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## Effects of Pocket Gophers, Bracken Fern, and Western Coneflower on Survival and Growth of Planted Conifers

### Abstract

This study was part of investigations on the Grand Fir Mosaic Ecosystem in northern Idaho that were undertaken because of poor regeneration success in harvested forests. Lack of regeneration appears to be related to high populations of northern pocket gophers (*Thomomys talpoides*), bracken fern (*Pteridium aquilinum*), and western coneflower (*Rudbeckia occidentalis*). This study quantified the effects of four treatments on survival and growth of planted conifers: unweeded with gophers, weeded with gophers, unweeded without gophers, and weeded without gophers. Subalpine fir (*Abies lasiocarpa*), grand fir (*Abies grandis*), lodgepole pine (*Pinus contorta*), and Engelmann spruce (*Picea engelmannii*) were planted at four study sites. After 3 years, Engelmann spruce and lodgepole pine had the lowest mortality from gophers, whereas grand fir and subalpine fir had the highest mortality. Most mortality caused by gophers occurred during the first summer and the first two winters after planting. Lodgepole pine was the tallest of the four species after 3 years; however, lodgepole pine appears to be susceptible to snow damage. Engelmann spruce is the recommended species for planting because of its good growth rate (even when growing with bracken fern and coneflower), low mortality from gophers, and its ability to withstand snowloads and senescing bracken fern.

### Introduction

Both animals and plants have effects on the direction and rate of secondary succession in forest ecosystems. This seems especially true in the Grand Fir Mosaic Ecosystem where northern pocket gophers (*Thomomys talpoides*), bracken fern (*Pteridium aquilinum*), and western coneflower (*Rudbeckia occidentalis*) rapidly increase in cutover forests.

The Grand Fir Mosaic (CFM) is found in upland forests that form drainages for tributaries of the Clearwater River in northern Idaho. It is named for the dominant conifer, grand fir (*Abies grandis*), and the variety of sizes and shapes of natural openings in the forest canopy. Sitka alder (*Alnus sinuata*), bracken fern, and fool's huckleberry (*Menziesia ferruginea*) are the dominant species found in these openings. Investigations on this ecosystem were begun because of poor plantation success and the slow rate of secondary succession to woody vegetation (Sommer 1991, Ferguson 1991a).

The CFM encompasses approximately 200,000 ha, occurring as scattered blocks of land at elevations between 1,300 and 1,800 m. Forests at these elevations in northern Idaho are usually subalpine fir (*Abies lasiocarpa*) habitat types, but the CFM is warmer than expected. The predominant habitat type is *Abies grandis*/*Asarum caudatum*

(grand fir/ginger), a cool-wet habitat type as defined by Cooper *et al.* (1991). Forests in the GFM are located in areas that receive high snowfall during the winter months, but the volcanic ash-influenced soils are well drained. GFM forests are typically moist hillsides rather than riparian situations such as forest meadows.

The number of conifer species that occur in the GFM is limited when compared to adjacent forest types. Grand fir is found most often, followed by Engelmann spruce (*Picea engelmannii*) and subalpine fir. Douglas-fir (*Pseudotsuga menziesii*), western white pine (*Pinus monticola*), and western larch (*Larix occidentalis*) are found infrequently, and elevations in the GFM are too high for ponderosa pine (*Pinus ponderosa*). Western redcedar (*Thuja plicata*) and mountain hemlock (*Tsuga mertensiana*) are only found in certain parts of the GFM. Interestingly, lodgepole pine (*Pinus contorta*) is found at higher and lower elevations, but not in the GFM.

Table 1 shows an inventory of commonly found plant species in cutover forests in the GFM. These data were collected in 1989 from sites used in this study. Percent cover is a visual estimation of plot coverage for each species. Bracken fern has the highest average coverage, followed by strawberry (*Fragaria vesca*) and mitrewort (*Mitella stauropetala*). Woody species are infrequent on these sites, even though the areas were disturbed more than 14 years ago.

TABLE 1. Major plant species and average percent coverage for Grand Fir Mosaic sites used in this study.

