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The effects of Vexar® seedling protectors on the growth and development of lodgepole pine roots

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The effects on the growth and development of lodgepole pine roots from the Vexar® tubes used to protect seedlings from pocket gopher damage were studied in the Targhee National Forest, Idaho and the Deschutes National Forest, Oregon. At each site, Vexar-protected and unprotected seedlings, with and without above-ground gopher damage were examined after six growing seasons for root deformities and growth. Undamaged seedlings exhibited greater growth, reflecting the importance of non-lethal gopher damage as a deterrent to tree growth. Protected seedlings with similar damage history as unprotected seedlings had greater root depth than unprotected seedlings, although unprotected seedlings with no above-ground damage generally had the greatest root weight. In general, the percent of seedlings with root deformities was greater for the unprotected seedlings than for the Vexar-protectd seedlings, although this could be largely due to the greater care required to plant protected seedlings. Acute deformities were more common for unprotected seedlings, whereas root deformities with less severe bending were more common for protected seedlings. The incidence of crossed roots was similar for protected and unprotected seedlings on the Deschutes site, where enough occurrences of this deformity permitted analyses. Protected seedlings were similar in root abundance, root distribution, root size and vigor to the unprotected seedlings, with some indication from the Deshutes study site that root distribution was improved with Vexar protection. Published by Elsevier Science Ltd

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Positive results (Marsh, Koehler and Salmon, 1990) have been obtained with the use of Vexar®[1] plastic mesh seedling protectors for reducing damage to conifer seedlings by pocket gophers (*Thomomys* spp.). Methods for reducing animal damage without lethal control of animals are the subject of increasing public interest (e.g. Acord, 1992). However, questions about root conditions of protected seedlings have yet to be answered for application of this method. Root deformities have been observed in black walnut (*Juglans nigra*) (Ellis, 1972) and Douglas-fir (*Pseudotsuga menziesii*) (Owsten and Stein, 1978) that were enclosed in heavy plastic mesh containers. Because Vexar protectors principally degrade in sunlight, underground portions theoretically could maintain their durability for decades, thereby adversely affecting root development and growth. Also, the extent of protection provided by the Vexar tubes from non-lethal gopher damage to roots is of interest. Extensive clipping and girdling of roots reduces growth and stability of conifers as they become larger.

[1]Reference to trade names does not imply US Government endorsement of commercial products.

This study was designed to determine the long-term (six growing seasons) effects of Vexar® seedling protectors on growth and form of roots of lodgepole pine (*Pinus contorta*) seedlings and to quantify pocket gopher injuries to roots of protected and unprotected seedlings.

Materials and methods

Study areas and planting

The study sites were on the Deshutes National Forest in central Oregon and the Targhee National Forest in east-central Idaho. The Deschutes study site used four blocks (clearcuts) ranging from 6 to 10 ha in size at 1707 m elevation and was comprised of a lodgepole pine/sedge (*Carex pensylvanica*) lupine (*Lupinus andersoni*), penstemon (*Penstemon euglaucus*) plant community (Type CL-G4-12, Volland, 1976). The Targhee study site was located at 1890 m elevation in large (>40 ha), contiguous clearcuts in a lodgepole pine/pine grass (*Calamagrostis rubescens*) habitat type (Steele, Cooper, Ondov and Pfister, 1983). The seedling protector evaluated in this study was a 76 cm cylinder of photodegradable polypropylene netting with an inside diameter of 5 cm. The mesh opening was 9 mm with a stand diameter of 1.5 mm. Equal numbers of protected and unprotected seedlings were planted at each study site. Seedlings were randomly designated as Vexar-protected or Vexar-unprotected (control) treatments. Protected seedlings were placed into the Vexar tubes by first inserting the seedling in a solid plastic pipe and then using the pipe as a carrier to place the seedling into the Vexar. Seedlings were positioned so that the lower roots were near (<5 cm) the bottom of the Vexar tube. Moistened soil from the study site was packed through the mesh around the roots. The Deschutes study area was auger-planted in 1976 with lodgepole pine seedlings that were nursery grown for 3 years. The Targhee study area was auger-planted in 1977 in machine-scalped spots with lodgepole seedlings that were nursery grown for 2 years. No rodenticide baiting for pocket gopher control was conducted on the study areas after planting.

