doi:10.2489/jswc.65.2.105

Evaluation of riparian forests established by the Conservation Reserve Enhancement Program (CREP) in Virginia

B.N. Bradburn, W.M. Aust, C.A. Dolloff, D. Cumbia, and J. Creighton

Abstract: Forested riparian buffer strips are recommended as an agricultural best management practice for protection of water quality and for wildlife habitat. Since the 1990s, federal and state conservation agencies in Virginia have been involved in establishment of riparian buffers under the auspices of programs, such as the Conservation Reserve Enhancement Program (CREP). Riparian buffers established by the CREP program are considered to be beneficial towards the protection of water quality. However, the benefit is based upon assumption that planted trees and shrubs survive and grow. Little evaluation has been done within the state to document the success of the establishment efforts. We evaluated 63 riparian planting sites located in the Coastal Plain, Piedmont, and Ridge and Valley physiographic provinces of Virginia. Overall, the riparian forests in the Coastal Plain and Piedmont were fully stocked due to a combination of planted and natural regeneration. Riparian forests in the Ridge and Valley region were inadequately stocked, and the region has problems with invasive, exotic species. Major recommendations for improving the success of future riparian restoration and establishment efforts are to (1) include the potential for natural regeneration when planning CREP plantings, (2) stop mechanized operations in the riparian buffers that reduce planted and natural regeneration (e.g., mowing and disking), (3) reduce herbivory (particularly cattle) within the riparian buffer, and (4) control invasive exotic species as necessary.

Key words: best management practices—natural regeneration—riparian buffers—water quality

Riparian forests, important for protection of water quality and wildlife habitat, are variously called riparian buffers, forest buffer strips, filter strips, riparian management zones, conservation strips, and stream-side management zones (Walbridge 1993; Castelle et al. 1994; Ilhardt et al. 2000; Verry et al. 2000; Lowrance et al. 2002). Riparian forests protect water quality by minimizing thermal pollution (Hewlett and Fortson 1982; Zwieniecki and Newton 1999), uptaking and storing nutrients (Peterjohn and Correll 1984), trapping sediment and sediment-attached nutrients and chemicals (Lowrance et al. 1984; Cooper et al. 1985; Daniels and Gilliam 1996; Snyder et al. 1998; Sheridan et al. 1999), transforming nutrients to non-polluting forms (Lowrance 1992; Young and Briggs 2007), and stabilizing streambanks (Ranganath et al. 2009). Riparian buffers enhance potential wildlife habitat and may provide diverse forested habitat in urban and agricultural settings, as well as in forested settings (Thurmond et al. 1995; Darveau et al. 2001). Riparian forests may provide woody debris that enhance the complexity of the stream channel morphology (McClure et al. 2004), as well as provide instream habitat for aquatic organisms (Potts and Anderson 1990).

Approximately 87% of the riparian forests in the eastern United States have been deforested, primarily for agricultural production (Allen et al. 2001). Within the Chesapeake Bay Region (Maryland, Pennsylvania, and Virginia), approximately 22% of the landscape is in agricultural production. Riparian forests have specifically been identified as one of the most important agricultural best management practices for protection of water quality in Chesapeake Bay (Lowrance et al. 1997). Over the past decade, numerous programs have been developed for restoration of these important riparian ecosystems on areas that were deforested for agricultural or urban activities (Allen et al. 2001; Lowrance et al. 2002). Excessive nutrients from livestock, sediment runoff from erodible soils, and runoff from chemical applications are all examples of potential contaminates from agricultural lands that can be reduced with riparian forests (Gianessi et al. 1985; Lowrance et al. 1997).

During the past decade, approximately 1,600 km (1,000 mi) of riparian forests have been restored by the Virginia Department of Forestry (VDOF) and the USDA Natural Resources Conservation Service on agricultural sites to protect and improve water quality and wildlife habitat. These riparian restoration efforts are expected to have a positive influence as the buffers develop, but few post-planting evaluations have been conducted. Literature regarding the effects of forest harvesting and stream recovery indicates that stream water quality in forested watersheds returns to initial conditions within three to eight years after forest operational disturbances as the vegetation and litter layer recover (Yoho 1980; Shepard 1994; Aust and Blinn 2004). However, forest successional patterns and rates are very different in agricultural environments. Natural succession patterns in abandoned old fields have been reported as taking between 15 to 60 years before natural regeneration becomes established (Oosting 1942; Pickett 1983). Therefore, artificial regeneration efforts are commonly used in riparian forest restoration initiatives to speed the recovery of ecosystem processes. Riparian restorations attempt to speed the recovery process as well as add species diversity (Allen 1997; Allen et al. 2001) that may be beneficial to wildlife species dependant on hard mast.