Species	Common name	Percent coverage
<i>Asarum caudatum</i>	wild ginger	6.9
<i>Carex</i> sp.	sedges	7.8
<i>Cirsium</i> sp.	thistle	10.3
<i>Fragaria vesca</i>	strawberry	21.9
Grass	grasses	6.4
<i>Mitella stauropetala</i>	mitrewort	11.1
<i>Penstemon attenuatus</i>	penstemon	8.2
<i>Phacelia heterophylla</i>	virgate phacelia	2.0
<i>Polygonum douglasii</i>	Douglas' knotweed	8.6
<i>Pteridium aquilinum</i>	bracken fern	38.5
<i>Rudbeckia occidentalis</i>	western coneflower	9.3
<i>Symphoricarpos albus</i>	snowberry	8.0
<i>Vaccinium globulare</i>	huckleberry	8.3

Gopher populations are very high in the GFM. Gophers inhabit natural openings in the forest canopy, and their populations expand rapidly after forest disturbance. Three factors may contribute to high gopher populations in cutover forests: deep soils that contain volcanic ash, adequate soil moisture during the summer months, and the establishment of forb communities.

Gopher predation on conifers is a major concern for reforestation efforts throughout the western United States and Canada (Marsh and Steele 1992, Crouch 1971). Gophers tunnel through the soil feeding on forbs, shrubs, and trees (Teipner *et al.* 1983). Smaller trees are usually clipped near groundline with the top of the seedling then pulled from below into tunnels (Marsh and Steele 1992). Gophers may eat all or most of the root system of larger seedlings and saplings. This type of feeding may not become evident until the foliage turns brown or the tree begins to tip over (Marsh and Steele 1992). Under the snow, gophers clip and girdle the stems of trees.

While many herbaceous species are present following timber harvests in the GFM, bracken fern and coneflower have, by far, the highest amounts of above- and below-ground biomass. Bracken fern and coneflower reach heights of 1.5 to 1.8 m. Znerold (1979) calculated bracken fern frond density of 286,300 fronds/ha at Eagle Point, a site

we used in this study. Bracken fern is more abundant than coneflower in northern parts of the GFM while coneflower is more abundant in southern parts. In discussions that follow, bracken fern and coneflower will be abbreviated "PTAQ/RUOC" because they grow intermixed on the same sites.

Allelopathic potential has been demonstrated for bracken fern and coneflower (Stewart 1975, Glessman 1976, Ferguson 1991b). Muller (1969) uses the term interference to include the effects of allelopathy and competition. Thus, removal of PTAQ/RUOC can demonstrate whether interference is occurring, but cannot evaluate the relative contributions of allelopathy and competition to reduced survival and growth of other plants.

It is difficult to determine the separate effects of gophers and PTAQ/RUOC where they occur together. A study was needed to separate these effects so the factors limiting successful reforestation could be determined. This study quantifies the separate and combined effects of gophers and PTAQ/RUOC on survival and growth of four planted conifer species for the first 3 years after planting.

## Methods

Four study sites were chosen to represent GFM conditions. A summary of site conditions is given in Table 2. Three of the sites (Bertha, Dogleg, and Lytle) are located in clearcuts where the habitat type is *Abies grandis*/*Asarum caudatum*. The fourth site (Eagle Point) is located in a 1.5 ha natural opening where PTAQ/RUOC have probably dominated for hundreds of years, as evidenced by the current lack of woody vegetation and lack of charcoal in the soil.

Gopher exclosures at Eagle Point and Dogleg were constructed in 1987; those at Lytle and Bertha were constructed in 1988. At each site, a 15-by 15-m exclosure was constructed. Narrow trenches were dug 1 m deep around the perimeter. Soil from the trench was placed to the outside of the exclosure to minimize disturbance within the exclosure. Vertical wooden posts were placed into the trench to support 1.25-by 1.25-cm wire mesh. The wire mesh was nailed to the wooden posts so that the fence extended 1 m below ground and 1.5 m above the soil surface.

Soil was replaced in the trench, a wooden top rail was added, and a gate was built. Gophers were eliminated from exclosures by poisoning and

TABLE 2. Description of the four study sites.

