Evaluation of Physical Barriers to Protect Ponderosa Pine Seedlings from Pocket Gophers

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ABSTRACT: *A 2 yr study on the Rogue River and Mt. Hood National Forests in Oregon evaluated physical barriers for protection of* Pinus ponderosa *seedlings against damage by* Thomomys talpoides. *Seedlings protected with one of three weights of: (1) plastic mesh tubing (Vexar®) or (2) sandpaper tubing (Durite®) were evaluated against control seedlings. On the Rogue River sites, Vexar® seedlings had the highest survival (62.6%), followed by the controls (59.1%), then Durite® seedlings (17.9%). Gophers were the primary cause of death for the Vexar® seedlings, versus desiccation for the Durite® seedlings. On the Mt. Hood sites, heavy-weight Vexar® seedlings had the highest survival (35.4%), medium-weight Durite® seedlings the lowest (2.7%). Seedling mortality caused by gophers was highest for controls (70.2%), followed by light-weight (62.2%) and heavy-weight (53.9%) Vexar® treatments. Overall survival was low (Rogue River = 42%, Mt. Hood = 19.8%). Growth was greatest for the control seedlings but only significantly greater than growth of Durite® seedlings on the Rogue River sites. Growth of seedlings was not compromised by the Vexar® tubing. Although neither type of tubing was highly protective, Vexar® tubes performed better than Durite® tubes. West. J. Appl. For. 14(3):164–168.*

Pocket gophers *(Thomomys talpoides)* cause substantial economic losses on forest, range, and agricultural lands in western North America every year (Borrecco and Black 1990). On forestlands, these losses are primarily associated with damage or destruction of seedlings and saplings by direct removal, clipping, or girdling. Land managers are equipped with a variety of options for controlling damage, ranging from habitat modification to more direct methods such as poison baiting and kill trapping (Black 1994, Case and Jasch 1994). Direct control methods are labor-intensive and can be expensive. Also, because of the nature of rodent population dynamics, direct control techniques must usually be repeated over many years to be effective. A big concern with poison baiting is the potential for secondary hazards to nontarget animals (Hegdal and Gatz 1976, Barnes et al. 1985). Baiting and trapping are currently the most widely used methods for alleviating pocket gopher damage. Integrating indirect control measures (reducing habitat suitability, providing alternate forage, practicing silvicultural modifications) with direct control approaches may prove more effective and less costly (Black 1994).

Exclusionary techniques aimed at protection of tree seedlings rather than removal of the problem animals have great potential for control of damage on forest lands. One of these techniques involves the use of protective barriers around individual plants. Use of this method has become more widespread since the development and commercial marketing of polypropylene plastic mesh (Vexar®) tubes in the early 1970s to protect seedlings from ungulate browsing (Campbell and Evans 1975). Still, concerns have been raised about the effects of this tubing on tree growth and form (Teipner et al. 1983, Engeman et al. 1997). We conducted a 2 yr (1993–1995) field study to evaluate the potential of different weights of Durite® tubing and Vexar® tubing for protecting seedlings.

Methods

The study sites were located in the Rogue River National Forest in southwestern Oregon and the Mt. Hood National Forest in northcentral Oregon. Eight harvest units were selected on each forest. The Rogue River study area has a mean maximum July temperature of 28°C and mean annual rainfall of 50 cm. Sites averaged 1070 m elevation with < 20% slopes. Soils are haploxerults, derived from sedimentary parent materials that are continuously dry for a long period of the year. Vegetation is classified in the mixed-conifer forest zone, dominated by Douglas-fir *(Pseudotsuga menziesii)*, sugar pine *(Pinus lambertiana)*, ponderosa pine *(P. ponderosa)*, incense cedar *(Calocedrus decurrens)*, and white fir *(Abies concolor)* (Franklin and Dyrness 1973). The

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Mt. Hood sites averaged 1,212 m elevation with < 20% slopes, a mean maximum July temperature of 27°C, and mean annual rainfall of 80 cm. Major soil groups originated from pyroclastic parent materials or basic igneous rocks. Glacial till soils are also common. Vegetation falls within the grand fir *(A. grandis)* and Douglas-fir zones (Franklin and Dyrness 1973).

