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Weed Management–Techniques

Managing Reed Canarygrass (*Phalaris arundinacea*) to Aid in Revegetation of Riparian Buffers

Timothy W. Miller, Laura Potash Martin, and Craig B. MacConnell*

An experiment compared 2 yr of mowing, mulching, spot treatment with glyphosate, or no maintenance for reed canarygrass control and measured their effect on the establishment of red alder and arroyo willow. At one site, pretransplant control of reed canarygrass was poor, and mulching or no maintenance gave 9 and 14% control, respectively, at 5 mo after planting (MAP), but glyphosate spot treatment and mowing resulted in 89% and 72% control, respectively. The highest leafiness percentage by 24 MAP for arroyo willow and red alder at that site occurred in spot-treated plots (59 and 6%, respectively). Tree protection resulted in 30% more arroyo willow saplings with leaves at 24 MAP, at an average height of 68 cm at 17 MAP. Over the 2-yr trial at that site, mowing required far more time (30.6 min/plot) than either mulching or spot spraying (18.6 and 13.5 min/plot, respectively). At a second site, pretransplant weed control was excellent and maintenance programs controlled reed canarygrass from 88 to 98% by 5 MAP. Tree leafiness of red alder was improved 20% at 24 MAP by tree protection, with protected trees being 107 cm tall compared with 64 cm when left bare. Over the 2-yr trial at that site, mulching required 14.8 min/plot, compared with 12.9 and 7.6 min/plot for mowing and spot treatment. Annual spot treatment of reed canarygrass regrowth with glyphosate may be the most cost-effective means of achieving successful reestablishment of native broadleaf trees in northwestern riparian systems.

Nomenclature: Glyphosate; reed canarygrass, *Phalaris arundinacea* L.; arroyo willow, *Salix lasiolepis* Benth.; red alder, *Alnus rubra* Bong.

Key words: Arroyo willow, red alder, tree protectors.

The listing of several Washington state salmon as threatened or endangered evolutionarily significant units, under the U.S. Congress' Endangered Species Act of 1973 (Pub. L. No. 93-205, 87 Stat. 884 [Dec. 28, 1973]), means factors affecting salmonid habitat need to be evaluated. Invasive plants can modify food and nutrient sources for fish; alter stream structure, complexity, and flow rates; and, potentially, increase water temperatures and decrease dissolved oxygen content, conditions that may detrimentally affect salmonids (Anonymous 1993, 1997; Cummins 1974; Gregory et al. 1991; Meehan 1991; Westbrooks 1998). Common broadleaf trees native to western Washington riparian areas are willow (*Salix* L. spp.), black cottonwood [*Populus balsamifera* L. ssp. *trichocarpa* (Torr. + A. Gray ex Hook) Bayshaw], and red alder (Hitchcock and Cronquist 1964). Falling catkins and bud scales from species such as these provide a major source of nutrients to aquatic bacteria (Sedell et al. 1974), which feed aquatic macroinvertebrates that are a critical component of the diet of juvenile salmon in the spring (Meehan 1991). Terrestrial arthropods that feed directly on native riparian trees and shrubs frequently fall into streams and are another important food source for juvenile salmon (Cummins 1974). In contrast, degraded riparian sites that consist primarily of invasive nonnative plants may not produce similar quantities of vegetative material for use by aquatic organisms in the spring, and such sites are often free of insect pests, potentially depriving juvenile salmon of two significant sources of food.

Native tree species may also benefit salmonids by shading water in summer, which may be important for maintaining optimal stream temperatures (Bestcha et al. 1987, Platts and Nelson 1989). Mature trees also provide bank stability, especially during flood events (Sedell and Froggatt 1984), and contribute large woody debris to streams, which aids in creation of spawning pools (Bissen et al. 1987). Weed infestations, however, may reduce the opportunity for native plant species to recolonize riparian sites. Thus, the development of weed management strategies to reestablish healthy mixes of plant species along riparian corridors may be beneficial to salmonids.

