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Riparian Forest Buffers for Trout Habitat Improvement

A review

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Table of Contents

Summary 1
Benefits of riparian forest buffers 1
Temperature moderation 1
Sediment and nonpoint source pollution filter 2
Stream habitat improvement 4
Wildlife habitat 4
Income potential 5
Design of riparian forest buffers 6
Identifying objectives 6
General buffer design 7
Selecting woody vegetation 8
Buffer width 8
"Naturalized" planting as an option 8
Establishment of riparian forest buffers 9
Site preparation 9
Planting trees and shrubs 9
Minimizing wildlife damage 10
Maintenance of riparian forest buffers 10
Weed control 10
Long-term maintenance considerations 11
Adoption potential 12
Appendix 15
References 19

Riparian Forest Buffers for Trout Habitat Improvement: A review

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Summary

Minnesota is home to over 450 miles of DNR-designated trout streams. As a cold water species, trout are sensitive to chronic summer stream temperatures above 19^0C (66^0F). Establishing trees in riparian buffers is widely recognized as a significant tool for stabilizing stream temperatures and improving trout habitat. Riparian forest buffers (RFBs) provide other benefits, as well. They filter nutrients, sediments and pesticides, thus preventing movement of these non-point pollution sources downstream and improving water quality. Trees in the buffer zone provide woody debris for the stream, an important component of trout habitat. The woody roots also help stabilize stream banks and help with flood control.

Multi-species, multi-use riparian forest buffers offer landowners an opportunity to not only improve stream habitat and water quality, but to explore income-producing options from the buffer itself. Options include planting specialty nut and fruit trees for harvest, species for timber production or decorative woody florals and grass zones for hay or biomass production.

This review will examine the benefits, design, establishment and maintenance of riparian forest buffers in more detail.

Benefits of riparian forest buffers

Temperature moderation

Stream water temperature has a strong influence on brown trout's metabolism, food consumption and growth rates. Growth rates of the brown trout are optimized at stream temperatures of 13.9^0C when feeding on invertebrates (Elliot 1975). When feeding on fish, the optimum growth rate occurs at 17^0C (Elliott and Hurley 2000). Growth occurs up to 19.5^0 C, above which brown trout will lose weight during prolonged exposure (Elliot et. al. 1995). As a cold water species, brown trout cannot tolerate water temperatures at or above 29.7^0C for even short periods of time (lethal temperature) (Elliot and Elliot 1995, Lee and Rhine 1980). The incipient lethal temperature for brown trout is 24.7^0C. At this temperature, fifty percent of the population dies with prolonged exposure (7 days) (Elliott 1981).

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Several studies have quantified the effect of riparian land use on stream temperature. Trees in a riparian buffer provide shade and can significantly moderate stream temperature (Anbumozhi et.al. 2005, Wilkerson et. al. 2006, Lyons et.al. 2000, Belt and O'Laughlin 1994). By limiting the amount of solar radiation that can reach a stream, trees influence both maximum stream temperatures and diurnal fluctuations. In studies in British Columbia and Washington, mean maximum stream temperatures were 1-2.4^{0}C cooler in shaded riparian buffers compared to areas where trees had been harvested (Rayne et.al. 2008, Pollock et.al. 2009). Maximum stream temperature differences as great as 4-7^{0}C have been reported between shaded and non-shaded stream segments (Johnson and Jones 2000, Kreutzweiser et.al. 2009). Trees in the riparian buffer also influence the how much stream temperature fluctuates during the day. These diurnal fluctuations are less in stream segments with shaded riparian buffers (Wilkerson et.al. 2006, Johnson and Jones 2000, Pollock et.al. 2009).

Other studies have looked more directly at the relationship between riparian land use and a stream's suitability for trout. In a comparison of streams bordered by riparian forest, pasture with a 15 meter wide riparian forest buffer and pasture with no buffer, stream temperatures were significantly higher in the non-buffered pasture reaches. This resulted in a shift toward warm water fish species in the pasture areas (Lorion et.al. 2009). In Oregon, stream water temperature decreased as the fraction of stream bank forestation increased (Barton et.al. 1985). In this study, weekly maximum stream temperature was the only environmental variable that distinguished between stream reaches with trout and those without. Trout were abundant in reaches where the weekly maximum temperature was less than 22^{0}C, while warmer areas had marginal populations.

Sediment and nonpoint source pollution filter

Riparian forest buffers play a significant role in improving stream water quality by filtering sediment, nutrients and pesticides. Most of the research cited in this review reflects an underlying assumption that a three-zone buffer offers the best approach for mitigating agricultural impacts:

Zone I: Narrow, unmanaged woody zone nearest the stream
Zone II: Managed woody zone (harvested for timber, fruit, nuts, etc.)
Zone III: Warm-season native grasses

The amount of fine sediments entering a stream has a negative effect on the number and types of fish found (Hemstad et.al. 2008, Atuke 2007, Nerbonne and Vondracek 2001). Riparian forest buffers can significantly reduce stream bank erosion, runoff volume and sediment transport thus improving fish habitat (Sheridan et.al. 1999, Zaimes and Schultz 2008, Udawatta et.al. 2002). The bulk of the filtering occurs in the grass zone (Zone III) of the RFB (Schultz et.al. 2004, Sheridan et.al. 1999) where the dense, erect grass stems are very effective at slowing and diffusing surface runoff (Dabney et.al. 2006). In one study, sediment transport was reduced over

95 percent in a 7 meter switchgrass filter (Schultz et.al. 2004. In another estimate, soil loss could have been reduced by 72 percent if RFBs had been established along all non-buffered segments of an Iowa stream (Zaimes et.al. 2004).

