Research Contribution 38

Riparian Forest Buffers on Agricultural Lands in the Oregon Coast Range: Beaver Creek Riparian Project as a Case Study

July 2002

by

Badege Bishaw

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Forest Research Laboratory

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Abstract

Bishaw, B, W Emmingham, and W Rogers. 2002. *Riparian Forest Buffers on Agricultural Lands in the Oregon Coast Range: Beaver Creek Riparian Project as a Case Study.* Research Contribution 38, Forest Research Laboratory, Oregon State University, Corvallis.

Riparian areas in the Pacific Northwest have traditionally been a source of natural resources, such as timber and grazing, and have been used as transportation corridors and homestead sites. A primary impact of use has been the removal of riparian trees, the crowns and roots of which provide shade and stream bank protection. Increases in water temperature can be lethal to salmonid fish, and decreasing salmon populations over the past few decades have resulted in an urgent need for improving the management of watersheds, fish habitat, and water quality. Leaving stream-side buffers is now required by state forest practices regulations on forest lands, but no regulations are in place on agricultural lands, where riparian trees have frequently been removed.

In 1995, the Beaver Creek Riparian Buffer Project was established to develop better information about how to establish riparian buffers on coastal pastureland near Newport, Oregon. No riparian trees were present when the trial was begun. A replicated tree filter belt trial was established along the south bank of the creek to compare unplanted pasture (controls) with commercially valued red alder (*Alnus rubra*) planted at 6-ft spacing in belts 1 row, 3 rows, and 6 rows wide. Tree survival and height and diameter growth were compared, as well as the amount of shade produced by the three treatments and control. We used a LI-COR LAI-2000 Plant Canopy Analyzer to quantify shade. We found that intensive site preparation, continued vegetation management, and both fencing and tubing of tree seedlings were necessary to gain survival and

protect seedlings from small rodents, beaver, and cattle. Fencing out cattle provided stream bank protection within 1 yr. Significant shading of the stream occurred 2–6 yr after planting, as trees grew tall enough to intercept a significant amount of light. Single row plantings that take a minimal amount of pasture offer significant shading only after 4–7 yr. A wider 6-row filter belt occupies a greater amount of pasture, but provides stream shading sooner than the other treatments.

Contents

List of Figures

List of Tables

Introduction

Riparian areas in the Pacific Northwest have traditionally been used as a source of natural resources, such as timber and grazing, as transportation corridors, and for homesteads and farming (Malanson 1993; Gregory 1997). Activities associated with these uses have modified the natural function of riparian areas (Hardesty 1995; Figure 1). A primary impact has been the removal of riparian tree canopy, including stems and roots that provide shade and stream bank protection. Streams flowing through many agricultural areas have little or no natural tree protection. This lack of vegetation reduces natural filtering and increases the velocity and erosive force of flowing water, compounding bank cutting and scouring that can eventually result in a lowering of the water table. Over the past few years, management practices for riparian areas on forestlands have been modified to protect and restore stream conditions for anadromous fish (Newton et al. 1996; Nicholas 1997). Buffering of streams on forestland is required by law; however, buffering on farmland is not regulated.

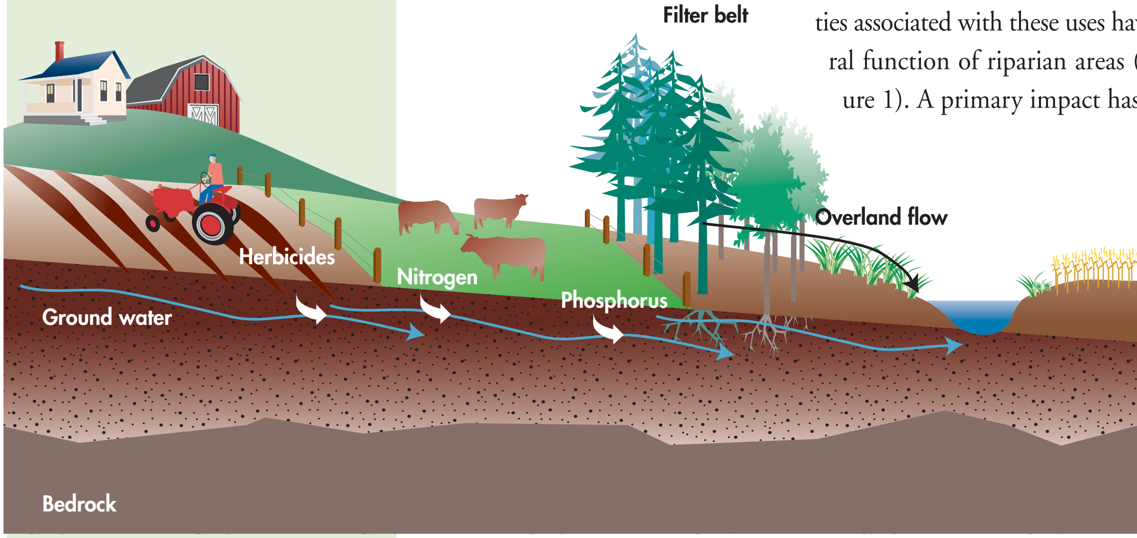

Figure 1. Intensive agriculture can contribute significant nonpoint source water pollution. Less intensive forms of agriculture (e.g., pasture management) are less likely to pollute, depending on management practices and how wastes (urine and manure) are recycled.

Figure 2. Cattle grazing along coastal streams (far bank) can lead to bank erosion. Lack of tree cover means that streams heat up during summer low flows. Note the heavy grass cover on the near bank (foreground) that developed in only 2 yr after the fencing to exclude the cattle.

We established the Beaver Creek Riparian Buffer project in 1995 to develop better information about how to establish riparian buffers on pasture land in western Oregon. Beaver Creek is a typical coastal stream, with its headwaters on the west flank of the

Coast Range and its lower reaches flowing through miles of pasture directly into the Pacific Ocean at Ona State Park. Pastures along Beaver Creek now used for raising beef cattle were once used for dairy production (Figure 2). Pasture "improvement" and grazing have eliminated most trees along the creek and have reduced vegetative cover to the water's edge (Figure 3). Our objective was to test options for the re-establishment of tree cover along the stream without significantly affecting grazing opportunities in adjacent pastures. We planted various sizes of filter belts of red alder (*Alnus rubra*), a commercial hardwood species with a rapid juvenile growth rate, along the creek. We chose red alder because it is a fast-growing species adapted to the coastal climate and has a persistent timber market value. This report summarizes our experience over the 5-yr early establishment period.