Reed canarygrass is a creeping perennial grass that forms monotypic stands (Apfelbaum and Sams 1987) and currently dominates portions of many western Washington riparian areas. It can spread by seeds or by creeping rhizomes, and it may also produce roots and shoots from culm nodes (Sheaffer and Marten 1995). Aboveground biomass of reed canarygrass ranges from 7,840 to 15,200 kg dry matter/ha/yr (Collins and Allinson 1995; Kätterer et al. 1998), and culms may achieve heights of 150 cm (Hitchcock 1935). Its dense growth slows water flow and increases siltation (Sheaffer and Marten 1995). Although it apparently inhibits growth of most other nearby plant species, reed canarygrass was shown not to be allelopathic to alfalfa (*Medicago sativa* L.) (Chung and Miller 1995). Few animals will eat the grass after anthesis because of its rank growth, and most waterfowl are unable to use infested habitat for nesting, food, or cover (Maia 1994). Carrasco (2000) reported that reed canarygrass infestation caused conditions that resulted in the stranding and death of 158 prespawn male and female coho (*Oncorhynchus kisutch*

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* Associate Weed Scientist, Washington State University Mount Vernon Northwestern Washington Research and Extension Center, Mount Vernon, WA 98273; Forest Botanist, Mt. Baker Snoqualmie National Forest, North Bend, WA 98045; Extension Educator, Washington State University Whatcom County Extension, Bellingham, WA 98225. Corresponding author's E-mail: twmiller@wsu.edu

Walbaum) in a western Washington stream. Reed canarygrass is able to tolerate extended periods of inundation, particularly in flowing water, although roots may be killed if anaerobic conditions occur because of ponding (Stannard and Crowder 2001).

Control of reed canarygrass is difficult, and most reports on reed canarygrass management in riparian situations are anecdotal. In Washington and Oregon, physical methods have included mowing, use of landscape fabrics or other ground coverings, inundation, and burning, whereas cultural strategies have included shading and grazing (Apfelbaum and Sams 1987; Dukes 2000; Gillespie and Murn 1992; Johnson and Schirato 2000; Kilbride and Paveglio 1999; McCauley 2000; Moore et al. 2000; Naglich 2000; Schat et al. 2000; Vlahakis 2000; Wilderman 2000). Chemical control using glyphosate or sethoxydim initially suppressed reed canarygrass, although regrowth was substantial (Apfelbaum and Sams 1987; Kilbride and Paveglio 1999; Stockhouse et al. 2000).

Controlling reed canarygrass growth before and after transplanting should aid in the successful revegetation of infested riparian sites with native tree species and help restore salmon habitat in the Pacific Northwest. Because 41% or greater shading reduced the root and total biomass of reed canarygrass in the greenhouse (Forman et al. 2000), long-term reed canarygrass control on infested sites might also be enhanced through establishment of trees that are capable of quickly growing taller than the weed. Once reestablished at a site, these trees may provide adequate shading to limit reed canarygrass regrowth and reduce the need for continued maintenance on infested sites. Therefore, an experiment was designed to determine the effect of reed canarygrass control on native tree establishment. The objectives of this experiment were (1) to compare several methods of posttransplanting weed management, including mowing, mulching, and spot treatment with herbicide and to monitor tree growth and development during the first 2 yr; and (2) to determine whether tree protectors used in combination with those maintenance programs aided tree establishment.