Study site	Location	Elevation (m)	Aspect	Slope (%)	Study site history
Eagle Point	Clearwater N. F. North Fork District T40N, R7E, S35	1,400	East	20	Natural opening dominated by PTAQ/RLOC
Bertha	Clearwater N. F. North Fork District T39N, R5E, S1	1,200	South	20	Clearcut in 1975. No site preparation.
Dogleg	Nez Perce N. F. Selway District T31N, R6E, S23	1,740	South	5	Clearcut in 1973, bulldozer piled and burned in 1973.
Lyle	Nez Perce N. F. Elk City District T31N, R6E, S34	1,585	East	15	Clearcut in 1973, bulldozer piled and burned in 1976.

trapping. Poisoning or trapping gophers was done, if needed, each time exclosures were visited.

The fencing below ground kept gophers from digging through the soil into the exclosure. Fencing above ground kept gophers from tunneling through the snow into the exclosure or from traveling over the snow to enter the exclosure. The fence above ground was important because it was not possible to routinely inspect the exclosures for gopher activity during the winter.

Two additional 15- by 15-m plots were established at each site. These plots were treated the same as the exclosures except gophers were not excluded. Two non-exclosure plots were necessary because of anticipated higher tree mortality rates caused by gophers. These plots had enough surviving trees to compare growth rates with trees in the exclosures.

Each 15- by 15-m plot where gophers were not excluded was surrounded by a 1.25 m tall commercial snow fence made from vertical wooden slats. The snow fence helped prevent cattle and big game access. Also, the snow fence duplicated any effects the exclosure fence had on wind patterns or snow deposition.

Each plot was divided in half in the direction of the slope. One half was chosen at random to be weeded, beginning in the fall of 1988. Weeding was the physical removal of bracken fern and coneflower 2-3 times each growing season. Bracken fern fronds were pulled from the soil because digging up the rhizomes would have caused too much soil disturbance. Herbicides were not

used to kill bracken fern because rhizomes extending into the unweeded area might have been killed.

Coneflower plants were removed by severing lateral roots with a shovel, then lifting the caudex from the ground. Loose soil was shaken from the caudex into the hole where it had been removed.

All weeded material was deposited at least 1.5 m outside the fence, but never on the uphill side of the plot. This prevented leachates of decomposing plant material from affecting the weeded area. Weeding also included removing PTAQ/RLOC for 1.5 m outside the fence around the weeded half of the plot. The last weeding of each growing season was done in the fall before the rainy season.

Thus, conditions were created for four treatments: unweeded with gophers, weeded with gophers, unweeded without gophers, and weeded without gophers.

Containerized seedlings were grown in a greenhouse in Moscow, Idaho. Within species, the same seed source was used. Species were subalpine fir, grand fir, lodgepole pine, and Engelmann spruce. Subalpine fir, grand fir, and Engelmann spruce were chosen as test species because they are commonly found in the GFM. Lodgepole pine was chosen because it is a fast growing seral conifer that is found at higher and lower elevations in forests adjacent to the GFM.

Prior to planting, the greenhouse potting mix was gently shaken from the roots of the containerized seedlings. This insured that roots came into contact with the native soil when planted. Thus, the potting mix did not buffer the trees from chemical or physical properties of the soil.

Sites were planted in the spring of 1989. Four randomly chosen quadrats of 24 trees of each species were planted on each side of the exclosure (weeded and unweeded) and each non-exclosure. Spacing was 0.75- by 0.90-m. A row of border trees (a mixture of the same four species) was planted along the outside of the quadrats and between the weeded and unweeded portions of the plots.

Mortality and tree condition were recorded each spring and fall for the 2,304 trees. Tree heights were recorded each fall. Seedlings that had become entangled in senescing bracken fern fronds were uncovered in the spring and fall. Freeing these seedlings may have resulted in less mortality from the smothering effects of bracken fern, but it was necessary to determine seedling mortality, tree condition, and height. Whenever a tree was uncovered, this condition was recorded for later analysis.

A simple gopher activity index was recorded each spring. Six 4.6-m long line intercept transects were systematically laid out between the four test species; three each in weeded and unweeded areas. The index was the number of times the line intersected a winter gopher mound, soil plug, or cast.