Active gopher burrow systems on each unit were determined by the open hole method (Barnes et al. 1970). Twenty-four hours after burrows were breached, holes were checked for closure (i. e., backfilling by the resident gopher). Multiple holes in the same burrow system were commonly opened. If even just a single hole in a given burrow system was closed, the system was considered active. Burrow systems were subjectively delimited by knowledge from previous trapping experience, with the additional proviso of a minimum separation of 10 m between any two closed holes. Twelve active (i.e., closed) burrow systems on each unit were randomly selected for plot locations. On each plot, 1/0 and 2/0 bareroot ponderosa pine stock were planted in four rows of four seedlings each, spaced at 2.4 × 2.4 m intervals. Plots were centered over active burrow systems to maximize exposure of all seedlings to the resident gopher(s). Individual seedlings were marked by wooden stakes labeled with the respective plot/row numbers.

Seedlings were randomly assigned to one of four treatments. Treatments on the Mt. Hood National Forest included: (1) light-weight Vexar®, (2) medium-weight Durite®, (3) heavy-weight Vexar®, (4) no tubing (= control). Treatments on the Rogue River National Forest were: (1) medium-weight Vexar®, (2) light-weight Durite®, (3) heavy-weight Durite®, (4) no tubing. Durite® is a coated abrasive product commercially used for sanding plywood. It is composed of 60% silicon carbide attached to a cloth backing with a resin binder. It was provided by the manufacturer (Norton Company, P.O. Box 808, Troy, NY 12180) custom cut to specifications with ventilation holes drilled.

All tubes were approximately 25 cm in length and slit longitudinally so they could be easily opened to insert seedlings. Although this increased the potential for exposure of the aboveground portion of the seedling to gophers (and other foraging animals), the free edges of the tubes tended to mesh together, forming a suitable barrier. With the seedling positioned in the tube, soil was then added around the root plug up to the crown to fill the space between the roots and the tubing wall. Approximately one-third of the tubing was positioned below ground to provide protection to the roots. Each treatment was randomly assigned to each row to reduce bias associated with the possibility of preferential foraging in a plot by the resident gopher(s). All planting was conducted by tree planting crews contracted by the USDA Forest Service.

Seedlings were checked for health/damage at 1, 4, 6, 12, 15, and 24 months (Rogue River) and at 2, 4, 6, 12, 16, and 26 months (Mt. Hood). Heights were recorded at planting and at 1, 6, 12, 15/16 and 24/26 months. At death, each seedling was carefully unearthed and examined for below-ground root damage. Mortality was classified as nonanimal (related to climatological factors, poor planting technique, etc.), gopher (directly attributed to the foraging activity of one or more gophers) or other (big game browsed/uprooted, unknown causes).

We tested for differences in the proportion of seedlings damaged or dead using a Wilcoxon chi-square test statistic (Kalbfleish and Prentice 1980). Nonparametric survival analyses (Kaplan and Meier 1958) were selected for analyzing the distributions of survival times because such data are typically characterized by right-censoring and nonnormal distributions. Right-censoring is the occurrence of observations in the data set that have survival times greater than the specified value (e.g., seedlings surviving through the end of the study). If ignored, censored observations can bias the data analysis (SAS Institute Inc. 1995). Survival analyses were conducted using JMP Version 3.1 (SAS Institute Inc. 1995). To evaluate the influence of physical barriers on seedling growth, we compared seedling height gain using a mixed linear model ANOVA (SAS Institute Inc. 1996). Only surviving, undamaged seedlings were included in the analyses. Those seedlings still living, but growth-impaired by browsing or unknown causes of damage, were omitted. Growth analysis was performed with SAS Version 6.12 (SAS Institute Inc. 1996).

Results

On the Rogue River study area, Vexar®-protected seedlings exhibited the highest survival (62.6%), though not different ($P = 0.3997$) from that of the control seedlings (59.1%) (Table 1, Table 2). Gopher-caused mortality was high, ranging from 20.2–28.9%, with control seedlings receiving the greatest damage. Nonanimal mortality was the leading cause of seedling death for both the light-weight and heavy-weight Durite® treatments (51.4% and 40.4%, respectively) (Table 1). Total seedling survival (across treatments) was 42.0%.

Survival distributions for the four treatments were different ($\chi2 = 341.0883$, df = 4, $P < 0.01$). Of the pairwise comparisons of all possible treatment combinations, differences in survival distributions were noted for all but two comparisons: control vs. medium-weight Vexar® ($\chi^2 = 0.7092$, df = 1, $P = 0.3997$) and heavy-weight Durite® vs. light-weight Durite® ($\chi^2 = 7.2051$, df = 1, $P = 0.0273$) (Table 2). The latter comparison (heavy-weight Durite® vs. light-weight Durite®) was considered nonsignificant because it is not within the comparisonwise error rate of 0.008 (= α/s, where α = the experimentwise error rate and s = the number of pairwise comparisons) but is well within the experimentwise error rate ($P = 0.05$) and hence warrants more than a passing glance.