Materials and Methods

The experiment was conducted at two sites: Four Mile Creek (FM), approximately eight km south of Lynden, WA, April, 2000 through April, 2002, and Joe Leary Slough (JL), approximately 16 km west of Burlington, WA, April, 2001 through April, 2003. Both sites were infested with near-monotypic stands of reed canarygrass. Plots at the FM site were within 6 m of the south bank of Four Mile Creek, a small tributary of the Nooksack River system. Plots at the JL site were within 10 m of the north bank of the freshwater slough, about 5 km inland of the mouth at Padilla Bay of northern Puget Sound. All plots received initial 1.68 and 3.36 kg ae glyphosate/ha,[1] applied to actively growing, 60-cm reed canarygrass on April 18, 2000, at FM and April 25, 2001, at JL using a CO_2-pressurized backpack sprayer equipped with five flat-fan nozzles,[2] delivering 383 L/ha at 255 kPa. Reed canarygrass was cut to within 2.5 cm of the soil surface using a gasoline-powered trimmer April 27, 2000, and May 3, 2001, at FM and JL, respectively, and was immediately followed by transplanting of two native tree species: 46-cm, bare-root red alder saplings and 90-cm cuttings of arroyo willow. A 2.5-cm-diam metal rod was driven into the soil to create individual planting holes approximately 46 cm deep, into which, willow cuttings were inserted, whereas alder saplings were planted into a 30-cm-deep slit in the soil made with a shovel (Washington Association of Conservation Districts planting protocol, http://www.wacd.org/PMC/index.htm). Plots measured 2.4 m by 2.4 m (5.8 m^2), into which four trees of a single species were planted near the center in a square pattern, with each tree spaced about 90 cm apart. Two of the four trees were fitted with tree protectors[3] (60 cm tall, 13 cm diam) within 5 d of transplanting, and two were left bare. Plots at FM were subject to occasional transitory flooding from Four Mile Creek, whereas plots at JL were located about 1 m above high water and were not flooded during the course of the trial.

Reed canarygrass maintenance was initiated shortly after tree transplanting and consisted of one of four programs applied to the plot: mowing, mulching, spot treatment with glyphosate, or no maintenance. In mowed plots, reed canarygrass was cut to within 2.5 cm of the soil surface using hand shears near the trees and a gasoline-powered trimmer in the remainder of the plot. Reed canarygrass was mowed twice in summer of year 1 and three times spring and summer of year 2. Reed canarygrass was approximately 60 cm tall at the time of each cutting. In mulched plots, 1 to 2-cm-diam Douglas fir chips were placed to a depth of 8 cm in a 1.5-m-diam circle centered on the four trees 1 wk after transplanting. In an effort to reduce reed canarygrass height in mulched plots during the second summer, grass was trampled for 3 min/plot on the same days mowed plots were mown. In sprayed plots, reed canarygrass and other weeds were spot treated once annually with glyphosate[1] (1.5% solution, applied spray to wet) when growth reached approximately 60 cm in height. Maintenance glyphosate was applied using a CO_2-pressurized backpack sprayer operated at 138 kPa with a single flat fan nozzle.[2] A plastic shield held between the nozzle and tree minimized inadvertent glyphosate application to alder or willow stems and foliage. Dates for the various maintenance treatments are provided in Table 1.

Percentage of reed canarygrass control was visually estimated by comparing grass cover in plots to nontreated reed canarygrass adjacent to the experimental areas (100%, no reed canarygrass; 0, complete coverage with living reed canarygrass) in the fall of year 1 and summer and fall of year 2. Tree leafiness was recorded in the fall of year 1, spring and fall of year 2, and spring of year 3. Tree height (centimeters from base to highest green leaf on living trees) was measured in fall of year 1 and year 2; tree heights were not measured in spring of either year. Dates for weed rating, tree survival, and tree height are in Table 1.

The time required for initial spraying, planting, and all maintenance operations during the 2 yr of each study was recorded for each plot. A rate of $7.50/h was assumed for these labor costs, and that value was added to the cost of trees (average $0.50/tree), tree protectors ($0.50/protector), herbicide (average of $0.05/plot for initial application, and $0.28/

Table 1. Overview of plot activity timings.