The establishment of riparian buffers has been identified as one of the most feasible and potentially effective agricultural best management practices for protection

Benjamin N. Bradburn is a graduate research assistant, and **W.M. Aust** is a professor in the Forest Resources and Environmental Conservation Department of the College of Natural Resources, Virginia Tech, Blacksburg, Virginia. **Charles A. Dolloff** is a project leader for the US Forestry Service Southern Research Station Coldwater Fisheries Research Unit, Virginia Tech, Blacksburg, Virginia. **Dean Cumbia** is the director of the Forest Resource Management Division, and **Jerre Creighton** is the research program manager in the Virginia Department of Forestry, Charlottesville, Virginia.

of water quality (Lowrance et al. 1997). Therefore, a variety of federal and state conservation programs have been developed to encourage farmers to reforest riparian zones. The VDOF, because of its expertise in planting forests, has been involved in hundreds of riparian restoration projects in agricultural settings. From 2004 through 2005, the VDOF established over 967 km (600 mi) of riparian forests, primarily as part of the Conservation Reserve Enhancement Program (CREP). However, the VDOF has little quantitative data to document the success of the riparian buffer restoration efforts. The goal of this project was to examine riparian buffer restoration plantings across the Coastal Plain, Piedmont, and Ridge and Valley regions of Virginia in order to document trends and make recommendations for future riparian restorations. We accomplished our goals by answering the following questions: (1) What species and stocking levels can be expected in CREP plantings in the different regions? (2) Is natural regeneration an important component? and (3) What are the major deterrents associated with sites having poor stocking?

Table 1

General characteristics of the one- to five-year-old Conservation Reserve Enhancement Program (CREP) sites evaluated by physiographic region.

Parameter	Coastal Plain*	Piedmont*	Ridge and Valley*
Average tract size (ha)	4.0	5.0	4.2
Average stand age (years)	2.25	2.6	3.2
Contractor planted (%)	94	100	100
Average planting density (stems ha^{-1})	403	272	279
Planting density range (stems ha^{-1})	272 to 1,087	272	272 to 477
Planting tubes used (%)	81.25	100	100
Planting mats used (%)	75	95.6	100
Site fenced (%)	12.5	78.2	92.3
Site mowed before planting (%)	6.25	8.7	3.8
Herbicides used before planting (%)	12.5	4.3	0

* Average value (ranges where appropriate).

Materials and Methods

Study Site Selection. The riparian buffer study sites were selected from the VDOF CREP database. Selections were random but stratified based on the total acreage planted in each physiographic region. Landowners were contacted to gain access to their properties. The VDOF personnel provided information from landowner files pertaining to the study sites. The files were examined for background information regarding planting density, species planted, contractor information, year planted, age of planted seedlings, site preparation treatments, competition control, establishment techniques (planting tubes, planting mats, fencing), and maps of the site locations. Some sites were rejected due to lack of information regarding initial planting density, site location, or landowner contact information. A total of 63 sites were selected: 16 in the Coastal Plain, 23 in the Piedmont, and 24 in the Ridge and Valley physiographic regions of Virginia.

Field Methods. Measured field data were based upon conversations with the USDA Natural Resources Conservation Service, VDOF, and planting contractor personnel who were experienced with CREP plantings. Field data for each riparian buffer were collected using circular subsample plots having fixed radii. The subsample plot size and radii were variable between sites and were dependent upon site and stand conditions; thus, subsample plots used in the study ranged from 1/2,500 ha (1/1,000 ac) to 1/25 ha (1/10 ac). For stands with thousands of stems per hectare, smaller subsample plot sizes were used, and for stands with less regeneration, larger subsample plot sizes were used. Our sampling protocol required a minimum of five subsamples and a maximum of fifteen subsamples for any given riparian buffer. This allowed us to characterize the large planting areas in a timely fashion. At each subsample location, herbaceous competition, condition of fences, presence of livestock, evidence of anthropogenic disturbances, evidence of herbivory, and evidence of pathogens were noted to identify potential deterrents. Individual tree data for both planted species and volunteer species were recorded for each subsample. Individual tree data consisted of recording the use of any planting aids (tubes, mats, or fencing), tree or shrub species, total tree height, and diameter at breast height. For analyses, all subsample data were converted to numbers per hectare. The individual tree data were intended to identify survival by species of planted trees and to determine the potential of natural regeneration for contributing to the riparian forests.

Statistical Analysis. These data were collected from 63 operational CREP sites and were not originally intended nor arranged to be part of a controlled experiment. We simply collected data from the 63 sites located across the three physiographic provinces in order to provide general statistics for CREP plantings, natural regeneration on the sites, and identification of major deterrents. Data collected in this study were organized by physiographic region. Response variables such as tree survival were converted to per hectare values and were analyzed by region using the Kruskal-Wallis (for medians) and one-way analysis of variance (ANOVA) (for means) procedures (Steel and Torrie 1980).

Results and Discussion

The general characteristics of the CREP stands evaluated by our project are provided in table 1. Overall, the riparian buffer general characteristics were uniform for all regions. Contractors planted nearly all sites; only 6% of the Coastal Plain was planted by VDOF personnel. Average planting densities were greater in the Coastal Plain than the two other regions, but 272 trees ha^{-1} (≈110 trees ac^{-1}) were found to be the minimum planting density for all regions. This was expected because it is a standard CREP planting guideline. Planting aides, such as planting tubes and planting mats, were used in all regions. Fencing was more common in the Piedmont (78.2%) and Ridge and Valley (92.3%) regions than in the Coastal Plain (12.5%), where more of the plantings were conducted on pasture as opposed to the agricultural fields.

