NOTES

Natural regeneration after harvest and residue treatment in a mixed conifer forest of northwestern Montana

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Abstract: In 1974, two clearcuts, two shelterwoods, and two sets of eight group selections (equally divided between two elevation zones) were harvested on the Coram Experimental Forest in northwestern Montana. Four levels of tree and residue utilization were compared. Moist fuels on approximately half of each area were poorly burned by prescribed fires in September 1975. Natural regeneration on these treatments was compared in 1979, 1987, and 1992. Regeneration of western larch (*Larix occidentalis* Nutt.) began in 1975 on soil exposed during yarding of logs and continued mostly in 1977 and 1979 on these scarified sites and other burned areas. Competing vegetation curtailed establishment of larch seedlings much past 1979 on these sites. Few Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) regenerated before 1979 but aggressively established through 1992. Engelmann spruce (*Picea engelmannii* Parry) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt) regeneration began in 1979 and is increasing slowly throughout the area. Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and western red cedar (*Thuja plicata* Donn.) also slowly regenerate moister areas of the lower elevation units.

Résumé : Dans la forêt expérimentale de Coram, située dans le nord-ouest du Montana, on a réalisé en 1974 deux coupes à blanc, deux coupes progressives et deux ensembles de huit coupes de jardinage par bouquet (réparties également entre deux zones altitudinales). Quatre niveaux d'utilisation des tiges et des résidus ont été comparés. Sur environ la moitié de chacune des surfaces, on a légèrement brûlé les combustibles humides par des brûlages dirigés réalisés en septembre 1975. On a comparé l'établissement de la régénération naturelle suite à ces traitements en 1979, 1987 et 1992. La régénération du mélèze occidental (*Larix occidentalis* Nutt.) a débuté en 1975 sur les sols exposés par le débusquage des grumes. Elle s'est poursuivie en 1977 et 1979 dans ces stations scarifiées ainsi que dans les zones brûlées. La végétation concurrente a beaucoup restreint l'établissement des semis de mélèze au-delà de 1979 dans ces stations. La régénération du Douglas taxifolié (*Pseudotsuga menziesii* (Mirb.) Franco) était peu abondante avant 1979 mais elle s'est établie très agressivement par la suite jusqu'en 1992. L'épinette d'Engelmann (*Picea engelmanii* Parry) et le sapin subalpin (*Abies lasiocarpa* (Hook.) Nutt) ont commencé à s'établir en 1979 puis leur régénération a lentement progressé sur l'ensemble des surfaces. La pruche de l'Ouest (*Tsuga heterophylla* (Raf.) Sarg.) et le thuya géant (*Thuja plicata* Donn.) se sont également établis lentement dans les lieux plus humides des parcelles situées à plus basse altitude.

[Traduit par la rédaction]

Introduction

Wildfire is an important ecological process within forests of the northern Rocky Mountains (Barrett et al. 1997) maintaining seral species such as western larch (*Larix occidentalis* Nutt.) (Schmidt et al. 1976) and lodgepole pine (*Pinus contorta* Dougl. ex Loud.) (Arno et al. 1997). Arno and Fischer (1995) identified three historic fire regimes operating within western larch forests: frequent surface fires, mixed-severity fires, and infrequent stand-replacement fires. Fire usually exposed mineral soil seedbed and left a mosaic of dead and surviving trees to provide seed, overhead shade, and increased survival of subsequent conifer seedlings (Shearer and Stickney 1991). Natural regeneration of conifers is enhanced after harvest by using fire and scarification to expose mineral soil, by viable seed reaching the site, and by having a favorable environment for germination and seedling survival (Shearer 1976). Conversely, the probability of regeneration decreases for larch and lodgepole pine when only slight disturbance accompanies the treatment.

In 1974, a multidisciplinary research and development program began in northwestern Montana to investigate biological consequences of alternative harvesting systems, silvicultural prescriptions, and utilization standards (Barger

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Table 1. Tree cutting requirements, utilization standard, and fire treatment for sub-blocks established on regeneration cuttings (blocks) in 1974, Coram Experimental Forest, Montana (from Barger 1980).

