Function, Design, and Establishment of Riparian Forest Buffers: A Review

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(ABSTRACT)

Through the interaction of their soils, hydrology, and biotic communities, riparian forests protect and improve water quality, provide habitat for plants and animals, support aquatic communities, and provide many benefits to humans. Virginia, along with other states in the Chesapeake Bay region, has recognized the importance of riparian forests by implementing a plan to restore forested buffers along streams, rivers, and lakes. This project reviews selected literature on riparian forest buffers, including water quality functions, benefits to fish and wildlife, and human benefits. The review also discusses riparian buffer restoration and some of the costs and barriers associated with riparian forest buffer establishment. Information on financial and technical assistance programs available to Virginia landowners is included.

KEYWORDS: riparian forest, water quality, aquatic communities, wildlife, recreation, aesthetics, community benefits, restoration, alternative income, cost-share, technical assistance

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Chapter 1

Riparian Forest Buffers: An Overview

The Commonwealth of Virginia has over 50,000 miles of streams, 248 publicly owned lakes, and almost 2,500 miles of coastal estuary. These waters play an important role in industry, transportation, and agriculture, and provide Virginia's citizens with a place to relax and enjoy the out-of-doors. They are a source of fresh drinking water and are home to many of the state's plants and animals. Unfortunately, human activities within and around the stream have often led to a loss of water quality and the destruction of habitat for fish and wildlife. As a result, 48% of Virginia's streams, 6% of Virginia's lakes and 71% of Virginia's estuaries are now considered threatened or impaired by some form of pollution. Over the past two decades, scientists at Virginia Tech, around the U.S., and in other parts of the world have begun to recognize the important role that riparian areas play in maintaining healthy surface waters.

The *riparian area* is that area of land located immediately adjacent to streams, lakes, or other surface waters. Some would describe it as the floodplain. The boundary of the riparian area and the adjoining uplands is gradual and not always well defined. However, riparian areas differ from the uplands because of high levels of soil moisture, frequent flooding, and the unique assemblage of plant and animal communities found there. Through the interaction of their soils, hydrology, and biotic communities, riparian forests maintain many important ecological functions.

Riparian Ecosystem:

> "a complex assemblage of plants and other organisms in an environment adjacent to and near flowing water. Without definitive boundaries, it may include streambanks, floodplains, and wetlands as well as sub-irrigated sites forming a transitional zone between upland and aquatic. Mainly linear in shape and extent, they are characterized by laterally flowing water that rises and falls at least once within a growing season" .
>
> (Lowrance, Leonard, and Sheridan 1985)

Water quality. One of the most important functions of riparian forests is to protect water quality by reducing the amount of sediment, nutrients and other pollutants that enter streams, lakes and other surface waters. This occurs as contaminants are buried in sediments, taken up by riparian vegetation, adsorbed onto clay and organic particles, immobilized or denitrified by soil microorganisms, and other processes.

Riparian forests also provide important physical protection for the stream. Plants protect the surface of the soil from wind and water erosion, stabilize streambanks, and modify temperature, light and humidity within the riparian area and the stream itself. The vegetation slows the force of stormwater runoff and allows time for the water to infiltrate the soil and for sediments to drop out. Within the soil, plants create small zones of aeration where oxygen diffuses from their roots, providing important places for microbial metabolism.

Living resources. Rich soils, regular inputs of nutrients, and availability of water contribute to high productivity and diversity of vegetation within the riparian area. The diversity and productivity of the riparian plant community and its proximity to water make these areas especially attractive for many species of wildlife. Some animals are permanent residents, while others visit the area to feed or find water. Because of their linear shape, riparian forests can also provide protected travel lanes for wildlife to travel from one area to another.

Just as riparian forests are important to terrestrial wildlife, they are critical components of the aquatic community. In headwater streams, riparian forests provide nearly all of the food for the aquatic community by dropping leaves, branches, insects, and other materials into the stream. The forest also contributes the most critical component of the stream's physical structure - large woody debris. Within the stream, woody debris provides cover and creates areas for resting, hiding, and reproduction. In addition to providing food and habitat for the aquatic community, riparian forests are important for the role they play in influencing stream chemistry and temperatures.

Social and community benefits. Riparian forests provide many important benefits to humans. Their pleasing combination of land, water, vegetation, and wildlife draw us as a place to relax and observe nature. These areas are attractive for many recreational pursuits, like swimming, boating, fishing, hunting, hiking, and nature observation. Riparian forests can also provide important benefits to communities, as they moderate the impacts of flood waters, improve water quality, and reduce sedimentation into streams and reservoirs.

