 weeks later. All other species began germination a day or two after snowmelt. Peak germination usually occurred the following week, then declined rapidly, and finally ended 3 to 4 weeks later.

For the first 2 years after burning, germination was greater on burned mineral or scarified seedbeds than on unburned duff more than 13 mm in depth. However, after the second year, germination differences were not apparent because of the decrease in residual duff. On some poorly burned units with deep duff, cracks (similar to those in clay) developed, and some seedlings became established in them. Germination percent on burned mineral soil or scarified seedbed remained about the same for all species in all years.

Seedling survival was strongly influenced by several biotic and abiotic factors. Seeds sown in 1967, the first postfire year, on unscreened test plots on burned seedbed were more susceptible to rodent depredation than were those sown on lightly burned seedbeds where considerable unburned duff remained. In early May 1968, the coincidence of the peaks of western larch and Douglas-fir germination and feeding by migrating juncos [*Juncos oregonus* (Townsend)] resulted in the loss of nearly all seedlings that had not shed their seed coats. On some seeded test plots, losses approached 100 percent. Engelmann spruce was less affected because of its late germination. Juncos were not a problem in any subsequent year. Damping-off fungi caused considerable seedling losses through May.

Important abiotic factors causing mortality were drought, frost heaving, and high surface soil temperatures. Because clearcutting and burning removed most of the protective cover, the surface was exposed to direct radiation and wide temperature extremes resulted. Surface soil temperatures as high as 79° C were measured on unshaded seedbed of east-, south-, and west-facing slopes from mid-June through early August. New seedlings growing in these environments quickly succumbed. Seedlings growing on north-facing slopes were seldom affected by high temperatures (recorded maximum 55° C). In addition, temperature of soil to 50 cm in depth increased 3° to 8° C compared to that at corresponding depths in the adjacent forest. Insufficient soil water caused much mortality on all aspects from midsummer through early fall, except in 1968 when ample rain fell during this period. Frost heaving caused some losses when the seeds germinated and during the first fall and spring following seedling emergence. At the time of germination, seeds together with soil particles were lifted and suspended on ice crystals. When the ice thawed, the seeds and newly germinated seedlings left suspended in the soil latice, dried. Year-old seedlings were killed when frost heaved the young trees from the ground.

Conifers regenerated most successfully on burned north-facing clearcuts. Regeneration rapidly decreased as the cutting units faced more southerly directions. For example, an east-facing clearcut at Newman Ridge changes in azimuth from 96° to 110° to 141°. At these locations, regeneration decreased respectively from 1,400 to 865 to 516 seedlings per acre and stocking from 50 to 45 to 32 percent.

At Miller Creek, the beneficial influence of shade on seedling establishment, especially on hot and dry south- and west-facing slopes, was demonstrated on four units burned in a wildfire before they could be logged. The trees (mostly dead) were left standing over the burned mineral seedbed. As seen in Figure 2, regeneration on the seedbeds of three of the four stands was greatly increased compared to average regeneration on seedbeds of eight burned clearcuts on the same aspects. Regeneration differed widely on two adjacent south-facing units that were uncut but burned. The unit with the higher regenera-

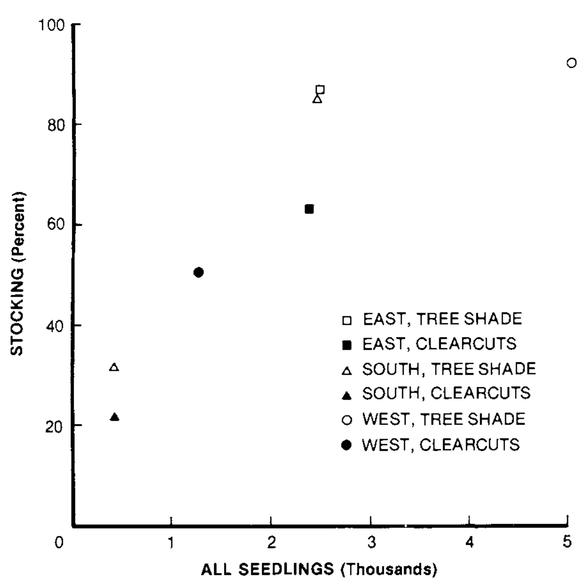

Fig. 2. Beneficial influence of shade on seedling survival. Comparison of natural regeneration on burned clearcuts and on burned uncut stands, Miller Creek.

tion also had more trees survive the fire. Although the east-facing clearcuts averaged about the same number of seedlings as that unit, seedling distribution was much better in the burned, uncut stand. Because a large number of trees survived the wildfire on the west-facing slope, the number of seeds that fell on the burned seedbed increased. Four times more seedlings and nearly twice as much stocking occurred on this seedbed as on the average west-facing, burned clearcut.

The number of filled seeds required to establish one seedling varied widely by aspect, by habitat type, and by the condition of the seedbed following prescribed burning (Table 5). As expected, moist, north-facing slopes had the most favorable seed-seedling ratios, and the poorly burned, moderately steep, south- and west-facing slopes, the least.