Sub-block	Trees cut	Utilization standard	Fire treatment
1	All trees except designated overstory shelterwood trees	Removed all material (live and dead, standing and down) to 7.6 cm diameter, 2.4 m length, and one-third sound	Burned
2	All trees except designated overstory shelterwood trees	Removed sawtimber material (living and recently dead) to 1974 Forest Service standards of 17.8 cm d.b.h., 2.4 m length, one-third sound	Burned
3	All trees except designated overstory shelterwood trees	Remove all timber (live and dead, standing and down) to 2.5 cm diameter-intensive fiber utilization	Unburned
4	Trees to 17.8 cm DBH except designated overstory shelterwood trees	Remove all material (live and dead, standing and down) to 7.6 cm diameter, 2.4 m length and one-third sound	Unburned

1980). The program provided opportunity to document long-term natural regeneration of conifers on an area with a history of mixed severity and infrequent stand-replacement fires (Sneck 1977). The object of this paper is to document and describe differences in conifer natural regeneration at two elevations for 18 years, especially for shade-intolerant western larch, for more shade tolerant Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and for other associated species as influenced by method of harvest cutting, residue utilization, and site preparation.

Study area

Research occurred within the western larch forest cover type (Eyre 1980) in northwestern Montana, 9 km south of West Glacier. Plots were established on an east-facing slope in Abbot Basin (48°25′N, 113°59′W) within the Coram Experimental Forest, on the Hungry Horse Ranger District, Flathead National Forest. Elevations range from 1195 to 1615 m, and slopes vary from 30 to 80%. Soils were derived from impure limestone and underlying material of loamy-skeletal soil families (Klages et al.1976), and the surface loess layer ranges from 25 to 40 mm thick. Farnes et al.(1995) reported annual precipitation averaged 1076 mm within the study area.

The study was mostly within the subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) / queencup (*Clintonia uniflora* (Schult.) Kunth) habitat type (Pfister et al. 1977). Composition of the pretreatment overstory, by volume, was 58% Douglas-fir, 20% western larch, 12% subalpine fir, 5% Engelmann spruce (*Picea engelmannii* Parry), and 3% western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), western red cedar (*Thuja plicata* Donn.), lodgepole pine, and western white pine (*Pinus monticola* Dougl.) (Shearer 1980). Shade-tolerant subalpine fir and Engelmann spruce made up much of the understory, and shade-intolerant larch and lodgepole pine were absent. Understory western hemlock and western red cedar grew on moister sites. Volume of the shelterwood was 49% Douglas-fir, 35% larch, 7% spruce, 6% subalpine fir, and 3% other species. The percentage retained as shelterwood (diameter at breast height (DBH) > 127 mm) was 60% Douglas-fir, 13% larch, 11% subalpine fir, 10% spruce, 3% lodgepole pine, and 3% other species (Benson and Schlieter 1980).

Before research began, sustained defoliation of subalpine fir, Douglas-fir, and Engelmann spruce by western spruce budworm (*Choristoneura occidentalis* Freeman) larvae was evident (Shearer 1980). Some understory subalpine fir trees were dead. Budworm larvae limited maturation of cones and seeds by direct feeding on developing conelets or by killing cone-producing areas within tree crowns (Fellin et al. 1983). In 1974, the year of harvest cutting, budworm larvae killed most flower buds or young developing cones of subalpine fir, Douglas-fir, and spruce, and reduced the number of developing cones of larch and western hemlock (Shearer 1980).

Methods

Treatments included three methods of regeneration cutting (blocks): shelterwood, clearcut, and group selection and four levels of residues utilization combined (sub-blocks, Table 1). The sub-blocks were superimposed within each cutting block (Barger 1980). These treatments were duplicated within two elevation zones: lower (1195–1390 m) and upper (1341–1615 m) pseudoreplication (Hurlburt 1984). In 1974, trees were felled, and logs were moved off site using a skyline yarding system. Each sub-block received a different level of timber and residue utilization and contained about one fourth of the block's area (Table 1). Half the sub-blocks were to be prescribed burned (Artley et al. 1978). Boundaries of sub-blocks within the shelterwood and clearcut blocks were laid out vertically to the slope. Sub-blocks designated for prescribed fire were laid out next to one another to simplify burning. Two openings within each group selection block received the same level of timber and residue utilization; openings designated for prescribed fire were established one above the other to simplify burning.

