Efficacy of Individual Barriers to Prevent Damage to Douglas-Fir Seedlings by Captive Mountain Beavers

Douglas E. Runde, Dale L. Nolte, Wendy M. Arjo, and William C. Pitt

ABSTRACT

We tested the ability of individual tree seedling protectors to deter mountain beavers from damaging Douglas-fir seedlings. Using captive mountain beavers in field pens, we tested 20 products representative of a wide range of barriers suitable for protecting individual tree seedlings from rodent damage. Eleven products protected 95% or more of seedlings from damage. Tree shelters and fabric shelters provided the most protection; 98 and 95% of seedlings were undamaged, respectively. Rigid mesh protector tubes protected 81% of seedlings, and protection netting protected 55% of seedlings. Purchase prices varied widely; protection netting was least expensive, followed by rigid mesh tubes, fabric shelters, and tree shelters. Seedling growth was greatest within fabric shelters and plastic tree shelters. Materials used to construct 15 of the 20 tree protectors were tested using captive mountain beavers in small sheltered pens. Here, samples of barrier materials were used to block access to a favored food. The four materials that excluded all test animals in all trials were from unvented tree shelters with solid seamless walls. Seven materials failed to exclude any animals in the sheltered-pen trials.

Keywords: mountain beaver, *Aplodontia rufa,* Douglas-fir, *Pseudotsuga menziesii,* tree shelters

The mountain beaver (*Aplodontia rufa*) is a largely fossorial rodent endemic to northwestern North America (Carraway and Verts 1993) and does more serious damage to Douglas-fir (*Pseudotsuga menziesii*) seedlings and saplings than any other mammal in the Pacific Northwest (Cafferata 1992). The mountain beaver can impede plantation establishment in the Pacific Northwest (Black and Lawrence 1992) and are managed as economically important pests largely because of the damage they cause to Douglas-fir seedlings (Hooven 1977, Borrecco and Anderson 1980, Campbell and Evans 1988). The majority of reported mountain beaver damage has occurred from the Olympic Peninsula to the Puget Sound Trough and the Coast Range to the Willamette Valley (Borrecco and Anderson 1980). Damage to Douglas-fir and red alder (*Alnus rubra*) has been especially severe in the Coast Range of Washington; in Grays Harbor County alone, tens of thousands of dollars are spent annually to control local mountain beaver populations to ensure establishment of new plantations after clearcut harvests.

Damage to conifers by the mountain beaver occurs above- and belowground. Major losses from cutting tree seedlings have been most severe immediately after and up to 4 years after planting and may be followed by stem girdling and root damage for the next 10–20 years (Feldhamer et al. 2003). Belowground, the mountain beaver may uproot or bury seedlings and undermine and damage roots of larger trees. They also may climb and clip lateral branches, as well as terminal shoots, of older saplings. Bark damage at ground level is most common in trees that are 10–15 cm in diameter but also may occur in larger-diameter trees. Stem and root girdling may affect over 50% of the trees within a stand (Cafferata 1992, Feldhamer et al. 2003). Prevention and control of mountain beaver damage in commercial plantations usually is applied after clearcut harvest and within 1 year of planting. Cultural methods such as intensive site preparation, slash removal, weed control, and planting large seedlings can be used where mountain beaver populations are known to be high (Cafferata 1992). Direct population control by extensive trapping and removal before planting is currently the most effective method for reducing damage (Feldhamer et al. 2003). However, even after intensive removal from an area and the surrounding buffer zone, the mountain beaver can quickly reinvade the seedling area from surrounding habitats (Hacker and Coblentz 1993).

Our objective was to evaluate a nonlethal exclusionary approach (for a review see Marsh et al. [1990]) to protecting newly planted Douglas-fir seedlings with individual tree seedling barriers applied shortly after planting. Captive mountain beavers were used to test and compare the efficacy of a variety of commercially available barriers and the synthetic materials used to make them. We also compared growth of seedlings inside the protectors and purchase prices. Use of these products and brand names does not constitute endorsement by the USDA.

Methods

We conducted two tests of single tree seedling protectors with captive mountain beavers at the National Wildlife Research Center's Olympia Field Station (OFS) in Olympia, Washington.

Received August 17, 2006; accepted March 21, 2007.

Douglas E. Runde (douglas.e.runde@aphis.usda.gov), USDA/APHIS Wildlife Services, NWRC, Olympia Field Station, 9730-B Lathrop Industrial Drive SW, Olympia, WA 98512; his current address is USDA/APHIS Wildlife Services, NWRC, Hawaii Field Station, Hilo, HI 96721. Dale Nolte (dale.l.nolte@aphis.usda.gov), USDA/APHIS Wildlife Services, NWRC, Olympia Field Station, 9730-B Lathrop Industrial Drive SW, Olympia, WA 98512; his current address is USDA/APHIS Wildlife Services, NWRC, 4101 Laporte Avenue, Fort Collins, CO 80521. Wendy M. Arjo (wendy.m.arjo@aphis.usda.gov), USDA/APHIS Wildlife Services, NWRC, Olympia Field Station, 9730-B Lathrop Industrial Drive SW, Olympia, WA 98512. William C. Pitt (will.pitt@aphis.usda.gov), is a wildlife research biologist, Hawaii Field Station, USDA/APHIS, Wildlife Research Services, NWRC, PO Box 10880, Hilo, HI 96721. *The authors thank Vida Billings, Julie Harper, Kelly Perry, Suzanne Rizor, and Richard Roberts for field assistance and animal care. The authors thank the following companies who donated test materials for this study: Farm Wholesale Products, Salem, Oregon; Quadel Industries, Inc., Coos Bay, Oregon; Sinorefor Products, Inc., Vancouver, BC, Canada; and Tree Pro, West Lafayette, Indiana. The authors thank the following companies who provided test materials at a discount: Certified Plant Shelters, Prince Rupert, BC, Canada; McKnew Enterprises, Elk Grove, California; and Terra Tech, LLC, Eugene, Oregon.*

Table 1. Categories, products, heights, diameters, and supports used for individual tree seedling barrier products evaluated to reduce mountain beaver (*A. rufa*) damage to Douglas-fir (*P. menziesii*) seedlings in outdoor pens, July 2004 through June 2005, Olympia, WA.

