United States
Department
of Agriculture

Forest Service

**Rocky Mountain
Research Station**

Research Paper
RMRS-RP-53

March 2005

Reforestation Trials and Secondary Succession with Three Levels of Overstory Shade in the Grand Fir Mosaic Ecosystem

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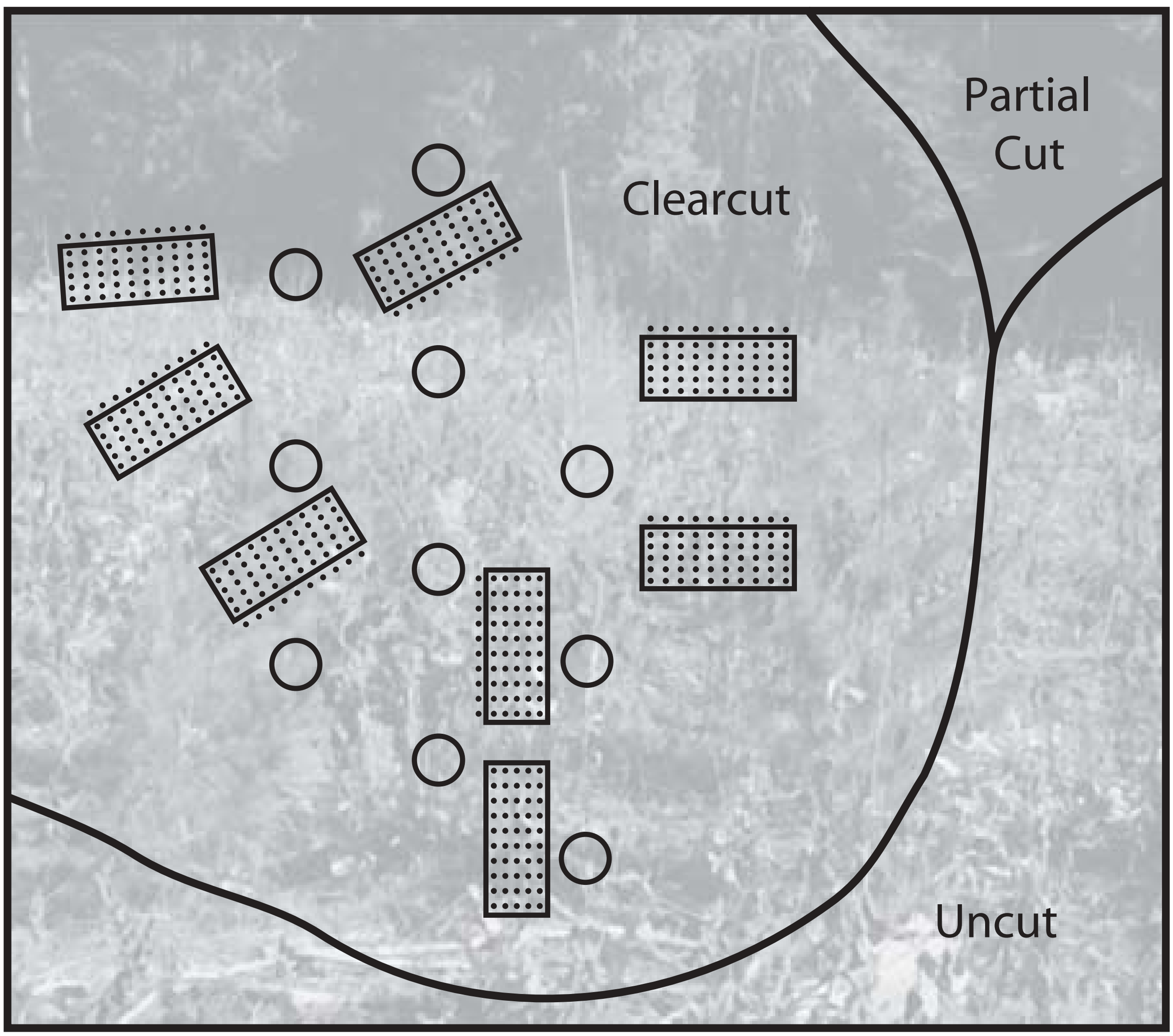

Abstract

Ferguson, Dennis E.; Byrne, John C.; Coffen, Dale O. 2005. **Reforestation trials and secondary succession with three levels of overstory shade in the Grand Fir Mosaic ecosystem**. Res. Pap. RMRS-RP-53. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 16 p.

Grand Fir Mosaic habitats are difficult to regenerate because of pocket gophers (*Thomomys talpoides*) and successional plant communities dominated by bracken fern (*Pteridium aquilinum*) and western coneflower (*Rudbeckia occidentalis*). This study tested reforestation practices recommended by previous research, tested hypotheses about the effects of overstory shade on regeneration success, and documented secondary succession. Natural regeneration is not a reliable reforestation method on Grand Fir Mosaic sites. Clearcut and planting was the best regeneration method if pocket gophers are controlled. Partial cutting and planting was the best regeneration method if pocket gophers were not controlled. Most gopher-caused seedling mortality occurred the first summer, first winter, and second winter after planting. The clearcut treatment resulted in the loss of shrub species and the dominance of bracken fern and/or western coneflower. In the partial cut treatment, shrubs were retained and there was less bracken fern and/or western coneflower than in the clearcut treatment.

Keywords: planting, *Pteridium aquilinum*, bracken fern, *Rudbeckia occidentalis*, western coneflower, *Thomomys talpoides*, pocket gophers

Acknowledgments

We thank Dave Powell for initiating our interest in the Grand Fir Mosaic ecosystem on the Umatilla NF, Kathy Roche for assisting with the study design at Little Big Hole, Larry Frank and Nancy Berlier for providing seeds of genetically adapted species at Little Big Hole, Phil Poulsen and Clare Brick for helping with study installation at French Mountain, and Victor Murphy for installing study sites and collecting data. Also, thanks to Dave Adams, Dave Powell, and Andy Youngblood for helpful technical reviews of the manuscript.

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Introduction

In the Grand Fir Mosaic (GFM) ecosystem in northern Idaho and northeastern Oregon (Ferguson and Johnson 1996), the establishment of conifer regeneration is difficult because of pocket gophers (*Thomomys talpoides*) and successional plant communities dominated by bracken fern (*Pteridium aquilinum*) and western coneflower (*Rudbeckia occidentalis*). This study was designed as a demonstration of reforestation practices recommended by previous research in the GFM, and also tested hypotheses about the effects of overstory shade on regeneration success and secondary succession.

The GFM occurs at elevations between 4,000 and 6,000 feet on and near the Clearwater, Nez Perce, and southern Idaho Panhandle National Forests (NF) in northern Idaho, and northern Umatilla NF in northeastern Oregon and southeastern Washington. The extent of the GFM is estimated at 500,000 acres, and the name for the GFM comes from the dominant conifer—grand fir (*Abies grandis*)—and the variety of sizes and shapes of natural openings in the forest canopy.

Wildfire is the major historical disturbance agent in the GFM, with long intervals between major fires. Grand Fir Mosaic sites stay relatively cool and moist, which reduces the potential for large or severe fires (Smith and Fischer 1997). Tree sizes in old growth stands indicate an uneven age distribution, with regeneration of shade-tolerant species occurring on rotten logs. Bracken fern glades, ranging up to about 15 acres, apparently persist for centuries. Timber harvesting has replaced wildfire as the most common disturbance. Green and Jensen (1991) have documented successional pathways in the GFM where some harvest and site preparation treatments result in protracted stages of secondary succession.

Bracken fern and western coneflower are usually present in small amounts under forest canopies, and both rapidly expand following disturbances that open up the overstory canopy. During secondary succession, bracken fern gains dominance via rhizome expansion, with fronds reaching heights of 6 feet and densities of 116,000 fronds per acre (Znerold 1979), and western coneflower expands via seeds and growth of the caudex, reaching heights of 5 feet. Bracken fern and western coneflower interfere with the establishment and growth of other species through competition for resources and allelopathy (Ferguson 1991, Gliessman and Muller 1978, Stewart 1975).

Pocket gopher populations are high in the GFM; for example, gopher mounds averaged 429 per acre in the stands listed by Green and Jensen (1991). Gophers directly affect succession by feeding on forbs, grasses, shrubs, and conifer seedlings. They can kill entire plantations of seedlings. Small seedlings are usually pulled from below ground into tunnels (Crouch 1971, Marsh and Steele 1992, Teipner and others 1983). With larger seedlings and saplings, gophers may eat all or most of the root system. Gopher feeding on root systems can go unnoticed until the tree dies or begins to tip over because there are not enough roots for support.

Previous research studies on the GFM have provided new information and additional hypotheses to test. Natural regeneration of conifers is not a reliable reforestation method in clearcuts because of high populations of gophers, bracken fern, and western coneflower (Ferguson and Boyd 1988). Planted trees survive interference from bracken fern and western coneflower, but growth is reduced (Ferguson 1999). For example, heights of lodgepole pine (*Pinus contorta*) 7 years after planting were 1.5 feet shorter in plots with bracken fern and western coneflower than in plots where bracken fern and western coneflower were removed.

Pocket gophers can cause a substantial amount of mortality to planted seedlings in GFM clearcuts. For example, gopher-caused mortality was 35.9 percent 2 years after planting for six species tested by Ferguson (1999). Most gopher-caused mortality to planted seedlings took place in the first summer after planting and during the first and second winters. Ferguson (1999) reported 76.8 percent of the seedlings killed by gophers were killed during the first summer, first winter, or second winter. Engelmann spruce (*Picea engelmannii*) and western white pine (*Pinus monticola*) had the lowest gopher-caused mortality, while subalpine fir (*Abies lasiocarpa*) and grand fir had the highest gopher-caused mortality. Western larch (*Larix* *occidentalis*) had high mortality rates from nongopher causes, and both western larch and lodgepole pine had high incidence of top damage.