Competing risks analysis reveals the relative importance of the various mortality sources to the survival distributions for each treatment. Any of the numerous mortality sources can lead to a "failure" of the system (i.e., death of a seedling). If the different sources are independent, the failure time (time until death) for each source can be modeled by estimating the failure time survival distribution while fixing the times for the other mortality sources (SAS Institute Inc. 1995). Addi-

Table 1. Mortality of ponderosa pine seedlings, unprotected and protected by various physical barriers, Rogue River and Mt. Hood National Forests, 1993–1995.

Treatment[1]	No. seedlings at start of study [2]	Gopher mortality	Nonanimal mortality[3]	Other mortality[4]	Total mortality	Seedlings alive at end of study
		[no. (%)]				
Rogue River						
C	384	111 (28.9)	42 (10.9)	4 (1.0)	157 (40.9)	227 (59.1)
LD	385	91 (23.6)	198 (51.4)	27 (7.0)	316 (82.1)	69 (17.9)
HD	384	89 (23.2)	155 (40.4)	31 (8.1)	275 (71.6)	109 (28.4)
MV	382	77 (20.2)	58 (15.2)	8 (2.1)	143 (37.4)	239 (62.6)
Mt. Hood						
C	336	236 (70.2)	8 (2.4)	46 (13.7)	290 (86.3)	46 (13.7)
LV	336	209 (62.2)	28 (8.3)	7 (2.1)	244 (72.6)	92 (27.4)
MD	336	49 (14.6)	259 (77.1)	19 (5.7)	327 (97.3)	9 (2.7)
HV	336	181 (53.9)	27 (8.1)	9 (2.7)	217 (64.6)	119 (35.4)

1 C = Control, HD = Heavy-weight Durite®, HV = Heavy-weight Vexar®, LD = Light-weight Durite®, LV = Light-weight Vexar®, MD = Medium-weight Durite®, MV = Medium-weight Vexar®.
2 Discrepancies in number of seedlings on Rogue River attributed to treatment misapplication and planting errors; reduced number of seedlings on Mt. Hood site reflect loss of data from one harvest unit (48 seedlings/treatment) resulting from widespread destruction of seedlings by unknown cause.
3 Attributed to climatological factors or poor planting technique.
4 Attributed to livestock or wild ungulate browsing/uprooting or unknown causes.

tionally, selectively removing one of the mortality sources (the "omitted cause") gives an adjusted survival distribution with no influence from the omitted cause. The most dramatic improvements in survival distributions of all four treatments, especially both Durite® treatments, were noted when nonanimal mortality assumed the omitted cause role. Hence, overall, nonanimal mortality was the most important seedling mortality factor on the Rogue River study area, though gopher mortality was more deleterious to control and Vexar®-protected seedlings (Table 1).

Because of differences in initial seedling heights among treatments on both the Rogue River ($F = 8.35$, $P = 0.0008$) and Mt. Hood ($F = 10.74$, $P = 0.0002$) sites, seedling growth, as opposed to final height, was selected as the variable for growth analysis. Control seedlings in the Rogue River study area showed the greatest amount of growth (mean = 19.7 cm) by the end of the 2 yr study (Table 3). We noted a treatment effect in the Rogue River study area on growth of undamaged seedlings surviving to the end of the study ($F = 7.38$, $P = 0.0022$). Control seedlings grew significantly more than either light-weight ($P = 0.0037$) or heavy-weight ($P = 0.0004$) Durite®-protected seedlings. Differences in growth of control and Vexar®-protected seedlings tended toward significance ($P = 0.0574$), with the control seedlings averaging just 9% greater growth (Table 3).

Table 2. Seedling survival analysis for physical barrier treatments, Rogue River and Mt. Hood National Forests, Oregon, 1993–1995.

Comparison[1]	Rogue River χ^2	DF	$P > \chi^2$
C vs. MV	0.7092	1	0.3997
HD vs. LD	7.2051	1	0.0273
MV vs. HD	132.8053	1	<0.0001
MV vs. LD	213.2670	1	<0.0001
C vs. HD	120.4108	1	<0.0001
C vs. LD	199.3982	1	<0.0001

Comparison[1]	Mt. Hood χ^2	DF	$P > \chi^2$
C vs. HV	105.3222	1	<0.0001
MD vs. LV	170.9414	1	<0.0001
HV vs. MD	229.8115	1	<0.0001
HV vs. LV	4.8212	1	0.0281
C vs. MD	0.0146	1	0.9039
C vs. LV	70.8200	1	<0.0001

1 C = Control, HD = Heavy-weight Durite®, LD = Light-weight Durite®, MV = Medium-weight Vexar®.
2 C = Control (no tubing), HV = Heavy-weight Vexar®, LV = Light-weight Vexar®, MD = Medium-weight Durite®.