Product name	Category	Height (cm)	Diameter (cm)	Support stake
Pro/Gro Tree Protector-heavy	Tree shelter	91.4	10.2	Wood
Tree Cone	Tree shelter	91.4	11.0–21.6[a]	Wood
Eco-tube	Tree shelter	91.4	12.7	Wood
Grow Tube	Tree shelter	78.7	12.7	Bamboo
Vented Miracle Tube	Tree shelter	71.1	8.9–10.8[b]	Wood
Unvented Miracle Tube	Tree shelter	71.1	8.9–10.8[b]	Wood
Tree Protector	Tree shelter	76.2	10.2	Wood
Standard Tree Shelter	Tree shelter	90.0	10.0–11.5[b]	Wood
Blue-X Treeshelter	Tree shelter	76.2	8.9	Bamboo
Rigid Seedling Protection Tube-light	Rigid mesh tube	61.0	11.4–12.7[b]	Bamboo
Rigid Seedling Protection Tube-heavy	Rigid mesh tube	91.4	11.4–12.7[b]	Bamboo
Tube Net	Rigid mesh tube	90.0	11.0	Wood
Rigid Seedling Protector Tube	Rigid mesh tube	91.4	8.9–11.4[b]	Bamboo
Budcap	Protection netting	30.0–80.0[c]	5.7–14.0[d]	None
Heavy-duty Protection Netting	Protection netting	30.0–80.0[c]	6.4–21.0[d]	None
Tiller Net	Protection netting	91.4	6.4–21.0[d]	None
Wide Mesh Protection Netting	Protection netting	71.1	6.4–15.3[d]	None
Open and Fine Mesh Shelters	Fabric shelter	86.4	15.2	Wood
Open Mesh Hybrid Shelter	Fabric shelter	91.4	11.4	Bamboo

[a] Pyramid-shaped shelter: 21.6 cm at base and 11.0 cm at top.
[b] Shipped in nested bundles of tubes with graduated diameters.
[c] Cut to length to fit seedling height.
[d] Protection netting stretched during installation: minimum and maximum diameters are approximate only.

Twenty different seedling protection products (see Table 2) were installed on Douglas-fir seedlings planted in outdoor field pens from July 2004 through June 2005. Materials from 15 of these barriers were tested for resistance to mountain beaver damage in unheated sheltered pens from January through April 2005. Here, captive mountain beavers had to breach the test materials to gain access to favored food treats.

Test Materials

Over 55 different products designed to enhance survival of tree seedlings were available in 2004. Based on characteristics described later, we tested 20 products representative of the range of products that were suitable for protecting young tree seedlings from rodent damage. In general, these were all open-ended tubes designed to surround a single tree seedling. We did not include wrap-around trunk protectors designed for nurseries and orchards.

Products for protecting individual tree seedlings have been called tree guards, tree shelters, tree protectors, protection tubes, and protection netting. A wide assortment of designs and sizes were available; product selection would depend on the size and growth form of the trees needing protection, the animal species being deterred, and local site conditions (Campbell and Evans 1975, Marsh et al. 1990, Campbell 1994, Jacobs and Steinbeck 2001, McCreary and Tecklin 2001). Diameters of products we examined ranged from 5.7 to 21.6 cm in diameter and were 30.0 to 91.4 cm tall (Table 1).

We grouped barriers into four easily recognized categories based on gross physical characteristics and structure of the materials used in each product. First, we referred to seedling protectors with solid walls as "tree shelters." Most of these were open-ended cylinders, but Sinocast Tree Cones (Sinorefor Products Inc., Vancouver, BC, Canada) were pyramidal and Sinocast Eco-tubes (Sinorefor Products, Inc.) were square tubes. Four of the nine tree shelters were formed from flat plastic sheets, which created vertical seams with exposed edges, and two of these were ventilated with small circular holes. The other five were continuous extruded tubes with solid seamless walls, and only one of these was vented.

Tree Pro Miracle Tubes (Tree Pro, West Lafayette, IN) and Tubex Standard Tree Shelters (Tubex Ltd., South Wales, U.K.) came in a range of diameters (Table 1) that fit inside one another to facilitate transport. Protex Pro/Gro Tubes (Norplex Inc., Auburn, WA) and Corrugated Plas-Tech Grow Tubes (Farm Wholesale Products, Salem, OR) arrived as flexible flat sheets that were wrapped around the seedlings; the two edges were joined with precut tabs to create cylinders with exposed vertical seams and tabs. Tree Pro Tree Protectors (Tree Pro) were similar but the two edges were butted together and fastened to wooden stakes so that seams were hidden and no edges were exposed. Sinocast Tree Cones and Eco-tubes were preformed from flat plastic sheets using staples, which created exposed overlapping edges. We used bamboo stakes for Blue-X Treeshelters (McKnew Enterprises, Elk Grove, CA), all other tree shelters required wooden stakes. Tree shelters were among the most expensive protectors available, and using wooden stakes further increased the purchase price. Purchase prices for preformed tree shelters tended to be higher than products assembled in the field from flat sheets.