Comparison of a GFM site to adjacent non-GFM sites showed some additional reasons for slow secondary succession to woody species in the GFM (Ferguson and Byrne 2000). The GFM site had a shorter growing season than adjacent forest habitat types, even though one of the sites was a subalpine fir habitat type 140 feet higher in elevation. Also, summer soil moisture at the GFM site did not dry to the permanent wilting point as often as non-GFM sites, so moisture at the GFM site was usually above the wilting point during the growing season.

The biggest difference between the GFM site and non-GFM sites was soil pH (Ferguson and Byrne 2000). Soil pH at the GFM site fluctuated between 6 and 7 during the winter, and then dropped to 4 to 5 during the summer. Adjacent sites did not have this seasonally cyclic pattern. The combination of acidic soils, high water availability in most years, high organic matter inputs from forb communities dominated by bracken fern and western coneflower, and a source of aluminum from weathered volcanic ash in the soil likely results in active aluminum that is complexed with soil organic matter. Aluminum toxicity is common to many agriculture crops below about pH 5.0 (Shoji and others 1993), so it is likely that aluminum toxicity is influencing succession at GFM sites (Johnson-Maynard and others 1997).

Consideration of the four factors that cause the slow rate of secondary succession to woody vegetation at GFM clearcut sites—competition for resources, allelopathy, pocket gophers, and low soil pH—led to the hypothesis that partial overstory retention may improve regeneration success. The study reported here was designed to quantify the tradeoffs among three levels of overstory density versus survival and growth of planted conifers. Partial shade should result in lower densities of pocket gophers, bracken fern, and western coneflower, but partial shade would also be expected to result in slower growth of conifers. In addition to studying planted trees, we quantified natural regeneration, secondary succession, and pocket gopher activity under various levels of overstory density, and tested recommendations for reforesting GFM sites.

Methods

Study Sites

Two study sites within the GFM were selected—one in Idaho (French Mountain) and one in Oregon (Little Big Hole). The French Mountain demonstration area was selected to represent typical GFM conditions in northern Idaho and initially was the only site planned for study. However, personnel from the Umatilla National Forest in northeastern Oregon had sites that were apparently similar to GFM sites in Idaho, and they wanted to know if recommendations for GFM sites in Idaho applied to GFM sites in Oregon. Therefore, a second demonstration area was chosen in Oregon.

The French Mountain site is on the Clearwater NF, Pierce Ranger District, T36N, R6E, S2. Mean elevation is 5,000 feet with a 190 degree aspect and 15 percent slope. At French Mountain, the habitat type is *Thuja plicata/Asarum caudatum*, *Taxus brevifolia* phase, as described by Cooper and others (1991). The Little Big Hole site is on the Umatilla NF, Walla Walla Ranger District, T4N, R39E, S11. Mean elevation is 4,200 feet with a 150 degree aspect and 15 percent slope. The habitat type at Little Big Hole is *Abies grandis/Taxus brevifolia*, *Clintonia uniflora* phase, as described by Johnson and Clausnitzer (1991).

Prior to treatment, the overstory species composition at French Mountain was 67.1 percent grand fir, 18.9 percent Engelmann spruce, 9.8 percent Douglas-fir (*Pseudotsuga menziesii*), 2.1 percent western redcedar (*Thuja plicata*), 1.4 percent western white pine, and 0.7 percent subalpine fir. The pretreatment overstory species composition at Little Big Hole was 75.0 percent grand fir, 11.5 percent western larch, 7.1 percent Engelmann spruce, and 6.4 percent Douglas-fir.

Each site had three overstory density treatments—uncut, partial cut, and clearcut. At French Mountain, overstory basal area densities were 264 square feet per acre in the uncut treatment, 128 square feet per acre in the partial cut, and zero in the clearcut treatment. At the Little Big Hole site, overstory densities were 268 square feet per acre in the uncut treatment, 132 square feet per acre in the partial cut, and zero in the clearcut treatment.

The French Mountain site was harvested during winter 1994 to 1995, the clearcut was broadcast burned in fall 1995, and seedlings were planted in spring 1996. Harvesting was done at the Little Big Hole site during winter 1996 to 1997; slash piles in the clearcut were burned in the fall 1997, and seedlings were planted in spring 1998. Environmental variables were recorded in each treatment at both sites with six remote data loggers. Environmental characteristics will be reported elsewhere (Ferguson and Byrne, in prep.).

Planted Seedlings

Eight 16.5 by 33 foot rectangular plots were spaced within a 2-acre area in each treatment away from stand boundaries to reduce edge effects. Five conifer species were tested in each rectangular plot by planting 10 trees of each species in rows 3.3 feet apart, with 3.3 feet spacing between trees. Within each rectangular plot, species were assigned randomly to rows. No trees were planted around the perimeter of the plots because our previous experience in GFM areas showed that mortality and differential growth rates among species nullified attempts to grow uniform plots of trees that were affected on all sides by competition. Instead, we planted trees far enough apart that there would be little adjacent competition from other trees for at least 5 years.

Planted species were Douglas-fir, Engelmann spruce, lodgepole pine, western larch, and western white pine. Seedlings for the French Mountain site were obtained from local Ranger District planting stock. Seedlings were 2-0 bareroot stock except western white pine, which was 3-0 bareroot stock. Seedlings for the Little Big Hole site were grown from seed obtained from the Walla Walla Ranger District except white pine seed, which came from the Moscow, ID, seed orchard. Seedlings for Little Big Hole were grown as containerized stock for 1 year, but loose planting soil was gently shaken from the roots prior to planting so that roots came in contact with native soil. Seedlings were genetically adapted to the planting sites at French Mountain and Little Big Hole (see Rehfeldt 1994), but this means that the same seed sources were not used at the two sites.

Seedlings were planted at the French Mountain site in spring 1996. Pocket gophers in all three treatments at French Mountain were controlled with strychnine oats (0.5 percent poison) in 1996 and 1997. The July 21, 1996, application used 4 pounds of bait in and adjacent to the treatments, and the July 25, 1997, application used 8.5 pounds of bait. Seedlings were planted at the Little Big Hole site in spring 1998, and pocket gophers were not controlled.

A total of 2,400 seedlings were planted. Seedling heights were recorded each fall for 5 years after shoot elongation had ceased. Seedling survival and condition were recorded each spring and fall. The cause of mortality was recorded when it could be determined; for example, seedlings eaten by pocket gophers. Seedlings that died were pulled from the ground to inspect roots for gopher feeding or other causes of death. Seedling condition included top damage, snow damage, gopher-caused damage, and damages caused by insects and diseases.

Additional Plantings

We had the opportunity to test other hypotheses about seedling survival and growth, but at a smaller scale. At French Mountain, we tested planting western white pine at different times of the year. At Little Big Hole, we tested planting older/larger western white pine (3 years old versus 1 year old) and Douglas-fir (2 years old versus 1 year old).

The Pierce Ranger District provided additional 3-0 bareroot western white pine to plant at French Mountain. The spring planted white pine were planted in 1996 along with the four other test species described in the previous section. An additional 240 trees from the same nursery stock were transplanted into containers and grown in a greenhouse in Moscow, ID, until planted later in the year. In the summer (July 30-31), 120 trees were planted by adding another 10-tree row to the odd-numbered rectangular plots. In the fall (September 24-26), the other 120 trees were planted by adding another 10-tree row to the odd-numbered rectangular plots.

We tested planting larger western white pine and Douglas-fir at Little Big Hole. The white pine and Douglas-fir planted in the test described in the previous section were 1-year-old containerized stock. An additional 80 3-1 containerized white pine seedlings were planted alongside the even-numbered rectangular plots in the clearcut (40 seedlings) and partial cut (40 seedlings) treatments. The Walla Walla Ranger District furnished and planted 50 2-0 bareroot Douglas-fir seedlings. Ten-tree rows of 2-0 Douglas-fir were added to rectangular plots 1, 5, and 7 in the clearcut, and plots 5 and 7 in the partial cut treatments.

Data analysis compared seedling heights and survival of 3-0 bareroot white pine planted in the spring, summer, and fall at French Mountain; 1-0 and 3-1 containerized white pine planted at Little Big Hole; and 1-0 and 2-0 Douglas-fir planted at Little Big Hole. The additional seedlings described in this section were compared only to the same species planted on the same rectangular plots; thus, the analyses compared side-by-side planting success.

Pocket Gopher Activity

A line intercept transect was used to quantify winter pocket gopher activity. The line transect was installed in each rectangular plot centered between rows 3 and 4 each spring. A 15-foot line segment, beginning 5 feet inside the rectangular plot, was searched for gopher activity. The gopher activity index was the number of times the line intersected a winter gopher mound, cast, or soil plug. Indices were recorded for 5 years after planting.

The purpose of the gopher index was to monitor variation in gopher populations by plot, treatment, and year. Without some information on gopher activity, it would be difficult to relate seedling survival to treatments. For example, seedling survival in the presence of gopher activity is important information for interpreting results. Because the indices quantify winter pocket gopher activity, they can be analyzed for correlation with percent gopher-caused mortality during the same winter periods. The correlation between the pocket gopher activity index and percent gopher-caused mortality should be high when gophers are actively killing seedlings. The correlation would decline if (1) gophers did not kill or stopped killing seedlings, (2) there were no more seedlings (or only a few) for the gophers to kill, or (3) gopher populations declined.

Correlations between the gopher activity index and percent gopher-caused mortality were done by site and winter time period, with line transects being the experimental unit. Pearson correlation coefficients were generated by PROC CORR in SAS (SAS 1999). The Pearson correlation is a parametric measure of association for two continuous random variables.

Natural Regeneration and Vegetation

Vegetation response to treatments was sampled on 10 1/300-acre circular plots that were systematically spaced within a 2-acre area in each treatment away from stand boundaries to reduce edge effects. The 2-acre area was the same as used for planted seedlings, but circular vegetation plots did not overlap the rectangular plots used for planted seedlings. The purpose of recording vegetation was to document changes in vegetation and to record any conifer regeneration that became established after treatment installation.