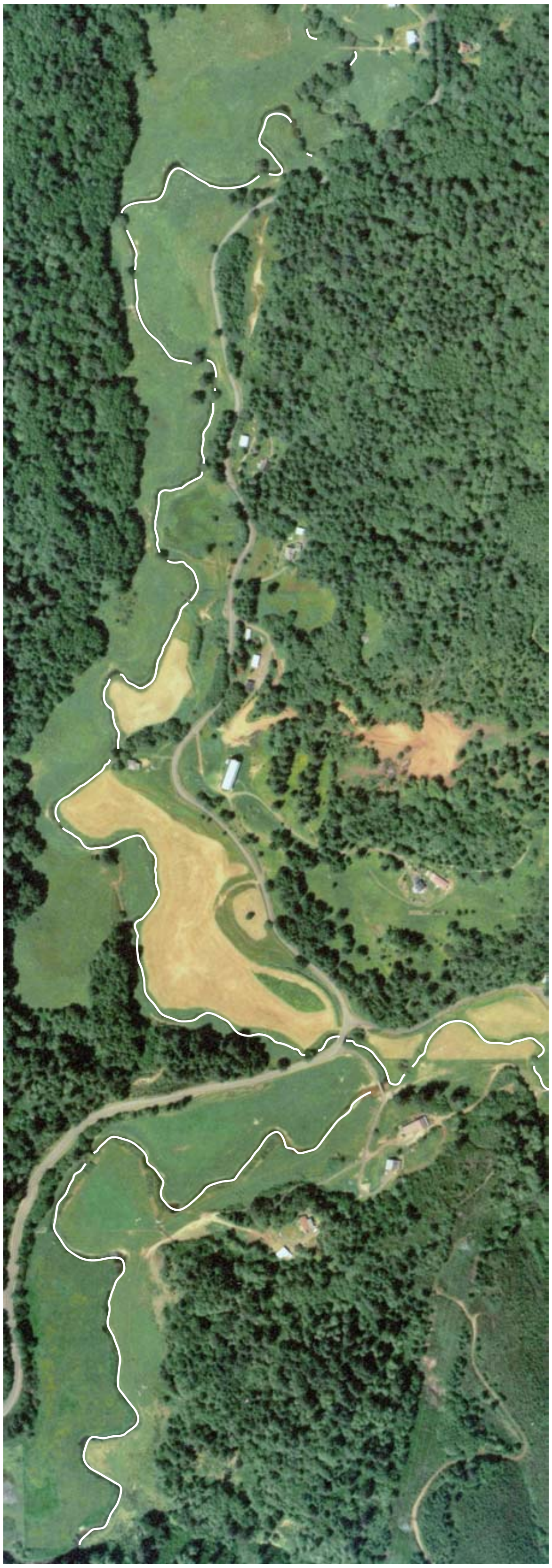

Figure 3. Aerial view of North Beaver Creek, Oregon (1997), showing a typical small stream meandering through pastures, with little forest vegetation on much of the streambank. The riparian planting project is barely visible toward the bottom of the picture.

Background and Literature Review

Loss of riparian tree cover can result in increases in water temperature that are lethal to salmonid fish, as well as in the depletion of wildlife habitat along streams (Brown 1969; Hardesty 1995; Beschta 1997). The importance of tree shade in regulating stream temperatures along riparian areas has been recognized since the early 1960s. Chapman (1962) compared logged and unlogged drainages in Oregon's Alsea River Basin and found that water temperatures in logged areas, where riparian vegetation was completely removed, were as much as 5.5°C (10°F) warmer than water temperatures in unlogged areas. Brown (1969) showed that removing the shade above a small, forested stream increased the solar heat load by about six times.

Other factors that affect stream temperature are stream channel morphology, flow rates, and stream surface area. These are important because the capacity of a stream to buffer against temperature increase is directly influenced by water volume and the size of the surface area that is exposed to the energy source. Beaver Creek is characterized as a narrow, meandering stream with a width of 2.4–3.7 m (8–12 ft) during the summer season. Like many coastal streams, the lower reaches of Beaver Creek are unconstrained. Beaver Creek is a flood-prone, moderately entrenched, medium fish-bearing stream with low (<3%) gradient. It meanders through a flat valley floor composed of post-glacial deposits capped by fine sediments. Sand and silt are predominant in the streambed, and the banks are kept bare of vegetation by grazing livestock (Figure 2, 3).

In the Pacific Northwest, decreasing salmon populations over the past few decades have resulted in an urgent need for improving the management of watersheds, fish habitat, and water quality (Beschta 1997; Nicholas 1997; Independent Multidisciplinary Science Team 1999). Riparian vegetation influences fish habitat in a variety of ways during different seasons or stages of the fish's life cycle. Anadromous fish spawn in streams tens to hundreds of miles inland from the ocean where they grow to maturity. Juvenile salmonids live in freshwater streams and rivers and are critically dependent upon the water temperature and quality of in-stream habitats. Thus, land uses anywhere within a watershed can affect the survival and reproductive success of salmonids (Hardesty 1995; Beschta 1997).

Along with helping to regulate stream temperatures, riparian buffers may also ameliorate nonpoint-source pollution (Bolton 2000). Nationally, nonpoint-source pollutants from agriculture include sediment, nitrogen, phosphorus, organic waste, and pesticides (Figure 1). Cropland, pasture, and rangeland contribute nearly 7 million tons of nitrogen (N) and 3 million tons of phosphorus (P) annually to the surface waters in the United States (Chesters and Schierow 1985). In addition, agricultural nonpoint sources have led to contamination of shallow aquifers with nitrate due to either fertilizer additions, application of animal waste, or mineralization of native organic N (Lowrence et al. 1984; Link et al. 2001).

Many riparian zones in crop and rangelands in the Northwest are considered to be in poor condition (Kauffman and Krueger 1984; Armour et al. 1991; Fleischner 1994; Schultz et al. 1995). Riparian areas in the Oregon Coast Range and Willamette Valley that were originally occupied by trees have been extensively impacted by agricultural cropping and grazing activities (Figure 2). The lower drainages of fifth-order streams (Straehler 1957) have been seriously impacted, resulting in decreased water quality, impaired riparian and stream biodiversity, and changes in the timing of stream flow (Hairston-Strang and Adams 1997; Kauffman et al. 1997; Bolton 2000). Much of the tree overstory has been lost due to clearing for agriculture and grazing, and restoration is now a priority (Hardesty 1995; Schultz et al. 1995). Thus, riparian restoration, including protection and improvement of water quality and aquatic habitat, is considered one of the most urgent land management issues in the Pacific Northwest (Osborne and Kovacic 1993; Oregon Department of Forestry 1994; Oregon Department of Environmental Quality 1996).

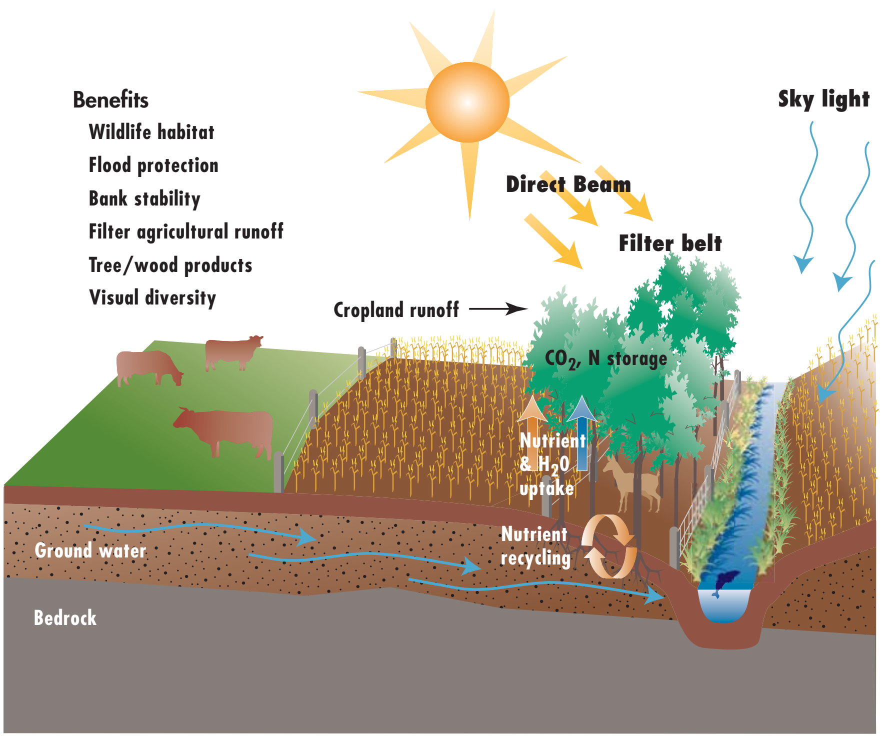

Figure 4. Tree filter belts are established to restore several functions of natural streamside trees, including stream shadings, bank stabilization, input of organic materials to support the in-stream food chain, and eventually coarse wood for fish habitat as trees fall into the stream. Filter belts can also help filter sediments or nutrients from overland or ground water flow as trees grow and retain both carbon (C) and nutrients such as nitrogen (N) in woody tissue.