The second category was "rigid mesh tubes," which were designed to protect seedlings in conifer plantations. These open mesh seedling protectors have been well-known by the duPont tradename "Vexar" (Campbell and Evans 1975). These were open-ended cylinders with firm, but bendable, walls made of extruded plastic mesh with diamond-shaped openings. To facilitate transport, some rigid mesh tubes were shipped in a range of different diameters (Table 1) that fit inside one another to form nested bundles. As recommended by the manufacturer, sawn wood stakes were used to support the Tubex Tube Net barriers (Tubex Ltd.); bamboo stakes supported the other three rigid mesh products.

"Protection netting" referred to lightweight tubular elastic sleeves designed to protect small conifer seedlings. Compared with rigid mesh tubes, protection netting had a lighter-weight elastic mesh. The netting was produced in long continuous tubes, three products were cut to fit the height of each seedling, and the fourth was applied precut to a standard length. The sleeves were held open to fit over the seedlings; when released, they contracted around the foliage, which allowed them to remain in place without added support. As the seedlings grew, the elastic mesh expanded as needed. Protection netting sleeves were the least expensive seedling protectors, and all other products that we evaluated required stakes for support.

The fourth category was "fabric shelters"; these were flexible cylindrical sleeves sewn from limp high-density polyethylene (HDPE) textile to form protection tubes with heavy seams facing outward. Spring steel rings, attached to both ends of the sleeves, were used to hold the sleeves open. The ends of these rings formed friction-grip clips used to fasten the shelters to wooden stakes and the clips were positioned on the stake to place vertical tension on the fabric sleeve. A hybrid design consisted of open-mesh fabric sleeves, without steel rings, placed over rigid mesh tubes and anchored with bamboo stakes.

Precise composition of seedling protectors we tested was undisclosed, but most were blends of polypropylene and polyethylene polymers. Most tree shelters were HDPE blends and many also contained polypropylene. Blue-X Treeshelters used a transparent layer of stiff blue-tinted polyester film (i.e., plain polyethylene terephthalate, or Mylar), which was rolled and slipped inside a thin limp outer sleeve of extruded HDPE. Rigid mesh tubes were proprietary blends of plastic copolymers such as low-density polyethylene and HDPE and polypropylene.

Purchase prices for individual seedling protectors varied widely and depended on quantity ordered, size, and durability of the material. Protection netting was least expensive followed by rigid mesh tubes, most of which required inexpensive bamboo stakes. Tree shelters and fabric shelters were most expensive and most required wooden stakes.

These products were tested using Douglas-fir seedlings obtained from the Washington State Department of Natural Resources Webster Forest Nursery, located adjacent to the OFS. The 1 + 1 seedling stock had been grown for 1 year in a seedbed, harvested, root pruned to 5 in., and transplanted back into a nursery bed at approximately 6 seedlings/ft^2 (0.56/m^2) and grown to a minimum height of 25 cm. The seedlings we used were obtained in the winter and were planted at a similar density in a small nursery area at the OFS and irrigated as needed. When transplanted into the OFS experimental field pens in May 2004 they were approximately 40 months old; heights ranged from 30 to 80 cm and averaged 50.0 ± 0.22 cm (SE).

Seventy-two seedlings were planted within each field pen (described in the following section) at a density of 0.41 seedlings/m^2 and were irrigated as needed throughout the duration of the study. Each product was randomly assigned to 3 seedlings in each pen, and 6 weeks after planting, they were installed according to directions supplied by the manufacturers or distributors. After the barriers were installed, a single mountain beaver was introduced into each pen.

Field-pen Trials

Thirteen mountain beavers (eight male beavers and five female beavers) captured in Grays Harbor County, Washington, were established in separate, but adjacent, outdoor pens with native plant cover. To prevent escape by climbing or burrowing, field pens were enclosed by walls of metal sheeting 1.0–1.2 m tall and by wire mesh buried to a depth of 1.2 m. The whole facility was covered by lightweight bird netting to exclude avian predators. Each field pen was 11 × 16 m and contained two nest boxes located at opposite corners of each enclosure. Nest boxes consisted of 76-l trash cans buried in the soil with an exit to the surface through a 1.5-m-long corrugated pipe (10 cm in diameter). Opposite the exit pipe, a 0.5-m corrugated pipe was buried in the soil to encourage natural burrowing by the animals. Each nest box was provided with straw for bedding and covered by an A-frame roof. A feeding station and water bowl were located near the middle of each pen and subjects had free access to water, alfalfa, apples, and lab rodent diet throughout the study.

Douglas-fir seedlings were planted 1 m apart in rows and seedling protectors were randomly assigned to 3 seedlings within each field pen. Observational units were the individual seedlings, and 9 unprotected seedlings within each pen served as controls. Experimental units were the 20 different seedling protection products, installed on 3 seedlings within each pen. This setup was replicated 13 times (i.e., 13 field pens) so that each product was tested on a total of 39 different seedlings. Initially, we included an opaque barrier (10 cm wide; 81 cm tall) that was designed to protect established saplings in nurseries or orchards. All the seedlings within these barriers died by the end of the study, presumably from a lack of light, and were excluded from analysis.

Field-pen trials were conducted from July 2004 to June 2005. Data included counts of live and dead seedlings and counts of seedlings with damaged stems, terminal buds, and lateral branches. We also noted if any buds, branches, or terminal leaders had grown outside of the tubes. We scored damage to the protectors on an ordinal scale, which reflected how well they resisted damage and protected the seedling from the mountain beaver. Scores were (1) protector penetrated, seedling removed or damaged; (2) protector undamaged, seedling damage limited to exposed branches or top; (3) protector upset or removed, but seedling undamaged; (4) protector penetrated, but seedling undamaged; (5) at least five chew marks on surface, but tube not penetrated and seedling undamaged; (6) fewer than five chew marks on surface, but tube not penetrated and seedling undamaged; (7) no evidence of damage to protector or seedling. These data were first collected 24 and 48 hours after introduction of a mountain beaver into the pen, and then at 1-week intervals for 18 weeks.