The average density and survival for planted trees and the density for naturally regenerated trees are provided by physiographic region (table 2). Overall, the survival of planted trees was quite variable, and no significant differences were found between the median values in the Coastal Plain, Piedmont, and Ridge and Valley regions ($p < 0.53$). However, the evaluation of natural regeneration revealed that each region's median values were different ($p < 0.0001$). The Coastal Plain had the highest total regeneration density (8,805.8

Table 2
Average surviving trees* per hectare of both planted and volunteer for each physiographic region studied in Virginia.

Physiographic region	Descriptive statistics	Planted tree survival (%)	Planted tree density (stems ha^{-1})	Natural regeneration density (stems ha^{-1})	Planted and natural density (stems ha^{-1})
Coastal Plain	Mean	97.6	265.3	8,540.5	8,805.8
(*n* = 16)	Standard error	7.0	54.4	3,521.1	3,527.7
	Median	80.9ns	224.8ns	2,620.5a	3,136.9a
	95% lower CI	60.6	175.6	601.7	792.5
	95% upper CI	89.1	407.5	15,611.8	15,830.6
Piedmont	Mean	90.5	232.2	2,782.3	3,014.5
(*n* = 23)	Standard error	10.0	27.1	673.6	688.9
	Median	81.8ns	222.3ns	1,472.1b	1,610.4a
	95% lower CI	69.9	190.0	1,521.3	1,735.6
	95% upper CI	96.3	302.3	4,315.2	4,593.2
Ridge and Valley	Mean	68.4	198.2	380	578.2
(*n* = 26)	Standard error	8.4	21.7	153.0	155.7
	Median	65.4ns	179.1ns	302.6c	537.2b
	95% lower CI	51.0	118.5	297.8	483.8
	95% upper CI	85.9	244.5	928.1	1,125.1

Notes: ns = nonsignificant. CI = confidence interval.

* The planted species encountered in each region is represented on an average per hectare basis in table 2. Each species, based on their survival and frequency of appearance in each region, are ranked with the highest average trees per hectare being 1 and increasing in rank as the average decreases. Median values followed by different letters within a column are significantly different from one another at $\alpha < 0.10$.

Figure 1
Typical coastal plain Conservation Reserve Enhancement Program (CREP) site with abundant loblolly pine and sweetgum natural regeneration overtopping the willow oak seedling in the planting tube.

trees ha^{-1} [3,565.1 trees ac^{-1}]), followed by the Piedmont (3,014.5 stems ha^{-1} [1,220.4 stems ac^{-1}]) and then the Ridge and Valley (578.2 trees ha^{-1} [234.1 trees ac^{-1}]). Overall, natural regeneration dominated the Coastal Plain (8,540.5 stems ha^{-1} [3,457.7 stems ac^{-1}]) and Piedmont sites (2,782.3 trees ha^{-1} [1,126.4 trees ac^{-1}]) (table 2 and figure 1), and natural regeneration values were much lower for Ridge and Valley sites (380 stems ha^{-1} [153.8 stems ac^{-1}]) (figure 2).

We also found important species differences in both planted and naturally regenerated species within each region. The average regeneration densities by species for each region are provided in tables 3, 4, and 5. Twenty-one planted species and 21 naturally regenerated species were found on Coastal Plain sites (table 3). The Coastal Plain riparian buffers were dominated by natural regeneration, averaging 8,540.5 trees ha^{-1} (3,457.7 trees ac^{-1}) versus an average of 265.3 trees ha^{-1} (107.4 trees ac^{-1}) for the planted trees. The planted trees also reflected the tendency of the CREP program to preferentially plant later successional, mast-producing oak species. The top five planted species were various oak species (*Quercus* spp.). However, the natural regeneration followed the old-field succession pattern consisting of a mix of light seeded, early successional species including sweetgum, red maple, and loblolly pine (table 3). Five species were found in both planted and natural regeneration categories (red maple, American sycamore, yellow poplar, southern red oak, and green ash). Overall, the Coastal Plain sites have adequate regeneration to form a fully stocked forest, and the stands are comprised of a variety of species that are desirable for both protection of water quality and wildlife habitat.

The Piedmont riparian buffers had adequate regeneration, averaging 29 planted species (232.2 trees ha^{-1} [94.0 trees ac^{-1}]) and 40 naturally regenerated species (2,782.3 trees ha^{-1} [1,126.4 trees ac^{-1}]) (table 4). Again oak species dominated the top five planted species, and light-seeded species such as red maple, yellow poplar, boxelder, and green ash were the common naturally regenerated species. Eighteen species were found in both natural and planted groups.

Figure 2
Good survival of planted seedlings and almost no natural regeneration on a Ridge and Valley buffer site.

Table 3
Average density of one- to five-year-old trees and shrubs by species (planted and naturally regenerated) found in 16 Conservation Reserve Enhancement Program (CREP) plantings in the Coastal Plain physiographic province of Virginia. Species are in descending order of density, and species in bold were regenerated by both natural and artificial methods.