Filter belts or riparian forest buffers are established by planting trees along streams where trees and streamside vegetation have been removed, generally for agricultural purposes (Figure 4). Important functions of tree filter belts in agricultural and grazing landscapes include filtering and retaining sediments; immobilizing, storing, and transforming chemical inputs; maintaining stream bank stability; modifying light and temperature environments; and providing water storage and recharge of substrate aquifers (Elmore and Beschta 1987; Welsch 1991; National Research Council 1993).

Riparian forest buffers in crop and grazing lands have gained increasing attention in the Pacific Northwest due to popular demand to protect salmon and steelhead, and through the Oregon Coastal Salmon Restoration Initiative of the Oregon Plan (Oregon Department of Forestry 1994, Nicholas 1997, Independent Multidisciplinary Science Team 1999). This has generated interest in riparian forest buffers from landowners, watershed councils, and extension workers in the region (Emmingham et al. 2000). However, there has been little research on the effects of riparian forest buffers on crop and grazing lands from which to develop and recommend suitable practices for the Pacific Northwest. Most studies that include recommendations for riparian planting come from other regions (Lowrance et al. 1984; Welsch 1991; Vellidis and Lowrance 1993; Adams and Fitch 1995; Shultz 1996). The unique qualities of Pacific Northwest climate, geology, and stream ecology require that caution be used in extrapolating results from other regions.

Objectives

The primary goal of the Beaver Creek Riparian project was to develop information on how to establish riparian filter belts that lead to improved stream protection and fish habitat in the agricultural portions of coastal watersheds, while removing as little pasture as possible from production. Specific objectives of the project were as follows:

- to control livestock access to the stream in order to allow natural plant regeneration to stabilize eroded stream banks and to prevent further deterioration
- to establish tree filter belts to determine the effectiveness of various widths of tree planting in providing stream shading over time
- to test a variety of approaches to establishing red alder, including planting individual trees, groups of trees, and rows of trees with and without predator protection, and using various vegetation management activities
- to compare the costs and benefits of different strategies. We were not able to measure water pollutants or stream temperatures.

Methods

Study Site

The Beaver Creek riparian project area lies on private property on the north fork of Beaver Creek, about 8 mi south of Newport, Oregon. Beaver Creek is a meandering perennial stream that supports a productive coho salmon (*Oncorhynchus kisutch*) run. The portion of the stream within the study area is classified as summer rearing habitat for coho. Almost the entire length of the stream after it leaves the Siuslaw National Forest is used as pasture. Cattle or horses graze to the edge of the stream in many places and there are very few streamside trees (Figures 2, 3). The stream channel is cut 3.1– 4.6 m (10–15 ft) into deep alluvial soils. Water depth ranges from <1 ft at summer low flow to bank full during winter flooding. The conditions found along Beaver Creek are typical of many coastal streams.

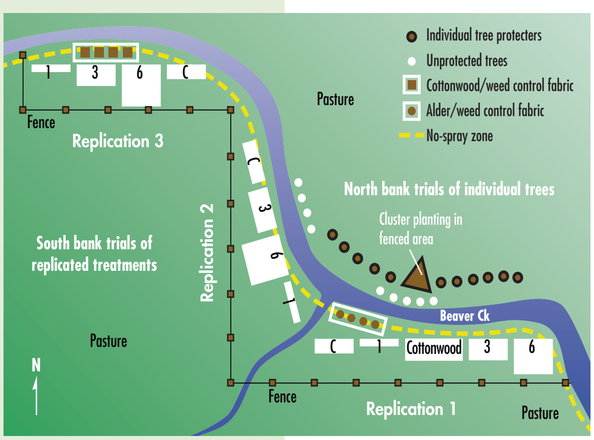

Figure 5. Diagram of the trial area, showing location of the three replications and placement of various unreplicated studies: 1 = 1 row of red alder trees, 3 = 3 rows, 6 = 6 rows, and C = control (no alders planted).

Installation

During winter and spring of 1995, we planted a riparian tree filter belt along the banks of Beaver Creek. Various trials were installed on the fenced south side and on the unfenced north side of the stream (Figure 5).

Figure 6. A four-strand barbed wire fence effectively excluded cattle from the filter belt.

Figure 7. During project initiation (spring 1995), the area was given a herbicide site-preparation treatment to eliminate pasture grass competition, and bare root red alder seedlings were planted. In May, as shown here, individual seedlings were not protected.

South Bank, Fenced Area

A stream reach of 335.3 m (1100 ft) along the south bank was fenced by four-strand barbed wire to keep livestock out and protect the study trees from animal browsing (Figure 6). Within the fenced area, a 3.1-m (10-ft)-wide grass strip along the entire bank of the stream was left untreated to minimize soil erosion. Treatment areas 30.5 m (100 ft) in length were identified and marked, and then were prepared for planting. Site preparation included herbicide treatment with a backpack sprayer. Accord (glyphosate, Monsanto, St. Louis MO), then Oust (sulfometuron, Dupont, Wilmington DE), herbicides were used to eliminate existing pasture grasses in all areas to be planted (Figure 7). Sites were then planted with tree seedlings (Figure 8). Follow-up treatments with Roundup Ultra (glyphosate, Monsanto, St. Louis MO) around individual seedlings occurred during the next 2 yr. The control area consisted of a 30.5-m (100-ft) strip of pasture that was neither sprayed nor planted with trees (Figure 5).

One replicated trial and several unreplicated tests were installed within the fenced area. The replicated trial involved planting a total of 1100 red alder seedlings (Weyerhaeuser, Inc., Turner OR; and DL Phipps Nursery, Elkton OR) in 30.5-m (100-ft)-long blocks that were either 1 row, 3 rows, or 6 rows of trees in width (Figure 9). Spacing between rows and between individual trees was 1.8 m (6 ft). Each treatment was replicated three times. A forestry crew from the U.S. Forest Service (FS) Job Corps planted the seedlings in April, 1995. Seedlings measured about 50–75 cm top height and from 0.25–1.0 cm at the root collar.

Unreplicated tests included

- an additional 30.5-m (100-ft) sprayed strip planted with 60 hybrid cottonwood (*Populus trichocarpa x deltoides*) cuttings (Spencer Nursery, Gold Beach OR)

Figure 8. A view of one of three replications just after planting, showing site preparation vegetation control and the 3-row treatment (foreground), unsprayed control, and 6-row treatment. Note the contrast between the vegetation on the fenced south bank and the unfenced and grazed north bank just 3 mo after fencing.