Vegetation was sampled at French Mountain in 1994 (preharvest), 1996 (second summer following the harvest in the partial cut and first summer following site preparation in the clearcut treatment), and 2003. Vegetation was sampled at Little Big Hole in 1995 (preharvest), 1997 (first summer following the harvest, except the uncut treatment was not sampled), and 2003. Percent canopy coverage was recorded for shrubs (by species), bracken fern, western coneflower, all remaining forbs combined, and all grasses combined. The canopy coverage method described by Daubenmire (1959) was used to record vegetation, except we used circular plots instead of rectangular.

Analysis of vegetation data included calculation of average percent canopy coverage and constancy. Percent canopy coverage is an ocular estimate of the vertical projection of the foliage on the horizontal plane of the plot, providing data on species dominance. Some ecologists calculate average coverage based only on the plots where the species occurs (for example, Cooper and others 1991). We calculated average percent canopy coverage based on all sample plots; therefore, our averages can be used to compare average coverage among species. Constancy is the percentage of plots on which a species occurs, providing data on dispersion throughout an area.

Results

The two sites were installed to demonstrate previous research findings, as well as to test different levels of overstory shade on survival and growth of planted conifers. The sites differ in several ways—location, habitat type, years of harvest and site preparation, site preparation method, seed source for planted seedlings, overstory species, and pocket gopher control. Because there is no replication of treatments within sites (for example, gopher controlled versus not controlled at each site), sites cannot be considered as blocks in a randomized block design (Kirk 1982). Therefore, sites were analyzed separately.

However, it is important to make comparisons between the two sites where it is appropriate, such as answering questions about the effects of overstory shade on regeneration success, the effects of overstory shade on vegetation development, as well as similarities and differences between the two sites. Results from the two sites are discussed together so that readers can more easily see trends that may be useful in developing prescriptions for GFM sites.

Planted Seedlings

Mortality—The causes of seedling mortality differed by gopher control, treatment, and species. The biggest difference in mortality was whether or not gophers were controlled. Where gophers were controlled at French Mountain, average gopher-caused mortality for all five species after 5 years was only 1.5 percent in the clearcut treatment (table 1). The corresponding percentage is 51.5 percent at Little Big Hole where gophers were not controlled. In the partial cut treatment, gopher-caused mortality averaged 12.7 percent for all species at French Mountain (gophers controlled) versus 28.0 percent at Little Big Hole (gophers not controlled).

Table 1—Average gopher-caused seedling mortality (percent) 5 years after planting.

Treatment	DF*	ES*	LP*	WL*	WP*	All
			French Mountain			
Clearcut	2.5	2.5	0.0	2.5	0.0	1.5
Partial	31.2	6.2	3.8	16.2	6.2	12.7
Uncut	15.0	10.0	17.5	2.5	11.2	11.2
			Little Big Hole			
Clearcut	56.2	50.0	47.5	50.0	53.8	51.5
Partial	32.5	18.8	14.8	41.2	32.9	28.0
Uncut	15.0	12.5	11.2	12.5	25.0	15.2

*DF =Douglas-fir, ES = Engelmann spruce, LP = lodgepole pine, WL =western larch, WP = western white pine

Overstory shade was associated with reduced gopher-caused mortality at Little Big Hole, where gophers were not controlled. All species had substantial declines in gopher-caused mortality as overstory density increased (table 1). At Little Big Hole, average gopher-caused mortality for all species was 51.5 percent in the clearcut, 28.0 percent in the partial cut, and 15.2 percent in the uncut treatment.

At the Little Big Hole clearcut treatment, gophers did not appear to have strong preferences for any species. The average gopher-caused mortality after 5 years varied from 47.5 percent for lodgepole pine to 56.2 percent for Douglas-fir (table 1). In the partial cut treatment at both sites, Engelmann spruce and lodgepole pine had the lowest gopher-caused mortality relative to the other species.

Gopher-caused mortality by time periods is shown in tables 2 and 3. At French Mountain, gophers were controlled in July of the first and second summers, and there was virtually no gopher-caused mortality during those two summers. Gopher-caused mortality was extremely low in the clearcut treatment, even after gophers were no longer controlled. Most additional gopher-caused mortality at French Mountain occurred in the partial and uncut treatments during the winter time periods.

At Little Big Hole (no gopher control), most gopher-caused mortality occurred the first summer, the first winter, and the second winter (table 3). In the clearcut treatment, gopher-caused mortality for all species averaged 14.5 percent the first summer, 25.2 percent the first winter, and 6.2 percent the second winter. This means that 89.1 percent of all gopher-caused mortality in the clearcut treatment took place during those three time periods. Corresponding averages for the partial cut treatment are 1.5 percent the first summer, 12.2 percent the first winter, and 5.5 percent the second winter; therefore, 68.6 percent of the gopher-caused mortality in the partial cut treatment took place during those three time periods. In the uncut treatment, 57.9 percent of all the seedlings that were killed by gophers died the first summer, first winter, and second winter.

Another feature about gopher-caused mortality is that it was higher in some areas of the treatments than in other areas. For

Table 2—Gopher-caused mortality (percent) by time periods at French Mountain.

Species	Summer 1	Winter 1	Summer 2	Winter 2	Summer 3	Winter 3	Summer 4	Winter 4	Summer 5	Winter 5	Cum. % mort.
Clearcut											
DF	0.0	1.2	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	2.5
ES	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	1.2	0.0	2.5
LP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WL	0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.2	0.0	0.0	2.5
WP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
All	0.0	0.2	0.2	0.0	0.0	0.2	0.2	0.2	0.2	0.0	1.5
Partial cut											
DF	1.2	3.8	0.0	2.5	0.0	16.2	1.2	5.0	1.2	0.0	31.2
ES	0.0	1.2	0.0	1.2	0.0	1.2	0.0	0.0	0.0	2.5	6.2
LP	0.0	0.0	1.2	1.2	0.0	1.2	0.0	0.0	0.0	0.0	3.8
WL	0.0	7.5	0.0	2.5	0.0	1.2	0.0	3.8	1.2	0.0	16.2
WP	0.0	0.0	0.0	1.2	0.0	2.5	1.2	0.0	0.0	1.2	6.2
All	0.2	2.5	0.2	1.7	0.0	4.5	0.5	1.8	0.5	0.7	12.7
Uncut											
DF	0.0	0.0	0.0	5.0	0.0	5.0	2.5	0.0	0.0	2.5	15.0
ES	0.0	0.0	0.0	8.8	0.0	1.2	0.0	0.0	0.0	0.0	10.0
LP	0.0	0.0	0.0	3.8	0.0	5.0	3.8	2.5	0.0	2.5	17.5
WL	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	2.5
WP	0.0	0.0	0.0	1.2	0.0	7.5	1.2	0.0	0.0	1.2	11.2
All	0.0	0.0	0.0	4.3	0.0	3.7	1.5	0.5	0.0	1.2	11.2

Table 3—Gopher-caused mortality (percent) by time periods at Little Big Hole.

Species	Summer 1	Winter 1	Summer 2	Winter 2	Summer 3	Winter 3	Summer 4	Winter 4	Summer 5	Winter 5	Cum. % mort.
Clearcut											
DF	8.8	41.2	0.0	3.8	0.0	0.0	0.0	2.5	0.0	0.0	56.2
ES	10.0	18.8	0.0	13.8	0.0	3.8	0.0	2.5	0.0	1.2	50.0
LP	8.8	30.0	2.5	3.8	0.0	1.2	0.0	1.2	0.0	0.0	47.5
WL	13.8	21.2	3.8	5.0	2.5	1.2	0.0	1.2	0.0	1.2	50.0
WP	31.2	15.0	1.2	5.0	0.0	1.2	0.0	0.0	0.0	0.0	53.8
All	14.5	25.2	1.5	6.2	0.5	1.5	0.0	1.5	0.0	0.5	51.5
Partial cut											
DF	2.5	15.0	0.0	6.2	0.0	3.8	0.0	3.8	0.0	1.2	32.5
ES	1.2	10.0	0.0	1.2	0.0	2.5	0.0	2.5	0.0	1.2	18.8
LP	0.0	7.4	1.2	5.0	0.0	0.0	0.0	1.2	0.0	0.0	14.8
WL	2.5	12.5	1.2	10.0	0.0	5.0	1.2	3.8	0.0	5.0	41.2
WP	1.2	16.4	3.8	5.0	0.0	3.8	0.0	1.2	0.0	1.3	32.9
All	1.5	12.2	1.2	5.5	0.0	3.0	0.2	2.5	0.0	1.8	28.0
Uncut											
DF	2.5	1.2	0.0	0.0	0.0	0.0	3.8	2.5	0.0	5.0	15.0
ES	3.8	2.5	0.0	1.2	0.0	0.0	0.0	0.0	0.0	5.0	12.5
LP	2.5	2.5	1.2	0.0	1.2	1.2	0.0	0.0	0.0	2.5	11.2
WL	3.8	5.0	1.2	0.0	0.0	0.0	2.5	0.0	0.0	0.0	12.5
WP	6.2	12.5	0.0	0.0	0.0	0.0	1.2	1.2	0.0	3.8	25.0
All	3.8	4.8	0.5	0.2	0.2	0.2	1.5	0.8	0.0	3.2	15.2

example, the eight rectangular plots in the clearcut treatment at Little Big Hole had a low of 24.0 percent gopher-caused mortality after 5 years and a high of 84.0 percent. Mortality in three of the plots was relatively low (24.0, 28.0, 32.0 percent), two intermediate (42.0, 44.0 percent), and three high (76.0, 82.0, 84.0 percent).

Seedling mortality not caused by gophers was substantial, and it varied by treatment and species 5 years after planting (table 4). The uncut treatment had the highest nongopher-caused mortality, averaging 67.5 percent at French Mountain and 47.6 percent at Little Big Hole; both of these averages are over twice as high as in the clearcut or partial cut treatments. Most of the mortality not caused by gophers in uncut treatments was attributed to unknown causes. Seedlings probably died from lack of adequate sunlight in these dense treatments, especially western larch, which is very intolerant of shade (Minore 1979).