Price information (Table 2) did not include shipping costs and reflected 2004 prices for relatively small orders, and prices per unit may vary 10–30% depending on quantity ordered. Where products were donated or provided at a discount, we used catalog prices as published in 2004. We measured initial heights (±2 cm) of the tree seedlings shortly after planting in the field pens and before the addition of new aboveground growth. Heights were remeasured after completion of the next years' spring growth and thus included two growing seasons. Seedlings damaged by mountain beavers in the pens were excluded from analyses of seedling growth.

Sheltered-Pen Trials

Eight additional adult mountain beavers (five male beavers and three female beavers) captured in the fall of 2004 in Grays Harbor County, Washington, were established in individual unheated roofed pens (2.4 × 2.4 m) with concrete floors. Each animal had access to two adjacent pens through a single small opening (0.25 × 0.25 m) that could be blocked by samples of the materials used in seedling barriers. The "home pens" contained a simple artificial burrow system consisting of three 76-l polyethylene cans with lids; these were connected by short sections of flexible plastic pipe (0.1-m diameter) and one can was provided with straw for nest building.

Table 2. Sources and purchase prices paid for individual tree seedling barrier products evaluated to reduce damage to Douglas-fir (*P. menziesii*) seedlings by captive mountain beavers (*A. rufa*) in outdoor pens, July 2004 to June 2005; Olympia, WA (listed in order of increasing purchase prices).

Product; source	Price[a]
Budcap; Quadel Industries, Inc., Coos Bay, OR	0.09
Tiller Net; Quadel Industries, Inc., Coos Bay, OR	0.09
Heavy Protection Netting; Quadel Industries, Inc., Coos Bay, OR	0.09
Wide Mesh Protection Netting; Terra Tech, LLC, Eugene, OR	0.09
Heavy-weight Seedling Protection Tube; Quadel Industries, Inc., Coos Bay, OR	0.17
Rigid Seedling Protector Tube; Forestry Suppliers, Inc., Jackson, MS	0.25
Light-weight Seedling Protection Tube; Quadel Industries, Inc., Coos Bay, OR	0.34
Tubex Tube Net; Treesentials, Co., St. Paul, MN[b]	0.48
Blue-X Treeshelter; McKnew Enterprises, Elk Grove, CA	0.65
Open Mesh Hybrid Shelter; Certified Plant Shelters, Prince Rupert, BC, Canada	0.85
Grow Tube; Farm Wholesale Products, Salem, OR	0.94
Eco-Tube; Sinorefor Products, Inc., Vancouver, BC, Canada	1.20
Pro/Gro Tree Protector; Terra Tech, LLC, Eugene, OR	1.20
Open- and Fine-Mesh Shelters; Certified Plant Shelters, Prince Rupert, BC, Canada	1.40
Tree Cone; Sinorefor Products, Inc., Vancouver, BC, Canada.	1.60
Tree Protector and Miracle Tube; Tree Pro, West Lafayette, IN	2.00
Tubex, Standard Treeshelter; Treesentials, Co., St. Paul, MN	2.12

[a] Approximate purchase price per barrier (USD) presented for comparison only and does not include stakes.
[b] No longer available (December 2006).

Throughout the study, each subject had free access to alfalfa, lab rodent diet, freshwater, and tree branches for gnawing in this pen. The adjacent pen contained only a food dish with slices of golden delicious apples, a favored mountain beaver food. Subjects were preconditioned to obtain apples from the adjacent pen by leaving openings unblocked for 1 week immediately before starting the study.

In the sheltered pens, we tested materials cut from 15 products, representing three of the four categories included in the field-pen trials. Protection netting, which performed poorly in the field pens, was excluded. Materials used to make Tree Cones and Eco-tubes differed only in the orientation of imbedded fibers, and we only tested material from the latter. To completely block the opening between pens, test materials were mounted on wooden frames and were solidly attached to the wall of the home pen. Thus, an animal had to breach the barrier and pass through the opening to obtain apples. Each of the eight animals tested all 15 materials.

Test materials were installed to mimic the configuration of the barrier as set up in the field. For example, if a seedling protector was formed by folding or rolling a flat sheet into a tube with overlapping exposed edges, then the sample was selected and mounted so that this seam was exposed to the test subjects. In contrast, if a protector was formed by extruding plastic material into a seamless tube, then it was presented as a flat surface. In all cases, the outer surface of the barrier faced the animal's home pen to present the barrier as it might be encountered in the field.

After initial conditioning, each barrier was left in place for up to 4 nights. Barrier materials were tested sequentially in a stratified random order that allowed solid and mesh materials to be presented alternately, after a random start, in each pen. If an animal was excluded for 4 nights, the barrier was removed, and the next trial was delayed for a 2-day reconditioning period, during which the animal had free access to apples through the unblocked opening.

Efficacy of each barrier material was evaluated daily and scored on an ordinal scale where higher scores reflected greater resistance to damage by test subjects. Scores were (1) barrier breached, and apple slices removed; (2) small opening(s) made in the barrier, but subject excluded and no apples taken; (3) surface of barrier damaged, subject excluded, no apples taken; (4) no evidence of damage to barrier, subject excluded, no apples taken.

Statistical Analysis

We used chi-square tests to examine differences among the efficacy of seedling protection barriers, and Fisher's exact test to examine damage to trees where some new growth was outside of the barrier. We used F-tests to compare height growth among the four categories of seedling protectors, and Tukey's studentized range tests to make pairwise comparisons, which were considered significant at the 0.05 level. The t-tests and sign tests were used to compare prices among the various barriers. All tests were run using XP Pro platform, SAS version 9.1 (SAS Institute, Cary, NC).