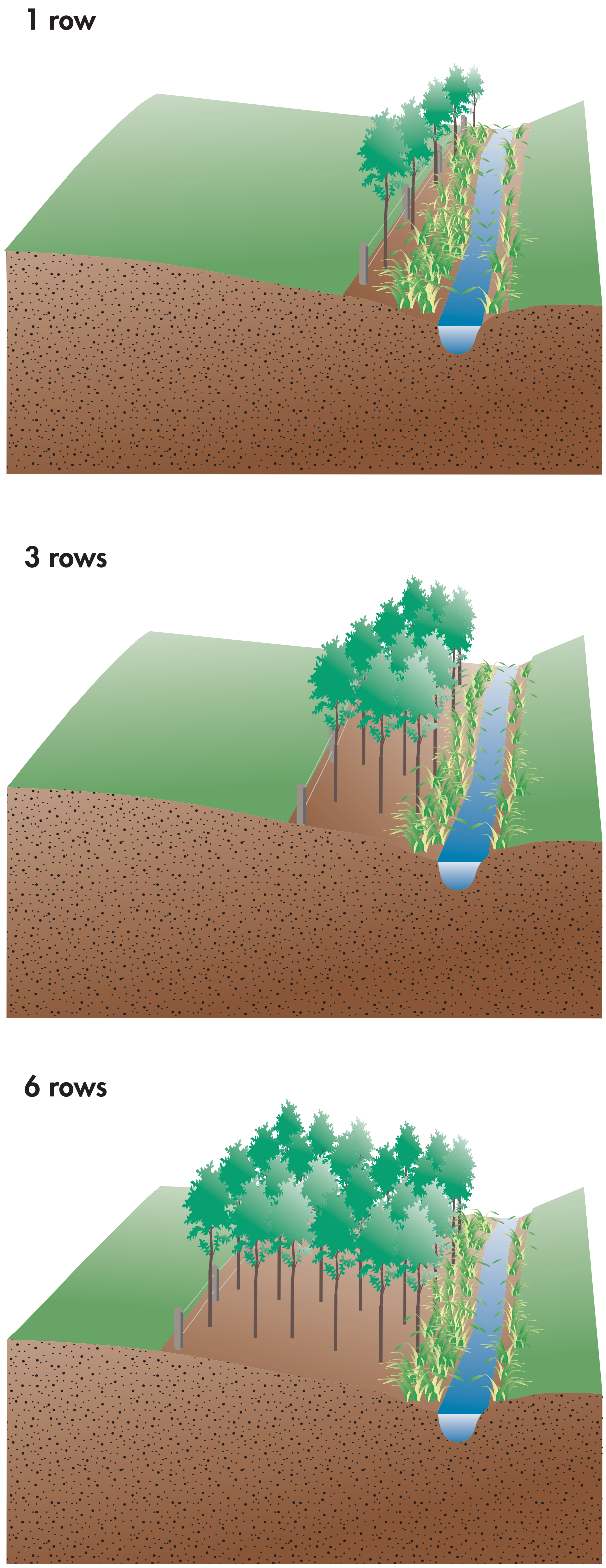

Figure 9. Diagram showing filter belts of differing numbers of rows of trees.

- a small area on the stream bank where alder seedlings or cottonwood cutting were inserted through a weed control fabric (Polyspun 350, ACF West Geosynthetic Products, Portland OR) that was pinned to the ground with metal staples to see whether weed control could be obtained without spraying herbicides (Figure 10)

- additional later plantings of western redcedar (*Thuja plicata*) (DL Phipps Nursery, Elkton OR), western hemlock (*Tsuga heterophylla*) (DL Phipps Nursery, Elkton OR), and grand fir (*Abies grandis*) (Emmingham's Bald Hill Tree Farm, Philomath OR) to test survival in a coastal riparian area.

Figure 10. Weed control fabric (Polyspun 350) was used in some areas to test its efficacy in controlling competition. Here, unprotected alder seedlings were planted on the unfenced north bank to demonstrate how cattle eat seedlings and the necessity of a cattle-excluding fence.

North Bank, Unfenced Area

Various trials were placed on the unfenced north bank of the stream. They included unprotected red alder planted through weed control fabric on unfenced pasture in Spring 1995 (Figure 10) and caged red alder planted on unfenced pasture in February 1998, to see whether trees could be established without a permanent cattle fence. The caged trees were protected either by individual 5-ft-tall (1.5-m-tall), no-climb wire cages with a diameter of 3 ft (0.9 m) around each tree (Figure 11), or by a three-sided cage designed to protect a small clump of seven trees. The sides of the three-sided cage were 10 ft in length and were constructed of 5-ft-tall (1.5-m-tall) wire with 6-ft-tall (1.8-m-tall) metal fence posts (Figure 12).

Figure 11. Individual tree protectors were designed to protect seedlings from cattle grazing in unfenced pasture. Although the cost of each device is high ($12.50), use of this strategy would eliminate the necessity of constructing an expensive cattle fence and minimize the amount of pasture lost in creating a tree cover. Note that mice and voles will girdle trees within these cages if vegetation management is not continued. Mouse-vole protection of individual trees within these shelters can be provided by wrapping the base of the tree in aluminum foil.

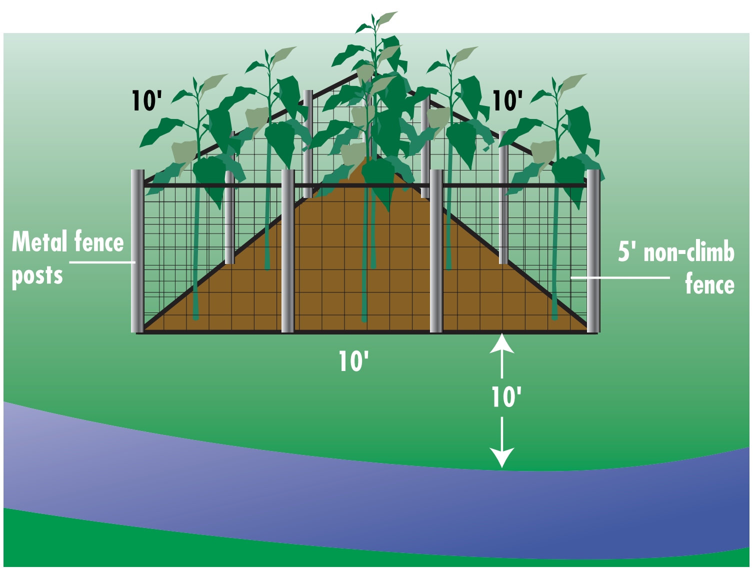

Figure 12. Diagram of a three-sided cage constructed to protect a small clump of seven trees. The sides of the cage were 3.1 m (10 ft) long, with 1.8 m (6 ft) metal fence posts and 1.5-m (5-ft)-high wire. This strategy would have the advantage in starting a small clump of trees—an advantage because it increases the chances of at least a few trees surviving.

Maintenance and Costs

We kept track of site visits and work and material expenses so that costs for various treatments could be compared.

Tree Growth and Light Measurement

We collected data on tree survival, height, and diameter growth for 5 yr. Damage and survival were determined by counting the number of browsed and dead trees. Height and diameter measurements were taken in September, at the end of each growing season. We used measuring poles and diameter tapes to measure height and diameter growth, respectively, and data were recorded in a spreadsheet.

To determine the amount of shade produced by tree filter belts, light measurements were recorded between 10:00 AM and 2:00 PM and analyzed with a LI-COR LAI-2000 Plant Canopy Analyzer (Lincoln NE). This instrument records the incoming direct sunlight and diffused skylight. We used two instruments simultaneously: one was set in an open field to measure total direct and diffused light, while the other measured the amount of light at various locations, depending on the filter belt treatment. Measurements were taken at the stream bank for all treatments, as well as next to the row of trees (on the stream side) for the 1-row treatment; next to row 1 and between rows 2 and 3 for the 3-row treatment; and next to row 1, between rows 2 and 3, and between rows 5 and 6 for the 6-row treatment (Figure 9). Light readings were taken at five sample points for each treatment. The mean amount of shade produced was then estimated as the difference between the amount of light received in the open and the amount beneath the trees. Light was recorded in August of each year, when trees were in full foliage.

Results and Discussion

Chronicle of Survival and Growth

Observations of tree performance and animal damage were made immediately after planting in spring of 1995. Within 2 mo of planting, cattle had eaten all trees planted in the unfenced areas on the north side of Beaver Creek (Figure 10). By early June 1995, 31 trees on the fenced south bank had been eaten by beaver. Half of the cottonwoods and a few red alder trees died from other causes. At that time, we began to implement the first of three different measures to protect trees from beavers (Figure 13). We initially installed 45.7 cm (18-in.) tall Vexar tubes (Terra Tech, Eugene OR) on 100 red alder trees (Figure 14). Later that month, 50 additional trees had been eaten by beaver. Magic Circle repellent was then applied to most trees to protect them from further animal browsing. In July 1995, all surviving trees were Vexar-tubed and double-staked by a FS Job Corps forestry crew, although there had been no additional losses in the month since Magic Circle was applied. Magic Circle was then applied to the stems and leaves of trees immediately above the Vexar tubes.