	Four Mile Creek			Joe Leary Slough		
Activity	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
Initial glyphosate application	April 18, 2000	—	—	April 25, 2001	—	—
Initial reed canarygrass cutting	April 27, 2000	—	—	May 3, 2001	—	—
Tree planting	April 27, 2000	—	—	May 3, 2001	—	—
Reed canarygrass maintenance mowings	July 10, 2000 August 4, 2000	May 10, 2001 June 29, 2001 August 1, 2001	—	June 29, 2001 August 1, 2001	May 13, 2002 July 1, 2002 August 5, 2002	—
Reed canarygrass maintenance glyphosate sprays	June 23, 2000	May 10, 2001	—	June 29, 2001	May 16, 2002	—
Reed canarygrass mulching (year 1) and trampling (year 2)	May 5, 2000	May 10, 2001 June 29, 2001 August 1, 2001	—	May 10, 2001	May 13, 2002 July 1, 2002 August 5, 2002	—
Reed canarygrass control evaluations	September 7, 2000	June 29, 2001 September 6, 2001	—	September 7, 2001	July 1, 2002 September 19, 2002	—
Tree leafiness determination	September 7, 2000	April 24, 2001 September 6, 2001	April 29, 2002	September 7, 2001	April 29, 2002 September 19, 2002	April 15, 2003
Tree height measurement	September 7, 2000	September 6, 2001	—	September 7, 2001	September 19, 2002	—

plot for maintenance sprays), and mulch ($1.75/plot) as appropriate to calculate a 2-y establishment cost/tree for each study. Dividing a target live-tree population of 100 by the survival percentage for a given treatment and tree species gave the number of trees necessary to be planted to achieve the target population. Finally, multiplying that value by the planting cost per tree gave the cost for establishing 100 live trees.

Statistics. The experimental design for FM and JL was a split-plot, randomized complete block with four replicates; presence or absence of tree protectors was the split-plot. Data were analyzed with a general linear models procedure using SAS software (SAS 2000). Means were separated using Fisher's Protected LSD at the 5% level of significance. Reed canarygrass control was not rated at the split-plot level, so those data represent reed canarygrass control regardless of tree protection. Reed canarygrass control and tree response at FM and JL differed significantly at nearly all evaluation times, so data were analyzed separately and results presented by site.

Results and Discussion

Reed Canarygrass Control. First-year reed canarygrass control differed markedly between the two sites and dramatically influenced success of subsequent maintenance programs. At FM, control by 5 MAP was 89% after glyphosate spot treatment and 72% after mowing, but only 9 and 14% in mulched or nonmaintained plots, respectively (Table 2). At JL, spot spray resulted in 98% reed canarygrass control by 5 MAP, whereas mulching gave 94% control. Mowing and no maintenance gave 88 and 90% control, respectively, by 5 MAP. Second-year reed canarygrass control in spot-sprayed plots at FM was 68% and was 94% by 14 and 17 MAP (late June and early September), respectively, but 98 and 96%, respectively, at JL (Table 2). Mowed plots at FM by 14 and 17 MAP showed 45 and 72% reed canarygrass control, respectively, compared with 59 and 73% control, respectively, at JL. Mulched and nonmaintained plots resulted in poor reed canarygrass control at both sites for these evaluation times, ranging from 0 to 62%. Thus, two annual spot treatments with glyphosate resulted in excellent control of this weed in the fall of years 1 and 2, whereas other treatments were inadequate.

The difference in initial reed canarygrass control between sites is difficult to explain, but three factors may have contributed to this result. First, during the week of pretransplant glyphosate application, air and soil temperatures measured at Washington State University Northwestern Washington Research and Extension Center near Mount Vernon, WA, averaged about 3 C warmer with 14 mm more rainfall in 2001 than in 2000 (FM is approximately 62 km north of this site; JL is approximately 16 km northwest; data not shown). If conditions at these sites were similar to where the weather measurements were made, more robust reed canarygrass growth may have resulted at JL than at FM, potentially improving glyphosate uptake and translocation to rhizomes at JL. Second, Klevorn and Wyse (1984) found that another rhizomatous perennial grass, quackgrass [*Elymus repens* (L.) Gould], translocated more foliar-applied glyphosate to rhizomes when exposed to 18 C soil than when exposed to 7 to 12 C soil. Similarly, Harker and Dekker (1988) observed greater glyphosate translocation to quackgrass rhizomes at diurnal day/night temperatures of 20/15 C