At both French Mountain and Little Big Hole, 5-year nongopher mortality rates were similar in the clearcut and partial cut treatments (table 4). Therefore, partial retention of the overstory did not increase levels of mortality from nongopher causes.

Figures 1 and 2 summarize the status of all seedlings, whether alive after 5 years or dead from various causes. These figures reinforce two results. First, gopher control resulted in higher seedling survival in the clearcut treatment (fig. 1). Second, where gophers were not controlled, the partial cut treatment resulted in the highest percentage of live trees at 5 years (fig. 2).

The overall survival of planted trees in figures 1 and 2 is also shown in table 5. At French Mountain (where gophers were controlled the first two summers), survival is highest in the clearcut (71.2 percent), intermediate in the partial cut (54.5 percent), and lowest in the uncut treatment (21.3 percent). The results at French Mountain show that the clearcut treatment is best for overall survival if gophers are controlled. At Little Big Hole (where gophers were not controlled), survival was highest in the partial cut (54.7 percent), intermediate in the uncut stand (37.2 percent), and lowest in the clearcut treatment (28.2 percent). The results at Little Big Hole show that the partial cut treatment is best for overall survival if gophers are not controlled.

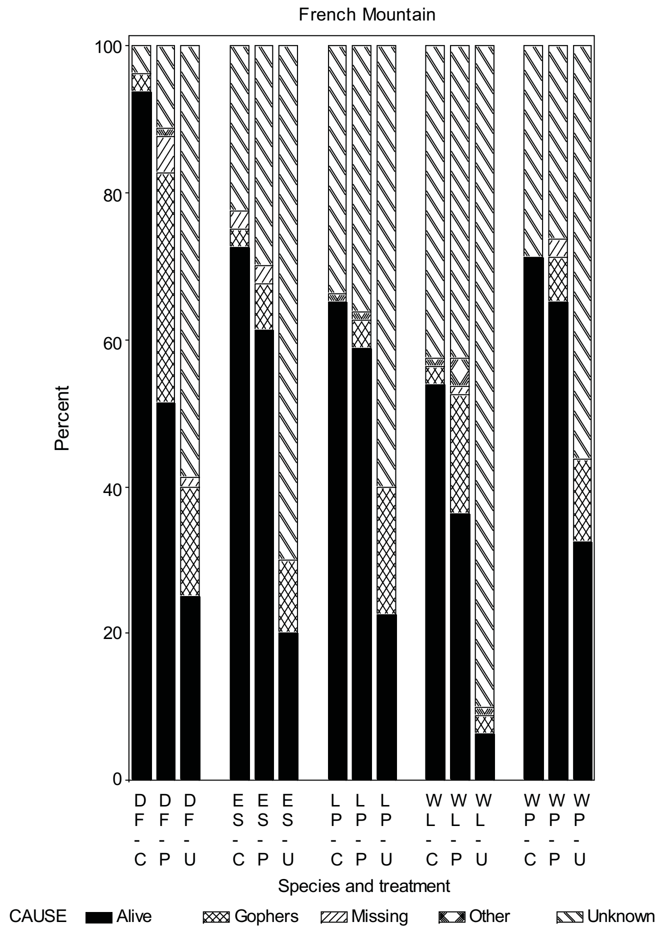

Figure 1—Seedling status 5 years after planting at French Mountain by species and treatment. DF=Douglas-fir, ES=Engelmann spruce, LP = Lodgepole pine, WL=Western larch, WP=White pine, C=Clearcut, P=Partial cut, U=Uncut. Filled portions on bars are live trees. Open patterns on bars are dead trees killed by various causes.

Table 4—Average nongopher seedling mortality (percent) 5 years after planting.

Treatment	DF	ES	LP	WL	WP	All
			French Mountain			
Clearcut	3.8	25.0	35.1	43.8	28.8	27.3
Partial	17.6	32.5	37.6	47.6	28.8	32.8
Uncut	60.1	70.0	60.0	91.3	56.3	67.5
			Little Big Hole			
Clearcut	21.3	21.3	12.5	23.8	22.6	20.3
Partial	16.3	16.3	12.4	16.4	25.3	17.3
Uncut	53.8	28.9	46.3	76.3	32.6	47.6

Western larch had the poorest overall survival of all species tested (table 5)—a result caused by both gopher and nongopher causes. Survival of Douglas-fir in the clearcut treatment was highest at French Mountain (93.7 percent) and lowest at Little Big Hole (22.5 percent). Lodgepole pine survival ranked highest among the five species at Little Big Hole in the clearcut and partial cut treatments. At Little Big Hole in the uncut and partial cut treatments, Engelmann spruce survival ranked first and second, respectively, among the five species.

Seedling survival in the uncut treatment was surprisingly high (table 5). At French Mountain, 21.3 percent of seedlings were alive after 5 years in the uncut treatment, and 37.2 percent were alive at Little Big Hole. Western larch, the most shade-

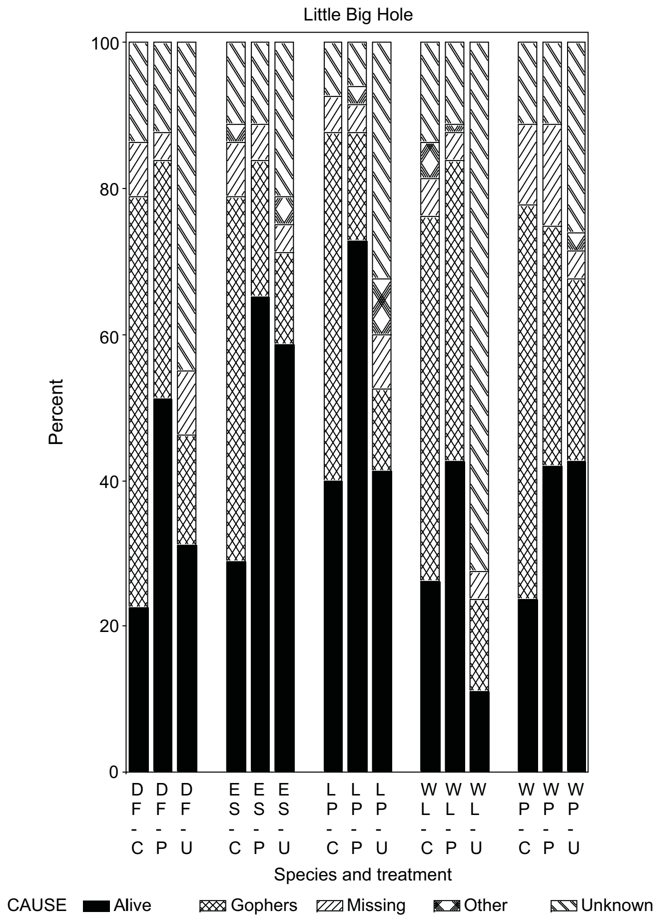

Figure 2—Seedling status 5 years after planting at Little Big Hole by species and treatment. DF=Douglas-fir, ES=Engelmann spruce, LP = Lodgepole pine, WL=Western larch, WP=White pine, C=Clearcut, P=Partial cut, U=Uncut. Filled portions on bars are live trees. Open patterns on bars are dead trees killed by various causes.

Table 5—Percent seedling survival 5 years after planting.

Treatment	DF	ES	LP	WL	WP	All
			French Mountain			
Clearcut	93.7	72.5	64.9	53.7	71.2	71.2
Partial	51.1	61.3	58.6	36.2	65.0	54.5
Uncut	24.9	20.0	22.5	6.2	32.5	21.3
			Little Big Hole			
Clearcut	22.5	28.7	40.0	26.2	23.6	28.2
Partial	51.2	64.9	72.8	42.4	41.8	54.7
Uncut	31.2	58.6	42.5	11.2	42.4	37.2

Table 6—Average seedling heights (feet) 5 years after planting.

Treatment	DF	ES	LP	WL	WP	All
			French Mountain			
Clearcut	2.9	2.4	3.6	3.4	2.4	2.6
Partial	1.8	1.4	1.9	2.2	1.7	1.6
Uncut	1.3	1.1	1.0	1.9*	1.1	1.0
			Little Big Hole			
Clearcut	1.6	1.7	3.1	4.0	1.5	2.7
Partial	1.2	1.3	1.8	2.0	1.1	1.6
Uncut	0.7	0.8	0.8	1.0*	0.6	0.7

*fewer than 10 trees used to calculate average

intolerant species in the study, had the lowest survival in the uncut treatment.

Growth—Seedling heights 5 years after planting, by species at both sites, were always largest in the clearcut, intermediate in the partial cut, and smallest in the uncut treatment (table 6). Average seedling heights for the five test species at French Mountain were 2.6 feet in the clearcut, 1.6 feet in the partial cut, and 1.0 foot in the uncut treatment. At Little Big Hole, average seedling heights at 5 years were 2.7 feet in the clearcut, 1.6 feet in the partial cut, and 0.7 foot in the uncut treatment. Lodgepole pine and western larch were the tallest of the five species treated.

Average 5-year heights of seedlings in the uncut treatment were low. Seedlings in the uncut treatment grew slowly because of the dense overstory shade, and they often had negative height growth because of terminal damage caused by pocket gophers, snow, or various other environmental causes.

Damages—The damages that occurred to the five test species were grouped into four categories by site, treatment, and species. Categories were:

1. Damage to the top of seedlings (terminal broken, terminal chewed by unknown animal, terminal chewed by gopher, and terminal dead).
2. Forked (two or more leaders).
3. Severe lean (which we defined as greater than or equal to 40 percent lean from vertical).
4. Gopher damage (branches chewed by gopher, main stem buried by gopher mound, terminal chewed by gopher {also included in the top damage category}, lateral branch chewed by gopher, seedling loose in the soil because of gopher feeding on the roots, and main stem chewed by gopher).

Top damage varied from a low of 5.5 percent for Engelmann spruce in the French Mountain clearcut treatment to 75.8 percent for western larch in the French Mountain uncut treatment (table 7). In nearly every instance, top damage was least in the clearcut, intermediate in the partial cut, and highest in the uncut treatment. Western larch was clearly the species with the most top damage.