By September 1995, beavers had been actively nipping trees off above the Vexar tubes, and had damaged 60% of the surviving trees. All hybrid cottonwood trees above 6 in. (15.2 cm) were eaten by beavers. We observed 20 to 25 active beaver feeding trails between the stream and the tree plantings. As a short-term emergency measure, one beaver was removed under a permit obtained from the Department of Fish and Wildlife.

Only about half of the trees planted in the Beaver Creek filter belt survived after 6 mo. Most of the deaths were caused by early browsing and clipping by beaver and cattle. There was no trend in tree survival among treatments. All surviving hybrid cottonwood had been clipped off near ground level, but most had resprouted.

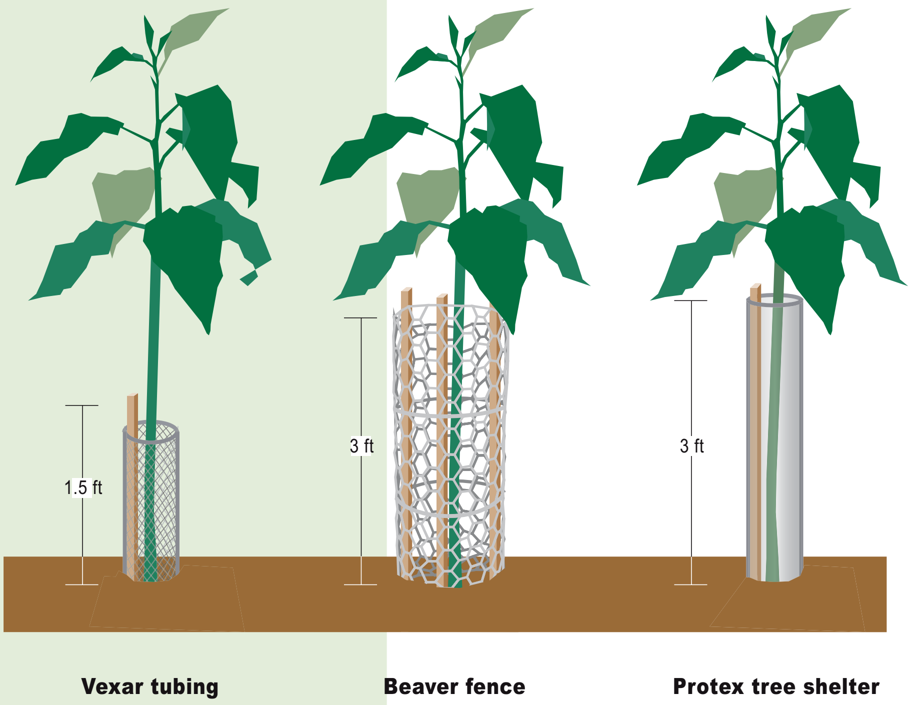

Figure 13. Diagram of three types of protective devices used in the project. Vexar plastic mesh tubes were not effective in protecting red alder trees from beavers. Plastic tree shelters were effective for a few years in providing protection against beavers and small rodents. Each protector required a sturdy wooden stake for support, and periodic maintenance to keep it tight around the tree. Wire cages were constructed with three stakes and 0.9 m (3 ft) wide chicken wire to protect trees from beavers after they outgrew the tree shelters. At 0.6–0.9 m (2–3 ft) in diameter and with periodic maintenance these cages should provide protection for many years.

Treatment	Trees/plot (average)	% Undamaged trees	
		6 mo	8 mo
6 rows of alder	102	54	39
3 rows of alder	51	26	12
1 row of alder	17	50	41
1 row of hybrid cottonwood	65	29	0

Table 1. Percent undamaged trees at Beaver Creek 6 and 8 mo after planting.

Figure 14. Alder trees were protected with 45.7-cm (18-in.)-tall Vexar plastic tubes when beavers began to eat the unprotected seedlings. These tubes were not effective protection because beavers either climbed the tubes to eat the tree tops or pushed the tubes up and clipped off the tree at the base.

Beaver damage continued through the fall of 1995, despite the fact that the trees were surrounded by Vexar tubes. By early November, the average number of undamaged trees per plot was 40 trees (39%) in the 6-row treatments, 6 trees (12%) in the 3-row treatments, and 7 trees (41%) in the 1-row treatments (Table 1). By August, 1996, 65 (81%) of the 80 alder trees protected only by Vexar tubes had been removed or heavily damaged by beaver. We concluded that Vexar tubes were not effective against beavers, since beavers were able to climb these plastic mesh tubes.

In December 1995 and January 1996, 3- or 5-ft (0.9- or 1.5-m)-tall Protex smooth-sided growth tubes (Terra Tech, Eugene, OR) were placed on half of the surviving trees (Figures 13, 15). Most of the 5-ft-tall (1.5-m-tall) tubes were later bent over or were removed by severe winter winds and floods. Very few of the shorter tubes were lost. Between January and March 1996, about 125 additional alder were planted to replace those that had died. At this time, additional hybrid cottonwood, along with western redcedar, western hemlock, and grand fir seedlings were also planted in small blocks and protected with Protex growth tubes. All of the western hemlock died within 2 mo during a period of heavy flooding in February 1996.

Because we were able to apply better protection, browsing damage to trees was very low after the first year. Only 10 out of 450 (2%) of the trees protected with Protex tubes had been damaged or removed. Beaver trails continued to be found up the riverbanks throughout the project, but the beavers were unable to climb these smooth-sided tubes. With all trees protected by Protex, only occasional beaver damage was observed during the following years. Protex tubes did, however, require maintenance each year to make sure they were secure before beaver feeding began each spring.

Figure 15. Tree shelters (Protex growth tubes) were installed on half of the surviving alder trees after the first growing season, when beavers ate unprotected or Vexar-protected trees. Here, the alder protected with 0.9-m (3-ft)-tall tree shelters are growing vigorously in their second growing season. Tubes require maintenance. Duct tape was used to secure tubes that had been opened by beavers, flooding, or wind. With proper maintenance, only 2% of the seedlings protected in this manner were killed by beavers after 5 yr.

Figure 16. Beavers fell alder that are not adequately protected and remove twigs and bark for food. The 45.7-cm (18-in.) Vexar tube was not effective in protecting this tree. Excess trees may provide a food source for beavers as protective devices are removed. Beavers can cut down trees up to 2 ft in diameter, so long-term tree protection is required.

In April 1998, 3 yr after the initial planting and 2 yr after the follow-up planting, the overall survival rate was 73% (264 trees) for the 6-row treatments, 75% (135 trees) for the 3-row treatments, and 67% (40 trees) for the 1-row treatments, for a total of 439 healthy young red alder trees growing along the stream. Beavers continued to cut down trees protected only by Vexar tubes (Figure 16).

Between September, 1998, and May, 1999, Protex tree shelters were replaced throughout the project with individual chicken wire cages (3-ft or 0.9-m diameter) supported by 3 stakes; 143 trees of the best trees spaced at about 15 ft (4.6 m) apart were protected with cages (Figure 17). The main reason for this replacement was that the diameter of many of the trees had grown to exceed the diameter of the Protex tubes. By March 2001, few trees protected by the wire cages or the Protex tubes had sustained any further damage. Crowns of the trees had began to compete for growing space. Therefore, a thinning was initiated to release the trees protected by the wire cages. Most of the Protex tubes were removed and many of the excess trees were cut. A few unprotected and partially protected trees were left for beavers. The excess trees could be considered a food source for beavers that may provide desired wildlife diversity.

Figure 17. When trees outgrew the tree shelter tubes, protective cages were constructed with chicken-wire fencing and wooden stakes. Cages were made 0.9 m (3 ft) in diameter to provide long-term tree protection.