### Analysis

Gopher activity indices were analyzed using the General Linear Model (GLM) procedure in SAS (SAS 1985). The GLM procedure was used to perform analysis of variance and repeated measures analysis on these data. Differences between means were determined using Dunn's procedure at the 0.05 significance level. Indices entered into the analysis were spring counts for 1989-1992. The spring 1989 index characterized gopher activity at the time trees were planted.

Seedling mortality was also analyzed with GLM and Dunn's procedure at the 0.05 significance level. For each species, the ratio of dead trees was calculated for each quadrat of 24 trees 3 years after planting. The inverse sine transformation was used to analyze these binomial mortality data as suggested by Steel and Torrie (1960). The transformation also resulted in additivity of effects (no interaction between study sites and treatments) (Kirk 1982).

Seedling heights after 3 growing seasons were analyzed using GLM and Least Square Means (LSMEANS) (SAS 1985) for comparison of treatment means at the 0.05 significance level. Surviving trees were analyzed by species. Study site and seedling height at planting were included as independent variables in GLM and LSMEANS in order to account for their sources of variation. The result was a smaller error variance and a more powerful test to detect differences between treatment means (Kirk 1982).

## Results

### Gopher Activity Index

Fencing used to exclude gophers was most effective at Bertha and Lytle (Table 3). At the other two locations, fencing greatly reduced gopher activity. The averages shown in Table 3 reflect winter activity. During the summer, gopher activity was effectively controlled inside exclosures through periodic poisoning and trapping.

Winter gopher activity indices were examined as a repeated measures analysis because the same line transects were measured over several years. There was not a significant time effect at any of the study sites. Time-treatment effects were also non-significant except at the Dogleg study site. At Dogleg, gophers gained access to the exclosure and were more active in two measurement periods than in the other two periods.

TABLE 3. Winter gopher activity indices. Means are for four spring counts taken in 1989-1992, with three replications. Within study site, different letters indicate significantly different means at the 0.05 level using Dunn's test.

Gopher control	Weeding	Study Site				All 4 Sites
		Eagle	Bertha	Dogleg	Lytle	
Non-exclosure	Not weeded	3.12 <sup>ab</sup>	1.58 <sup>a</sup>	5.62 <sup>a</sup>	4.50 <sup>a</sup>	3.71 <sup>a</sup>
Non-exclosure	Weeded	4.58 <sup>a</sup>	2.29 <sup>a</sup>	5.46 <sup>a</sup>	3.88 <sup>ab</sup>	4.05 <sup>a</sup>
Exclosure	Not weeded	1.08 <sup>c</sup>	0.00 <sup>b</sup>	2.42 <sup>b</sup>	0.67 <sup>c</sup>	1.04 <sup>b</sup>
Exclosure	Weeded	1.83 <sup>bc</sup>	0.00 <sup>b</sup>	3.17 <sup>b</sup>	0.83 <sup>bc</sup>	1.46 <sup>b</sup>

TABLE 4. Percent of trees that died within the first 3 years after planting. Within species and cause of death, different letters indicate significantly different means at the 0.05 level using Dunn's test. Numbers in the table are percentages; however, the inverse sine transformation of the ratio of dead trees was used to determine differences between means.