Results

Field-pen Trials

Nine control seedlings within each pen were not in protectors; 97% of these were damaged, and 68% had died by the end of the study. Because of mortality and replacement of six study animals, trials ran for 34 weeks in six pens and for 44 weeks in the other seven pens. Only 114 of the 780 (15%) seedlings within protectors were damaged by mountain beavers. Seventy-seven (68%) of these damaged seedlings died; 7 additional undamaged seedlings died. The distribution of damage scores was uneven; 96% of all seedlings received scores of either "1" (14%) or "7" (83%); i.e., the protectors were either penetrated and the trees were removed or damaged (score = 1) or they appeared undamaged (score = 7). In only 28 cases (less than 4%) the barriers were damaged but the trees remained undamaged. Thus, we summarized the condition of seedlings within protectors as either protected or damaged.

Eleven of the 20 products protected at least 95% of seedlings from damage, and six of these protected all their seedlings (Table 3). Differences in proportions damaged differed significantly among the four categories (chi-square = 168.34; df = 3; $P < 0.0001$). Tree shelters and fabric shelters performed best, with 98 and 95% of seedlings protected, respectively. The four rigid mesh tube products protected 81% of seedlings from damage, and the four protection netting products protected 55% (Figure 1).

New growth on 70% of seedlings extended outside of the protector tubes and was potentially exposed to browsing. To assess their vulnerability, we examined data on the condition of seedlings with exposed buds, branches, or terminal leaders to see if new growth had been clipped. At the conclusion of the field trials, there were 674 live trees in which their main stems were not cut by mountain beavers; 518 (77%) of these had some portion of new growth outside their tubes, but only 14 (2%) had damage to either branches or terminal leaders. Twelve of these 14 had outgrown their barriers, and 2 of the seedlings fully contained within their barriers were damaged by mountain beavers. There was no significant association between proportions of trees with exposed new growth and mountain beaver damage to live seedlings (Fisher's exact test; df = 1; $P = 0.54$).

Most (84%) damaged seedlings were clipped on the main stem at heights up to 37 cm. None of the barriers protected the tree roots

Table 3. Descriptions of individual tree seedling barriers products, and percent of Douglas-fir (*P. menziesii*) seedlings protected from damage by captive mountain beavers (*A. rufa*) in outdoor pens, July 2004 to June 2005, Olympia, WA.

Product and description	Protected seedlings (%)
Blue-X Treeshelter—Unvented tree shelter, solid seamless wall	100
Grow Tube—Unvented tree shelter, solid wall, exposed seam	100
Eco-tube—Vented tree shelter, solid wall, exposed seam	100
Pro/Gro Tube (Heavy)—Unvented tree shelter, solid wall, exposed seam	100
Tree Cone—Solid wall, vented tree shelter, exposed seam	100
Standard Tree Shelter—Unvented tree shelter, solid seamless wal.	100
Tube Net—Rigid mesh tube	97
Fine-Mesh Tree Shelter—Fabric shelter, exposed seam	97
Tree Protector—Unvented tree shelter, solid seamless wall	97
Open-Mesh Hybrid Tree Shelter—Fabric sleeve over rigid mesh tube	95
Miracle Tube—Unvented tree shelter, solid seamless wall	95
Open-Mesh Tree Shelter—Fabric shelter, exposed seam	92
Vented Miracle Tube—Vented tree shelter, solid seamless wall	87
Rigid Seedling Protector Tube—Rigid mesh tube	79
Rigid Seedling Protection Tube—Light weight, rigid mesh tube	74
Rigid Seedling Protection Tube—Heavy weight, rigid mesh tube	72
Tiller-net—Heavy-weight elastic protection netting	62
Bud Cap—Heavy-weight elastic protection netting	59
Heavy-duty Protection Netting—Heavy-weight, elastic netting	56
Wide-Mesh Protection Netting—Medium-weight elastic netting	44

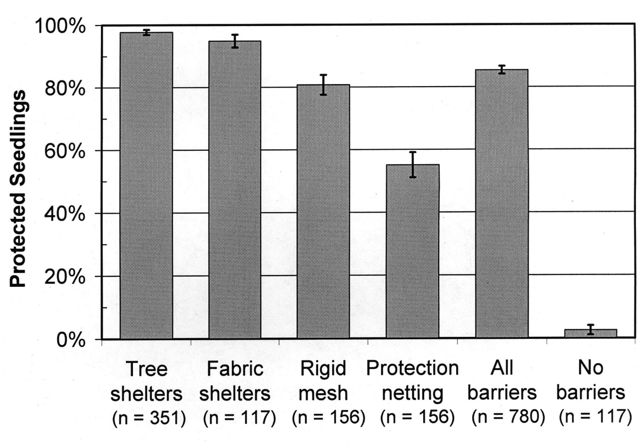

Figure 1. Douglas-fir (*P. menziesii*) seedlings protected from mountain beaver (*A. rufa*) damage in outdoor pens, July 2004 to June 2005 (Olympia, Washington). Sample sizes are total numbers of seedlings in each category.

below approximately 5 cm and seedlings were not closely inspected for root damage. However, signs of digging, suggestive of root damage, were observed near 53 (7%) of the seedlings within barriers. Compared with the other seedlings inside the barriers, a higher proportion of these died (19% versus 10%; chi-square = 3.88; df = 2; $P = 0.0488$).

Table 4. Mean and range of purchase prices, including support stakes, of four categories of individual tree seedling barriers evaluated to reduce damage to Douglas-fir (*P. menziesii*) seedlings by captive mountain beavers (*A. rufa*) in outdoor pens, July 2004 to June 2005, Olympia, WA.