Table 2. Effect of maintenance program on reed canarygrass control.[a,b]

	FM MAP			JL MAP		
Treatment[c]	5	14	17	5	14	17
	%					
Mow	72 b	45 bc	72 b	88 c	59 b	73 b
Mulch	9 c	52 ab	58 c	94 b	58 b	62 c
Spot spray	89 a	68 a	94 a	98 a	98 a	96 a
None	14 c	24 c	6 d	90 bc	33 c	0 d
$LSD_{0.05}$	12	22	10	4	12	8

[a] Abbreviations: FM, Four Mile Creek; MAP, months after planting; JL, Joe Leary Slough.

[b] All plots sprayed with glyphosate before planting trees. Means within a column followed by the same letter are not significantly different.

[c] Maintenance programs were (1) mow five times over two summers; (2) mulch with wood chips after planting, followed by trampling of grass during the second summer; (3) midsummer spot spray with glyphosate both years; or (4) no maintenance.

than at either 10/5 C or 30/25 C, at which times glyphosate translocation to shoots was greater. Because low-lying soil at FM was probably more nearly saturated in mid-April with spring runoff than the well-drained soil at JL, root zone soil temperature at FM could have been several degrees colder than at JL. If herbicide translocation in reed canarygrass is similar to quackgrass, cooler soil may have resulted in less glyphosate moving to rhizomes and poorer control at FM. Third, plots at FM were on a highly organic soil (44% organic material [OM], 56.2% sand, 18.8% silt, 25.0% clay) compared with a mineral soil at JL (7.6% OM, 42.5% sand, 41.9% silt, and 15.6% clay). The more porous medium at FM may have allowed more extensive rhizome penetration from untreated reed canarygrass adjacent to plots and a more extensive rhizome system within the plots. Organic soil may also have contributed to greater rodent activity, potentially resulting in greater rhizome fragmentation and reducing the effectiveness of the glyphosate application.

The presence of broadleaf weeds also differed markedly between maintenance treatments, although control percentages were too variable to be statistically significant (data not shown). In general, however, increased germination of broadleaf weed seed apparently resulted from improved reed canarygrass control, so the more successful the reed canarygrass control program, the more broadleaf weeds were found in the plots. Broadleaf weeds were particularly evident in plots spot treated with glyphosate. Major broadleaf species noted in the plots included bull thistle [*Cirsium vulgare* (Savi) Ten.], catchweed bedstraw (*Galium aparine* L.), and birdsrape mustard (*Brassica rapa* L.).

Tree Leafiness and Height. The interaction of tree species and maintenance program greatly affected tree leafiness at FM but not at JL (Table 3). Fall percentages of leafy trees at FM did not differ in either year (5 or 17 MAP). Percentage of leafy trees at FM fell precipitously between fall of year 1 and spring of year 2, with an average reduction of 66% among the four maintenance programs for arroyo willow between 5 and 12 MAP; tops of all red alder trees were dry and leafless by 12 MAP, an average 76% reduction from 5 MAP. By 17 MAP, red alder trees in mowed, mulched, and spot-sprayed plots had regrown from axillary buds low on the stem, only to be severely injured again during the second winter. By 24 MAP, top growth of all red alder was dry and leafless, except trees in spot-treated plots (6% of trees leafy). Percentage of leafy arroyo willow trees by 24 MAP was greatest in spot-sprayed plots (59%), followed by those in mowed plots (44%) and mulched plots (22%). Arroyo willow leafiness by 12 MAP exceeded red alder leafiness in every maintenance regime, except mulched arroyo willow. Leafiness of arroyo willow in nonmaintained plots was statistically the same as spot-treated red alder plots by 24 MAP (16 and 6%, respectively). Tree leafiness at JL did not differ among maintenance regimes at any evaluation, nor did trees at JL exhibit more than a slight change in leafy tree percentage from fall to spring.