In agricultural areas, runoff of excess nutrients and pesticides into streams can be a significant concern. While narrow filters are effective at trapping sediment, wider buffers are much better at transforming dissolved nutrients and pesticides (Dabney et.al. 2006). In a study that examined the effectiveness of RFBs in filtering swine wastewater, the pulse of wastewater never reached beyond 15 meters as it moved downslope through the filter (Entry et.al. 2000).

Nitrate-nitrogen is an example of a mobile nutrient that can be transported to surface water through runoff and soil erosion (O'Leary et.al. 2002). Riparian forest buffers have been shown to significantly reduce the amount of nitrate-N reaching the stream when compared to concentrations in the field (Anbumozhi et.al. 2005, Snyder et.al. 1998). For example, nitrate and phosphate concentrations were reduced by more than 60 percent in the grass zone of an RFB in an Iowa study (Schultz et.al. 2004). This is largely accomplished through denitrification and vegetative uptake (Hubbard and Lowrance 1994).

Since phosphorus (P) is largely immobile in the soil, water quality becomes a concern when soil particles carrying P reach surface waters (Busman et.al. 1997). Consequently, the factors that affect sediment loss will also affect P loss; these include runoff volume, runoff duration, maximum flow rates and vegetative cover (Udawatta et.al. 2004). In a separate Iowa study, riparian forest buffers were the most effective in reducing P loss to the stream when compared with row-crops, rotational grazing and pastures (no grazing) (Zaimes et.al. 2004, Zaimes and Schultz 2008). Reducing sediment loss through the use of a riparian forest buffer or grass filter is the most effective way to reduce nonpoint source P pollution (Zaimes and Schultz 2008, Udawatta et.al. 2004, Udawatta et.al. 2002).

RFBs are also effective in both filtering and degrading agricultural pesticides. Atrazine and alachlor concentrations were reduced by 61 and 95 percent, respectively, in a restored riparian forest buffer with the greatest reductions per meter occurring in the grass zone (Vellidis et.al. 2002). It is also encouraging to note that in this study, the 2-year-old, restored buffer was as effective in reducing pesticides as the mature buffer. Pesticides are also degraded more quickly in an RFB than in the field. For example, metolachlor's half-life was reduced from 23 days in the field to 10 days in a riparian buffer (Locke et.al 2008). This is largely attributed to enhanced soil characteristics in the buffer. Higher organic matter contents, greater infiltration capacity and higher microbial populations help bind and degrade pesticides more quickly (Locke et.al 2008, Dabney et.al. 2006).

Stream habitat improvement

Several studies look more directly at the relationship between the riparian buffer type and its affect on fish biota scores. Jones (1999) noted that fish abundance and habitat diversity decreased as the length of non-forested reaches along an Appalachian stream increased. He suggests that streams in that area cannot tolerate the disruption of forested riparian zones of more than one kilometer in length before fish biota scores are affected. More recent work in southern Appalachia supports this relationship. In a 2007 study of forest cover and fish populations, streams with the lowest forest cover (53-75 percent) had more warm water tolerant fish when compared to streams with higher forest cover (Burcher et.al. 2008). In addition, as the amount of deforestation increased the amount of riffles filled with fine sediments also increased (Jones et.al. 1999). As noted earlier, these fine sediments negatively affect the number and types of fish found in a stream (Atuke 2007, Hemstad et.al. 2008, Nerbonne and Vondracek 2001). In a economic analysis of restoration practices on fish populations, a mixed tree-grass buffer was the most cost effective method for recovering lost fish biota scores in an agricultural watershed (Frimpong et.al. 2006).

Wildlife habitat

Studies examining the relationship between riparian forest buffers and wildlife are generally conducted by removing trees in the riparian zone. Several studies focused on the capacity of riparian buffers to sustain bird communities after reducing buffer widths. In studies with varying buffer widths, bird species richness increased only in buffers that were at least 100 meters wide (Shirley and Smith 2005). Forest dependent song birds decreased dramatically in narrower buffers (<50 meters) (Shirley and Smith 2005, Hannon et.al. 2002) and the greatest population variability was found in the narrowest buffers (0-10 meters) (Shirley and Smith 2005). This suggests that very narrow buffers provide unpredictable habitat and are probably used as a travel corridor rather than as permanent breeding habitat.

In another study where different amounts of tree basal area were removed, there were significant changes in the bird populations the first year postharvest in all harvest treatments and the species compositions continued to diverge over time (Hanowski et.al. 2005). Similar to the studies cited above, Hanowski concludes that wider buffers are required to support forest dependent birds and any overstory removal will alter the bird community.

Other small vertebrate populations do not appear to be as sensitive to changes in RFBs as birds are. In studies with varying buffer widths, there were no changes in small mammal or amphibian abundance or composition (Hannon et.al. 2002, Darveau et.al. 2001). This is probably due to the fact that the species studied were habitat generalists which can go and breed anywhere.