Gopher control	Weeding	Species				All 4 species
		Subalpine fir	Grand fir	Lodgepole pine	Engelmann spruce	
Mortality due to causes other than gophers						
Non-exclosure	Not weeded	19.3 <sup>a</sup>	42.7 <sup>a</sup>	11.5 <sup>a</sup>	7.3 <sup>a</sup>	20.2 <sup>a</sup>
Non-exclosure	Weeded	23.4 <sup>a</sup>	44.8 <sup>a</sup>	1.0 <sup>a</sup>	8.3 <sup>a</sup>	19.4 <sup>a</sup>
Exclosure	Not weeded	26.0 <sup>a</sup>	49.0 <sup>a</sup>	3.1 <sup>a</sup>	12.5 <sup>a</sup>	22.7 <sup>a</sup>
Exclosure	Weeded	50.0 <sup>a</sup>	65.6 <sup>a</sup>	0.0 <sup>a</sup>	8.3 <sup>a</sup>	31.0 <sup>a</sup>
Mortality due to gophers						
Non-exclosure	Not weeded	46.4 <sup>ab</sup>	40.1 <sup>a</sup>	47.9 <sup>a</sup>	35.1 <sup>a</sup>	42.4 <sup>a</sup>
Non-exclosure	Weeded	63.5 <sup>a</sup>	42.2 <sup>a</sup>	45.3 <sup>a</sup>	38.0 <sup>a</sup>	47.3 <sup>a</sup>
Exclosure	Not weeded	10.4 <sup>c</sup>	20.8 <sup>a</sup>	20.8 <sup>a</sup>	6.2 <sup>a</sup>	14.6 <sup>b</sup>
Exclosure	Weeded	12.5 <sup>bc</sup>	22.9 <sup>a</sup>	6.2 <sup>a</sup>	5.2 <sup>a</sup>	11.7 <sup>b</sup>

### Non-gopher Causes of Mortality

Of the four species tested, grand fir had the highest mortality from causes other than gophers (Table 4). Within the first month of planting, 34.2% of the grand fir were killed by voles (*Microtus* sp.). Voles stripped the bark off trees beginning at groundline and extending upward 5 to 8 cm. Mortality from voles occurred at three of the four study sites, the exception being Eagle Point. After 3 years, 50.5% of the grand fir were dead from causes other than gophers.

Subalpine fir had the next highest mortality rate (29.7%) from causes other than gophers. For most of these trees, we were unable to determine the cause of mortality, although the average size of subalpine fir at the time of planting was the smallest of the four species tested.

During the winter of 1991-1992, a fungus killed many seedlings of all species at Lytle. Damage appeared similar to a snow mold except the main stem of the seedling became blackened and was girdled.

Lodgepole pine and Engelmann spruce suffered the least mortality from non-gopher causes. Lodgepole pine averaged 3.9% and Engelmann spruce averaged 9.1% mortality after 3 years.

Mortality may have been higher if we had not uncovered seedlings that were smothered by bracken fern. Lodgepole pine was the species most often smothered by bracken fern, averaging 8.0%

for the 3-year period. For grand fir and Engelmann spruce, 4.2% of each species had been smothered. Only 1.0% of subalpine fir trees had been smothered by bracken fern.

### Gopher-caused Mortality

Mortality caused by gophers is also summarized in Table 4. Subalpine fir had the highest rates of mortality caused by gophers, averaging 55.0% in non-exlosures.

Lodgepole pine had the second highest rate of mortality caused by gophers. An average of 46.6% of the seedlings were killed by gophers during the first 3 years in the non-exlosures.

Grand fir had the next highest rate of mortality due to gophers in non-exlosures, averaging 41.2%. Mortality would undoubtedly have been higher if voles had not killed many seedlings before gophers had a chance.

Engelmann spruce had the lowest mortality caused by gophers, averaging 36.7% in non-exlosures. Overall, spruce had good survival because of low gopher-caused mortality and low mortality from other factors.

The species preferences by gophers are masked by trees that died from other causes. Figure 1 shows the results of an analysis of mortality in non-exlosures where trees killed by causes other than gophers were not included. In these percentages, the numerator for each quadrat of 24 original trees