Tree species and use of tree protectors influenced leafy tree percentage and tree height. Percentage of leafy trees at FM did not vary by 5 MAP, but did at other evaluation timings (Table 4). Red alder did not benefit from use of tree protectors at FM because percentages of leafy trees were similar whether tree protectors were used or not. Conversely, 20 to 39% more arroyo willow trees were leafy by 12, 17, and 24 MAP when tree protectors were used. At JL, use of tree protectors with these two species did not statistically affect tree leafiness except by 24 MAT.

Tree protection did not improve leafiness of arroyo willow, although more bare arroyo willows were leafy than protected or unprotected red alder. A higher percentage of arroyo willows in tree protectors were also leafy (58%) than bare red alder trees that were leafy (28%) at 24 MAT. Tree protectors increased arroyo willow height in fall of both years at FM, but arroyo willow height did not vary at 17 MAP at JL (Table 5). Protected red alder were nearly twice as tall as bare red alder trees at FM at 5 MAP, but by 17 MAP, both protected and unprotected red alder were very short (4 cm). Tree height did not vary at JL by 5 MAP, but by 17 MAP, protected red alder trees were 107 cm tall compared with 64 cm for unprotected trees. Bare arroyo willow trees at JL were 1.4 times taller than protected red alder at 17 MAP, and 2.3 times taller than unprotected red alder.

Arroyo willow cuttings were superior to red alder saplings at both northwestern Washington sites in this study. Based on leafiness percentages, willows were hardier and grew more quickly than red alder. In addition, arroyo willow in spot-treated or mulched plots at JL were taller than most reed canarygrass culms by 17 MAP (data not shown) and, presumably, would be capable of providing shade and suppressing reed canarygrass regrowth during subsequent growing seasons. Arroyo willow height at FM, however, was

Table 3. Effect of reed canarygrass maintenance program and tree species on tree leafiness.[a,b]

Maintenance program[c]	FM MAP				JL MAP			
	5	12	17	24	5	12	17	24
	%							
Red alder								
Mow	81	0 b	13	0 e	56	53	53	50
Mulch	75	0 b	6	0 e	53	44	44	34
Spot spray	81	0 b	19	6 d	47	47	41	38
None	66	0 b	0	0 e	69	50	38	31
Arroyo willow								
Mow	97	32 a	47	44 b	66	66	59	59
Mulch	80	3 b	22	22 c	78	81	78	75
Spot spray	97	30 a	47	59 a	66	66	66	66
None	81	25 a	22	16 d	63	56	56	53
$LSD_{0.05}$	ns	9	ns	10	ns	ns	ns	ns

[a] Abbreviations: FM, Four Mile Creek; MAP, months after planting; JL, Joe Leary Slough; ns, not significant.

[b] Leafiness was determined in late April when most trees of the same species in the area had broken bud. Zeros indicate that top-growth was dead at the time of evaluation. Means within a column and species followed by the same letter are not significantly different.

[c] Maintenance programs were (1) mow five times over two summers; (2) mulch with wood chips after planting, followed by trampling of grass during the second summer; (3) midsummer spot spray with glyphosate both years; or (4) no maintenance.

generally inadequate to provide much shade and, therefore, to greatly inhibit reed canarygrass growth, regardless of maintenance program (data not shown).

Economics of Buffer Establishment. The time investment for tree plantings and reed canarygrass maintenance programs tested in this study are presented in Table 6. Site preparation took an average of 7.6 min/plot at FM compared with 3.5 min/plot at JL. This is primarily because the smooth soil surface at JL allowed plots to be more quickly mowed following the initial glyphosate application than did the very uneven soil surface at FM. There were no great differences in time investment for the various maintenance programs between the two sites during the 2 yr, except for mowing. Because initial reed canarygrass control was far better at JL than FM, year 1 mowing time at FM was 14.2 min/plot compared with 5.9 min/plot at JL. Over the duration of the 2-yr project, time required for establishing and maintaining mowed plots at FM exceeded 30 min/plot, compared with about 13 min/plot at JL. In a similar way, spot spraying with glyphosate took a little longer at FM than at JL (about 3 and 2 min/plot, respectively) because of the presence of more reed canarygrass at FM. Time required for mulch treatments was similar at both sites for both years (between 5 and 6 min/plot). Treatment time at FM was greatest for mowing, followed by mulching, spot spray, and no maintenance, whereas at JL, mulching took the most time, followed by mowing, spot spray, and no maintenance.