Sampling

After six growing seasons at each study area, at least 100 seedlings from each of the Vexar-protected and unprotected treatments (>200 total seedlings from each site) were excavated and examined for root deformities and pocket gopher damage. Each group of protected or unprotected seedlings contained at least 50 seedlings that had been damaged above ground by pocket gophers and at least 50 undamaged seedlings.

On the Deschutes plots, seedlings were excavated by digging away dirt to form a trench around from the outside of a metal cylinder, 50 cm in diameter and 50 cm deep, surrounding the seedling. The cylinder was used to protect the roots and insure uniform excavation. Roots extending beyond the 50 cm diameter of the cylinder were cut off. On the Targhee plots, a hydraulic tree lifter was used to excavate seedlings. In both excavations, the soil around the roots was gently removed with a small hand rake. Residual soil was washed from the roots with tap water before examination.

Measurements

Six size measurements were made on each seedling at excavation. Immediately before excavation, stem diameter at ground level and height (distance from the root collar to the top of the seedling) of each seedling were measured. Root collar depth was measured as the distance from the soil surface to the top of the first root. Post-excavation measurements included root depth, which was defined as the distance from the top of the first root to the deepest root tip. The dry weight of roots was specified as the weight of the roots below the top of the first root after oven drying at 70°C for 48 h. The dry weight of the seedling top was specified as the weight of the seedling above the top of the first root after oven drying at 70°C for 48 h. Root distribution for each seedling was measured as the number of the four quadrants (when viewed from above the stem) around the center of the root mass that contained roots (Mexal and Burton, 1978). In addition, initial heights of seedlings were measured at planting.

Roots were examined for five major deformities; bent, J-rooted, L-rooted, balled, and crossed. Bent roots were defined as bent >45° and angled <90° from the direction of the rest of the root. Roots that were bent 90° from the rest of the root were called L-roots. Roots that were bent >90° from the rest of the root were labeled as J-roots. Crossed roots occurred when two or more roots were intertwined, with overgrowth by one or all involved roots. When all roots were bent upward and intertwined, with no geotrophic response, they were described as balled roots. Damage by gophers was described as the type and extent of injury and the size of the root affected.

Analytical methods

The smaller discreet clearcuts in the Deschutes study area defined a randomized block design, where a two-factor factorial experiment was contained in each of the four blocks (clearcuts). The two factors were damage (damaged vs undamaged) and protection (Vexar vs no protection). Thus, the terms used in the denominators for the F-ratios in the ANOVA for testing the main effects and interaction were comprised of each effect's respective interaction with the block. The large contiguous area of the Targhee portion of the study defined a completely randomized design, with the main effects and interaction each using the same error term in the denominator of the F-tests. Discrete data were analyzed with chi-square tests when adequate cell sizes resulted.

Results

Size measurements

Table 1 summarizes the size variables among treatment groups at each study area. For the Deschutes study site, no protection–damage interaction was detected for any of the variables. Differences were found between seedings with and without above-ground damage, with the undamaged seedlings having larger measurements. The mean height of undamaged seedlings was 82.4 cm vs only 65.3 cm for the damaged seedlings ($F = 56.7$, d.f. = 1,3, $P = 0.005$). At 2.57 cm, the mean diameter for undamaged seedlings was greater than the 2.10 mean diameter for the damaged seedlings ($F = 63.3$, d.f. = 1,3, $P = 0.004$). The strongest difference was shown in mean root weight where the undamaged seedlings averaged 69.7 g, as opposed to 41.4 g for the damaged seedlings ($F = 247.9$, d.f. = 1,3, $P = 0.001$). The difference in above ground weight of seedlings less strongly indicated a difference ($F = 11.5$, d.f. = 1,3, $P = 0.077$), with undamaged seedlings averaging 725 g vs 534 g for damaged seedlings. A difference in height between protected ($\bar{x} = 82.7$ cm) and unprotected ($\bar{x} = 65.4$) seedlings was found ($F = 11.8$, d.f. = 1,3, $P = 0.041$). The mean root depth of 47.6 cm for protected seedlings exceeded the mean depth for unprotected seedlings, 37.7 cm ($F = 17.79$, d.f. = 1,3, $P = 0.024$). However, there was a general trend for damaged seedlings with no Vexar protection to produce smaller measurements for each variable than the damaged seedlings with protection, as well as being smaller than both protected and unprotected seedlings that were undamaged.