One of the eight units on the Mt. Hood study area was omitted from the analyses because of the complete destruction of tubes and seedlings (indeterminate human or animal cause). Heavy-weight Vexar®-protected seedlings showed the highest survival (35.4%), medium-weight Durite®-protected seedlings the lowest at 2.7% (Table 1). Gopher-caused mortality was the leading cause of failure for the control, light-weight Vexar®-protected, and heavy-weight Vexar®-protected seedlings (81.4%, 85.7% and 83.4%, respectively, of all mortalities). The medium-weight Durite®-protected seedlings suffered more than the other treatment seedlings from nonanimal mortality (77.1%); in fact, this was the leading cause of mortality for this treatment (Table 1). Across treatments, seedling survival was 19.8%.

Survival distributions for the four treatments were different (Wilcoxon test, $\chi 2 = 273.2024$, df = 4, $P < 0.01$). Pairwise comparisons of all possible treatment combinations revealed differences in survival distributions for all but two comparisons: control vs. medium-weight Durite® ($P = 0.9039$) and heavy-weight Vexar® vs. light-weight Vexar® ($P = 0.0281$) (Table 2). The latter comparison ($P = 0.0281$) did not meet the comparisonwise error rate of 0.008.

Competing risks analysis (evaluation of the relative importance of the various mortality source survival distributions) showed dramatically improved survival distributions for the control, light-weight Vexar®-protected, and heavy-weight Vexar®-protected seedlings on the Mt. Hood study area with

Table 3. Growth of ponderosa pine seedlings, unprotected and protected by various physical barriers, surviving 24 month (Rogue River National Forest, Oregon) and 26 month (Mt. Hood National Forest, Oregon) study periods, 1993–1995.

Treatment[1]	No. of surviving seedlings	Initial ht	Stand. Dev.	Final ht	Stand. Dev.	Growth	Stand. Dev.
		(cm)					
Rogue River							
C	195	15.87	4.97	35.54	9.10	19.67	8.33
LD	56	20.96	4.23	34.88	7.46	13.92	6.50
HD	89	19.94	4.62	34.57	8.22	14.63	7.81
MV	189	17.30	5.21	35.25	9.11	17.95	8.44
Mt. Hood							
C	43	13.53	2.97	25.46	5.90	11.93	5.38
LV	77	13.08	3.42	24.18	8.25	11.10	7.59
MD	9	15.22	2.77	24.44	3.61	9.22	3.70
HV	98	12.72	3.29	23.33	7.57	10.61	6.27

[1] C = Control, HD = Heavy-weight Durite®, HV = Heavy-weight Vexar®, LD = Light-weight Durite®, LV = Light-weight Vexar®, MD = Medium-weight Durite®, MV = Medium-weight Vexar®.

gopher mortality as the omitted cause. Gopher mortality, then, was the most important mortality source for these three treatments. Nonanimal mortality, on the other hand, had the most profound impact on the medium-weight Durite®-protected seedlings. However, because so many Durite®-protected seedlings were lost to this mortality source (by desiccation), proportionally fewer were available to gophers.

Control seedlings on the Mt. Hood study area showed the most growth (mean = 11.93 cm) over the 26 month study (Table 3). Growth of undamaged seedlings surviving the full course of the study was not different ($F = 0.35$, $P = 0.7879$). Few ($n = 9$) of the medium-weight Durite®-protected seedlings, however, survived through the end of the study (Table 3).

Discussion

Across both study sites, survival of seedlings protected with Vexar® (42.7%) was higher than that of seedlings protected with Durite® (16.9%). Gopher-caused mortality, however, was proportionally higher among seedlings protected by Vexar® tubing (44.3% of all Vexar®-protected seedlings) compared to Durite® tubing (20.7% of all Durite®-protected seedlings). Damage to Vexar®-protected seedlings typically was associated with damage to the tubing; seedlings were most commonly accessed from below ground. None of the Durite® tubes sustained any gopher-related damage. The rapid decomposition of the below-ground portion of the tubing, however, made this difficult to evaluate.