The average costs of site preparation, tree planting, and site maintenance are presented in Table 7. Not surprisingly, when costs are calculated as dollars per planted tree, the no-maintenance program was the cheapest for either tree species, followed by spot treatment with glyphosate, mowing, and mulching. When these costs were calculated based on established trees (i.e., trees still alive at 24 MAP), however, the comparison changed dramatically. Because red alder practically failed to establish at FM, 100-tree costs for that species were at least $2,150. Even though red alder was apparently well suited to the habitat at JL, and reed canarygrass control was better than at FM, if mowing were to be used for site maintenance, 200 trees would be required to be planted to establish 100 trees at a cost of $238. If spot treatment with glyphosate were used for site maintenance, 263 trees would be required at a cost of $284 to establish 100 trees. Cost for a no-maintenance program would be the same

Table 4. Effect of tree species and use of tree protectors on tree leafiness.[a,b]

Tree protection and species[c]	FM MAP				JL MAP			
	5	12	17	24	5	12	17	24
	%							
Bare red alder	66	0 c	11 b	2 c	45	39	34	28 c
Protected red alder	86	0 c	8 b	2 c	67	58	53	48 b
Bare arroyo willow	78	13 b	14 b	20 b	72	73	72	69 a
Protected arroyo willow	100	33 a	55 a	50 a	64	61	59	58 ab
$LSD_{0.05}$	ns	8	10	9	ns	ns	ns	12

[a] Abbreviations: FM, Four Mile Creek; MAP, months after planting; JL, Joe Leary Slough; ns, not significant.

[b] Leafiness was determined in late April when most trees of the same species in the area had broken bud. Zeros indicate that top-growth was dead at the time of evaluation. Means within a column and species followed by the same letter are not significantly different.

[c] Maintenance programs were (1) mow five times over two summers; (2) mulch with wood chips after planting, followed by trampling of grass during the second summer; (3) midsummer spot spray with glyphosate both years; or (4) no maintenance.

Table 5. Effect of tree species and use of tree protectors selection on tree height.[a,b]

Tree protection and species[c]	FM MAP 5	FM MAP 17	JL MAP 5	JL MAP 17
	cm			
Bare red alder	38 c	4 c	36	64 c
Protected red alder	65 b	4 c	53	107 b
Bare arroyo willow	62 b	18 b	55	149 a
Protected arroyo willow	111 a	68 a	51	123 ab
LSD$_{0.05}$	10	13	ns	34

[a] Abbreviations: FM, Four Mile Creek; MAP, months after planting; JL, Joe Leary Slough; ns, not significant.

[b] All plots sprayed with glyphosate before planting trees. Means within a column followed by the same letter are not significantly different.

[c] Maintenance programs were (1) mow five times over two summers; (2) mulch with wood chips after planting, followed by trampling of grass during the second summer; (3) midsummer spot spray with glyphosate both years; or (4) no maintenance.

($284), but 323 trees would be required to be planted. The most costly method to establish 100 red alder on a well-suited site, with excellent initial reed canarygrass control, would be to use mulch, which would require nearly 300 trees be planted at a 2-yr cost of $517.

Because arroyo willow plantings were more successful than red alder plantings in these trials, costs for establishing willow were lower than for red alder for most maintenance programs (Table 7). Costs for establishing 100 arroyo willows were minimized at both sites in the spot treatment with glyphosate program, which cost $206 at a harsh site with poor initial reed canarygrass control (FM) and $161 at a well-suited site with excellent initial reed canarygrass control (JL). To establish 100 willows using spot treatment, 152 and 169 cuttings would have had to have been planted at JL and FM, respectively. Initial reed canarygrass control was particularly important when mulching or no maintenance was used on willow plantings. When such control was poor (FM), 100-tree costs were $606 for no maintenance (requiring 625 cuttings), compared with $163 when cuttings were planted on sites with excellent control (189 cuttings); similarly, the 100-tree costs were $796 for mulched trees (requiring 455 cuttings) when reed canarygrass control was poor, contrasted with $233 (133 cuttings) on well-controlled sites.