Height and Diameter Growth

Throughout the measurement period, height growth was greater in the 6-row treatments (Figure 18). Trees grew about 1 m (3.28 ft) during the first year, 1995 (Figure 19). By the end of the third growing season (1997), trees averaged 3 m (9.84 ft) in height and had formed a closed canopy in the 3- and 6-row treatments (Figure 20). Trees achieved an average height of 5.6 m (18.2 ft), 6.1 m (20.0 ft), and 7.4 m (24.4 ft) for the 1-, 3-, and 6-row treatments in 5 yr. The mean 5-yr tree height for the 6-row treatment was statistically significantly greater than that in the 3- and 1-row treatments at ($P = 0.05$).

The diameter of trees in the 6-row treatment was greater than that in the 1- and 3-row treatments, which had similar diameters in 1997 and 1998 (Figure 21). After 5 yr, trees had achieved a mean diameter at breast height (DBH) of 7.3 cm (2.87 in.), 6.5 cm (2.56 in.), and 7.7 cm (3.03 in.) for the 1-, 3-, and 6-row treatments, respectively. The mean 5-yr tree diameter for the 6-row treatment was statistically significantly greater than the 3-row treatments at $P = 0.05$. The 1-row treatment apparently had better diameter growth than the 3-row treatment in 1999 (Figure 21), although the difference was not statistically significant. The fact that trees in the 6-row plots grew better for the first 5 yr fits a common pattern and may be explained by better

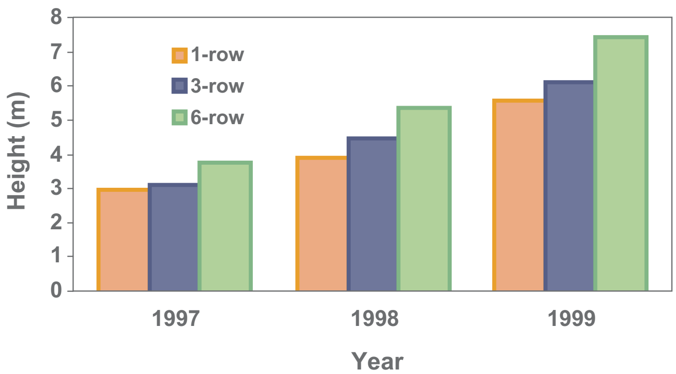

Figure 18. Mean height of red alder trees planted in 1-row, 3-row, and 6-row plots in the Beaver Creek riparian area after the third, fourth, and fifth years (1997, 1998, and 1999, respectively) of growth.

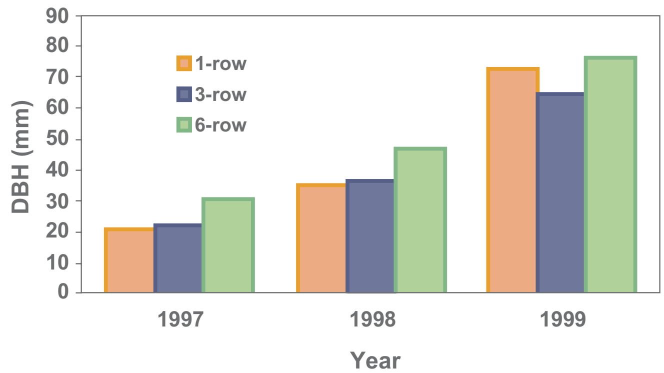

Figure 21. Mean diameter at breast height (DBH) of red alder trees planted in 1-row, 3-row, and 6-row plots in the Beaver Creek riparian area after the third, fourth, and fifth years (1997, 1998, and 1999, respectively) of growth.

Figure 19. These red alder were growing well at mid-summer during their second growing season (1996). Note that most had grown well above the 0.9-m (3-ft)-tall tree shelters, and vegetation had re-established over most of the ground surface.

Figure 20. During the third growing season (1997), the red alder in the 3- and 6-row treatments formed a closed canopy and were nearly 3.1 m (10 ft) tall.

overall weed control, as trees shaded out grass and weeds, or by mutual benefits provided by trees growing close together. In the long run, trees in the 6-row plots may also begin competing, which will slow their growth.

Other Management Observations

Certain weeds began to appear in large numbers as soon as the fence excluded cattle. Thistles of various kinds and Himalayan blackberry (*Rubus discolor*) were the most numerous. Reed canarygrass (*Phalaris arundinacea*) that had been growing along the stream also began to invade the fenced enclosure. After 5 yr, all of these weeds were less numerous and vigorous where deeper shade was cast by the growing trees.

The weed control fabric provided 1 yr of weed control. By the second year, however, soil had been deposited on the top of the fabric by floods and the new ground surface was soon covered with weeds.

Of the trees planted in the steel post and wire cages on the north side of the stream, only two trees had been damaged by cattle after 2 yr. Nearly half had died from other causes, such as poor weed control (weed control that did not reduce competing vegetation cover to <10% during the first growing season) or girdling by small rodents. One notable success in this effort was the establishment of the island planting, where seven trees had been planted in a protected, three-sided cage (Figure 12). Five of the trees survived after 2 yr. Long-term survival within these cages was not assured, however, because voles or mice invaded the small protected clumps of grass and began girdling the alder trees at the base. Some form of protection from basal girdling would therefore be necessary to prevent this. In other applications, a simple 10-cm (4-in.) wrap of aluminum foil around the base of trees has provided protection against damage from small rodents.

Creation of Shade With Riparian Filter Belts

An important function of tree filter belts is the provision of shade for streams, thereby lowering stream temperature. Filter belts intercept both direct and diffuse solar radiation, preventing it from reaching the surface of the earth or a body of water. In general, shade is constrained by a number of factors. The angle and direction of solar radiation are controlled by latitude, time of the year, and time of day. The greatest solar angle during the summer in the northern hemisphere occurs at noon on June 21 and decreases on succeeding days. Similarly, the greatest daily solar angle occurs at noon (standard time) and decreases in both the morning and afternoon (Larson and Larson 1996; Beschta 1997). At about 45°N, the sun is never directly overhead. Even at noon on June 21, the sun is still about 21° from vertical; therefore, tree height, direction, and distance away from the stream are all important components in determining the amount of shade a given tree or stand of trees casts on the stream. Trees placed on the south side of an east-west flowing stream are far more effective in providing shade than are trees on the north side.

The percent shade produced by each treatment at the Beaver Creek site during midday (10:00 AM to 2:00 PM) is shown in Figure 22. Shade at the water's edge was produced by reed canary grass, shrubs, and trees. The amount of shade produced at the bank of the stream ranged from 22% to 34% at the end of the fifth growing season (Table 2), up only slightly from the 20% shade early in the experiment before the trees were established. As expected, the lowest percent shade was recorded for the 1-row treatment, while the highest reading was recorded for the 6-row treatment. Thus, the wider tree filter belts provided more shade than did single rows after 5 yr. This can be attributed to the fact that there were more trees in the 6-row treatment and they were a bit taller (Figure 18); therefore, less light could penetrate through the canopy of the stand.

Shade was greatest between rows in the 3- and 6-row treatments, at 90% and 99%, respectively. Overall, the 6-row treatment produced the highest percentage of shade at all measurement points, i.e., at the bank (34%), near the first row of trees (87%), between rows 2 and 3 (99%), and between rows 5 and 6 (96%) (Figure 22C). This was followed by the 3-row treatment, which produced 25% shade at the bank, 82% near the first row of trees, and 90% between rows 2 and 3 (Figure 22B). The 1-row treatment produced the least shade, 22% at the bank and 75% next to the row of trees (Figure 22A).

Both tree height and percent shade increased with the increase in the number of rows in the filter belts, i.e., from the 1-row to the 6-row treatments (Table 2). There was a

Table 2. Fifth-year tree height and percent shade produced near the first row of trees by all treatments.

Treatment	Average tree height	Shade (%)	
		Stream bank	Near row 1*
1-row	5.6 m (18.2 ft)	22	75
3-row	6.1 m (20.0 ft)	25	82
6-row	7.4 m (24.3 ft)	34	87

* Measurements were taken next to the first row of trees, on the side facing the stream.