A habitat change model was developed in Iowa to predict how land cover and agricultural management scenarios would affect wildlife (Santelmann et.al. 2006). Three scenarios were described: 1) Production - most likely to emerge if profitable agriculture production continues to dominate the landscape: Woodlands nearly disappear, corn-soybean rotations dominate, riparian buffers are narrow and there is little pasture or alfalfa production; 2) Water Quality - Landowners try to maintain water standards: Woodlands are maintained, riparian buffers are widened from 3-6 m to 15-60 m., small wetlands are created and pasture and alfalfa production is common; 3) Biodiversity - Land use is changed to increase habitat for wildlife: Large areas are set aside in permanent ecosystem reserves, riparian buffers are 30-90 m wide, agroforestry and strip intercropping with native perennials are developed. The model suggests that continued intensification of the Production scenario will lead to further decline of wildlife population and habitat. In contrast, the Water Quality and Biodiversity scenarios benefit wildlife and result in increases in all taxa.

Income potential

Riparian forest buffers offer several opportunities for agroforestry income. In Zone II of the RFB, high value hardwoods and specialty forest products may be grown (Josiah 2000). In Minnesota, the high value hardwoods might include walnut, oak, maple or ash. Potential income from hybrid poplars harvested for saw logs and pulp chips was evaluated in Washington. Researchers found that a partial harvest of the buffer could be economical if at least half of the harvest was sold as logs, but at 2005 prices, harvesting only for pulp was not (Henri and Johnson 2005). Specialty forest products include food products, such as fruits and nuts, specialty woods and decorative woody florals (Josiah 2000).

An economic model for the harvest of non-timber products in the RFB has been developed for the Chesapeake Bay region (Robles-Diaz-de-Leon and Kangas 1999). The model is based on a multi-layered, multi-species Mayan practice that has been used successfully in tropical forest preservation. The objective is to adapt the tropical practice for the temperate region to ultimately produce sustainable forest products that can be marketed locally. In the Chesapeake Bay model, the forest zone included five species of fruit, four species of edible nuts and three woody ornamentals. It assumes that the forest matures in 10 to 15 years and estimates a gross income up to $60,000 per hectare per year. The author concludes that the economic forest can provide both production and environmental protection.

Design of riparian forest buffers

Identifying objectives

Landowner objectives need to be identified before designing a riparian forest buffer. As an agroforestry practice, a riparian forest buffer can be designed to improve water quality as well as provide income opportunities (CFA 2005, Fox et.al 2005a, Josiah 2000, Robles-Diaz-de-Leon and Kangas 1999). When a landowner is interested in generating income from the riparian zone, he/she should explore potential markets for specialty forest products before planting. When markets are identified, the buffer can be designed to produce income on both short- and long-term bases. Decorative woody florals, for example, may be ready to harvest in two years, while income from edible berries and nuts may take 2 to 15 years to produce. Over the long-term, timber trees may be a sustainable income source (CFA 2005, Henri and Johnson 2005).

Government and other agency programs that provide technical and financial assistance to conserve and enhance soil and water resources may also be a source of income (Fox et.al 2005a, CFA 2005). The Continuous Conservation Reserve Program (CCRP) offers cost share for riparian forest buffer establishment and annual rental and maintenance payments for the length of the contract (10-15 years). According to the National Resource Conservation Service (NRCS), over 700,000 miles of riparian buffers had been installed by 2003 under this program throughout the nation (Schnepf 2003). Another voluntary NRCS program, the Conservation Stewardship Program, provides technical and financial assistance to extend or manage an existing riparian forest buffer (NRCS 2009).

Improving wildlife habitat may be another of the landowner's goals. Plant materials for the riparian buffer can be selected to provide food, shelter or nesting areas for various species (Walter and Pierce 2008, MFRC 2005, NRCS-MN 2008). For example, wild turkeys prefer red and white oak acorns, but will also consume seeds and fruits from species such as dogwoods, hawthorns, and wild grape (Walter and Pierce 2008). In Zone III, a wide variety of native grasses and forbs provide greater habitat diversity and will attract more wildlife species (CFA 2005). Buffer design may also be modified to accommodate different wildlife species. Wild turkeys, for example, nest on the ground, often along field edges where they can find a thicket or dense understory (Walter and Pierce 2008). Since poults rely on insects as a food source, planting shrubs near an insect source, such as an alfalfa field, provides escape cover for the young birds.

Problem areas, such as gullies and eroded streambanks, should be identified and addressed before the riparian buffer is installed (CFA 2005). Additional riparian management practices may be required to repair eroded areas, reduce undercutting of the streambank and slow water movement. Types of stabilization practices include installing rock rip-rap, staking dead trees

along eroded banks (tree revetment), planting live post and stakes or fascines in the streambank and installing in-stream structures.

General buffer design

A three-zone riparian forest buffer is widely recognized as the best approach for mitigating agricultural impacts (CFA 2005; Fox et.al 2005a, Hubbard and Lowrance 1994, Schultz et.al. 2004, Schultz et. al. 1997, Sheridan et.al. 1999, Vellidis et.al. 2002, Johnson and Buffler 2008).