Data collection and analysis

From nested, circular, fixed-area plots within each cutting block and residues utilization sub-block, we estimated (*i*) the mean number of conifer seedlings per hectare both for all plots and for only regenerated plots (density) and (*ii*) the percentage of plots stocked with conifer regeneration (stocking). These plots were superimposed along transects that connected 40 preexisting permanent points that were 30.5 m apart in the shelterwood and clearcut units and at lesser variable intervals depending on size of each small group selection opening (Shearer 1980). Five permanent points were established within both of the eight group selections at variable distances between each point.

In 1979, eighty plots (each 0.004 ha in area) were permanently established at 15.2-m intervals within the two shelterwoods and the two clearcuts. Also, 10 plots were established at various intervals within each of the two group selection cuts (8 per location). Regeneration was counted on each plot, and the age of each seedling was recorded. Only 75 of 80 plots were measured on shelterwood and clearcut units and only 72 of 80 plots on group selection units to eliminate edge effects of adjacent treatments. In 1987 and 1992, we also measured "established" conifer regeneration on larger 0.0013-ha permanent plots circumscribed around the same permanent points as the smaller plots.

The experiment was treated as a split-split plot using elevation as blocks. The main plots were the three regeneration cutting

Table 2. Estimated natural regeneration in 1992 by species and by number of trees per hectare and percent stocking following harvest and residue treatments, Coram Experimental Forest, Montana.

	Mean no. of trees /ha		Stocking (%)	
Species	Total	Established	Total	Established
Western larch	649*b*	553*b*	15.0	27.7
Douglas-fir	15 119*a*	10 221*a*	60.2	74.6
Subalpine fir	268*b*	105*b*	6.0	10.6
Engelmann spruce	175*b*	113*b*	6.3	11.5
Western hemlock	159*b*	137*b*	4.2	1.3
Western white pine	56*b*	40*b*	2.3	5.4
Western redcedar	36*b*	31*b*	1.5	2.3
Lodgepole pine	31*b*	103*b*	1.0	2.3
All species	16 494*a*	11 303*a*	64.4	79.8
Density*	25 622 (309)	14 166 (383)	—	—

Note: Means followed by the same letter in a column do not differ significantly at $p < 0.01$. Trees were considered to be established if western larch, western white pine, lodgepole pine were >0.30 m tall, and all other species were >0.15 m tall. Total number of trees, regardless of height, were measured on 0.0004-ha plots; established trees were measured on 0.0013-ha plots.

*Based on plots with regeneration. Data within parentheses are *n* values.

methods. The split plots were the four residue treatments within each main plot. Initially the total number of seedlings and the number of established seedlings per plot were analyzed separately for western larch, Douglas-fir, and for all conifers using Proc GLMMIX as described in Littell et al. (1996), a SAS macro fitting a generalized linear model assuming a Poisson distribution for counts by iterative calls to PROC Mixed of SAS (SAS Institute Inc.1997). An overall analysis considering species and years as further splits was also run as a split-split-split-split plot design with subsampling at the subplot level.

Analysis of deviance was used to indicate significant differences in stocking percent of natural regeneration by the three treatments (SAS Institute Inc. 1993). But this analysis could not identify differences between the three harvesting means or between the four utilization standard and fire treatment means.

Results and discussion

Natural regeneration

Seeds dispersed into all units from surrounding uncut forest and also into the shelterwoods from trees retained for cone production and site protection. Except for western larch, most regeneration counted in 1987 began in 1981 after dispersal of seed from the 1980 bumper cone crop (Shearer and Schmidt 1991).

Number

Natural regeneration began slowly after harvest and fire treatments, then accelerated rapidly between 1979 and 1992. Eighty percent of seedlings were tall enough to be considered established in 1992 (Table 2). Regeneration grew on less than one fourth of the plots in 1979. However, from 1979 to 1992, Douglas-fir seedlings increased over 26-fold (significantly greater than other species), while the number of larch seedlings decreased 20%. The combined number of seedlings per hectare for the other six species increased nearly 13 times during the same time interval (Table 2).

Density

Mean seedling density (plots with at least one seedling) increased substantially (Table 2) over the average number of trees per ha (all plots). In 1979, the density of regeneration on stocked plots (56% larch growing mostly on disturbed sites) was 4.7 times greater than on all plots. By 1987 and 1992, Douglas-fir was established on several sites, and the mean density on stocked plots was 1.6 times more than the mean of all plots. Now, Douglas-fir is evident nearly everywhere, except for residues treatment 4 where understory trees were retained.