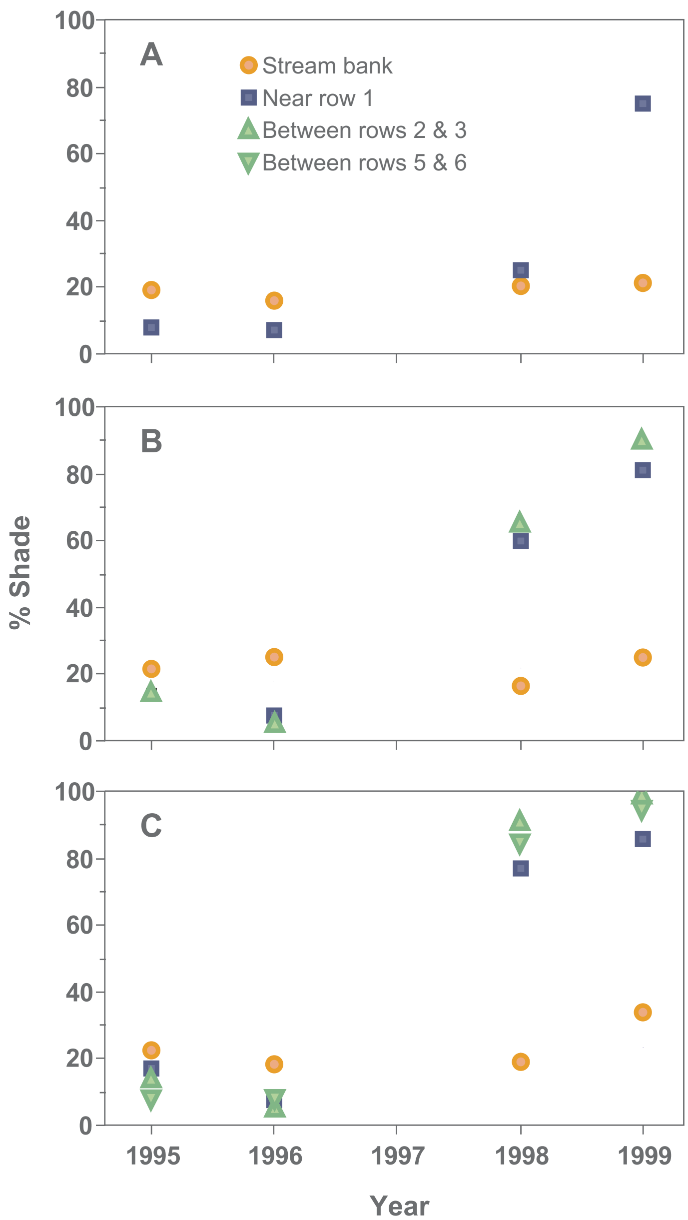

Figure 22. The amount of shade provided by the A) 1-row, B) 3-row, and C) 6-row treatments at mid-day during 5 yr (1995–1999) of growth. Shade estimates were made at the stream bank, as well as next to the first row of red alder trees for each treatment; between rows 2 and 3 for the 3-row treatment; and between rows 2 and 3 and rows 5 and 6 for the 6-row treatment.

positive relationship between tree height and percent shade, i.e., as tree height increased, so did percent shade.

A study by Larson and Larson (1996), on riparian shade and stream temperature illustrates the influence of solar angle on shading. In that study, the site was located at 45°N, the trees were 6.1 m (20 ft) and 15.2 m (50 ft) tall, and shade was measured at 12:00 noon and 2:00 PM. The trees were located 3.1 m (10 ft) from the edge of a 12.2-m (40-ft)-wide water channel that flowed from east to west. The 6.1- m (20-ft)-tall trees cast a 2.7 m (9-ft) shadow at 12:00 noon and a 4.3-m (14-ft) shadow at 2:00 PM; the 15.2-m (50-ft)-tall trees cast 6.7-m (22-ft) and 11.0-m (36-ft) shadows at 12:00 noon and 2:00 PM, respectively. The smaller trees did not cast shadow on the water at either time; however, the taller trees cast a shadow that extended 3.7 m (12 ft) into the channel at noon and 4.6 m (15 ft) into the channel at 2:00 PM. The 15.2-m (50 ft)-tall trees reduced direct solar radiation on the water surface by 30% to 40%.

In the Beaver Creek riparian area study, the shade produced at the water's edge (measured at mid-day) had increased after 5 yr. During other times, when the sun is lower, trees 6.1 m (20 ft) tall will cast more shade. The much greater amount of shade produced earlier at the edge of the stand illustrates the importance of planting the filter belt trees close to the stream. Given the effectiveness of the treatments and considering both the average tree height of 6.1 m (20 ft) and stream width of 2.4– 3.7 m (8–12 ft) at Beaver Creek, we anticipate that the trees will cast more shade on the stream with each passing growing season.

Maintenance and Costs

Over 5 yr, we visited the site more than 70 times, but almost half of those visits were attributed to the research and demonstration nature of the project. About 30 visits were for management actions, half of which were for observation and work lasting about 1 hr. Many of the other visits involved several people and several working hours. Frequent short visits for monitoring were important to detect predator problems. In an operational filterbelt installation, time-consuming measurements would not be necessary, but monitoring would still be important. With more experience, less monitoring would be required.

Table 3. Estimated project costs in U.S. dollars for cattle fencing, vegetation management, beaver protection, and maintenance for 335.3 m (1100 ft) of stream reach.

Management step	Cost
Fencing (1995)	3000.00
335.3 m (1100 ft) of 4-strand barbed wire fence (materials and labor)	
Site preparation (1995)	
Oust (5 oz/acre @ 12.50/oz)	43.75
Accord +surfactant (51 oz/acre @ $50/gal)	13.28
Labor (5 hours @ $10/hr)	50.00
Follow-up weed control (1996 and 1997)	
Labor (5 hours @ $10/hr)	50.00
Seedlings and planting	
143 red alder seedlings @ $0.40 each	57.20
Planting labor @ $0.40/tree	57.20
Tree protection	
143 individual chicken-wire tree cages @ $2.40/tree, including stakes measuring 2.5 x 2.5 x 182.9 cm (1 x 1 x 72 in.)	343.00
Labor (10 hr @ $10/hr)	100.00
Continued maintenance	
Replacing 50 broken stakes @ $0.32 each	16.00
Labor (29 visits of 2 hr @$10/hr)	580.00
Total cost	4346.29

Many different types of weed- and animal-damage control techniques were tried, although not all proved necessary. The essential steps were fencing, herbicide application, planting good seedlings, tree protection with Protex growth tubes and chicken wire cages, and continued maintenance. The total cost for these items for the 335.3-m-long (1100-ft-long) project area, including estimated labor costs, was $4346.29. The cost per tree (assuming 143 final crop trees) was $57.20 (Table 3).

The cost of constructing 5-ft (1.5-m)-high, no-climb wire cages, with four 6-ft (1.8-m) steel posts was $12.50/tree. These cages were effective for protection from both cattle and beaver outside of fenced areas. We recommend planting three trees per cage to assure survival of at least one tree. At $0.80/tree, one cage with three trees represents only a $14.90 total expense. Continued weed control would add extra costs, but it is essential to ensure survival of the trees inside these cages. Without weed control or other preventive measures, small rodents that inhabit grassy areas will girdle trees at the base.