- **Zone I** is the unmanaged woody zone nearest the stream. Trees in this zone are selected for rapid root development and tolerance of wet conditions (Schultz et. al. 1997, CFA 2005, Schultz et.al. 2004, MFRC 2005). Zone I trees provide perennial root systems to stabilize streambanks, woody debris for aquatic habitat and shade for stream temperature moderation (Anbumozhi et.al. 2005, Schultz et.al. 2004, Zaimes and Schultz 2008, Wenger 1999, CFA 2008). A minimum width of 35 feet is required by NRCS programs for Zone I.
- **Zone II** is the wider managed woody zone. Trees and shrubs in this zone should be fast-growers that can tolerate periodic flooding (Fox et.al 2005a). The primary role of this zone is to absorb and store nutrients, degrade pesticides and slow floodwaters (CFA 2005, Lyons et.al. 2000, Schultz et. al. 1997; Johnson and Buffler 2008). It can also add diversity for wildlife habitat and be managed for additional income (Schultz et. al. 1997; CFA 2005). Four to five rows of trees and 1 to 2 rows of shrubs have been recommended for this zone (CFA 2005).
- **Zone III** consists of at least a 20 to 24 foot width of warm-season native grasses and forbs and is an essential part of the riparian buffer in an agricultural setting (Schultz et. al. 1997; CFA 2005). Nutrient uptake and sediment filtering are major roles of this high infiltration zone (Schultz et.al. 2004, CFA 2005, Dabney et.al. 2006). Where runoff is an issue, switchgrass is the preferred species due to its dense, stiff stems that slow water flow. In areas where runoff is not a major concern, other warm season native grasses, such as Indiangrass and Big and Little bluestem, can be used (Schultz et.al. 2004; Schultz et. al. 1997). Cool season grasses are not appropriate for Zone III, since they have less root mass than warm season grasses and they tend to lay down under water flow (Schultz et. al. 1997). Table A1 offers suggestions for native grasses that could be selected for Zone III. Native cool season grasses should be included as part of the seed mixture, since they establish more quickly than warm season grasses. As the warm season natives become well established, the cool season grasses will naturally diminish (MNDOT 1992).

Selecting woody vegetation

Trees and shrubs should be tolerant of the wet soils and periodic flooding that occurs in the riparian environment, particularly those selected for Zone I (CFA 2005; Schultz et. al. 1997; NRCS-MN 2008). Tables A2 and A3 (see appendix) are compilations of tree and shrub species that have been identified as appropriate for riparian areas of Minnesota. Several of these species can also produce a marketable crop and are listed in Table A4 (Streed and Walton 2001). Table A5 includes recommended widths between and within rows for trees and shrubs.

Buffer width

Narrow buffers are effective at trapping sediment, but extensive buffers are better at transforming nutrients and pesticides (Dabney et.al. 2006, Wenger 1999). Buffers narrower than sixty-six feet generally do not hold water long enough for the chemicals to be removed (Schultz et. al. 1997). A review of riparian forest buffer best management practices found that agency recommendations for buffer width varied from 35 to 100 feet (Broadmeadow and Nisbet 2004). Widths at the low end were generally adequate to protect a stream's physical and chemical characteristics, while widths at the upper end were better at maintaining ecological integrity. To achieve wider buffers, any of the zones can be increased (Schultz et. al. 1997) Widths may also vary to address runoff hotspots or to accommodate machinery (CFA 2005). When a landowner wishes to support wildlife, wider buffers may be required (Johnson and Buffler 2008). For example, NRCS practice standards include widths of 600 feet for supporting bald eagles, two hundred feet for deer and 100 feet for frogs and salamanders (NRCS-MN 2008). In general, width guidelines of 100 to 300 feet are considered a minimum for enhancing wildlife habitat and providing a travel corridor (Santelmann et.al. 2006, Shirley and Smith 2005, Schultz et. al. 1997).

"Naturalized" planting as an option

Although establishment and maintenance of a buffer is more convenient when it is arranged in rows, its benefits are greatest when it replicates native riparian woodlands (Broadmeadow and Nisbet 2004). A mixed planting of trees and shrubs in Zones I and II is particularly beneficial for wildlife since it provides excellent cover and food sources (MN-DNR 2009, CFA 2005). A multi-layered, multi-species model adapted from a Mayan practice has been successful in the Chesapeake Bay region in both producing forest products and protecting the environment (Robles-Diaz-de-Leon and Kangas 1999).

Establishment of riparian forest buffers

Site preparation

Adequate site preparation is essential for buffer establishment (Fox et.al 2005b). Control of competing vegetation will vary somewhat depending on the zone being prepared and its land use. When the land being prepared is in pasture, burndown of the vegetation with glyphosate and tillage, if desired, is recommended in the fall before planting (Fox et.al 2005b, Schultz et. al. 1997, CFA 2005). This recommendation is supported by a Wisconsin study that compared seedling survival among different reed canarygrass preplant control methods. The highest two-year seedling survival rate (85 percent) was obtained with a fall application of glyphosate followed by spring plowing (Hovick and Reinartz 2007). The simplest treatment included in the study, a single fall application of glyphosate, resulted in a somewhat less optimal survival rate (62 percent). However, since a single herbicide application requires relatively little labor or equipment and because the treatment's survival rate was significantly higher than the control (14 percent), it was considered a good option for site preparation. When a landowner chooses to use herbicide only for site preparation in Zones I and II, glyphosate should be applied in 3 to 4 foot strips or circles where the trees will be planted (Schultz et. al. 1997). If the pasture area will be planted to Zone III grasses, the fall glyphosate treatment should be followed with an additional herbicide application in the spring and the desired grasses seeded with a prairie seed drill (CFA 2005).