Table 6. Time investment[a] required for native tree establishment on reed canarygrass-infested ground.

Treatment	Initial site preparation	Year 1	Year 2	Total, both years
	min/plot			
Four Mile Creek				
Mow	7.6	14.2 a	8.8 a	30.6 a
Mulch	7.6	5.0 b	6.0 b	18.6 b
Spot spray	7.6	3.1 c	2.8 c	13.5 c
None	7.6	0 d	0 d	7.6 d
LSD$_{0.05}$	—	0.4	0.6	1.0
Joe Leary Slough				
Mow	3.5	5.9 a	3.6 b	12.9 b
Mulch	3.5	5.3 b	6.0 a	14.8 a
Spot spray	3.5	2.2 c	1.9 c	7.6 c
None	3.5	0 d	0 d	3.5 d
LSD$_{0.05}$	—	0.2	0.9	1.1

[a] Includes time for mixing and spraying initial glyphosate application, initial mowing of grass residue, planting (four trees), tree protector installation (on two of four trees), plus one of four maintenance programs: (1) mow five times over two summers; (2) mulch with wood chips after planting, followed by trampling of grass during the second summer; (3) midsummer spot spray with glyphosate both years; or (4) no maintenance. Plots measured 5.8 m^2. Means within a column and location followed by the same letter are not significantly different.

Table 7. Costs of successful tree establishment.[a,b]

Treatment	Red alder FM	Red alder JL	Arroyo willow FM	Arroyo willow JL
Cost/planted tree ($)				
Mow	1.75	1.19	1.69	1.14
Mulch	1.81	1.76	1.75	1.75
Spot spray	1.29	1.08	1.22	1.06
None	1.03	0.88	0.97	0.86
No. trees planted to establish 100 trees				
Mow	0	200	227	169
Mulch	0	294	455	133
Spot spray	1,667	263	169	152
None	0	323	625	189
Cost to establish 100 trees ($)				
Mow	nc	238	384	193
Mulch	nc	517	796	233
Spot spray	2,150	284	206	161
None	nc	284	606	163

[a] Abbreviations: FM, Four Mile Creek; JL, Joe Leary Slough; In red alder column at FM: 0, no trees established; nc, not calculable.

[b] Costs and no. of trees are for 2 yr, based on actual costs incurred under the conditions of these trials for tree establishment after 2 yr for a planting density equivalent to 6,726 trees/ha (2,723 trees/acre) and including initial glyphosate application, plus one of four maintenance programs: (1) mow five times over two summers; (2) mulch with wood chips after planting, followed by trampling of grass during the second summer; (3) midsummer spot spray with glyphosate both years; or (4) no maintenance. Calculated from mean tree survival percentages; therefore, statistics were not performed.

Based on the results of these trials, revegetation of streamsides infested with reed canarygrass in northwestern Washington can be accomplished, but best results will probably require overplanting with well-suited broadleaf trees and some level of maintenance after tree planting. If reed canarygrass control before tree planting is poor, maintenance options are, at once, more limited and more important, if tree establishment is to be successful. In such cases, annual spot treatment of reed canarygrass regrowth with glyphosate may be the most cost-effective means of achieving successful reestablishment of native broadleaf trees in these riparian systems.

Sources of Materials

[1] Roundup Pro, Monsanto Company, St. Louis, MO 63167.

[2] TeeJet 8002 nozzles, Spraying Systems Co., Wheaton, IL 60189-7900.

[3] Norplex tree protectors, Norplex, Inc., Auburn, WA 98003.

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