Artificial regeneration (planted) species	Artificial regeneration density (stems ha^{-1})	Natural regeneration species	Natural regeneration density (stems ha^{-1})
Quercus phellos (willow oak)	42.5	*Liquidambar styraciflua* (sweetgum)	3,477.0
Q. velutina (black oak)	42.5	***Acer rubrum* (red maple)**	2,760.7
Q. palustris (pin oak)	37.1	*Pinus taeda* (loblolly pine)	1,091.5
Q. alba (white oak)	30.9	*Juniperus virginiana* (eastern red cedar)	301.3
Q. michauxii (swamp chestnut oak)	26.2	*Rhus copallinum* (winged sumac)	294.7
Malus spp. (common apple)	11.6	*Baccharis salicifolia* (salt bush)	196.1
***Platanus occidentalis* (American *sycamore*)**	11.4	***Liriodendron tulipifera* (yellow poplar)**	160.8
Q. accutissima (sawtooth oak)	8.9	***Platanus occidentalis* (American sycamore)**	67.4
***Q. falcata* (southern red oak)**	8.6	*Prunus serotina* (black cherry)	47.7
Cornus sericea (red osier dogwood)	7.9	*Myrica cerifera* (wax myrtle)	45.2
Q. rubra (northern red oak)	6.9	*Betula nigra* (river birch)	41.2
Taxodium distichum (baldcypress)	5.9	***Q. falcata* (southern red oak)**	22.7
***Fraxinus pennsylvanica* (green ash)**	5.9	*Ulmus americana* (American elm)	13.6
Diospyros virginiana (common persimmon)	4.9	*Ilex opaca* (American holly)	13.6
C. racemosa (red panicle dogwood)	4.4	*Acer negundo* (boxelder)	11.4
Robinia pseudoacacia (black locust)	3.5	*Poncirus trifoliate* (trifoliate orange)	2.2
***Liriodendron tulipifera* (yellow poplar)**	2.2	*Q. nigra* (water oak)	2.2
Q. bicolor (swamp white oak)	1.5	***Fraxinus pennsylvanica* (green ash)**	1.2
Cercis Canadensis (eastern redbud)	1.5	*Crataegus spp.* (hawthorn)	1.2
Pyrus cornaria (sweet crab)	0.5	*Q. stellata* (post oak)	1.2
***Acer rubrum* (red maple)**	0.5	*Juglands nigra* (black walnut)	1.2
All species	265.3		8,540.5

Table 4

Average density of one- to five-year-old trees and shrubs by species (planted and naturally regenerated) found in 23 Conservation Reserve Enhancement Program (CREP) plantings in the Piedmont physiographic province of Virginia. Species are in descending order, and species in bold were regenerated by both natural and artificial methods.

Artificial regeneration (planted) species	Artificial regeneration density (stems ha^{-1})	Natural regeneration species	Natural regeneration density (stems ha^{-1})
***Quercus falcata* (southern red oak)**	37.5	***Acer rubrum* (red maple)**	653.3
Quercus palustrus (pin oak)	31.9	***Liriodendron tulipifera* (yellow poplar)**	477.9
Q. alba (white oak)	25.7	*Acer negundo* (boxelder)	470.2
***Q. phellos* (willow oak)**	24.9	***Fraxinus pennsylvanica* (green ash)**	392.5
Q. accutissima (sawtooth oak)	18.0	*Juniperus virginiana* (eastern red cedar)	188.5
***Fraxinus pennsylvanica* (green ash)**	15.3	*Alnus serrulata* (hazel alder)	96.6
Q. rubra (northern red oak)	15.1	*Symphoricarpus orbiculatus* (coralberry)	83.0
Taxodium distichum (baldcypress)	10.6	***Liquidambar styraciflua* (sweetgum)**	70.1
Juglands nigra (black walnut)	8.6	*Ulmus rubra* (slippery elm)	56.1
***Liriodendron tulipifera* (yellow poplar)**	6.4	*U. alata* (winged elm)	43.0
Q. bicolor (swamp white oak)	5.9	*Carya tomentosa* (mockernut hickery)	38.5
Fagus grandifolia (American beech)	5.2	***Prunus serotina* (black cherry)**	33.1
***Diospyros virginiana* (common persimmon)**	5.2	***Diospyros virginiana* (common persimmon)**	24.2
Alnus serrulata (hazel alder)	3.5	*Ailanthus altissima* (ailanthus)	21.7
Q. michauxii (swamp chestnut oak)	3.2	***Juglands nigra* (black walnut)**	21.7
***Cornus florida* (flowering dogwood)**	2.7	***Cersis canadensis* (eastern redbud)**	15.8
***Cephalanthus occidentalis* (buttonbush)**	2.5	*Robinia pseudoacacia* (black locust)	12.4
***Liquidambar styraciflua* (sweetgum)**	2.0	*Pinus virginiana* (Virginia pine)	10.8
***Morus rubra* (red mulberry)**	2.0	***Q. falcata* (southern red oak)**	9.6
***Prunus serotina* (black cherry)**	1.0	*Populus tremuloides* (quaking aspen)	9.4
***Q. velutina* (black oak)**	1.0	***Platanus occidentalis* (American sycamore)**	8.9
***Malus spp.* (crab apple)**	1.0	*Carya cordiformis* (bitterut hickory)	7.7
Pyrus cornaria (crab apple)	1.0	***Q. rubra* (northern red oak)**	7.7
***Acer rubrum* (red maple)**	1.0	*Pinus taeda* (loblolly pine)	5.4
***Platanus occidentalis* (American sycamore)**	0.2	*Rhus copallinum* (winged sumac)	5.4
Q. pagoda (cherrybark oak)	0.2	*Gleditsia triacanthos* (honey locust)	4.7
***Cersis canadensis* (eastern redbud)**	0.2	*Carpinus caroliniana* (iron wood)	4.7
***Betula nigra* (river birch)**	0.2	*Cephalanthus occidentalis* (buttonbush)	4.0
Populus heterophylla (swamp cottonwood)	0.2	***Q. phellos* (willow oak)**	2.5
		Salix nigra (black willow)	1.5
		Sassafras albidum (sassafras)	1.5
		***Cornus florida* (flowering dogwood)**	1.2
		Elaegnus umbellate (autumn olive)	0.7
		Corylus cornuta (American hazelnut)	0.7
		Q. prinus (chestnut oak)	0.7
		***Betula nigra* (river birch)**	0.7
		Hamamelis virginiana (witch hazel)	0.7
		***Q. velutina* (black oak)**	0.2
		***Malus spp.* (common apple)**	0.2
		***Morus rubra* (red mulberry)**	0.2
All species	232.2		2,782.3