When crop land is being prepared for Zones I and II, light tillage, such as disking, is recommended to control the early spring weed flush (Schultz et. al. 1997, CFA 2005, Fox et.al 2005b). Planting this area with a mixture of perennial ryegrass and timothy will provide soil protection without competing with the young trees. Spring disking is also recommended if crop land will be planted to Zone III grasses. In addition, the area should be cultipacked to prepare a good seedbed for switchgrass or other native grasses (Schultz et. al. 1997, CFA 2005).

Planting trees and shrubs

Plant materials for the woody zones include both seeds and seedlings (Fox et.al 2005a).
Tree seeds can be collected in the fall and planted by hand or specialized machine (Fox et.al 2005b, Schultz et. al. 1997). Planting depth should not exceed 2 to 3 times the seed diameter. Large seeds, such as acorns and walnuts, can also be broadcast with a fertilizer spreader and disked in to a depth of 1 to 2 inches. Lighter seeds, such as maple, can be broadcast and dragged in lightly (MDA).

Trees can be purchased as unrooted cuttings and bareroot or container seedlings, but the most common is the bareroot seedling (Fox et.al 2005b). Survival and growth of bareroot and container seedlings were compared over a four-year period in a riparian buffer with no significant differences found (Sweeney et.al. 2002). When bareroot seedlings are purchased, they should be kept moist and protected until planting. In addition, the seedling roots should be submerged in water for 2 to 4 hours before planting (Schultz et. al. 1997). The planting hole needs to be large enough to contain the entire root system (without turning any roots up) (Fox

et.al 2005b). This is also true for container seedlings. After being placed in the hole, roots of both seedling types need to be covered and packed with soil.

Unrooted cuttings should be placed in the ground with 2 to 3 buds above the soil surface and watered immediately (Fox et.al 2005b). Cuttings are the hardest to establish with the possible exception of willow (Fox et.al 2005a).

Minimizing wildlife damage

Protecting tree seedlings from animal damage in the first few years of establishment is important for their long-term survival (Schultz et. al. 1997, Fox et.al 2005b). Significant damage from browsing deer, rabbits, voles and gophers can be minimized with an integrated pest management (IPM) approach. It can include exclusion, habitat modification, repellents and population management (Fox et.al 2005b).

Solid, translucent tubes that surround the seedling are among the most common exclusion tools to provide protection from wind and animal browse and girdling damage. These tree shelters also provide a greenhouse-like environment that promotes rapid growth. Sweeney (Sweeney et.al. 2002, Sweeney and Czapka 2004) found that long-term survival and growth of tree seedlings was significantly increased when tree shelters were used at establishment. In the 2004 study, survival was 39 percent greater and growth was enhanced 300 percent for seedlings with shelters five years after establishment. There was also a significant interaction between use of the tree shelters and the weed control method. Trees with shelters grew faster when weeds were controlled through an herbicide application or a weed mat compared to mowing or no weed control. The height of the shelter also has to be considered. In a Vermont study, sixty-centimeter (2 foot) shelters did not provide enough protection from deer browse, resulting in high mortality in both sheltered and unsheltered seedlings (40.1 vs. 47.0 percent) (Keeton 2008). Fences can also be used to exclude animals from tree and shrub seedlings (Fox et.al 2005b).

Managing vegetation to minimize herbivore habitat can be included in the integrated pest management approach (Fox et.al 2005b). For example, late fall mowing is recommended in the buffer rows to reduce habitat for rodents (Schultz et. al. 1997). Other IPM options include using repellents and controlling the herbivore populations through hunting or trapping (Fox et.al 2005b).

Maintenance of riparian forest buffers

Weed control

Until tree seedlings can compete with surrounding vegetation, weed control is the primary maintenance activity in the critical zone around the seedling. University Extension publications from neighboring states include mulching, mowing and shielded herbicide applications as viable options for grass control in Zones I and II (CFA 2005, Fox et.al 2005b, Schultz et. al. 1997). Organic mulch, such as wood chips or shredded hardwood, can be applied to a 4 to 6 inch depth around the seedling to suppress weed competition (Schultz et. al. 1997). However, mulching

may not be adequate if the site preparation weed control is poor. In a study that compared reed canarygrass control methods at two sites, the mulching treatment at a site with poor initial control resulted in only 9 percent control 5 months after planting (MAP) (Miller et.al. 2008). In contrast, reed canarygrass was 94 percent controlled 5 MAP in the mulching treatment at the site that had excellent control before planting. Similar results were obtained with the mowing treatment in this study. While mowing can be useful to mark rows and reduce rodent habitat, it will not be adequate if preplanting weed control is poor. Miller concludes that annual spot treatments of glyphosate are the most cost effective control method for riparian buffer establishment.