Table 7—Percent of damaged seedlings by site, treatment, species, and cause of damage 5 years since planting.

Damage category	Species	French Mountain Clearcut	French Mountain Partial	French Mountain Uncut	Little Big Hole Clearcut	Little Big Hole Partial	Little Big Hole Uncut
Top	DF	13.5	23.8	32.0	8.9	12.0	33.4
	ES	6.4	14.9	36.4	5.4	5.5	18.9
	LP	7.2	18.1	43.9	17.0	10.0	32.3
	WL	21.3	49.9	75.8	23.0	23.6	40.0
	WP	5.0	10.3	40.1	16.2	16.2	30.0
Forked	DF	17.7	13.3	7.9	23.8	18.6	21.4
	ES	8.9	12.8	9.5	9.6	12.1	17.5
	LP	11.1	11.9	9.3	22.8	13.6	17.0
	WL	16.6	19.8	7.6	16.6	13.3	4.1
	WP	10.2	11.4	12.3	18.6	18.5	20.4
≥40% lean	DF	1.4	10.9	18.7	2.1	3.8	11.3
	ES	0.6	3.5	3.5	1.6	0.9	5.0
	LP	0.4	5.2	19.1	3.2	3.5	18.4
	WL	3.7	21.3	28.4	8.1	12.3	39.1
	WP	1.9	8.0	17.1	3.3	4.6	7.4
Gopher	DF	1.0	5.1	6.4	8.2	6.2	9.0
	ES	0.8	3.1	7.4	4.5	3.2	10.0
	LP	1.1	3.0	7.1	9.1	5.7	11.7
	WL	0.6	6.2	9.5	7.1	8.2	6.6
	WP	0.4	3.6	9.4	9.5	6.7	11.1

The percentage of seedlings with forked tops varied from 4.1 percent for western larch in the Little Big Hole uncut treatment to 23.8 percent for Douglas-fir in the Little Big Hole clearcut treatment (table 7). Even though the percentage of seedlings with top damage increased with increasing overstory density, the percentage of seedlings with forked tops did not follow the same trend. For example, western larch had 75.8 percent top damage in the French Mountain uncut treatment, but only 7.6 percent forking. Across all treatments and sites, Engelmann spruce had the least forking (11.7 percent) and Douglas-fir had the most forking (17.1 percent).

Snow damage to seedlings was common. The number of leaning trees was always highest in the spring inventories and lowest in the fall inventories. Seedlings frequently recovered from snowlean during the summer. The average percentages of seedlings with severe lean are shown in table 7. Averages varied from 0.4 percent for lodgepole pine in the French Mountain clearcut treatment to 39.1 percent for western larch in the Little Big Hole uncut treatment. Severe lean increased with increasing overstory density, except for Engelmann spruce at Little Big Hole. Across all treatments and sites, there were low averages for Engelmann spruce (2.5 percent), intermediate averages for white pine (7.0 percent), Douglas-fir (8.0 percent), and lodgepole pine (8.3 percent), and high averages for western larch (18.8 percent).

Seedlings eventually grew large enough to withstand the heavy snow loads, and since seedling growth was negatively related to overstory density, seedlings in the clearcut treatment were the first to become large enough to withstand snow loads (table 8). Engelmann spruce had the lowest number of winter time periods where severe lean occurred on greater than or equal to10 percent of the seedlings versus highest averages for

Table 8—Number of winters (out of five) when severe lean (≥40 percent from vertical) occurred on ≥10 percent of the seedlings.

Species	French Mountain Clearcut	French Mountain Partial	French Mountain Uncut	Little Big Hole Clearcut	Little Big Hole Partial	Little Big Hole Uncut
DF	0	2	4	1	2	4
ES	0	1	2	0	0	2
LP	0	3	5	1	1	4
WL	1	5	5	3	4	5
WP	1	3	5	1	2	2

lodgepole pine and western larch. Across all treatments and sites, severe lean occurred approximately the first winter in the clearcut, winters 1 and 2 in the partial cut, and winters 1 through 3 in the uncut treatment (data not shown).

Nonlethal pocket gopher damages to seedlings varied from 0.4 percent for white pine in the French Mountain clearcut treatment to 11.7 percent for lodgepole pine in the Little Big Hole uncut treatment (table 7). In general, gopher-caused damages were less at French Mountain, where gophers were controlled for 2 years, compared to Little Big Hole, where gophers were not controlled. At French Mountain, gopher-caused damages increased with increasing shade. At Little Big Hole, gopher-caused damages were lowest in the partial cut treatment, except for western larch. Within treatment and site, there were no strong differences between the five test species relative to gopher damages.

Additional Plantings

Table 9 shows summary statistics for the summer and fall planted western white pine at French Mountain compared to the spring planted white pine. Each planting time has 120 trees (3 treatments x 4 rectangular plots x 10 tree rows).

Few trees were killed by pocket gophers in the clearcut treatment, while more trees were killed by gophers in the partial and uncut treatments (table 9). Within the partial and uncut treatments, more summer and fall planted white pine were killed by gophers than spring planted seedlings. A total of 12.5 percent of spring planted white pine were killed by gophers in the partial cut treatment, while 30.0 percent of the summer and 20.0 percent of the fall planted white pine were killed by gophers. Similarly, 7.5 percent of the spring planted white pine were killed by gophers, while 20.0 percent of the summer planted and 17.5 percent of the fall planted white pine were killed by gophers. In the partial cut and uncut treatments, gopher-caused mortality remained relatively high during the third winter for summer planted and fall planted white pine (data not shown).

Generally, death from nongopher causes increased as the amount of overstory shade increased, regardless of planting time (table 9). A large difference in mortality occurred in the clearcut treatment where only 17.5 percent of summer-planted white pine died from nongopher causes, while 35.0 percent of the spring-planted and 32.5 percent of the fall-planted white pine died from nongopher causes.

Overall survival of the three planting times for white pine was always highest in the clearcut, intermediate in the partial cut, and lowest in the uncut treatments (table 9). Summer-planted white pine had the highest overall survival (80.0 percent) in the clearcut, but had the lowest survival (27.5 percent) in the uncut treatment. In the partial cut treatment, spring-planted white pine had the best overall survival (62.5 percent).

There is a definite trend of declining 5-year heights of white pine with later plantings (table 9). For example, seedling heights in the clearcut treatment after 5 years were 2.4 feet for spring planting, 1.3 feet for summer planting, and 1.0 foot for fall planting. The partial and uncut treatments follow the same trend. Also, there is a clear decline in heights as the amount of overstory shade increases.

Table 10 shows summary statistics for 3-1 versus 1-0 western white pine and 2-0 versus 1-0 Douglas-fir at Little Big Hole. Each age class for white pine has 80 trees (2 treatments x 4 rectangular plots x 10 tree rows). Douglas-fir age classes have 30 trees each in the clearcut treatment and 20 trees each in the partial cut treatment.

There was higher gopher-caused mortality for 3-1 white pine (75.0 percent) versus 1-0 (60.0 percent) in the clearcut, with the same trend in the partial cut treatment (table 10). However, death from nongopher causes was much lower for 3-1 versus 1-0 white pine. The 3-1 white pine in the clearcut treatment had zero percent nongopher-caused mortality after 5 years, while there was 17.5 percent for 1-0 white pine. The partial cut treatment was similar, with 5.0 percent nongopher-caused mortality for 3-1 white pine versus 25.0 percent for 1-0 white pine.

Overall survival was slightly higher in the clearcut treatment for 3-1 white pine (25.0 percent) versus 1-0 (22.5 percent), and survival in the partial cut treatment was higher for 3-1 white pine (62.5 percent) versus 1-0 (47.5 percent). Also, survival was much higher for white pine in the partial cut than the clearcut treatment.

Seedlings were taller for 3-1 white pine than 1-0 (table 10). After 5 years, 3-1 white pine seedlings were approximately twice the height of 1-0 seedlings in both the clearcut and partial

Table 9—Fifth year summary statistics for spring-, summer-, and fall-planted western white pine at French Mountain.

Treatment	Spring planted	Summer planted	Fall planted
	Death caused by gophers (%)		
Clearcut	0.0	2.5	0.0
Partial	12.5	30.0	20.0
Uncut	7.5	20.0	17.5
	Dead from nongopher causes (%)		
Clearcut	35.0	17.5	32.5
Partial	25.0	22.5	35.0
Uncut	55.0	52.5	45.0
	Alive (%)		
Clearcut	65.0	80.0	67.5
Partial	62.5	47.5	45.0
Uncut	37.5	27.5	37.5
	Average seedling heights (feet)		
Clearcut	2.4	1.3	1.0
Partial	1.6	1.0	0.8
Uncut	1.1	0.5	0.5

Table 10—Summary statistics for 3-1 versus 1-0 western white pine and 2-0 versus 1-0 Douglas-fir at Little Big Hole 5 years after planting.

Treatment	WP 1 year old	WP 3 years old	DF 1 year old	DF 2 years old
		Death caused by gophers (%)		
Clearcut	60.0	75.0	63.3	6.7
Partial	27.5	32.5	40.0	5.0
		Dead from nongopher causes (%)		
Clearcut	17.5	0.0	20.0	3.3
Partial	25.0	5.0	0.0	0.0
		Alive (%)		
Clearcut	22.5	25.0	16.7	90.0
Partial	47.5	62.5	60.0	95.0
		Average seedling heights (feet)		
Clearcut	1.7	3.3	1.5	3.2
Partial	1.1	1.8	1.0	1.7

cut treatments. Both 3-1 and 1-0 white pine were taller in the clearcut than the partial cut treatment.

Planting success for the 2-0 Douglas-fir was much better than for 1-0 Douglas-fir (table 10). Pocket gophers killed 63.3 percent of 1-0 Douglas-fir in the clearcut treatment, but only 6.7 percent of 2-0 Douglas-fir. Similarly, gophers killed 40.0 percent of the 1-0 Douglas-fir in the partial cut treatment, but only 5.0 percent of the 2-0 Douglas-fir. Death from nongopher causes in the clearcut treatment was 20.0 percent for 1-0 Douglas-fir and 3.3 percent for 2-0. No Douglas-fir seedlings died from nongopher causes in the partial cut treatment.