Thirty-one planted species and 27 naturally regenerated species, having respective densities of 198.2 and 380.0 trees ha^{-1} (80.2 and 153.8 trees ac^{-1}) comprised the average make-up of the Ridge and Valley sites (table 5). The natural and artificial regeneration had 11 species in common. The Ridge and Valley sites are not well stocked with planted species, and the natural regeneration is insufficient. Perhaps more importantly, 43.5% of the natural regeneration is comprised of two exotic invasive species: ailanthus and autumn olive. Ailanthus is considered nondesirable due to negative effects on native species and invasive traits. Autumn olive is also considered to be a nonnative, invasive species, but it is sometimes planted for wildlife habitat purposes.

The identified and major regeneration deterrents for each riparian buffer are provided in table 6. Some deterrents were due

Table 5
Average density of one- to five-year-old trees and shrubs by species (planted and naturally regenerated) found in 26 Conservation Reserve Enhancement Program (CREP) plantings in the Ridge and Valley physiographic province of Virginia. Species are in descending order, and species in bold were regenerated by both natural and artificial methods.

Artificial regeneration (planted) species	Artificial regeneration density (stems ha^{-1})	Natural regeneration species	Natural regeneration density (stems ha^{-1})
Quercus alba (white oak)	56.1	*Ailanthis altissima* (ailanthus)	103.5
Q. rubra (northern red oak)	28.2	*Acer negundo* (boxelder)	87.9
Q. palustrus (pin oak)	22.2	*Elaeagnus umbellate* (autumn olive)	61.8
***Fraxinus pennsylvanica* (green ash)**	18.0	*Juniperus virginiana* (eastern red cedar)	45.9
Q. velutina (black oak)	13.3	***Acer rubrum* (red maple)**	14.3
Q. prinus (chestnut oak)	7.7	*Cornus sericea* (red-osier dogwood)	12.1
Taxodium distichum (baldcypress)	6.9	*Symphoricarpos orbiculatus* (coralberry)	10.6
***Q. phellos* (willow oak)**	6.7	***Fraxinus pennsylvanica* (green ash)**	10.6
Q. michauxii (swamp chestnut oak)	5.7	***Juglands nigra* (black walnut)**	4.2
***Pinus strobus* (white pine)**	4.4	*Cornus amomum* (silky dogwood)	4.2
***Acer rubrum* (red maple)**	4.0	***Pyrus coronaria* (sweet crab)**	3.7
Q. accutissima (sawtooth oak)	3.7	***Diospyros virginiana* (common persimmon)**	3.7
F. americana (white ash)	3.0	***Gleditsia triacanthos* (honey locust)**	3.5
***Juglands nigra* (black walnut)**	2.5	*Ulmus rubra* (slippery elm)	2.7
***Pyrus cornaria* (sweet crab)**	2.5	***C. florida* (flowering dogwood)**	2.5
Robinia pseudoacacia (black locust)	2.2	*Morus rubra* (red mulberry)	2.2
Diospyros virginiana (common persimmon)	2.2	*Carya cordiformis* (bitternut hickory)	1.5
P. echinata (shortleaf pine)	2.0	*Sassafras albidum* (sassafras)	1.5
***Malus spp.* (crab apple)**	2.0	***Malus spp.* (crab apple)**	0.7
Alnus serrulata (hazel alder)	0.7	*Acer saccharinum* (silver maple)	0.7
Liriodendron tulipifera (yellow poplar)	0.7	*Pinus virginiana* (Virginia pine)	0.7
Celtis occidentalis (hackberry)	0.5	*Crateagus spp.* (hawthorn)	0.5
Corylus cornuta (American hazelnut)	0.5	***P. strobus* (white pine)**	0.2
***Gleditsia triacanthos* (honey locust)**	0.5	*Paulownia tomentosa* (Paulownia)	0.2
Morus rubra (red mulberry)	0.5	*C. racemosa* (gray dogwood)	0.2
Betula nigra (river birch)	0.5	***Cersis canadensis* (eastern redbud)**	0.2
Prunus serotina (black cherry)	0.2	***Q. phellos* (willow oak)**	0.2
***Cornus florida* (flowering dogwood)**	0.2		
***Cersis canadensis* (eastern redbud)**	0.2		
Acer saccharum (sugar maple)	0.2		
Liquidambar styraciflua (sweetgum)	0.2		
All species	198.2		380.0