Stocking

Stocking of natural regeneration increased rapidly through 1992 (Table 2). In 1979, only 22% of the plots had one or more seedlings because of low seedfall and poor site preparation. Following the 1980 bumper cone crop, stocking of all and established regeneration nearly tripled, mostly from the dramatic increase in Douglas-fir. Western larch stocking remained static from 1979 through 1992, while more shade-tolerant species increased slowly during the period.

Composition

In 1979, fifty-seven percent of the natural regeneration was western larch, and 39% was Douglas-fir, reflecting the greater initial larch seedfall. Composition of Douglas-fir reached 92% in 1992 (Table 2), while western larch fell to 4%. The remaining 4% was mostly subalpine fir, spruce, and hemlock, with occasional western redcedar, western white pine, and lodgepole pine.

Successful larch regeneration was restricted to a 5-year window following harvest. Seedling inspection in 1979 showed 55% of the larch germinated in 1975, twenty percent in 1977, and 25 percent in 1979. Many larch established on “skyline roads” (less than 5% of the area) oriented up and down the slope and scarified during cable yarding in 1974 (Shearer 1980). New seedlings growing on these disturbed sites usually escaped the low-intensity prescribed fires in September 1975 and were briefly free from intense vegetative competition. Patterns of larch in vertical rows still mark locations of some skyline roads. The larch decline after 1979 is attributed to increased competition for light and moisture.

Table 3. Summary of *p* values derived from Poisson analysis of deviance (from SAS PROC GLMMIX) for total and established western larch, Douglas-fir, and all conifer natural regeneration, Coram Experimental Forest, Montana, 1992.

Source of variation	df	Western larch	Douglas-fir	All conifers
Total				
Harvest (H)	2	0.3286	0.0611	0.0612
Residues (R)	3	0.4531	0.0334	0.0403
H×R	6	0.3714	0.0459	0.0355
Established				
Harvest (H)	2	0.1924	0.0857	0.0833
Residues (R)	3	0.0396	0.0068	0.0050
H×R	6	0.5067	0.0409	0.0437

Note: Regeneration was considered to be established if western larch, western white pine, and lodgepole pine were >0.30 m tall, and all other species were >0.15 m tall.

After the western spruce budworm population collapsed in 1975, Douglas-fir cone production increased substantially and triggered regeneration that extended through 1992 (Table 2). Of the Douglas-fir seedlings counted in 1979, twelve percent germinated in 1975; nineteen percent, in 1977; and 69%, in 1979. After 1979, Douglas-fir regenerated under conditions that were lethal to western larch. Douglas-fir stocking stabilized by 1992; counts in 1992 showed the rate of Douglas-fir regeneration was declining.

All Engelmann spruce seedlings identified in 1979 germinated in 1977. Most subsequent spruce regeneration resulted from the 1980 cone crop. Despite the large number of residual subalpine fir, regeneration began slowly when crowns rebuilt after decimation by budworm larvae and were established within most sub-blocks by 1992. Some western hemlock, western red cedar, and western white pine established on moister sites (Table 2), but blister rust (*Cronartium ribicola* Fisch.) limited survival of western white pine regeneration.

Treatments

By 1992, significant or near significant differences existed in the amount of Douglas-fir natural regeneration (Table 3) by harvest method (p = 0.06) and residues treatment (p = 0.03). Analysis showed little interaction among the main effects in 1979, but interactions were significant in 1987 and 1992 for total and established seedlings. Failure to burn sub-blocks 1 and 2 on lower elevation shelterwood greatly reduced natural regeneration compared with the same sub-blocks burned on nearby lower elevation clearcut and group selection blocks. Stocking also declined on the unburned units, but differences were not significant.

Harvest

Method of harvest cutting strongly influenced natural regeneration. Significantly more conifers grow within shelterwoods providing onsite seeds and overhead shade than within the group selections or clearcuts (Table 4). Probability values for the level of stocking also showed a significant difference by harvest method, although there was not a statistical test for multiple comparisons for this analysis. There was greater stocking within the shelterwoods than within the clearcuts and group selections, and Douglas-fir regeneration predominated. However, stocking differences between mean values of the clearcuts and group selections compared with the means of the shelterwoods converged: 23% in 1979, 16% in 1987, and 12% in 1992.