Overall survival of Douglas-fir in the clearcut treatment was lowest for 1-0 seedlings (16.7 percent) and highest for 2-0 seedlings (90.0 percent). Survival of Douglas-fir in the partial cut treatment was lowest for 1-0 seedlings (60.0 percent) versus 2-0 seedlings (95.0 percent). As was the case with white pine, overall survival of Douglas-fir was higher in the partial cut than the clearcut treatment, especially for the 1-0 seedlings.

Seedling heights were taller for 2-0 versus 1-0 Douglas-fir in both the clearcut and partial cut treatments (table 10). For example, 2-0 Douglas-fir were 3.2 feet tall after 5 years in the clearcut treatment, while 1-0 Douglas-fir were 1.5 feet tall. Both 2-0 and 1-0 Douglas-fir were taller in the clearcut than the partial cut treatment.

Pocket Gopher Activity

An average winter pocket gopher activity index was calculated from the line transects installed in the rectangular plots. For each 15 foot line transect, we counted the number of times the line intersected a pocket gopher mound, cast, or soil plug. At French Mountain for the 3 years when gophers were not controlled (1998 to 2000), the average gopher activity index was 2.1 in the clearcut, 4.5 in the partial cut, and 1.2 in the uncut treatments. At Little Big Hole, the 5-year (1998 to 2002) gopher activity index was 4.9 in the clearcut, 4.1 in the partial cut, and 1.9 in the uncut treatments.

Pearson correlation coefficients between the gopher activity index and gopher-caused mortality to planted seedlings during winter time periods are shown in table 11, and scatter plots are shown in figure 3. At French Mountain where gophers were controlled in the summers of 1996 and 1997, the gopher

Table 11—Pearson's correlation coefficients showing correlation between pocket gopher activity index and gopher-caused mortality to planted seedlings, by site.

Winter number	French Mountain: Gopher activity index	French Mountain: % gopher-caused mortality	French Mountain: Correlation	Little Big Hole: Gopher activity index	Little Big Hole: % gopher-caused mortality	Little Big Hole: Correlation
1	0.58	0.92	0.02	4.25	14.08	0.72*
2	2.12	2.00	0.82*	3.63	4.00	0.60*
3	2.00	2.83	0.48*	3.08	1.58	0.02
4	2.58	0.83	0.35	3.33	1.58	0.03
5	3.21	0.67	0.25	3.79	1.83	0.38

* significant at the 0.05 confidence level

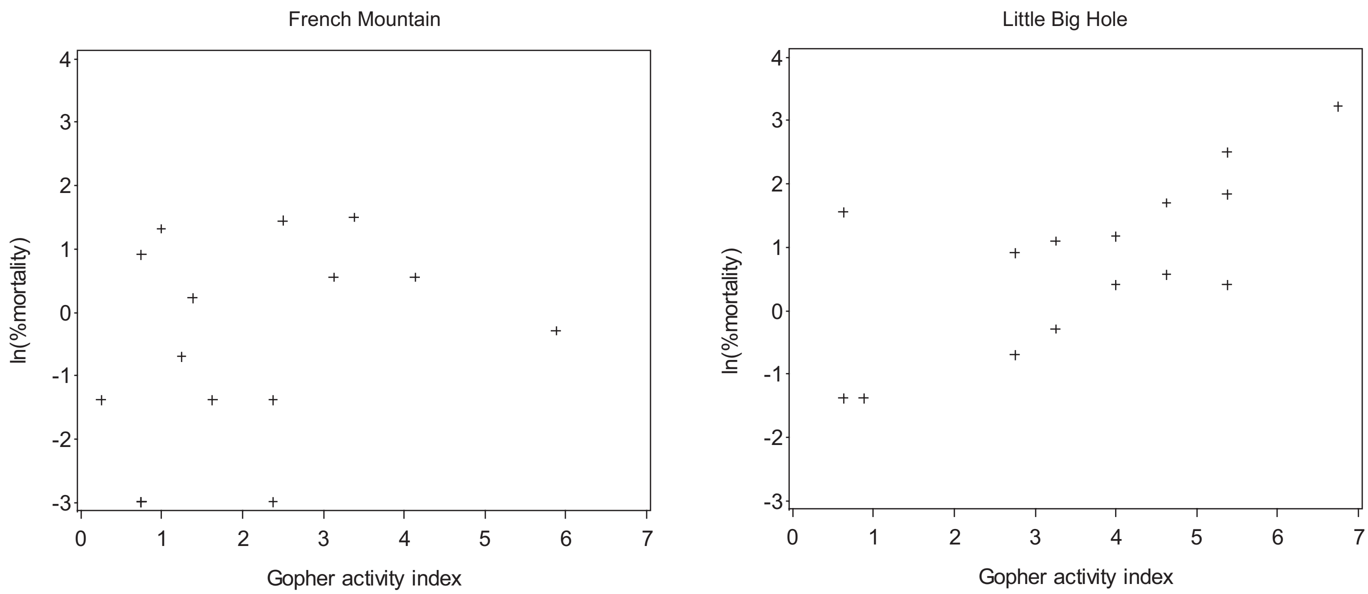

Figure 3—Scatter plots of gopher-caused seedling mortality (natural log scale) versus the gopher activity index.

activity indices account for virtually no correlation with gopher-caused mortality the first winter (0.02), a significant correlation the second winter (0.82), a smaller but still significant correlation in winter 3 (0.48), and nonsignificant correlations in winters 4 (0.35) and 5 (0.25). The pocket gopher index was low in all three treatments the first winter after planting, which likely resulted from pocket gopher control. Significant correlations during the second and third winters agree with high gopher-caused seedling mortality during winters 2 and 3 (table 2).

At the Little Big Hole site where gophers were not controlled, the correlation between pocket gopher activity and gopher-caused mortality is significant the first and second winters (0.72 and 0.60, respectively), then is nonsignificant in winters 3, 4, and 5. Significant correlations during the first and second winters agree with high gopher-caused seedling mortality during winters 1 and 2 (table 3). Gopher activity continued after the second winter, but gophers killed few additional seedlings.

Natural Regeneration and Vegetation

The 1/300-acre circular plots were used to record natural regeneration and vegetation development. There were 10 circular plots in each site/treatment combination.

Establishment of natural regeneration by 2003 was sparse. The best stocking was found in the clearcut treatment at French Mountain, where 13 seedlings were found on eight of the 10 1/300-acre circular plots, totaling 390 trees per acre. Species composition was Douglas-fir, Engelmann spruce, and grand fir. Only three seedlings were found on two plots in the partial cut treatment at French Mountain, and no seedlings were found in the uncut treatment.

In 2003, seven seedlings were found on five plots in the clearcut treatment at Little Big Hole, totaling 210 trees per acre. Species in the clearcut were Engelmann spruce (three trees), grand fir (three), and western larch (one). Four plots were stocked with seven seedlings in the partial cut treatment (210 trees per acre), consisting of Douglas-fir (one tree), Engelmann spruce (two), and grand fir (four). The uncut treatment at Little Big Hole had only one tree on 10 plots—a lodgepole pine.

Nonconifer vegetation responded differently to the treatments, yet responses by species were similar at both sites. We chose five species for analysis that had the highest constancy during the study to characterize vegetation dynamics initiated by the treatments.

Rocky Mountain maple (*Acer glabrum*) coverage decreased over time in the clearcut treatment from pretreatment averages of 3.0 percent at French Mountain and 2.3 percent at Little Big Hole to nearly absent in 2003 (table 12). Coverage declined only slightly in the partial cut treatment. Constancy (the percentage of plots with maple) declined an average of 22.5 percent over time in both the clearcut and partial cut treatments at both sites (table 13). Most of the decline in maple coverage took place between the pre- and postharvest inventories, but most of the decline in constancy took place after the postharvest inventory.

Pacific yew (*Taxus brevifolia*) had moderate coverage and constancy before the clearcut treatment, but was entirely gone in 2003 at both clearcut sites (tables 12 and 13). The largest decline was between the pre- and postharvest inventories. Yew

Table 12—Percent coverage of representative plant species, by site, treatment, and year.

Species*	Treatment	French Mountain Preharvest (1994)	French Mountain Postharvest (1996)	French Mountain Postharvest (2003)	Little Big Hole Preharvest (1995)	Little Big Hole Postharvest (1997)	Little Big Hole Postharvest (2003)
ACGL	Clearcut	3.0	0.3	0.1	2.3	0.1	0.0
	Partial	5.7	4.2	4.2	0.7	0.3	0.6
	Uncut	2.1	3.1	2.3	0.2	–	0.1
TABR	Clearcut	10.5	0.0	0.0	0.4	0.1	0.0
	Partial	15.5	8.3	10.0	0.4	0.2	0.1
	Uncut	9.0	9.6	7.7	18.3	–	15.2
VAME	Clearcut	6.1	0.5	0.8	0.3	0.2	0.1
	Partial	8.3	7.4	11.3	0.4	0.2	0.5
	Uncut	17.2	19.1	19.2	0.7	–	1.2
PTAQ	Clearcut	1.6	5.2	18.2	2.8	2.5	8.8
	Partial	0.1	1.7	1.1	3.0	1.0	5.5
	Uncut	0.6	0.6	1.1	12.3	–	3.4
RUOC	Clearcut	0.0	0.0	0.2	3.4	4.2	40.5
	Partial	0.1	2.1	4.6	0.7	1.2	14.7
	Uncut	1.7	4.1	3.1	1.6	–	2.9

*ACGL = *Acer glabrum* (Rocky Mountain maple); TABR = *Taxus brevifolia* (Pacific yew); VAGL = *Vaccinium membranaceum* (big huckleberry); PTAQ = *Pteridium aquilinum* (bracken fern); RUOC = *Rudbeckia occidentalis* (western coneflower); – = no data

coverage declined slightly after the partial cut treatment at French Mountain, but constancy increased. Yew coverage and constancy both decreased over time at the Little Big Hole partial cut treatment, which was also the trend in the uncut treatment.