to natural causes, such as wet or rocky sites, herbaceous competition, and deer browsing. Other deterrents were due to specific farm management issues such as mowing, cattle, disking, and road construction activities within the riparian buffer (table 6). Mowing was often conducted by the landowners in order to control weeds and improve appearance of the riparian buffers, but these efforts actually reduced survival of planted species and in some instances almost totally eliminated natural regeneration. Three sites had roads that were built through the CREP planting after planting, and four tracts had opened gates to allow cattle to graze within the riparian buffer. One owner had disked between the planted trees and planted wheat, and the disking sheared regeneration and tree roots. Another important identified problem was invasive exotic species in the Ridge and Valley, particularly ailanthus and autumn olive, as previous noted in table 5. When we summed the deterrents for the sites, we found that the Coastal Plain, Piedmont, and Ridge and Valley regions had more than one problem that affected regeneration on approximately 31%, 39%, and 77% of the sites, respectively (table 6).

Based on planted tree survival, the CREP plantings were more effective for reestablishment of riparian forests in the Coastal Plain and Piedmont regions. In both of these regions, planted tree survival is above 90%. Natural regeneration is more abundant than artificial regeneration for all regions. The ratios of natural:artificial regeneration for the Coastal Plain, Piedmont, and Ridge and Valley regions were 32:1, 12:1, and 2:1, respectively. Both the natural and artificial regeneration species are capable of providing water quality protection. The CREP plantings are providing species that have additional wildlife benefits (e.g., oak species) in stands that have little hard mast species. Similar to our findings, research on bottomland hardwood restoration efforts indicates it is common to plant oak species with the assumption that natural regeneration of additional species

Table 6

Major regeneration deterrents on 65 Conservation Reserve Enhancement Program (CREP) plantings by physiographic region. Regeneration deterrents were defined as less than 50% survival of planted trees and/or fewer than 1,000 trees ha^{-1}.

Identified problem	Coastal Plain (%)	Piedmont (%)	Ridge and Valley (%)	All regions (%)
Mowed	6.25	13.04	15.38	12.30
Cattle	6.25	8.70	3.85	6.15
Road	—	4.35	7.69	4.62
Disk	6.25	—	—	1.53
Invasive spp.	—	4.35	30.77	13.85
Deer	—	8.70	11.53	7.69
Rocky site	—	—	3.85	1.53
Wet site	6.25	—	—	1.53
Herbaceous competition	6.25	4.35	11.53	9.23
All deterrents	31.25	39.13*	76.9*	52.31*

Note: — shows that this problem was not found at the indicated site.

* Sites having multiple deterrents were only counted once so column totals may not agree with individual percentages.

will supplement the diversity and stocking (Allen 1997). We found that the CREP plantings in the Coastal Plain and Piedmont regions are contributing additional species that could enhance water quality protection. The natural regeneration is more abundant than the artificial regeneration. If water quality, rather than species diversity and wildlife habitat, is a more important goal, then fencing followed by minimum site preparation (e.g., disking for seed bed preparation), could be recommended for establishing adequately stocked riparian buffers in the Coastal Plain and Piedmont regions. Research on other restoration sites indicates that seed sources within 60 m (≈197 ft) of the riparian buffer can provide natural regeneration (Allen 1997).

The CREP riparian buffers in the Ridge and Valley are not as well stocked as they are in the other two regions. The overall survival of planted species is low (68.4%), and the natural regeneration is also low (380 stems ha^{-1} [153.8 stems ac^{-1}]). The inadequate natural regeneration is due to a combination of deterrents, including management (mowing, grazing, etc.) and a lack of nearby natural regeneration seed sources. We suspect the primary problem is due to the herbaceous competition combined with the competition of invasive, exotic woody species, which was found on 42.3% of the sites in the ridge and valley (table 6). Although the invasive exotic species are potentially having some positive effects on water quality and wildlife habitat, their presence is reducing the overall potential for natural regeneration of more desirable species on these sites. Therefore, we suggest that mechanical and/or chemical controls appropriate to the site and nondesired species be considered. Herbivory control, increased planting densities, and periodic fence inspections would be beneficial for problem regeneration sites. Other researchers have reached similar conclusions and recommended livestock exclusion and herbivory control (Opperman and Merenlender 2000; Sweeney et al. 2002; Ranganath et al. 2009). For future sites having potential regeneration deterrents, such as we found in the Ridge and Valley buffers, we suggest that the current minimum planting density of 272 trees ha^{-1} (≈110 trees ac^{-1}) should be increased to at least 1,000 trees ha^{-1} (≈400 trees ac^{-1}). These recommendations are also in agreement with previous CREP research (Sweeney et al. 2002).