Barrier category (no. products)	Mean/tree	Range
Protection netting (4)	$0.09	$0.09–0.09
Rigid mesh tube (4)	$0.49	$0.29–0.85
Fabric shelter (3)	$1.50	$0.97–1.77
Tree shelter (9)	$1.84	$0.77–2.49

Purchase prices, per unit without stakes, for the 20 different tree protectors used in the field-pen trials, varied widely (Table 2). We purchased bamboo stakes for $0.12 each and sawn wooden stakes for $0.37 each; when support stakes were used, these prices were added to barrier prices to calculate total purchase prices, which varied by a factor of over 27 (approximately $0.09–2.49). Protection netting was least expensive and did not require staking; purchase price for each of the four products was only approximately $0.09/seedling. Purchase prices were higher for all other products, and they all required support stakes. Total purchase prices for the three rigid mesh tube products with bamboo stakes ranged from $0.29 to $0.46 each. The most expensive rigid mesh product (Tube Net) required wooden stakes; total purchase price was approximately $0.85 each. Two fabric shelters required wooden stakes; total purchase price, approximately $1.77 each, was the same for both. Hybrid fabric shelters used bamboo stakes; total purchase price was approximately $0.97 each. Two tree shelters used bamboo stakes; total purchase prices were approximately $0.77 and $1.06 each. The other seven tree shelters required wooden stakes; total purchase prices averaged approximately $2.10 each. Total purchase prices ranged from $0.09 to $2.49/seedling (Table 4). Values for the six products that used bamboo supports averaged only $0.65, and the 10 that required wooden stakes averaged $1.91 (one-tailed *t*-test; df = 14; $P = 0.0002$).

Data on height growth of Douglas-fir tree seedlings within protection barriers were collected over two growing seasons (Figure 2). We analyzed growth of 645 live undamaged seedlings; only 3% of the unprotected control trees were undamaged, and these were not included in growth comparisons. Sample sizes among the four categories differed widely because of several factors. Numbers of products tested, and thus initial numbers of trees, in each category differed; we tested four different protection nets, four rigid mesh tubes, three fabric shelters, and nine solid shelters. Unequal proportions of trees in each category were available at the end of the study because of the differential damage by mountain beavers. Thus, numbers of seedlings suitable for growth comparisons were lowest for protection netting, followed by rigid mesh tubes, fabric shelters, and tree shelters.

Initial heights of trees within protectors averaged 49.5 ± 0.29 cm (SE) and final heights averaged 91.6 ± 0.66 cm. Thus, seedling growth averaged 42.1 ± 0.52 cm but differed significantly among trees in the four categories of seedling protectors ($F_{3,644} = 16.25$; $P < 0.0001$). Height growth was greatest in tree shelters (44.7 ± 0.71 cm; $n = 334$) and fabric shelters (42.4 ± 1.09 cm; $n = 108$)

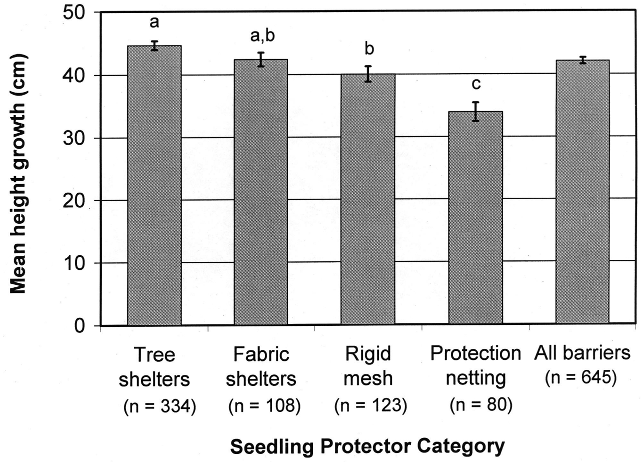

Figure 2. Mean (SE) growth of undamaged Douglas-fir (*P. menziesii*) seedlings in individual protection barriers in outdoor pens, July 2004 to June 2005 (Olympia, Washington). Categories sharing a common letter did not differ significantly using Tukey's studentized range tests ($P > 0.05$).

and these two categories did not differ significantly (Figure 2). Mean growth of trees within rigid mesh tubes (40.0 ± 1.22 cm; $n = 123$) was greater than within protection netting (34.0 ± 1.50 cm; $n = 80$).

Sheltered-Pen Trials

Materials from 15 different seedling protectors were exposed to eight different captive mountain beavers housed in separate pens. Included were eight tree shelters, all three fabric shelters and all four rigid mesh tubes. In 83 (69%) of the 120 trials, mountain beavers breached the barriers and obtained apples from the adjacent pen and received damage scores of 1 (Table 5). Few barriers that resisted penetration showed evidence of damage (score = 3); most showed no evidence of damage (score = 4). In most cases (87%), if a barrier was breached, it occurred during the 1st day of the trial.

The four materials that excluded all eight test subjects (Table 5) were from tree shelters with solid, unvented, seamless walls; the other four were vented with small circular holes or were formed from flat sheets into shelters that had exposed overlapping edges, and these excluded the mountain beavers in only 4 of 32 (13%) trials. Rigid mesh resisted penetration in only 1 of 32 (3%) trials. The seven materials that failed to exclude any of the test subjects were from all three fabric shelters, two rigid mesh tubes, and one tree shelter.

Discussion

The two most expensive categories of seedling protectors, tree shelters, and fabric shelters performed very well in the field-pen trials (Figure 1). Tree shelters were the most expensive products tested (Table 4), and six of the nine products tested protected all 39 (100%) seedlings from damage by mountain beavers (Table 3). Fabric shelters, at 92–97% protected, were comparable, followed by rigid mesh (72–97% protected) and protection netting (44–62% protected). Only 3% of unprotected seedlings escaped damage. Less than 4% of barriers with undamaged seedlings showed evidence of having been damaged but not penetrated; thus, it appeared that many of the seedling barriers were unchallenged by mountain beavers.