Big huckleberry (*Vaccinium membranaceum*) coverage declined in the clearcut treatment at both sites and is barely represented in the 2003 inventory (table 12). In the partial cut treatment, huckleberry coverage showed slight declines after treatment and is increasing slightly over pretreatment coverages (table 12), and constancy follows this same pattern (table 13).

Bracken fern increased in coverage and constancy after the clearcut and partial cut treatments at both sites. Increases in bracken were largest at French Mountain compared to Little Big Hole. In the French Mountain clearcut treatment, average bracken coverage increased from 1.6 percent pretreatment to 18.2 percent in 2003 (table 12). At the Little Big Hole clearcut

Table 13—Constancy (percent) of representative plant species, by site, treatment, and year.

Species	Treatment	French Mountain Preharvest (1994)	French Mountain Postharvest (1996)	French Mountain Postharvest (2003)	Little Big Hole Preharvest (1995)	Little Big Hole Postharvest (1997)	Little Big Hole Postharvest (2003)
ACGL	Clearcut	30	30	10	40	10	0
	Partial	80	60	60	30	30	20
	Uncut	30	40	50	20	–	10
TABR	Clearcut	20	0	0	40	10	0
	Partial	40	70	70	40	20	10
	Uncut	20	30	40	90	–	70
VAME	Clearcut	40	10	40	30	20	10
	Partial	80	60	70	40	20	50
	Uncut	60	50	60	70	–	80
PTAQ	Clearcut	70	70	100	70	80	80
	Partial	10	30	20	90	60	90
	Uncut	20	20	20	70	–	70
RUOC	Clearcut	0	0	20	70	70	100
	Partial	10	20	30	70	80	100
	Uncut	30	30	30	20	–	60

treatment, average bracken coverage increased from 2.8 percent pretreatment to 8.8 percent in 2003. Constancy of bracken in 2003 is 100 percent at French Mountain and 80 percent at Little Big Hole in the clearcut treatment (table 13). Bracken coverage increased slightly in the partial cut treatment at both sites.

Western coneflower increased in coverage and constancy after the clearcut and partial cut treatments at both sites. Increases in coneflower were largest at Little Big Hole compared to French Mountain. Average coverage for western coneflower increased from 3.4 percent preharvest to 40.5 percent in 2003 at Little Big Hole in the clearcut treatment (table 12). Average coverage of coneflower in the French Mountain clearcut treatment was only 0.2 percent in 2003, but constancy had increased from zero to 20 percent. Constancy of coneflower at Little Big Hole in 2003 is 100 percent in both the clearcut and partial cut treatments (table 13). Western coneflower coverage increased somewhat in the partial cut treatment at both sites—from 0.1 percent pretreatment to 4.6 percent in 2003 at French Mountain, and from 0.7 percent pretreatment to 14.7 percent in 2003 at Little Big Hole.

In table 14 we summarize the relationship between the combined coverage of shrubs and the combined coverage of bracken/coneflower. The average sum of coverages for individual shrubs was compared to the average sum of coverages for bracken and coneflower by site and treatment. In the clearcut treatment, there is a decline in the sum of coverages for shrubs, especially at French Mountain where average preharvest coverage of 20.9 percent dropped to 3.5 percent in 2003. There is a corresponding increase in bracken/coneflower in the clearcut treatment; increasing from 1.6 percent preharvest to 18.4 percent in 2003 at French Mountain, and increasing from 6.2 percent preharvest to 49.3 percent in 2003 at Little Big Hole. In the partial cut treatment, shrub cover decreases over time, with a corresponding increase in bracken/coneflower coverage; however, the changes are not large compared to the changes occurring in the clearcut treatment.

In addition to increases in bracken fern and western coneflower constancy, other forb species increased or decreased substantially as a result of the treatments. Forb species that decreased following treatment were pathfinder (*Adenocaulon bicolor*), queen cup beadlily (*Clintonia uniflora*), and starry Solomon-seal (*Maianthemum stellatum* = *Smilacina stellata*).

Pathfinder constancy decreased in the clearcut treatment from 100 percent preharvest to 70 percent in 2003 at French Mountain, and from 90 percent preharvest to 30 percent in 2003 at Little Big Hole. Constancy at both sites in the partial cut treatment remained about the same.

Constancy of queen cup beadlily decreased in the clearcut treatment from 90 percent preharvest to 30 percent in 2003 at French Mountain, and from 40 percent pretreatment to 0 percent in 2003 at Little Big Hole. Constancy at both sites in the partial cut treatment remained about the same.

Starry Solomon-seal constancy decreased in the clearcut treatment at both sites but stayed about the same in the partial cut treatment. At French Mountain, constancy decreased in the clearcut treatment from 80 percent preharvest to 10 percent in 2003. At Little Big Hole, the decrease was from 100 percent preharvest to 60 percent in 2003.

Forb species that increased substantially following treatment were fireweed (*Chamerion* spp. = *Epilobium* spp.), strawberry (*Fragaria vesca*), globemallow (*Iliamna rivularis*), varileaf phacelia (*Phacelia heterophylla*), and thistle species (*Cirsium* spp.).

Fireweed constancy increased in both the partial cut and clearcut treatments. Preharvest constancy was zero in both treatments at both sites. By 2003, fireweed constancy increased to 10 percent in the French Mountain partial cut, 70 percent in the French Mountain clearcut, and 80 percent each in the Little Big Hole partial cut and clearcut treatments.

Strawberry increased in both the partial cut and clearcut treatments at both sites. At French Mountain, constancy increased from 30 percent preharvest in the partial cut treatment to 80 percent in 2003, and from 20 percent preharvest in the clearcut treatment to 100 percent in 2003. At Little Big Hole, constancy increased from 70 percent preharvest in the partial cut treatment to 80 percent in 2003, and from 60 percent preharvest in the clearcut treatment to 100 percent in 2003.

Globemallow was quite interesting because of high postharvest constancy in the French Mountain clearcut, the only place where this species was recorded. Globemallow stores seed in the soil, which then germinates following fires (see Smith and Fischer 1997). Probably as a result of the broadcast burn site preparation in the French Mountain clearcut treatment, globemallow constancy increased from zero per-

Table 14—Average sum of coverages (percent) for shrubs versus average sum of coverages for bracken/coneflower.

		French Mountain			Little Big Hole		
Treatment	Lifeform	Preharvest (1994)	Postharvest (1996)	Postharvest (2003)	Preharvest (1995)	Postharvest (1997)	Postharvest (2003)
Clearcut	Shrubs	20.9	2.6	3.5	4.4	1.1	3.4
	PTAQ/RUOC	1.6	5.2	18.4	6.2	6.7	49.3
Partial	Shrubs	33.7	25.3	29.8	3.8	1.8	2.7
	PTAQ/RUOC	2.0	3.8	5.7	3.7	2.2	20.2
Uncut	Shrubs	31.2	36.3	31.1	21.1	–	20.3
	PTAQ/RUOC	2.3	4.7	4.2	13.9	–	6.3

cent preharvest to 90 percent postharvest. New seeds from these globemallow plants are probably now stored in the soil, awaiting the next fire.

Varileaf phacelia increased following treatment at both sites in both the partial cut and clearcut treatments. No phacelia were recorded preharvest at French Mountain, but constancy in 2003 was 20 percent in the partial cut and 90 percent in the clearcut treatment. At Little Big Hole, phacelia constancy increased from 10 percent preharvest in the partial cut to 70 percent in 2003, and from 30 percent preharvest to 90 percent in 2003 in the clearcut treatment.

Thistles were not recorded in the preharvest inventory at French Mountain, but in 2003, constancies were 10 percent in the partial cut and 100 percent in the clearcut treatment. At Little Big Hole, thistle constancy increased from zero preharvest to 50 percent in 2003 in the partial cut, and from 20 percent preharvest to 70 percent in 2003 in the clearcut treatment.

Discussion

This study quantifies the tradeoffs among three levels of overstory density for plantation success, pocket gopher activity, and vegetation development.

If pocket gophers were controlled, the clearcut treatment was best for meeting reforestation objectives because of higher seedling survival and better growth rates. Gopher-caused mortality was only 1.5 percent at French Mountain where gophers were controlled versus 51.5 percent at Little Big Hole where gophers were not controlled. Nongopher causes of mortality were lower in the clearcut treatment, so overall seedling survival was highest in the clearcut treatment where gophers were controlled. For example, overall survival after 5 years in the French Mountain clearcut treatment averaged 71.2 percent for the five test species, while overall survival in the French Mountain partial cut treatment averaged 54.5 percent. Also, seedling heights were tallest in the clearcut treatment at both sites, regardless of gopher control. Average 5-year seedling heights in the clearcut treatment were 2.4 times taller than in the partial cut treatment at French Mountain, and 1.9 times taller than in the partial cut treatment at Little Big Hole. Seedlings in the uncut treatment grew very little.

If pocket gophers were not controlled, the partial cut treatment was best for meeting reforestation objectives because fewer seedlings were killed by gophers and seedling growth was adequate, compared to the clearcut treatment. At Little Big Hole (no gopher control), gophers killed 51.5 percent of the five test species within 5 years of planting in the clearcut treatment, while only 28.0 percent of seedlings were killed by gophers in the partial cut, and 15.2 percent were killed in the uncut treatment. Compared to the clearcut treatment, the partial cut treatment had lower gopher-caused mortality (28.0 versus 51.5 percent) and lower nongopher-caused mortality (17.3 versus 20.3 percent). Therefore, overall seedling survival was highest in the partial cut (54.7 percent), intermediate in the uncut (37.2 percent), and lowest in the clearcut treatment (28.2 percent). The partial cut treatment did not increase nongopher-caused mortality to seedlings relative to the clearcut treatment. Seedling heights were not as tall in the partial cut versus clearcut treatment; however, the nearly double survival in the partial cut versus clearcut treatment compensates for slower growth.