Summary and Conclusions

Our overall summary regarding our original research questions are as follows:

1. What species and stocking levels can be expected in CREP plantings in the different regions? Across all three regions, we identified 21, 29, and 31 species of artificial trees and shrubs planted in the Coastal Plain, Piedmont, and Ridge and Valley, respectively. The planted trees have >90% survival in the Coastal Plain and Piedmont and <70% in the Ridge and Valley. Oak species were preferentially planted. Stocking was in excess of 1,000 stems ha^{-1}(≈400 stems ac^{-1}). in the Coastal Plain and Piedmont but was less than 1,000 stems ha^{-1} in the Ridge and Valley.
2. Is natural regeneration an important component? The overall success of the riparian restorations will be greatly influenced by natural regeneration, which was dominated by light seeded, early successional species in the Coastal Plain and Piedmont. The Ridge and Valley had natural regeneration that was dominated by ailanthus and autumn olive, two nondesirable exotic invasive species.
3. What are the major deterrents associated with sites having poor stocking? Major deterrents encountered on the sites included anthropogenic management issues (24.6%) (e.g., mowing, disking, roads, and cattle), deer herbivory (7.69%), invasive species (13.85%), rocky or wet sites (3.06%), and herbicide competition (9.23%). For sites having regeneration deterrents, primarily Ridge and Valley sites, competition and invasive species were the most serious deterrents.

Based upon our answers to the research questions, we have made the following recommendations for management:

1. Where adequate natural seed sources exist within 60 m (≈197 ft) of the buffer, fence the riparian buffer and rely on natural regeneration. This management option may provide less desirable species for wildlife habitat in the short term, but funds saved on these sites could be expended on additional areas or problem sites.
2. Periodic inspections of the riparian buffers should be conducted in order to observe and correct deterrents with mowing, cattle, roads, competition, or other problems.
3. Landowners should be made aware that a riparian buffer with weeds and natural regeneration may be more desirable for water quality than a maintained riparian buffer where mowing occurs.
4. Species lists of desirable riparian species should be expanded. We examined numerous stands where nonlisted species were clearly more suitable to existing site conditions than the planted species. For example, in the Coastal Plain region, loblolly pine, sweetgum, and red maple were abundant and faster growing than planted species. A mixed pine-hardwood stand provides water quality protection and wildlife habitat.
5. On problem sites, such as those in the Ridge and Valley region, we suggest that

exotic, invasive species be aggressively controlled with methods compatible with water quality concerns. We believe that careful use of labeled herbicides will improve stocking and actually promote more desirable species for both water quality and wildlife habitat.

6. On sites with inadequate seed sources and regeneration deterrents, such as those in the Ridge and Valley region, we suggest that planting densities be increased. A minimum planting density of 1,000 trees ha^{-1} (≈400 trees ac^{-1}) is recommended.

Acknowledgements

We wish to acknowledge the financial and logistical support of the Virginia Department of Forestry, USDA Forest Service, USDA Natural Resources Conservation Service, and Virginia Polytechnic Institute and State University.

References

Allen, J.A. 1997. Reforestation of bottomland hardwoods and the issue of woody species diversity. Restoration Ecology 5(2):125-134.

Allen, J.A., B.D. Keeland, J.A. Stanturf, A.F. Clewell, and H.E. Kennedy. 2001. A Guide to Bottomland Hardwood Restoration. Joint Publication of the USDI US Geological Survey (Informations and Technology Report USGS/BRD/ITR-2000-0011 and US Forest Service (General Technical report SRS-40).

Aust, W.M., and C.R. Blinn. 2004. Forestry best management practices for timber harvesting and site preparation in the eastern United States: An overview of water quality and productivity research during the past 20 years (1982-2002). Water, Air, and Soil Pollution Focus 4:5-36.

Castelle, A.J., A.W. Johnson, and C. Conolly. 1994. Wetland and stream buffer size requirements - a review. Journal of Environmental Quality 23(5):878-882.

Cooper, J.R., J.W. Gilliam, R.B. Daniels, and W.P. Robarge. 1985. Riparian areas as filters for agricultural sediment. Soil Science Society of America Journal 51:416-420.

Daniels, R.B., and J.W. Gilliam. 1996. Sediment and chemical load reduction by grass and riparian buffers. Soil Science Society of America Journal 60:246-251.

Darveau, M., P. Labbe, P. Beauchesne, L. Belanger, and J. Huot. 2001. The use of riparian forest strips by small mammals in a boreal balsam fir forest. Forest Ecology and Management 143:95-104.