Residues

Regeneration varied widely within the four residues utilization treatments. From 1979 to 1992 seedlings increased 11-fold on these treatments. In 1992, natural regeneration (Table 4) was significantly greater within residues treatments 1 and 3 than within treatment 4. In 1979, more seedlings were counted on burned sites than on other treatments. Shade-tolerant regeneration surged on all residues treatments between 1979 and 1987, especially lower elevation shelterwood (treatment 3). Regeneration escalated between 1987 and 1992 except on treatment 4 where competition from residual vegetation limited survival of new conifers. Stocking varied significantly within residues treatments, but multiple comparisons could not be made. The plots stocked with conifers on these four treatments tripled between 1979 and 1987 then stabilized through 1992.

By 1992, total and established regeneration stocked about 77 and 92% of plots on burned sub-blocks and 52 and 67% of plots on unburned sub-blocks (Table 4). Light prescribed fire or minor scarification during log yarding promoted natural regeneration compared with no treatment. The benefit, even from light prescribed burning, cannot be overstated. Disturbance was essential to quickly regenerate larch, and it enhanced regeneration of Douglas-fir and other more shade-tolerant species over longer periods. Removal of understory trees and shrubs to 25 mm diameter also increased regeneration of Douglas-fir, especially on shelterwood cuttings, where overhead shade slowed vegetation regrowth. Conversely, if this vegetation is retained, regeneration decreases (treatment 4).

Elevation

Mean number of seedlings per hectare varied little by elevation in 1979. By 1992, over twice as much regeneration and stocking occurred on the lower units (Table 4). These differences could not be tested because elevations were used as blocks. Percent stocking on shelterwoods was similar, although twice as many trees grew on the lower elevation block. The similarity in stocking was attributed to not burning designated sub-blocks on the lower shelterwood. Even with low counts on sub-blocks 1 and 2 of the lower elevation shelterwood included, they had more regeneration than all upper elevation blocks. When comparing designated unburned sub-blocks 3 and 4 on the shelterwoods, over five times more natural regeneration were counted on the lower than the upper sites.

Conclusions

Eighteen years after management treatments within this western larch – Douglas-fir forest, Douglas-fir dominates regeneration regardless of cutting method, residue treatment, or site disturbance. Shade-intolerant western larch and lodgepole pine regenerated almost entirely during the first 5 years. Regeneration of the other five shade-tolerant conifers has been slow. Western larch is underrepresented within

Table 4. Influence of cutting method, residues treatment, and elevation zone on estimated natural regeneration and stocking, Coram Experimental Forest, Montana, 1992.

	No. of Trees /ha		Stocking (%)*	
Treatment	Total	Established	Total	Established
Harvest cutting method				
Shelterwood	31 398*a*	19 895*a*	72.5	87.5
Group selection	9 344*b*	7 168*b*	61.2	74.4
Clearcut	8 741*b*	6 843*b*	59.4	77.5
Residues treatment				
1	19 109*a*	13 443*a*	75.8	93.3
2	14 435*ab*	11 756*a*	77.5	91.7
3	24 052*a*	16 438*a*	54.2	75.0
4	8 381*b*	3 570*b*	50.0	59.2
Elevation zone				
Lower	23 629	16 510	76.2	88.6
Upper	9 359	6 097	52.5	70.8

Note: Mean numbers of trees followed by the same letter in columns for harvest cutting method and residues treatment do not differ significantly ($p > 0.05$). Regeneration was considered to be established if western larch, western white pine, and lodgepole pine were >0.30 m tall, and all other species were >0.15 m tall. Total trees, regardless of height, were enumerated on 0.0004-ha plots; established trees were enumerated on 0.0013-ha plots. See Table 1 for residues treatment definitions.

*Percentage of plots with at least one tree.

most of this developing forest and without some management action will continue to diminish. Survival and growth of western larch can be enhanced by thinning and weeding. Most sites are overstocked with Douglas-fir, and numbers will continue to increase. Without further disturbance, the new forest on the clearcuts will be dominated by Douglas-fir and western larch, probably similar to the surrounding virgin forest. However, the group selections will have a greater proportion of dominant Douglas-fir. If the shelterwood is retained indefinitely, dominant larch will continue to lose vigor because of low sunlight. Future measurements will document conifer succession in this developing forest.

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