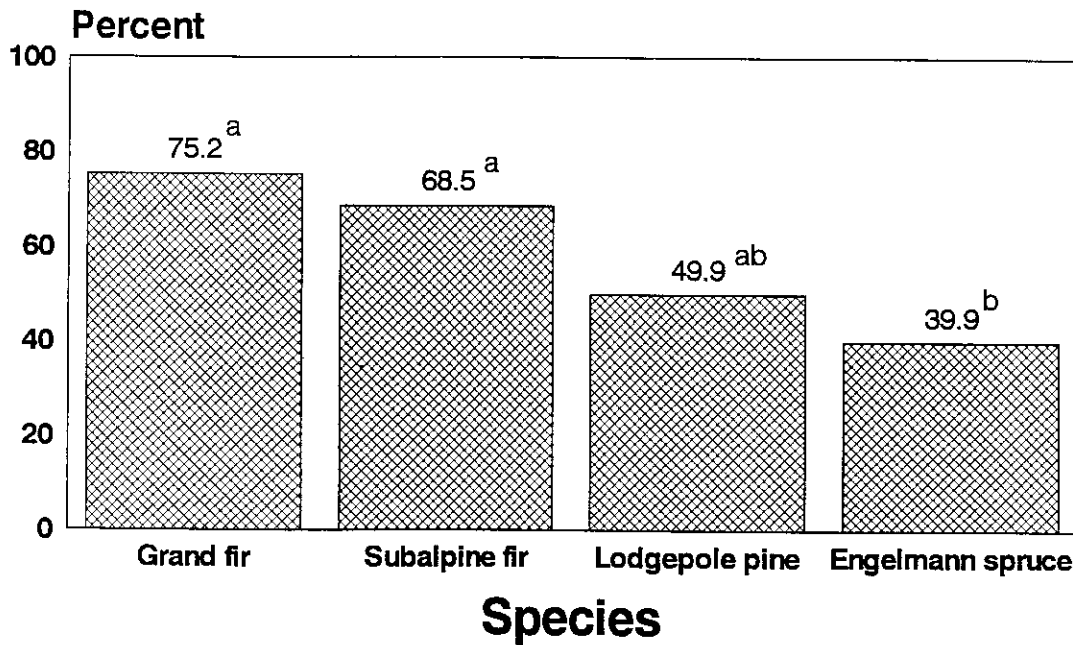


Figure 1. Average percent mortality due to gophers in non-exlosures. Percentages were calculated after eliminating trees killed by causes other than gophers. Means followed by different letters are significantly different at the 0.05 level using Dunn's test.

was the number killed by gophers and the denominator was 24 minus the number of trees killed by other causes. These results show the average percent killed by gophers in non-exlosures was 75.2% for grand fir, 68.5% for subalpine fir, 49.9% for lodgepole pine, and 39.9% for Engelmann spruce.

#### Gopher-caused Mortality by Time Periods

The percent of trees killed by gophers during summer and winter time periods is shown in Table 5. Data were obtained for each species by averaging mortality in the four study sites for each measurement period.

Mortality caused by gophers was highest the first summer and the next two winters after planting. Gopher-caused mortality was lowest in the second and third summer periods. For all four species, gopher-caused mortality averaged 13.0% the first summer, 15.0% the first winter, and 11.1% the second winter. Mortality the second and third summers averaged only 2.8 and 0.8%, respectively.

Fewer trees were killed by gophers during the third winter (1991-1992), but many trees were loose when gently tugged at groundline in the

spring of 1992. Prior to the spring 1992 measurement (3 years after planting), only one tree was recorded as being loose in the soil. The spring 1992 tally found 73 loose trees. Most of the loose trees were of the larger species—lodgepole pine and Engelmann spruce. Observations on a few of these trees showed that gophers had severed many, but not all, lateral roots.

#### Seedling Heights

Seedling heights at the end of the third growing season were analyzed by species. Only trees with no top damage were used in this analysis because trees with top damage mask height growth rates. Ninety-three trees were eliminated because of top damage: 29 subalpine fir, 19 grand fir, 30 lodgepole pine, and 15 Engelmann spruce. Tops had been chewed by animals or terminals had died from other causes.

Seedling heights after 3 growing seasons are shown in Table 6. These means account for study site and seedling height at the time of planting using LSMEANS (SAS 1985). The first trend evident was taller trees in the exclosures than in the non-exlosures, except for spruce. This provides

TABLE 5. Percent mortality due to gophers by time periods for non-exclosures.