We note that the level of gopher-caused mortality was very high on the Mt. Hood study area, about twice the level observed on the Rogue River study area. Comparing controls alone, gopher-caused mortality was more than two times greater on the Mt. Hood sites. This probably resulted from the extremely high densities of gophers on the sites recommended for study by Mt. Hood National Forest personnel. Another point needing clarification regards the status of control seedlings on the Rogue River sites, which exhibited a survival rate nearly the same as that of Vexar®-protected seedlings. Although control seedlings suffered higher mortality from gophers, the Vexar®-protected seedlings suffered proportionally greater losses from the nonanimal and "other" mortality categories. These greater losses are very likely due to the increased difficulty of adequately planting Vexar®-protected seedlings (minimizing air pockets) and the attractiveness of the Vexar® tubing to domestic livestock and/or wild ungulates. On more than one occasion, numerous Vexar® tubes in a given plot were removed from the seedlings with no damage to the seedlings themselves. This attraction did not appear to extend to the Durite® tubes.

Durite®, as evaluated in this study, was not a suitable material for protecting seedlings from foraging gophers. We speculate that the cause of the dramatic mortality of Durite®-protected seedlings was the result of poor ventilation in the tubes. Although ventilation holes were provided, they were not sufficient to counteract heating effects. Over time, constriction of the tubes accentuated this "heat trap" effect. This problem was more severe with the light-weight Durite® tubes. The heavy-weight Durite® tubes, being more rigid, tended to open over the course of time, reducing their protective effect, as well as the heat trap effect, thereby lessening the impact of temperature-related mortality. The negative effects of the Durite® tubes greatly increased the level of nonanimal mortality of seedlings on both study areas.

The effect of tubing on the growth of seedlings has received much attention in the literature. Most such studies (Pauls 1986, Anthony et al. 1978, Campbell and Evans 1975, Engeman et al. 1999) have found Vexar® tubing to confer a growth advantage on seedlings. In this study, we noted no such growth benefit resulting from the use of Vexar®; in fact, control seedlings outgrew Vexar®-protected seedlings on the Rogue River area by 9% and on the Mt. Hood study area by 7% (light-weight Vexar®) and 11% (heavy-weight Vexar®). Despite the high seedling mortality associated with the Durite® tubes, this experimental material did not confer any growth benefits on seedlings.

Problems associated with use of Vexar®, such as deformity of terminal branches growing through the mesh (Pauls 1986, Anthony et al. 1978), can be detrimental to health and vigor of seedlings. Breakage and compression of tubes under freezing and accumulating snow conditions, respectively, have also been documented (Anthony et al. 1978). Although terminal death was common in this study, it was not caused by the tubing in any cases. Furthermore, in such instances, a lateral would invariably soon assume the role of terminal dominance. Health or vigor of such affected seedlings did not appear to be compromised.

Another point of concern surrounding the use of protective tubing has been root constriction. In this study, roots were not observed to grow through the mesh openings (diamond pattern, 0.64 x 2.22 cm inner dimensions) of the Vexar®. In general, the finer the mesh, the greater the potential for restricting root growth (Marsh et al. 1990). Engeman et al. (1997) showed that Vexar®-protected seedlings had greater root depth than unprotected seedlings, although unprotected seedlings showed greater root weight. The Durite® tubes tended to be unobstructive of root growth because of tube decomposition. By 4 months post-planting, the belowground portion of the tubing was already in an advanced stage of decomposition, as evidenced by its friable nature, and fine root hairs were visible surrounding the tubing in the rooting zone. By the 15/16 month checks, many of the tubes were rotted off at ground level and could easily be pulled over the seedlings. Although these observations raise questions about the durability of Durite®, they do illustrate that it is not completely obstructive of root growth. It could be argued that roots penetrating the Durite® were exposed to foraging gophers, but these roots were of such small size that, even if targeted, they would not impact survival of the seedling. However, if, in fact, gophers did feed on these fine roots, the proximity of burrows could impact survival by desiccation of the root systems.

Vexar® tubing provides other benefits. It has proven effective against various other damage-causing wildlife species (Campbell and Evans 1975), and thus could preclude the use of numerous control techniques (Anthony et al. 1978). Furthermore, access to areas by wildlife is not restricted, and competing vegetation is often browsed, thereby reducing the need for chemical control (Campbell and Evans 1975).

Results of this study indicate that Vexar® tubes show more promise as a seedling protector than Durite® tubes. Despite less than ideal results obtained using Vexar® tubes, we found they provided greater protection against gopher damage compared to the control seedlings, but resulted in slightly reduced seedling growth. The damage control efficacy provided by Vexar® may offset the shortcomings of increased cost and required labor (Anthony et al. 1978). With attention to careful planting techniques, the use of protective tubing can further enhance survival of tree seedlings.

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