Table 1. Size variable means (standard deviation) measured after six growing seasons for Vexar-protected and unprotected seedlings, exposed or not to above-ground gopher damage, in the Deschutes and Targhee National Forests

	Variable					
Site	Height (cm)	Diameter (cm)	Root collar depth (cm)	Root depth (cm)	Top wt (g)	Root wt (g)
Deschutes						
Damaged[a]	77.2	2.28	12.2	47.9	567	43.0
Vexar	(24.5)	(0.77)	(6.55)	(9.6)	(424)	(30.5)
Damaged[a]	56.2	1.97	10.9	37.3	509	40.2
no Vexar	(30.0)	(1.03)	(4.74)	(14.4)	(660)	(51.7)
Damaged[b]	88.1	2.58	11.8	47.3	711	66.2
Vexar	(33.1)	(1.12)	(4.68)	(10.3)	(848)	(75.2)
Damaged[b]	76.8	2.57	12.8	38.1	741	73.1
no Vexar	(36.5)	(1.25)	(4.43)	(13.3)	(1068)	(94.9)
Targhee						
Damaged[a]	70.4	1.64	5.56	46.0	334	13.6
Vexar	(25.5)	(0.61)	(3.55)	(14.9)	(311)	(13.5)
Damaged[a]	58.0	1.61	6.40	37.9	273	13.7
no Vexar	(27.0)	(0.63)	(2.97)	(16.0)	(270)	(12.5)
Damaged[b]	73.8	1.61	6.49	45.2	307	13.8
Vexar	(25.7)	(0.47)	(3.86)	(13.3)	(246)	(11.3)
Damaged[b]	72.3	1.87	6.77	45.8	373	21.8
no Vexar	(22.1)	(0.55)	(3.75)	(13.3)	(299)	(22.0)

[a]Seedlings were damaged above ground by pocket gophers at least once from planting until time of examination
[b]Seedlings were undamaged above ground from planting until time of examination

Inferences from the Targhee study site are more complex because differences were indicated among the means in the interaction (*Table 1*) between protected/unprotected and damaged/undamaged seedlings for root depth ($F = 4.65$, d.f. = 1208, $P = 0.032$), and also, but less strongly for root weight ($F = 3.41$, d.f. = 1207, $P = 0.066$) and stem diameter ($F = 3.62$, d.f. = 1201, $P = 0.059$). The unprotected–damaged seedlings had smaller mean root depth than the mean root depths for the other three groups, which were nearly the same (*Table 1*). The mean root weight and stem diameter for undamaged–unprotected seedlings stood out by being somewhat larger than the means for Vexar-protected, undamaged seedlings and for damaged seedlings with and without protection (*Table 1*). Differences in height were indicated between Vexar-protected and unprotected seedlings ($F = 4.14$, d.f. = 1209, $P = 0.043$) and between undamaged seedlings and seedlings receiving above-ground gopher damage ($F = 6.53$, d.f. = 1209, $P = 0.011$). The mean heights for protected and unprotected seedlings were 72.2 and 64.6 cm, respectively. The mean heights for seedlings with and without above-ground gopher damage were 63.6 and 73.0 cm, respectively. Next to the unprotected–damaged seedlings, protected–damaged seedlings presented the next smallest mean height, but it still was 21% greater than for the unprotected–damaged seedlings.

Initial heights

For both study sites, we also analyzed the initial height of seedlings to: (1) see if this variable related to susceptibility to damage; (2) determine if there was any size bias in the seedlings that were given Vexar protection; and (3) check for possibility of an interaction between susceptibility and protection. No differences were found for the Deschutes study site for any of the effects, however, for the Targhee study site, the initial heights for the seedlings that subsequently received above ground damage was greater ($\bar{x} = 19.3$ cm for damaged vs $\bar{x} = 17.6$ cm for undamaged) than for the seedlings that received no subsequent above ground damage ($F = 6.72$, d.f. = 1208, $P = 0.010$). Also, the initial heights of seedlings receiving protection was greater ($\bar{x} = 19.5$ cm for protected vs $\bar{x} = 17.5$ for unprotected) than for unprotected seedlings ($F = 8.47$, d.f. = 1208, $P = 0.004$). An interaction was not detected ($P = 0.503$). A reversal was shown after the six growing seasons where the heights were greater (as previously noted) for the undamaged trees (*Table 1*).