DISCUSSION AND SUMMARY

Fires on clearcuts during the first 2 or 3 weeks following the spring snowmelt caused relatively little duff reduction. During this period, only the smaller fuels burned because the larger fuels and the duff layer were nearly saturated. Soil water content was seldom decreased by evaporation during spring burning. As the duff and the larger slash dried and evapotranspiration decreased soil water, fires were progressively more effective in decreasing the duff layer, exposing the mineral soil seedbed, and heating the surface layers of soil. Once the slash and duff dried, considerable precipitation was required to saturate these fuels again. Even with short drying periods after heavy summer or early fall rains, prescribed burning bared some mineral soil that was protected from the full effects of the moisture. After burning, duff reduction continued for several years, baring considerably more mineral soil.

Prescribed broadcast burning under the most extreme conditions caused the average soil temperature to increase to 260° C at the surface and to 66° C at a depth of 29 mm. As a result, the underground systems of the plants were relatively unaffected during burning, and reestablishment of most species was accomplished by vegetative reproduction. The amount and composition of most nonconif-

Table 5. Seed-seedling ratios as influenced by aspect and habitat type.

Aspect	Location	Habitat type	Seed:seedling
North	Newman Ridge	*Thuja plicata/Clintonia uniflora*	13:1
Upper north and east	Miller Creek	*Abies lasiocarpa/Clintonia uniflora—Menziesia ferruginea*	17:1
Northeast to east	Newman Ridge	*Abies grandis/Clintonia uniflora — Clintonia uniflora*	40:1
Lower north, east, and west	Miller Creek	*Abies lasiocarpa/Clintonia uniflora — Clintonia uniflora*	67:1
East and southeast	Newman Ridge	*Abies grandis/Xerophyllum tenax*	92:1
West	Newman Ridge	*Abies grandis/Xerophyllum tenax*	149:1
South	Newman Ridge	*Pseudotsuga menziesii/Zerophyllum tenax*	185:1
South—rapid revegetation	Newman Ridge	*Pseudotsuga menziesii/Xerophyllum tenax*	659:1
West—poorly burned	Newman Ridge	*Pseudotsuga menziesii/Xerophyllum tenax*	668:1

erous regeneration appeared to be largely determined before cutting by the amount of understory vegetation capable of sprouting. Notable exceptions were fireweed and ceanothus that regenerated from seed. Prescribed burning reduced duff depth and prepared a seedbed more receptive for regeneration, but did not necessarily reduce subsequent vegetative reproduction substantially. One exception occurred at Miller Creek on south- and west-facing clearcuts that burned in the August 23, 1967, wildfire. On these units, root-sprouting species recovered most rapidly, but species normally regenerating from rhizomes recovered slowly, if at all.

Although the 1971 cone crop potential was generally classified as good for all species in most stands surrounding the clearcuts at Newman Ridge, the seedfall did not always match the prediction. This was the first good seed crop produced at Newman Ridge since the study began in 1969, but successful natural regeneration was dependent on plentiful dispersal of seed to all portions of the large clearcuts.

Most seed that fell on the clearcuts originated from the timber adjacent to the opening. However, some seed came from unidentified sources, perhaps many miles distant. Such seed fell on the clearcuts during periods of turbulence associated with fronts moving over the areas. We have observed seeds and leaves being lifted hundreds of feet in the air while being carried away from the point of origin. On the largest clearcuts, seed distribution decreased rapidly from the timber edge, but remained at a low, relatively constant level throughout the center portion of clearcuts. Probably, a higher proportion of the total seed that fell in the center came from unidentified sources than from timber adjacent to the opening.

Germination was adequate on all seedbeds, but was greater on bare mineral soil (burned or scarified) than on scorched or unburned duff. Germination began sooner and was greater in the clearcuts because soil temperatures were higher (more favorable) than those under residual timber.

Natural regeneration established slowly on clearcuts where duff reduction was minimal. Significantly more conifer seedlings became established on clearcuts that were thoroughly burned. All burned clearcuts facing from about 300° to 90° azimuth (west-northwest to east) regenerated adequately; some were overstocked from the standpoint of timber production. Those clearcuts with least regeneration usually had poor seed sources. Regeneration was more unsure on the harsher aspects where high surface temperatures and low soil water limited seedling establishment. However, smaller burned units with three or four adjacent timber edges usually had more regeneration because of more available seed and possibly more shading from the adjacent forest.

Successful regeneration was also strongly associated with habitat type. Regeneration was particularly high under shade cast by either living or dead trees on burned seedbed. However, regeneration was sparse on poorly burned seedbeds and on hot open slopes with little or no shade. Habitat types associated with moist conditions regenerated easily, but drier habitat types remained understocked; insufficient seed fell on these large clearcuts and the upper soil was quickly depleted of available water by heavy vegetative competition.

These studies demonstrated that clearcutting coupled with prescribed broadcast burning on north- and east-facing slopes usually leaves the cutover receptive to natural regeneration if sufficient seed is produced. On hot, dry, and steep south- and west-facing slopes, shelterwood or very small clearcuts (group selections) provide greater assurance of regeneration success by leaving a greater seed source and more protection for the site. Clearcuts without seedbed preparation, regardless of the aspect, restock slowly.

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