Herbicide use has resulted in the most consistent control in several studies. In an evaluation of weed control methods on long-term seedling survival and growth, treatments that included an herbicide were significantly better. In 2002, fourth-year seedling survival was 56.6 percent for the single glyphosate application treatment compared to the tree mat and mowing treatments (36.9 & 13.9 percent, respectively) (Sweeney et.al. 2002). Similarly, seedling growth was significantly greater in the glyphosate treatment 4 years after planting compared to treatments with tree mats or mowing (66.3 vs. 36.3 & 32.3 cm, respectively). In a similar study at a second site, conditions appeared to be more optimal for tree seedlings resulting in no treatment differences on seedling survival. However, seedling growth five years after planting was affected by weed control method (Sweeney and Czapka 2004). Again, the greatest growth was in the herbicide treatment, followed by the tree mat and mowing (128.4, 114.0, 89.5 cm, respectively).

Glyphosate was the herbicide used in the three studies noted above. Sethoxydim, a systemic annual and perennial grass herbicide, was the focus of a reed canarygrass control study in Wisconsin (Annen et.al. 2005). It evaluated the effect of four control treatments on inflorescence density and biomass: 1) control (no applications), 2) Early summer application, 3) Early summer + late summer applications, and 4) Late summer mow + late summer application. In the season of application, the single and double treatments (treatments 2 and 3) were equally effective in reducing inflorescence density (94.5, 96.0 percent, respectively) and biomass (50 percent) and significantly better than the control. Since the second application late in the summer did not further decrease either inflorescence density or biomass, a single early summer application became the most economical treatment. Unfortunately, the herbicide effects did not carry over into the following year, so multiple year herbicide applications would likely needed to control reed canarygrass. In addition, the researchers found no evidence that a single mowing enhances the effectiveness of sethoxydim. It should be noted, however, that only one mow-herbicide schedule was included in the study when several could be possible and studied.

Weed control recommendations for Zone III are quite different than those for Zones I and II. During the first year of warm season grass establishment, the area should be mowed at a height of 6 inches when weeds are about a foot tall and again in mid-late September to help prevent annual weeds from going to seed (Schultz et. al. 1997, CFA 2005). Appropriate herbicides may be used, if needed. When possible, early spring burns during the first few years of establishment help reduce competition from cool-season grasses, weeds and woody plants (CFA 2005).

Long-term maintenance considerations

Long-term maintenance activities promote strong plants that can survive environmental stress and optimize nutrient uptake and storage. In Zones I and II, harvesting or cutting back shrubs and pruning trees will stimulate vigorous growth (Fox et.al 2005b, CFA 2005, Schultz et. al. 1997). After 8 to 12 years, thinning or selectively harvesting fast growing trees (ex. willows, cottonwoods, silver maple) will remove captured nutrients and chemicals from the riparian zone and promote growth. A continual annual harvest where a portion of the tree zone (1/8 to 1/12) is taken is an option. Harvesting in the winter also has some advantages. The root systems of the harvested trees will be retained and continue to stabilize soil while allowing trees to regenerate from stump sprouts in the spring.

After the first five years, the grass zone should be harvested or burned, if possible, on an annual or biannual basis (Schultz et. al. 1997). This will promote both root and dense upper plant growth and prevent a build-up of dead material on the surface.

Replanting or reseeding may be required during the life of the buffer. If 3 to 4 consecutive trees or shrubs die in Zones I or II, they should be replaced (CFA 2005, Fox et.al 2005b). Likewise, trees should be replanted after harvest if they are not regenerating on their own (Schultz et. al. 1997). In Zone III, if grass establishment is poor, the area should be treated with glyphosate and redrilled (CFA 2005). If there has been some establishment but it is less than optimal, new seed can be drilled directly into the existing stand. Small areas can be hand seeded and raked.

Buffers should be inspected regularly for any eroded areas and repaired immediately (Fox et.al 2005b). Sediment may also build up, particularly on the field edge of Zone III. If this occurs, the sediment can be re-spread onto the field and the area replanted, as necessary.

Other maintenance activities might include insect and disease management, particularly if fruit and nut trees are included in Zone II. If the buffer is established during a drought, additional watering may be required. Finally, Zones I and II should be protected from livestock (Fox et.al 2005b). Careful grazing of Zone III (only) may be an option, although this has not been thoroughly tested (Schultz et. al. 1997).

Adoption potential

Riparian forest buffers provide many benefits to society through enhancing both fish and wildlife habitats as well as reducing nonpoint source pollution. Successful adoption of this agroforestry practice may very well depend on the development of innovative policies or programs that will attract individual landowner participation.

Researchers in Missouri developed a model for RFB adoption based on surveys with landowners currently farming (mostly small farms) in the northeastern and southeastern portions of the state along the Mississippi River (Valdivia and Poulos 2009). They found that while economic considerations were important, the most important factor influencing the farmers' interest in RFBs was the amount of knowledge they had about the practice. Farmers that valued the environment and had concern for future generations also had a stronger interest in RFBs. In general, older farmers were less interested in this practice.

In 2001, Klapproth (2001) examined the issues surrounding adoption of RFBs on private land and highlighted policies that may be used to implement them. A review of general conservation practices that have been adopted may shed some light on the potential for RFB adoption. The review found that the majority of farmers had positive attitudes about protecting the environment and were concerned about the possible effects of agricultural chemicals in groundwater. Concern, however, doesn't necessarily translate into action. In Maine, for example, full-time farmers were less likely to develop plans for an RFB than their part-time counterparts. Similarly, in Illinois, the majority of the CRP contracts that included trees were on farms of less than 100 acres.