Root distribution

The distributions of seedlings with roots in two, three or four quadrants (*Table 2*) was compared among damaged vs undamaged seedlings and among protected vs unprotected seedlings using chi-square contingency table analyses. No differences in the grouping of seedlings into root distribution categories were detected between damaged and undamaged seedlings on either study site ($\chi^2 < 1.75$, d.f. = 2, $P > 0.4$ for both sites). However, on the Deschutes study site there was a difference between the root distributions of protected and unprotected seedlings ($\chi^2 = 13.10$, d.f. = 2, $P = 0.001$). This pattern was not evident at the Targhee site ($\chi^2 = 0.078$, d.f. = 2, $P = 0.962$). Further examination of the Deschutes data revealed that differences in root distribution between protected and unprotected seedlings held true for both the damaged and undamaged seedlings ($\chi^2 > 6.25$, d.f. = 2, $P \leqslant 0.04$), and this was most notably reflected by the fact that two-thirds of the protected seedlings had roots in all four quadrants vs less than one-half of the unprotected seedlings, for both the damaged and undamaged seedlings.

Root deformities and root damage

Uniformly for both study sites and for both damaged

Table 2. Number of Vexar-protected and unprotected seedlings, exposed or not to above-ground gopher damage, having roots in two, three or four quadrants around the stem for the Deshutes and Targhee study sites

Site	Number of seedlings with roots in 2 Quadrants	3 Quadrants	4 Quadrants
Deschutes			
Damaged[a], Vexar	2	15	33
Undamaged[b], Vexar	1	15	34
Damaged[a], no Vexar	12	22	31
Undamaged[b], no Vexar	6	21	24
Targhee			
Damaged[a] Vexar	3	16	30
Undamaged[b] Vexar	0	19	33
Damaged[a] no Vexar	2	21	36
Undamaged[b] no Vexar	2	18	32

[a]Seedlings were damaged above ground by pocket gophers at least once from planting until time of examination
[b]Seedlings were undamaged above ground from planting until time of examination

Table 3. Number of Vexar-protected and unprotected seedlings exposed or not to above-ground gopher damage, with deformities or gopher damage to lateral or tap (in parentheses) roots

Site	Root problem: Bent at one point	J-Root	L-Root	Crossed root	Balled root	Gopher damage
Deschutes						
Damaged[a] Vexar	28 (11)	7 (1)	3 (7)	22 (2)	0 (0)	3(0)
Damaged[a] no Vexar	3 (0)	43 (24)	18 (10)	21 (1)	0 (0)	4(2)
Undamaged[b] Vexar	30 (10)	7 (1)	5 (3)	21 (5)	0 (0)	1(0)
Undamaged[b] no Vexar	5 (1)	37 (28)	24 (6)	22 (2)	5 (0)	4(1)
Targhee						
Damaged[a] Vexar	28 (19)	14 (3)	6 (3)	4 (1)	0 (0)	0(0)
Damaged[a] no Vexar	0 (0)	30 (14)	28 (6)	1 (0)	0 (0)	3(0)
Undamaged[b] Vexar	34 (14)	17 (3)	7 (10)	4 (0)	0 (0)	1(0)
Undamaged[b] no Vexar	0 (0)	36 (13)	33 (7)	2 (1)	0 (0)	0(0)

[a]Seedlings were damaged above ground by pocket gophers at least once from planting until time of examination
[b]Seedlings were undamaged above ground from planting until time of examination

and undamaged seedlings, the incidences of J-roots and L-roots were greater for unprotected seedlings than for protected seedlings ($\chi^2 > 10.4$, d.f. = 1, $P < 0.001$). For both study sites and both damage categories, the Vexar-protected seedlings had substantially higher incidence of bent roots ($\chi^2 > 27.5$, d.f. = 1, $P < 0.001$). No differences in the incidence of seedlings with crossed roots could be detected between Vexar-protected and the unprotected seedlings at either site with or without damage. Balled roots at both sites and crossed roots at the Targhee site occurred too infrequently for sound inferences to be made.