Landowners could cut out-of-pocket expenses considerably by doing much of the work themselves. Excluding labor and fencing, the cost for basic materials was $1110. Fencing materials could add another $1500, bringing the total to $2610, or $18.25/tree. Manage-

Table 4. Estimated costs in U.S. dollars of three alternative strategies for establishing a 304.8-m (1000-ft) riparian buffer strip.*

Management steps	Fencing: 1 tree wide	Fencing: 6 trees wide	Cages, no fencing
Fencing			
304.8 m (1000 ft) 4-wire barb	1500.00	1500.00	0.00
Labor: 80 hr @ $11/hr	880.00	880.00	0.00
Site preparation			
Herbicide	1.88	11.28	1.88
Labor @ $11/hr	11.00	66.00	11.00
Follow-up weed control (2 yr)			
Herbicide	5.98	35.86	5.98
Labor @ $11/hr	22.00	132.00	11.00
Seedlings and planting			
Red alder seedlings @ $0.40 each, 83	33.20	199.20	99.20
Planting labor @ $0.40/tree	33.20	199.20	99.20
Tree protection			
Materials	199.20	1195.00	830.00
Labor @ $11/hr	64.00	444.00	383.00
Maintenance and monitoring (5 yr)			
Replacing broken stakes	9.00	54.00	0.00
Labor @ $11/hr	220.00	660.00	220.00
Total cost	2979.26	5376.54	1660.26
Cost per tree	35.89	10.70	20.02

* The estimates for the planting options were calculated with the following assumptions and estimated costs:

- One-row fenced option—83 trees planted at 3.7 m (12 ft) spacing, protected with chicken wire cages 0.9 m (3 ft) in diameter, 0.9 m (3 ft) tall ($2.40/cage), 5.8 hr total to install the cages
- Six-row fenced option—498 trees planted at 3.7 m (12 ft) spacing, protected with chicken wire cages 0.9 m (3 ft) in diameter, 0.9 m (3 ft) tall ($2.40/cage), 34.8 hr total to install the cages
- Unfenced option—83 cages at 3.7 m (12 ft) spacing, each cage containing three tree seedlings protected with no-climb wire, 0.9 m (3 ft) in diameter and 1.5 m (5 ft) tall, and three 1.8 m (6 ft) metal fence posts ($10/cage), 40 hr total to install the cages
- Herbicide applications to a 0.9 x 0.9 m (3 x 3 ft) area around each tree. Oust and Accord used for site preparation, Roundup Ultra applied each year for 2 yr after planting
- Maintenance and monitoring was required 4 times/yr over 5 yr. The unfenced and 1-row treatments required 1 hr each time; the 6-row treatment required 3 hr. Monitoring was done over 5 yr.

ment costs for decision making and organizing preventive measures were not estimated, but would not be trivial even for an experienced farmer/tree planter.

In order to project realistic costs for operational filter belt plantings, we compared the cost of providing stream protection with three strategies: a 6-row filter belt with fence; a 1-row filter belt with fence; and no fence, individual caged trees (Table 4). Note that these three options would not provide the same amount of stream protection within the same time frame. For example, the 6-row filter belt would supply the most protection in the shortest amount of time at the highest cost. The no-fence/individual cage option would provide considerable protection in the long run at low cost, but much less stream protection in the near term. In addition, there is a big difference in the amount of pastureland taken out of production by the three options. However, once the trees are well established, cattle can be grazed on the land again. Landowners can bring in cattle once the trees reach a height of about 6.1 m (20 ft) and DBH of 6.5 m (25 ft) (Figure 23).

Finally, there were additional costs for miscellaneous materials that were part of this project but were found to be ineffective or unnecessary (Table 5). Although those costs are reported here, they would not be needed in an operational filter belt using the suggested strategy.

Figure 23. Cattle grazing beneath established trees in filter belt.

Table 5. Miscellaneous project materials costs in U.S. dollars for items that are not required for recommended treatment options.

Material	Notes	Cost
Polyspun 350 weed-control fabric, 1.8 x 91.4 m (6 x 300 ft)		84.00
Stakes		15.00
Magic Circle repellent	Free from Oregon Department of Fish & Wildlife	0.00
45.7-cm (18 in.)Vexar tubes plus 2 bamboo stakes/tree @ $0.40/tree (143 trees)	Ineffective against beavers	57.20
0.9-m (3-ft) Protex growth tubes plus 1 stake per tree@ $1.60 per tree	Effective 2–3 yr control for beavers	228.80
Duct tape used to maintain growth tubes, @ $3.00/roll (7 rolls)		21.00
Total cost		406.00

Conclusions

Effective establishment of a red alder filter belt along a coastal stream required close attention to the details of site preparation, vegetation management, and animal damage prevention. Site preparation with herbicides created essentially weed-free conditions, and trees with adequate protection from animal browsing survived and grew well (Figure 24A). Additional herbicide treatments in the second and third growing season allowed trees planted at 1.8 x 1.8 m (6 x 6 ft) spacing to form a closed canopy in 3 yr. After five growing seasons, all three treatment options were producing increased shade at the edge of the stream (Figure 24B).

Although weeds may have an important function in filtering and nutrient cycling in riparian areas, weed control near planted trees is important to ensure early survival and growth of red alder trees. Herbicides, as used in this study, were the most cost-effective way to control weed growth and competition; however, it maybe possible with extreme diligence to accomplish required levels of weed control with mechanical methods. Keeping grass and weeds from growing close to the base of trees also was important to prevent small rodents from girdling the base of trees. With good protection and weed control, trees grew to a height of 5.5–7.3 m (18–24 ft) in 5 yr, tall enough to begin to cast shade on the stream.

Protection of tree seedlings from small rodents, beaver, deer, and cattle was critical. Very early in this study, we learned that the successful establishment of alder trees along riparian areas on agricultural lands required protection from small rodents, beaver, and cattle. In this trial, cattle were effectively excluded by a conventional barbed wire fence. The exclusion of cattle also provided other benefits such as stream bank stabilization and reduced soil erosion. Small rodents and beavers had to be restricted by use of plastic tree shelters at least 0.9 m (3 ft) high. Plastic mesh (Vexar) tubes were not effective in controlling beaver damage.

Figure 24. Red alder filter belt A) just after planting and B) after five growing seasons. In B), the red alder filter belt was well established and the 6.1–7.6 m (20–25 ft) tall trees provided shade to the stream. They also provided considerable habitat for wildlife. At this point, protective devices could be removed from excess trees to provide a food source for beavers.

The use of 0.9 m (3-ft) high, smooth plastic tree shelters (Protex growth tubes) was important for promoting tree survival and growth in this riparian area. Tree shelters provided good protection of trees from browsing by beaver and prevented girdling by small rodents. However, the Protex tubes also required maintenance at least once a year, and had to be replaced by an effective larger protective mechanism when trees outgrew the 10.2 cm (4-in.) diameter tubes. We installed chicken wire cages, reinforced by wooden stakes; these appeared effective after 2 yr, but will surely require annual maintenance to remain effective. Flooding could cause problems with any of the shelters early in the establishment process. Another effective, but very short-term technique for protecting seedlings from animal browsing was to use Magic Circle repellent. In this study, no animal browsing was observed for a few weeks after applying Magic Circle on the trees. After more than a month, the repellent had no effect.

Although it was not quantified in this study, it appears that restoring riparian vegetation by planting trees and allowing natural regeneration on the bank of the stream will also benefit channel stabilization and reduce soil erosion. By fencing the riparian area to protect young seedlings from cattle and beaver, we have seen the natural spread of grasses, herbs, and shrubs along the stream bank (Figures 24, 25). This will have direct impact in reducing soil erosion and sediment transport.

In summary, the Beaver Creek Riparian project has provided valuable information on growing tree filter belts along riparian areas in the Pacific Northwest region. We were able to measure and quantify the amount of shade produced by filter belts, which is critical to improving stream temperatures. Overall, this work has helped generate important information that could be used to improve water quality for fish habitat in Oregon.

Figure 25. A) During the third growing season, reed canary grass had formed a protective cover on the fenced south bank of the stream (foreground). Grazing on the unfenced north bank continued to remove grass cover (left foreground). At mid-right, 1-row, then 3-row alder, had begun to provide shade. B) Two years later (fifth year of study), both 1-row and 6-row alder plantings on the same bank are providing considerable shade during part of the day. Note that the unfenced north bank was not grazed during this growing season, and considerable grass cover was evident.

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