Weeding	Time period					
	Summer 1989	Winter 1989/90	Summer 1990	Winter 1990/91	Summer 1991	Winter 1991/92
			Subalpine fir			
Not weeded	12.5	12.5	2.1	13.5	1.6	4.2
Weeded	12.5	35.4	4.7	8.9	1.0	1.0
			Grand fir			
Not weeded	17.2	5.7	4.2	9.4	0.5	3.1
Weeded	16.7	15.6	3.1	6.3	0.0	0.5
			Lodgepole pine			
Not weeded	11.5	16.1	2.6	14.6	1.6	1.5
Weeded	13.5	16.2	1.0	11.5	1.0	2.1
			Engelmann spruce			
Not weeded	7.8	9.4	2.6	12.5	0.0	3.1
Weeded	13.0	8.9	2.1	12.5	0.5	1.0
			All 4 species			
Not weeded	12.2	11.0	2.8	12.5	1.0	2.9
Weeded	13.9	19.0	2.8	9.7	0.7	1.2
Average	13.0	15.0	2.8	11.1	0.8	2.0

TABLE 6. Mean seedling heights (cm) at 3 years using LSMEANS (SAS 1985), which accounted for variation attributable to study site and seedling height at planting. Within species, means followed by different letters are significantly different at the 0.05 level.

Gopher control	Weeding	Species			
		Subalpine fir	Grand fir	Lodgepole pine	Engelmann spruce
Non-exclosure	Not weeded	14.7 <sup>b</sup>	34.6 <sup>ab</sup>	40.1 <sup>c</sup>	39.7 <sup>a</sup>
Non-exclosure	Weeded	16.0 <sup>ab</sup>	31.8 <sup>b</sup>	52.4 <sup>b</sup>	40.7 <sup>a</sup>
Exclosure	Not weeded	15.8 <sup>ab</sup>	39.4 <sup>a</sup>	49.5 <sup>b</sup>	42.0 <sup>a</sup>
Exclosure	Weeded	17.3 <sup>a</sup>	35.7 <sup>ab</sup>	59.9 <sup>a</sup>	39.7 <sup>a</sup>
Number of trees in analysis:		190	107	326	396

evidence that gophers negatively affect growth on seedlings they do not kill. Reduced growth is probably caused by partially devoured roots and/or soil disturbance.

For subalpine fir, weeding and gopher control had significantly positive effects on 3-year seedling heights compared to the control (gophers without weeding). However, subalpine fir is the slowest growing of the four species; weeding and gopher control only improved 3-year heights by 2.6 cm.

Grand fir was shorter in the weeded areas than in unweeded areas, although the differences were

not significant. The number of grand fir available for analysis (107) was lower than for other species in the study because of high mortality rates; further, the lowest number of grand fir seedlings was in the weeded areas. Grand fir were significantly taller in unweeded sections of exclosures (39.4 cm) than in weeded sections of non-exclosures (31.8 cm).

Lodgepole pine was the tallest of the four species after 3 years. Weeding PTAQ/RUOC resulted in increased heights of 10.4 cm in the exclosure and 12.3 cm in the non-exclosure, an average of

11.4 cm for weeding. Providing protection from gophers increased heights of surviving lodgepole pine 9.4 cm in the unweeded and 7.5 cm in the weeded areas, an average of 8.4 cm for gopher protection. With both weeding of PTAQ/RUOC and protection of trees from gophers, the gain in height averaged 19.8 cm after 3 years.

Engelmann spruce showed no statistically significant differences in heights among the four treatments. This is somewhat surprising and is an important finding. Evidently, neither gopher activity nor interference from PTAQ/RUOC was detrimental to height growth of Engelmann spruce.

## Discussion

Mortality caused by gophers was highest during winter months, compared to summer months, except for the first summer after the seedlings were planted. High winter mortality to seedlings is consistent with other studies in the western United States (Marsh and Steele 1992, Crouch 1971). Therefore, the most important time to reduce gopher populations is just before winter. Eliminating or drastically reducing gopher populations in the fall should result in fewer seedlings killed during the winter.

High gopher-caused mortality following spring planting is circumstantial evidence that gophers found nursery-grown seedlings quite palatable. Another possibility is that nursery-grown seedlings have not developed enough defense chemicals to discourage gopher feeding.

Gophers preferred subalpine fir and grand fir over lodgepole pine and Engelmann spruce. Crouch (1971) found no gopher preferences among three pine species: ponderosa, Jeffrey (*Pinus jeffreyi*) and lodgepole pine, where two-thirds were killed by gophers within 3-1/2 years in south-central Oregon. Okello (1993) reported the highest gopher feeding preference for ponderosa pine, moderate preference for Douglas-fir, and lowest preference for western redcedar.