Fewer seedlings in all groups had damage or deformities to tap roots compared to lateral roots (*Table 3*). However, tap root deformities were still more common among unprotected seedlings, with patterns of tap root deformities being somewhat similar to those for lateral roots. Vexar protected seedlings in both areas and in both damage categories had lower incidence of J-tap roots ($\chi^2 > 7.4$, d.f. = 1, $P < 0.006$), but greater incidence of bent tap roots ($\chi^2 < 8.3$, d.f. = 1, $P < 0.004$). In contrast to the lateral roots, no differences for L-tap roots were detected ($\chi^2 < 1.1$, d.f. = 1, $P > 0.4$).

Too few seedlings at each site received damage to roots to make solid inferences relative to Vexar protection or above-ground damage. Lateral root damage occurred in less than 6% of seedlings and tap root damage in less than 2% at the Deschutes site. Even fewer seedlings at the Targhee site had root damage, as less than 2% had lateral root damage and none had tap root damage.

Discussion

Pocket gopher damage to roots of seedlings in all treatment groups was negligible at both study areas (*Table 3*). The total number of seedlings with gopher-damaged roots and number of roots damaged per seedling were quite low. However, only living trees were selected for our study on the effects of Vexar to roots and because gopher damage usually results in seedling mortality, root damage was unlikely to have been prevalent in either the unprotected or protected seedlings sampled.

There can be little surprise that seedlings without above-ground gopher damage generally were larger than damaged seedlings. Nevertheless, this illustrates the importance of non-lethal gopher damage as a deterrent to tree growth, a factor often easily overlooked in damage analysis if only the survival of seedlings is examined. Protected and unprotected seedlings that had been damaged showed little difference in root weight. However, unprotected seedlings that escaped damage generally had greater root weight than protected seedlings. Regardless, protected seedlings of similar damage history usually had greater root depth than unprotected seedlings, perhaps because the protectors guide the roots downwards. There was some indication from the Deschutes study site that protected seedlings had better distribution among the four quadrants about the stem than unprotected seedlings with similar damage histories. The same effect was not observed at the Targhee study site.

In general, we observed that the number of seedlings with root deformities was greater for unprotected seedlings than for Vexar protected seedlings (see *Table 3*). This probably is due to the greater care required to prepare and plant protected seedlings compared to unprotected seedlings, J- or L-roots were the most common deformities among unprotected seedlings and could be attributable to poor planting technique. On the other hand, protected seedlings may have had fewer root deformities from planting, but they had more bending after planting when roots encountered the strands of protectors. This caused an 80°–90° bend before the roots continued downward.

We found few roots growing out the bottom of protectors. No roots exited through the bottom of 55% of the protectors, while another 33% had only one root escaping through the bottom. This is probably explained by the planting procedure that involved: (1) positioning the roots of seedlings within 5 cm from the bottom of the protector; (2) packing soil through the mesh and around the roots; and (3) compressing soil in the bottom of the protector to hold the soil column in place. Because the root tips were near the bottom of the protectors, they were apparently displaced laterally when the soil plug was pressed in place. Compaction of soil in the bottom of the tubes probably prevented root penetration (Heilman, 1981). The long-term effect of this divergence is unknown, however, it would be desirable for the taproot of seedlings to grow out of the bottom of the protectors to give it better vertical orientation.

Few roots had grown large enough to be seriously affected by the Vexar tubes. About 60% of the protected seedlings had one or two roots encompassing the mesh. Generally, the plastic strands were being stretched and enveloped by the roots. This overgrowth might cause concern that the stability of trees would be reduced, although we have not observed this in 15- to 20-year-old Douglas-fir.

Results from this investigation indicate that protected seedlings are similar in root abundance, distribution, size, and vigor to unprotected seedlings. Like many studies, in answering many questions, others are created. Information from many studies supports the use of protectors on conifer plantations with severe gopher problems where other methods are economically, environmentally, or operationally impractical. However, longer-term effects of protectors on root strength and tree vigor can only be answered as seedlings grow larger.

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