Gianessi, L.P., H.M. Peskin, and C.A. Puffer. 1985. A National Data Base of Nonurban Nonpoint Source Discharges and their Effect on the Nation's Water Quality. Report submitted to the Office of Standards and Regulations of The U.S. Environmental Protection Agency. Washington DC: Renewable Resources Division, Resources for the Future.

Hewlett, J.D., and J.C. Fortson. 1982. Stream temperature under an inadequate buffer strip in the southeast piedmont. Water Resources Bulletin 18(6):983-988.

Ilhardt, B.L., E.S. Verry, and B.J. Palik. 2000. Defining riparian areas. *In* Riparian Management in Forests of the Continental Eastern United States, ed. E.S. Verry, J.W. Hornbeck, and C.A. Dolloff, 23-42. Boca Raton, FL: Lewis Publishers.

Lowrance, R. 1992. Groundwater nitrate and denitrification in a coastal plain riparian forest. Journal of Environmental Quality 21(3):401-405.

Lowrance, R., L.S. Altier, J.D. Newbold, R.S. Schnabel, P.M. Groffman, J.D. Denver, D.L. Correll, J. Wendell Gilliam, J.L. Robinson, R.B. Brinsfield, K.W. Staver, W. Lucas, and A.H. Todd. 1997. Water quality functions of riparian forest buffers in Chesapeake Bay watersheds. Environmental Management 21(5):687-712.

Lowrance, R., S. Dabney, and R. Shultz. 2002. Improving water and soil quality with conservation buffers. Journal of Soil and Water Conservation 57(2):26-43.

Lowrance, R., R. Todd, J. Fail, Jr., O. Hendrickson, R. Leonard, and L. Asmussen. 1984. Riparian forests as nutrient filters in agricultural watersheds. Bioscience 34:374-377.

McClure, J.M., R.R. Kolka, and A. White. 2004. Effect of forest harvesting best management practices on coarse woody debris distribution in stream and riparian zones in three Appalachian watersheds. Water, Air, and Soil Pollution Focus 4:245-261.

Oosting, H.J. 1942. An ecological analysis of the plant communities of Piedmont, North Carolina. American Midland Naturalist 28:1-126.

Opperman, J.J., and A.M. Merenlender. 2000. Deer herbivory as an ecological constraint to restoration of degraded riparian corridors. Restoration Ecology 8(1):41-47.

Peterjohn, W.T., and D.L. Correll. 1984. Nutrient dynamics in an agricultural watershed: Observations on the role of a riparian forest. Ecology 65(5):1466-1475.

Pickett, S.T.A. 1983. The absence of an Andropogon stage in old-field succession at the Hutcheson Memorial Forest. Bulletin of the Torrey Botanical Club 110(4):533-535.

Potts, D.F., and B.K.M Anderson. 1990. Organic debris and the management of small stream channels. Western Journal of Applied Forestry 5(1):25-28.

Ranganath, S.C., W.C. Hession, and T.M. Wynn. 2009. Livestock exclusion influences on riparian vegetation, channel morphology, and benthic macroinvertebrate assemblages. Journal of Soil and Water Conservation 64(1):33-41, doi:10.2489/jswc.64.1.33.

Shepard, J.P. 1994. Effects of forest management on surface water quality in wetland forests. Wetlands 14:18-26.

Sheridan, J.M., R. Lowrance, and D.D. Bosch. 1999. Management effects on runoff and sediment transport in riparian forest buffers. Transactions of the American Society of Agricultural Engineers 42(1):55-64.

Snyder, N.J., S. Mostaghimi, D.F. Berry, R.B. Reneau, S. Hong, P.W. McClellan, and E.P. Smith. 1998. Impact of riparian forest buffers on agricultural nonpoint source pollution. Journal of the American Water Resources Association 34(2):385-395.

Steel, R.G.D., and J.H. Torrie. 1980. Principles and Procedures of Statistics: A Biometrical Approach. 2nd edition. New York: McGraw Hill.

Sweeney, B.W., S.J. Czapka, and T. Yerkes. 2002. Riparian forest restoration: Increasing success by reducing plant competition and herbivory. Restoration Ecology 10(2):392-400.

Thurmond, D.P., K.V. Miller, and T.G. Harris. 1995. Effect of streamside management zone width on avifauna communities. Southern Journal of Applied Forestry 19(4):166-169.

Verry, E.S., J.W. Hornbeck, and C.A. Dolloff, ed. 2000. Riparian Management in Forests of the Continental Eastern United States. New York: Lewis Publishers.

Walbridge, M.R. 1993. Functions and values of forested wetlands in the southern United States. Journal of Forestry 91(5):15-19.

Yoho, N.S. 1980. Forest management and sediment production in the South - a review. Southern Journal of Applied Forestry 4(1):27-35.

Young, E.O., and R.D. Briggs. 2007. Nitrogen dynamics among cropland and riparian buffers: Soil-landscape influences. Journal of Environmental Quality 36(3):801-814.

Zwieniecki, M.A., and M. Newton. 1999. Influence of streamside cover and stream features on temperature trends in forested streams of western Oregon. Western Journal of Applied Forestry 14(2):106-113.