Table 5. Numbers of successful trials where barrier materials excluded captive mountain beavers from adjacent pens, and distribution of damage scores for 15 barrier materials (each material was tested in eight trials by test subjects in sheltered pens, January to April 2005, Olympia, WA).

Product and description	No. successful trials	Distribution of damage scores[a]			
		1	2	3	4
Miracle Tube—Unvented tree shelter, solid seamless wall	8	0	0	0	8
Tree Protector—Unvented tree shelter, solid seamless wall	8	0	0	1	7
Standard Tree Shelter—Unvented tree shelter, solid seamless wall	8	0	0	0	8
Blue-X Treeshelter—Unvented tree shelter, solid seamless wall	8	0	0	8	0
Vented Miracle Tube—Vented tree shelter, solid seamless wall	3	5	0	2	1
Eco-tube—Vented tree shelter, solid wall, exposed seam	2	8	0	0	0
Grow Tube—Unvented tree shelter, solid wall, exposed seam	1	7	0	0	1
Rigid Protection Tube (Heavy)—Rigid mesh tube	1	7	0	0	1
Pro/Gro Tube—Unvented tree shelter, solid wall, exposed seam	0	8	0	0	0
Tube Net—Rigid mesh tube	0	8	0	0	0
Rigid Seedling Protector—Rigid mesh tube	0	8	0	0	0
Rigid Protection Tube—Light-weight rigid mesh tube	0	8	0	0	0
Open Mesh Fabric Shelter—Fabric shelter, exposed seam	0	8	0	0	0
Fine Mesh Fabric Shelter—Fabric shelter, exposed seam	0	8	0	0	0
Hybrid Tree Shelter—Fabric sleeve over rigid mesh tube	0	8	0	0	0
Total	39	83	0	11	26
(%)	(31)	(69)	(0)	(9)	(22)

[a] Scores were (1) barrier breached, and apple slices removed from adjacent pen; (2) small opening(s) made in the barrier, but test subject excluded from adjacent pen; (3) surface of barrier damaged, test subject excluded; (4) no evidence of damage to barrier, test subject excluded.

Many seedlings had new growth that extended outside the protectors, and although they appeared vulnerable to mountain beaver feeding, numbers damaged were no different than fully enclosed seedlings. Over one-half (56%) of all damaged seedlings were injured during the initial 9 weeks of exposure to mountain beavers, and after 26 weeks of exposure this figure was 95%. Both field-pen trials extended well beyond this time period and very few seedlings were damaged during the final weeks. The pattern of damage over time in any particular pen was erratic, and periods of 12 weeks or more with no additional seedling damage occurred in 10 of the 13 pens. Numbers of damaged seedlings were lowest from mid-January through March, normally a season of low mountain beaver activity. Little evidence of digging, indicative of possible root damage, was observed near the seedlings, but where this did occur, the seedlings died at a significantly higher rate (19%) than other seedlings. Thus, in some cases additional belowground protection may be needed to protect effectively seedlings.

Fabric shelters and many tree shelters were designed to moderate microclimate and thus to act as miniature greenhouses to enhance plant growth and survival (Potter 1988, Kerr 1996, Jacobs and Steinbeck 2001) and protection from wildlife damage often was a secondary and indirect benefit. For some hardwoods (e.g., *Quercus* spp.) tree shelters have reduced the time required for seedlings to grow to a size where they are less vulnerable to browsing (McCreary and Tecklin 2001). Less research has evaluated the advantages of tree shelters for growing conifers (Jacobs and Steinbeck 2001) and growth increases may be only marginal (Kays 1996). Ward et al. (2000) found that solid tree shelters had less effect on initial height growth of eastern white pine (*Pinus strobus*) seedlings than on northern red oak (*Quercus rubra*) but the shelters reduced deer browsing damage to seedlings of both species. Our results showed that, on average, Douglas-fir seedlings grew tallest in tree shelters and fabric shelters. Compared with protection netting and rigid mesh tubes, this advantage seemed marginal and ranged from only 4.7 to 10.7 cm over two growing seasons, and seedling growth in fabric shelters did not differ significantly from rigid mesh tubes. Field trials tracking seedling development and long-term economic analyses are needed to verify and evaluate the potential advantages of enhanced seedling growth rates.

Total purchase prices, including stakes, for fabric shelters averaged over 16 times higher than for protection netting, and over 3 times higher than the average for rigid mesh tubes; for tree shelters these differences were even greater. Purchase prices for sawn wooden stakes were three times more than for bamboo and including this in the total price inflated, but did not change the relative differences both within and among the four barrier categories. This was because no supports were needed for the least expensive barriers (protection netting), and bamboo supports were specified for most of the lower-priced rigid mesh tubes and tree shelters, but wooden stakes were specified for use with the most expensive tree and fabric shelters. Overall, the more expensive products protected the most seedlings, and the rank order of products according to purchase price (see Table 2) did not change significantly after adding the additional prices for stakes (sign test, $M = -0.5$; $P = 1.000$) or after adjusting these total purchase prices to account for numbers of undamaged seedlings (sign test, $M = -0.5$; $P = 1.000$). Although we did not measure the effort or costs required to install the different protectors, in our experience installing barriers with bamboo support stakes was faster and easier than installing those with wooden stakes. Including such costs would likely have further amplified differences between the more expensive and less expensive products in our short-term trials. Thus, additional research is needed to quantify installation costs and to track durability of barriers and stakes over the long run to determine if more expensive barriers and support stakes are cost-effective.

Before reliable economic recommendations can made for large-scale use, longer-term field studies are needed to clarify cost differences among the wide range of individual seedling barriers and to determine if higher acquisition and installation costs are balanced by extended life and, perhaps, reuse. Three- to 5-year trials in commercial plantations where mountain beaver damage is expected to be high would help to verify efficacy and economy of the different barriers in the field. To compare cost efficiency, future field trials might track costs of shipping, installing, maintaining, and replacing barriers and support stakes. Tracking replanting costs would be critical for evaluating the less expensive barriers; in our trials seedling losses were as high as 28% for rigid mesh tubes and 45% for protection netting. If accurate, rather than just comparative, cost figures are needed and then initial costs associated with obtaining and planting seedlings would be needed as well.