In 1992, the DNR in Maine developed a cost-share program for establishing riparian buffers. The typical participant in this program was more educated (66 percent held at least a college degree), was younger and had less farm management experience and a smaller farm. Fifty-five percent earned less than 1000 dollars from the farm, with an additional 27 percent earning between 1000 and 19,000 dollars annually. Non-participants in the program derived most of their income from the farm and gave a variety of reasons for not participating. There was concern about the impact of current and future land laws that may threaten farm income. Tree planting occurs at an already busy time and buffer maintenance was seen as too time-consuming. Previous experience with government programs also had a negative impact and farmers preferred to install grass in a buffer rather than trees.

For the farmer that derives most of his/her income from the farm, establishing a forest buffer provides little economic value, requires money and time and reduces land options in the future. In 1994, the Chesapeake Bay Watershed developed guidelines for a buffer policy that addresses some of these concerns. They agreed that the policy should be voluntary and based on scientific research. It should be flexible to take a "whole farm" approach and be coordinated with state and federal policies so there is consistency in establishment and maintenance guidelines. Educational, technical and financial assistance should be available for buffer establishment as well as compensation for lost production income. They also stated that markets for buffer products should be developed.

In a voluntary approach, the landowner's perception of the problem is key to adoption. Education must clearly identify the issues, demonstrate benefits to the local environment and illustrate the specific role that the individual landowner plays in the solution. Education will help encourage adoption, but a landowner may still feel that it is beyond the scope of what he/she can do.

Technical assistance is also important in a voluntary approach. Ohio's DNR established the TREES (Tree Resource Establishment and Enhancement Service) program to address landowners' time and expertise concerns. The Resource council contracts with local vendors to provide tree planting, tree shelters, mowing and other maintenance services. Landowners pay a flat fee to the council for a 3-year contract. State and federal cost share dollars may be applied toward the contract.

Economic incentives are also essential for voluntary adoption. While cost-share programs are common, survey respondents have a mixed response to them due to the amount of red tape,

design requirements or the application process. Land retirement programs (ex. CCRP) and subsidy payments are also possible avenues for economic incentives. In the Pacific Northwest, tax incentives have been used to restrict harvesting in the riparian zone.

Regulatory approaches typically include the threat of fines or taxes. For example, the Chesapeake Bay Preservation Act requires local governments to incorporate water quality protection in zoning ordinances and comprehensive plans. Most governments in this area have adopted 100-foot buffer requirements. Fines can be levied against anyone who violates local regulations and may be as high as 5,000 dollars per day.

Klapperoth compared results from a voluntary program in Virginia with a regulatory approach in Maine. Similar improvements in water quality were achieved with both approaches, but the voluntary program costs to the landowners and forestry service were significantly less. Education, technical assistance and financial support can encourage voluntary adoption of riparian forest buffers, but landowners' needs and concerns must be taken into account. Policies and programs that address these concerns may significantly enhance the outlook for successful adoption.

Appendix

Table A1. Native grasses (not inclusive) for Zone III of the riparian buffer and their tolerance to drought and flooding[1].

Common name	Scientific name	Cool/Warm season	Drought	Flooding	Wet soil
Canada wildrye	Elymus canadensis	Cool	Fair	Good	No
Slender wheatgrass*	Elymus trachycaulus	Cool	Good	Good	No
Big bluestem*	Andropogon gerardii	Warm	Fair	Poor	No
Little bluestem*	Schizarium scoparium	Warm	Good-Exc.	Poor	No
Indiangrass*	Sorghastrum nutans	Warm	Fair	Poor	No
Sideoats grama*	Bouteloua curtipendula	Warm	Good-Exc.	None	No
Prairie cordgrass	Spartina pectinata	Warm	Poor	Excellent	Yes
Switchgrass*	Panicum virgatum	Warm	Good	Good	Yes

*Varieties adapted for different areas of Minnesota. See NRCS Conservation Practices Standard: Filter Strip.
[1]Native grass list compiled from NRCS Conservation Practices Standard: Filter Strip; *Producing Marketable Products from Living Snow Fences*, University of Minnesota Center for Integrated Natural Resources and Agricultural Management; MN/DOT Seeding Manual: 2007 Edition.

Table A2. Deciduous woody species recommended for riparian forest buffers in Minnesota[1].