Where protected from gophers, planted seedlings in this study readily survived in plant communities dominated by PTAQ/RUOC. This is consistent with Dimock (1964), who reported 79% survival after 5 years for Douglas-fir seedlings planted in dense bracken fern; however, growth was reduced. Seedlings averaged only 45.5 cm tall after 5 years on a high site in western Washington.

Staebler *et al.* (1954) also reported that bracken fern reduced growth of Douglas-fir regeneration. Port-Orford-cedar (*Chamaecyparis lawsoniana*) regeneration had a moderate reduction in heights when growing in dense bracken fern, but western hemlock heights were not affected.

## Conclusions and Recommendations

This study separated the effects of gophers from interference caused by PTAQ/RUOC. Even though it was not possible to keep all gophers out of the exclosures, their activity inside the exclosures was drastically reduced, resulting in reliable data.

None of the trees in this study appeared to die from allelopathy, probably because planting stock was large enough to buffer adverse soil chemical properties. Conversely, for natural regeneration, Ferguson and Boyd (1988) found that four species of conifer seed sown at the Eagle Point study site died after germination but before shedding seed coats. Natural regeneration is not a reliable reforestation option in the GFM.

We recommend planting 2 or 3 year old nursery stock with large basal diameter. Larger seedlings will survive better and become big enough to withstand gopher activity more quickly. Large caliper seedlings will withstand the smothering effects of bracken fern. Plant promptly after harvest before PTAQ/RUOC become tall and dense.

Interference from PTAQ/RUOC can slow growth of seedlings. Eventually, seedlings will overtop PTAQ/RUOC and shade them out. Of the four species tested, lodgepole pine was the most sensitive to interference from PTAQ/RUOC. Lodgepole pine growing in weeded areas of plots were significantly taller than those growing in unweeded areas.

Although lodgepole pine grew the fastest of the four species tested and is surviving well in the non-exclosures, we cannot recommend its widespread use for reforesting cutover forests in the GFM. Boyd and Znerold (in preparation) have found extensive snow damage to lodgepole pine planted at the Eagle Point study site in 1978. Snow has caused extensive damage to our gophers exclosures and to the snow fence that surrounds the non-exclosures. Perhaps lodgepole pine is not adapted to the kinds of snowpacks that occur in the GFM.

Grand fir was shorter in weeded areas of plots after 3 years, so there appears to be no advantage to weeding PTAQ/RUOC for grand fir growth.

Weeding PTAQ/RUOC also did not improve 3-year heights of subalpine fir.

Engelmann spruce 3-year heights were not significantly different in weeded versus unweeded areas or in exclosures versus non-exclosures. In addition, it had the lowest mortality from gophers; other causes of mortality were low, and it had the fewest trees with top damage. Although Engelmann spruce generally grew more slowly than lodgepole pine, it was as tall as lodgepole in the control where gophers were not excluded and PTAQ/RUOC were not weeded. We also observed that spruce is more resistant to being bent over by snow and senescing bracken fern. Engelmann spruce is the best choice among the four species tested for reforesting cutover forests in the GFM.

Engelmann spruce is commonly found in the GFM, and long-term survival of Engelmann spruce should be very good. Establishment of spruce plantations would appear to be the easiest way to reforest these sites; however, species diversity could

become a problem. To avoid monocultures, we recommend also planting other species and leaving seed trees of species other than Engelmann spruce on the site, especially if they are seral species such as Douglas-fir, western larch, or western white pine. These species may be able to regenerate in enough numbers to provide species diversity.

Gophers were more of a problem for planted trees than was interference from PTAQ/RUOC. Mortality is decreasing as the seedlings become larger, but many of the trees were loose in the soil after 3 years. This is evidence that gophers are still actively feeding on the root systems.

The critical times to reduce gopher populations would be the summer trees are planted and each fall until trees are large enough to survive despite gopher activity (about 10 years old [Marsh and Steele 1992]). This study will continue until at least 10 years after planting to allow monitoring of longer term survival and growth.

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