Four materials from the tree shelter category were never breached in the sheltered pens (Table 5). These included the lowest priced tree shelters, Blue-X Treeshelters, and three of the most expensive barriers: Tubex Standard Tree Shelters, Tree Pro Tree Protectors, and Miracle Tubes (Table 2). All four were preformed in unvented tubes with no exposed seams or overlapping edges. Otherwise, results from the field pens and sheltered pens were strikingly different (Tables 3 and 5). Materials from seven products were breached in all sheltered-pen trials, but in the field-pen trials five of these protected more than 90% of their seedlings from damage. In both sets of trials, barriers rarely showed evidence of being damaged unless they were breached. The exceptions were Blue-X Tree Shelters. When the outer HDPE layers were damaged, the surfaces of the inner Mylar sleeves usually were scratched but never breached. In the sheltered pens, damage to materials from tree and fabric shelters appeared to start at vent holes and exposed seams. Damage to barriers formed from flat sheets was initiated where overlapping edges were exposed and at the tabs or slots used to form the cylinder (D.E. Runde, NWRC, pers. obs. Feb. 2005). These results suggest if mountain beavers are constantly probing and frequently challenging the seedling protectors, then unvented tree shelters with no exposed seams or overlapping edges would prove most durable.

Literature Cited

Black, H.C., and W.H. Lawrence. 1992. Animal damage management in Pacific Northwest forests: 1900–1990. P. 23–55 in *Silvicultural approaches to animal damage management in Pacific Northwest forests*, Black, H.C. (ed.). US For. Serv. Gen. Tech. Rep. PNW-287, PNW Res. Stn., Portland, OR.

Borrecco, J.E., and R.J. Anderson. 1980. Mountain beaver problems in the forests of California, Oregon and Washington. P. 135–142 in *Proc. of 9th vertebrate pest conf.*, Clark, J.P. (ed.). Univ. of California, Davis, CA.

Cafferata, S.L. 1992. Mountain beaver. P. 231–251 in *Silvicultural approaches to animal damage management in Pacific Northwest forests,* Black, H.C. (ed.). US For. Serv. Gen. Tech. Rep. PNW-287, Pacific Northwest Res. Stn., Portland, OR.

Campbell, D.L. 1994. Mountain beavers. P. B53–B59 in *Prevention and control of wildlife damage*, Hygnstrom, S.E., R.M. Timm, and G.E. Larson (eds.). Univ. of Nebraska Cooperative Extension, Lincoln, NE.

Campbell, D.L., and J. Evans. 1975. *"Vexar" seedling protectors to reduce wildlife damage to Douglas-fir*. Wildlife Leaflet 508, USDI Fish and Wildlife Serv., Washington, DC. 11 p.

Campbell, D.L., and J. Evans. 1988. Recent approaches to controlling mountain beavers (*Aplodontia rufa*) in Pacific Northwest forests. P. 183–187 in *Proc. of the13th vertebrate pest conf.*, Crabb, C., and R.E. Marsh (eds.). Univ. of California, Davis, CA.

Carraway, L.N., and B.J. Verts. 1993. Aplodontia rufa. *Mamm. Species* 431:1–10.

Feldhamer, G.A., J.A. Rochelle, and C.D. Rushton. 2003. Mountain beaver. P. 179–187 in *Wild mammals of North America: Biology, management, and economics*, Chapman, J.A., and G.A. Feldhamer (eds.). Johns Hopkins University Press, Baltimore, MD.

Hacker, A.L., and B.E. Coblentz. 1993. Habitat selection by mountain beavers recolonizing Oregon Coast Range clearcuts. *J. Wildl. Manag.* 57:847–853.

Hooven, E.F. 1977. *The mountain beaver in Oregon: Its life history and control.* For. Res. Lab., Res. Pap. 30, Oregon State Univ., Corvallis, OR. 20 p.

Jacobs, D.E., and K. Steinbeck. 2001. Tree shelters improve the survival and growth of planted Engelmann spruce seedlings in southwestern Colorado. *West. J. Appl. For.* 16:114–120.

Kays, J.S. 1996. Deer protection for small forest plantations: Comparing costs of tree shelters, electric fencing, and repellents. P. 5–12 in *Proc. of the tree shelter conf.*, Brissette, J.C. (ed.). US For. Serv. Gen. Tech. Rep. NE-221, Northeast Forest Experiment Station, Radnor, PA.

Kerr, G. 1996. The history development and use of tree shelters in Britain. P. 1–4 in *Proc. of the tree shelter conf.*, Brissette, J.C. (ed.). US For. Serv. Gen. Tech. Rep. NE-221, Northeast Forest Exp. Stn., Radnor, PA.

Marsh, R.E., A.E. Koehler, and T.P. Salmon. 1990. Exclusionary methods and materials to protect plants from pest mammals-a review. P. 174–179 in *Proc. of the 14th vertebrate pest conf.*, Crabb, A.C., and R.E. Marsh (eds.). Univ. California, Davis, CA.

McCreary, D.D., and J. Tecklin. 2001. The effects of different-sized tree shelters on blue oak growth. *West. J. Appl. For.* 16:153–158.

Potter, M.J. 1988. Tree shelters improve survival and increases early growth rates. *J. For.* 86:39–41.

Ward, J.S., M.P.N. Gent, and G.R. Stephens. 2000. Effects of planting stock quality and browse protection-type on height growth of northern red oak and eastern white pine. *For. Ecol. Manag.* 127:205–216.