Common Name	Scientific name	Growth	Flooding tolerance	Large woody debris	Shade value	Wildlife merit
Shrubs						
American cranberry	Viburnum trilobum	Slow	H-M	L	L	H
Arrowwood	Viburnum dentatum	Moderate	H	L	L	H
Black chokeberry	Aronia melanocarpa		M	L	L	H
Black elderberry	Sambucus nigra	Mod/fast				H
Dogwood, red osier	Cornus sericea	Fast	H	L	L	M
, silky	C. amomum		H	L	L	M
, gray	C. racemosa	Moderate	M	L	L	M
Nannyberry	Viburnum lentago	Slow	M	L	L	H
Ninebark, common	Physocarpus opulifolius	Moderate	L	L	L	H-M
Willow, sandbar	Salix exigua	Fast	H	L	L	H
Winterberry	Ilex verticillata	Moderate	H	L	L	H
Small deciduous						
American plum	Prunus americana	Fast	L-M	L	L	H
Chokecherry	Prunus virginiana	Fast	L-M	L	L	H
Crabapple	Malus spp.	Moderate				H
False indigo	Amorpha fruiticosa		H	L	L	L
Hawthorne, cockspur	Crataegus crusgalli	Slow/Mod	M	L	L	H
Hazelnut, american	Corylus americana	Moderate	M	L	L	H
Serviceberry (Juneberry)	Amelanchhier alnifolia	Moderate	M-L	L	L	H
Willow, peachleaf	Salix verticillata	Fast	H	L	L	H
Tall deciduous						
Ash, green	Fraxinus, pennsylvanica	Fast	M	M	M	M
, white	F. americana		M	M	M	M
, black	F. nigra	Moderate	H-M	M	M	M
Aspen, quaking	Populus tremuloides	Fast	L	M	M	H
Birch, white	Betula papyrifera	Fast	M-H	M	M	H
, river	B. nigra	Fast	M-H	M	M	M
, yellow	B. alleganiensis	Fast	M-H	H	M	H
Basswood	Tilia americana	Moderate	L-M	H	H	L
Cherry, black	Prunus serotina	Fast				M
Cottonwood, eastern	Populous deltoids	V. fast	H-VH	H	H-VH	M
Hackberry, common	Celtis occidentalis	Fast	M	M-H	H	H
Maple, silver	Acer saccharinum	Fast	H	H	H	M
, red	A. rubrum	Fast	H	H	H	M-H
, sugar	A. saccharum	Slow				
Oak, bur	Quercus macrocarpa	Slow/mod	H-M	H	H	H
, northern pin	Q. ellipsoidalis		M-L	H	H	H
, red	Q. rubrum	Mod/fast	L	H	H	H
, swamp white	Q. bicolor	Fast	H	M	H	H
Poplar, hybrid	Populus	Fast				H
Walnut, black	Juglans nigra	Fast	H	M	H	M
, white (Butternut)	J. cinerea	Fast	L	M	M	H
Willow, black	Salix nigra	Fast	H	M	H	M

Relative ranking values: VH=Very high; H=High; M=Medium; L=Low

[1]Tree list compiled from NRCS Conservation Practice Standard, Riparian Forest Buffer, Code 391; 2009 Minnesota State Forest Nursery Order; Forest Management Guidelines.

Table A3. Woody conifer species recommended for riparian forest buffers in Minnesota[1].

Common Name	Scientific name	Growth	Flooding tolerance	Large woody debris	Shade value	Wildlife merit
Small conifers						
Cedar, red	Juniperus virginiana	Slow/mod	M	M	H	H
, white (arborvitae)	Thuja occidentalis	Slow/mod	H-M	M	H	H
Tall conifers						
Balsam fir	Abies balsamea	Slow/mod	M-H	M	M	H
Pine, jack	Pinus banksiana	Fast	L	L	M	L
, red	P. resinosa	Mod/fast	M	H	M	M
, white	P. strobes	Fast	M	H	H	H
Spruce, black	Picea mariana	Moderate	H-V	M	M	M-H
, white	P. abies	Moderate	M-L	H	M-H	H
Tamarack (Larch)	Larix laricina	Fast	H-M	H	M	M

Relative ranking values: V=Very high; H=High; M=Medium; L=Low

[1]Tree list compiled from NRCS Conservation Practice Standard, Riparian Forest Buffer, Code 391; 2009 Minnesota State Forest Nursery Order; Forest Management Guidelines.

Table A4. Woody plant materials for the riparian buffer that can produce marketable crops[1].

Common Name	Product	Minnesota Regions
Shrubs		
American cranberry	Fruit preserves, wine	all
Elderberry	Fruit preserves, wine	all
Dogwood, red-osier	Woody ornamentals	all, but not as well in SW
Nannyberry	Fruit preserves	all
Small deciduous		
American plum	Fruit preserves, wine	all
Chokecherry	Fruit preserves, wine	all
Crabapple	Fruit preserves	all
Hawthorne	Fruit preserves	all
Hazelnut, hybrid	Biofuels (oil), biomass, nuts	all
Serviceberry (Juneberry)	Fruit preserves	all
Tall deciduous		
Birch, white	Woody ornamentals	all but Red River valley
, river	(branches, birch cones)	better in south
Maple, sugar	Maple syrup	all
Poplar, hybrid	Fuel biomass, pulp & paper	all
Walnut, black	Nuts, shells, lumber	Southeast (best), southwest

[1]Tree list compiled from *Producing Marketable Products from Living Snow Fences*, University of Minnesota Center for Integrated Natural Resources and Agricultural Management.

Table A5. Recommended spacing within and between rows of trees and shrubs in the riparian buffer[1].	
	Spacing
Spacing within rows	**(feet)**
Shrubs	3-8
Small trees	6-10
Tall trees	10-16
Spacing between rows	
Shrubs	10
Shrubs and small trees	12
Small trees	12
Small trees and tall trees	16
Tall trees	16
Fast growing trees/conifers and conifers	20
[1]G. Kopp, personal communication, 2009.	

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