Of the seedling mortality caused by pocket gophers, most of it occurred during the first summer, the first winter, and the second winter after planting. At Little Big Hole, 89.1 percent of all the gopher-caused mortality in the clearcut treatment took place the first summer, first winter, and second winter. Corresponding averages were 68.6 percent for the partial cut and 57.9 percent for the uncut treatment. The finding of highest gopher-caused mortality during the first summer, first winter, and second winter is consistent with other research (Crouch 1971, Ferguson 1999).

Knowledge of the time periods when pocket gophers kill seedlings in GFM plantations allows managers to plan control strategies and design silvicultural prescriptions. If the objective is to reduce gopher predation on planted seedlings, our data suggest that gophers would need to be controlled prior to or at the time of spring planting, and throughout the summer if necessary. Before the end of the first summer (prior to the first winter time period), gophers may need to be controlled again because juvenile pocket gophers disperse in late spring, summer, or early fall (Marsh and Steele 1992). Gophers should again be controlled before the second winter. The objective of fall gopher control is to control gophers as late as possible (so the tunnels are not reinvaded prior to winter) but early enough that a thorough job can be done finding the gopher tunnels.

There appears to be no reason to control gophers in the spring/early summer beyond the first summer. Gophers preferentially feed on forbs that are plentiful during the growing season (Marsh and Steele 1992), and they killed few seedlings during the summers (other than the first summer after planting) in this and other studies (Crouch 1971, Ferguson 1999).

Increasing overstory density at Little Big Hole was associated with decreased pocket gopher activity. The 5-year average gopher activity index at Little Big Hole was 4.9 in the clearcut, 4.1 in the partial cut, and 1.9 in the uncut treatment. It is also interesting to note that gophers are present in uncut forests, which means that gophers do not need to invade a newly disturbed area because they are already present in undisturbed areas.

There was not a strong preference by pocket gophers for any of the five conifer species planted in the clearcut treatment. At Little Big Hole in the clearcut treatment, average 5-year gopher-caused mortality varied from a low of 47.5 percent for lodgepole pine to a high of 56.2 percent for Douglas-fir, a range of only 8.7 percent. Gopher-caused mortality to Engelmann spruce and lodgepole pine were relatively low in the partial cut treatment at both sites, which translated to high overall survival of spruce and lodgepole in the partial cut treatment. White pine also had lower gopher-caused mortality and high overall survival in the partial cut treatment at French Mountain.

The additional plantings provided information about options for managing GFM sites. The summer- and fall-planted white pine had higher gopher-caused mortality versus spring-planted in the partial and uncut treatments, so no advantage was gained by a delayed planting time. Delayed planting had a large negative effect on 5-year heights. Average seedling heights of spring-planted white pine in the clearcut treatment at French Mountain were 2.4 feet versus 1.3 feet for summer-planted and 1.0 foot for fall-planted white pine. Similar trends occurred in the partial and uncut treatments. Therefore, delayed planting was not beneficial for survival or growth.

The summer and fall plantings tested the idea of delayed planting to avoid anticipated gopher-caused mortality the first summer. An alternative test would be to plant seedlings in the fall before the usual spring planting; this schedule may have merit and should be tested because the seedlings would have time to acclimate to the planting site, expand their root systems, and begin growth early the next spring. However, fall-planted seedlings may be vulnerable to gopher predation during the winter when preferred food sources are not available.

Planting older/larger seedlings was helpful—both for increased survival and growth. The 2-0 Douglas-fir planted at Little Big Hole had less gopher-caused mortality than the 1-0 Douglas-fir (6.7 versus 63.3 percent in the clearcut, and 5.0 versus 40.0 percent in the partial cut treatment). Death from nongopher causes was also higher for 1-0 Douglas-fir, compared to 2-0 planting stock. Douglas-fir heights after 5 years were about double for 3-0 Douglas-fir (3.2 feet for 2-0 and 1.5 feet for 1-0) in the clearcut, and 1.7 times larger in the partial cut treatment.

Compared to the 1-0 white pine, the 3-1 white pine had higher gopher-caused mortality (75.0 versus 60.0 percent in the clearcut, and 32.5 versus 27.5 percent in the partial cut treatment), but 1-0 white pine had much higher mortality from nongopher causes. The 3-1 white pine were about twice as tall as 1-0 white pine (3.3 feet versus 1.7 feet) in the clearcut, and 1.6 times taller in the partial cut treatment (1.8 feet versus 1.1 feet).

The close spacing for planted seedlings (3.3 by 3.3 feet) was necessary for accurately relocating the exact planting spot to determine if the seedling was still alive and, if not, the cause of death. It is certainly possible that close spacing resulted in higher gopher-caused mortality, but this conclusion cannot be made based on available data, and we know of no studies that have tested this hypothesis. The effect of planting density will depend on pocket gopher density, size and shape of gopher home ranges, and availability of alternative forage. Even if gopher-caused mortality were higher because of close spacing, relative comparisons among treatments and by time periods are still valid.

Overstory density had a dramatic effect on vegetation development. The clearcut treatment at French Mountain became dominated by bracken fern, and the Little Big Hole clearcut treatment by western coneflower. Meanwhile, shrubs present before treatment became nearly nonexistent after treatment. Coverage and constancy of Rocky Mountain maple decreased in the clearcut treatment at both sites (from 2.6 percent preharvest to 0.05 percent at 8 and 9 years, and constancy decreased from 35 to 5 percent). Pacific yew, which has a shrubby growth form in the GFM, had an average of 5.5 percent coverage and 30 percent constancy in the clearcut treatment, but decreased to zero coverage and constancy at 8 and 9 years. Big huckleberry also decreased in coverage (from 3.2 to 0.4 percent) and constancy (from 35 to 25 percent).

Conversely, bracken fern and western coneflower increased rapidly in the clearcut treatment. At French Mountain in the clearcut treatment, bracken coverage increased from 1.6 to 18.2 percent in 9 years, and constancy increased from 70 to 100 percent. At Little Big Hole in the clearcut treatment, coneflower coverage increased from 3.4 to 40.5 percent, and constancy increased from 70 to 100 percent. There is a clear transition in the clearcut treatment from a shrub-dominated understory preharvest to bracken/coneflower dominance postharvest.

The partial cut treatment retained good shrub representation while limiting development of bracken and coneflower. Coverage and constancy of Rocky Mountain maple decreased only slightly (coverage decreased 0.8 percent), Pacific yew coverage decreased only 2.9 percent, and big huckleberry coverage increased slightly in the partial cut treatment (1.6 percent). Bracken coverage in the partial cut treatment at French Mountain increased only 1.0 percent, and coneflower coverage in the partial cut treatment at Little Big Hole increased 14.0 percent.

As was the case with pocket gophers, bracken fern and western coneflower are present under dense overstory canopies. Bracken is poised to respond to disturbances by rapid growth of rhizomes. Coneflower increases following disturbances with larger plants and increased number of plants via seeds.

None of the treatments resulted in adequate natural regeneration within a 5-year timeframe. This finding agrees with our observations at other GFM sites: the process of natural regeneration following disturbance of GFM sites is slow and unreliable.

Planted Engelmann spruce did well in these tests. Gopher-caused mortality was low, overall survival was high, growth was adequate, percent top damage was low, percent forking was low, and percent severe lean was low. Spruce was also a recommended species in another GFM study (Ferguson 1999).

Lodgepole pine also had low mortality caused by gophers and good overall survival. Heights were almost always the tallest among the five test species. Snow damage is a big concern for lodgepole pine (Ferguson 1999). We have seen several lodgepole pine plantations in the GFM where trees have severe lean, twisting, and broken stems. In these plantations, it appears that lodgepole may not be well adapted to snow loads in the GFM, so managers should evaluate the potential for snow damage to lodgepole pine. Interesting, it is unusual to find naturally occurring lodgepole pine in the GFM (Ferguson and Johnson 1996).

Western larch grew well in the clearcut treatment, but this species performed poorly in the partial cut and uncut treatments.

Larch had the highest mortality from nongopher causes, had a high percentage of top damage, had a high percentage of severe lean, and took a relatively long time to withstand snow loads. Ferguson (1999) reported that western larch had the highest incidence of top damage at other GFM sites. Also, Haig and others (1941) reported that western larch had the highest percentage of trees killed by snow damage, compared to Douglas-fir, lodgepole pine, and western white pine (they did not have data for Engelmann spruce).

Douglas-fir had good overall performance. Nongopher causes of mortality were relatively low, so overall survival was good. Douglas-fir had a tendency to fork more than the other species. Planting larger Douglas-fir boosted survival and growth of this species.

Western white pine ranked in the middle for many attributes among the five test species. Gopher-caused mortality was not as high as some other species. Overall survival ranked among the best at French Mountain, but ranked in the middle at Little Big Hole. White pine is ranked intermediate in shade tolerance, so it grew relatively well in the partial cut treatment. Planting larger white pine seedlings improved survival and growth compared to smaller seedlings.

This study shows that GFM sites are similar in Idaho and Oregon, and there are a number of alternatives for regenerating GFM sites. If reforestation within a reasonable amount of time is an objective, trees should be planted for all regeneration methods. A clearcut is a viable regeneration method if pocket gophers are controlled during the first summer, first winter, and second winter after planting. Clearcuts will most likely lose most of their preharvest component of shrubs, and they will rapidly develop high coverages of bracken and/or coneflower. Our observations are that bracken fern will dominate GFM sites on and near the Clearwater National Forest, and coneflower will dominate GFM sites on and near the Nez Perce and Umatilla National Forests. Pocket gopher populations will be abundant in GFM clearcuts.

A partial cut should result in lower pocket gopher populations, less coverage by bracken and coneflower, and better retention of the preharvest shrub component. If gophers are not controlled, planted trees will have better overall survival in partial cuts than in clearcuts. A drawback of partial cuts is slower growth of seedlings than in clearcuts. Height growth can be increased by removing part or all of the overstory a few years after planting.

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