Virginia's Riparian Buffer Implementation Plan

In October 1996 members of the Chesapeake Executive Council, including the governor of Virginia, recognized the role that riparian forests play in benefiting stream water quality and living resources and adopted what is known as the Riparian Forest Buffer Initiative. In doing so, council members agreed to work to preserve, protect, and enhance existing forested buffers and to plant an additional 2010 miles of streamside buffers in the Chesapeake Bay Watershed by the year 2010. Virginia's commitment to that goal is to restore 610 miles of riparian forest buffer.

In 1998 the Commonwealth of Virginia expanded the effort statewide by adopting the Virginia Riparian Buffer Implementation Plan. The goal of the Plan is to continue to restore the quality of Virginia's streams and lakes by ensuring that all streams and shorelines in the Commonwealth will be protected by a riparian buffer. To meet that objective, the agencies of the Commonwealth have agreed to work with individuals and communities in their efforts to restore streamside lands. They are increasing their efforts to provide education, technical assistance and funding to Virginia's landowners.

Riparian Forest Buffer

"A permanent area of trees, usually accompanied by shrubs and other vegetation, that is adjacent to a body of water and is managed to maintain the integrity of the stream channels and shorelines; to reduce the impact of upland sources of pollution by trapping filtering, and converting sediments, nutrients, and other chemicals; and to supply food, cover, and thermal protection to fish and other wildlife"

Virginia Riparian Buffer Implementation Plan

Join the effort

If you are the owner of riparian lands, or live in a community that borders a stream, you can join in the effort to restore Virginia's streamside forests. Probably the best place to start is to contact your local Soil and Water Conservation District, county forester, wildlife biologist, or local extension office. Let them know that you have riparian lands that you wish to restore, or that you would like to volunteer to help restore community areas. Or, you can fill out the attached "Count Me In" sign-up sheet and return it to the Virginia Department of Forestry.

For more information:

Division of Soil and Water Conservation Districts
203 Governor St. Suite 206
Richmond, VA 23219
(804) 786-2064

U.S. Army Corps of Engineers
803 Front St.
Norfolk, VA 23510
(757) 441-7652

U.S. Department of Agriculture
Natural Resource Conservation Service
1606 Santa Rosa Rd.
Richmond, Virginia 23229
(804) 287-1668

U.S. Fish and Wildlife Service
P.O. Box 99
Gloucester, VA 23061
(804) 693-6694 x124

Virginia Department of Conservation and Recreation
203 Governor Street, Suite 206
Richmond, VA 23219
(804) 371-7486

Virginia Department of Forestry
P.O. Box 3758
Charlottesville, VA 22903
(804)977-6555

Virginia Department of Game and Inland Fisheries
P.O. Box 11104
Richmond, VA 23230
(804) 367-1000

Virginia Polytechnic Institute & State University
College of Forestry & Wildlife Resources
324 Cheatham Hall
Blacksburg, VA 24061
(540) 231-7664

COUNT ME IN!

Virginia Riparian Forest Buffer Sign-up Sheet

Interested in helping Virginia conserve and restore 610 miles of riparian forest buffers? We need your active participation to achieve this ambitious goal. Sign up now and let us know where and how you or your group wants to help.

Group Name ______________________________
Contact Person ______________________________
Address ______________________________
Telephone (___) ____________ Fax (_____) ____________
E-Mail ______________________________

I/we are interested in helping with:

ACTION	TIME FRAME
1.	
2.	
3.	
4.	
5.	

I/we need:

SUPPORT	INFORMATION	PARTNERS

Please contact us with more information: ❑ **Yes**

RETURN TO: Mike Foreman, Virginia Department of Forestry
P.O. Box 3758, Charlottesville, VA 22903-0758
Phone (804) 977-6555
Fax: (804) 296-2369

Chapter 2

Water Quality

Today, over a third of the streams, lakes, and estuaries in the United States are impaired by some form of water pollution (US EPA 1998). While many pollutants enter surface waters from *point sources* of pollution, such as industrial discharges and water treatment plants, most pollutants result from *nonpoint source* pollution activities, including runoff from agricultural lands, urban areas, construction and industrial sites, and leaky septic tanks. These activities introduce excessive sediment, nutrients, bacteria, organic wastes, chemicals, and metals into surface waters. Damage to streams, lakes and estuaries from nonpoint source pollution was estimated to be about $7-9 billion a year in the mid-1980s (Ribaudo 1986).

One of the most important functions of riparian areas is to protect water quality by reducing the amount of sediment, nutrients and other pollutants that enter streams and lakes. Riparian forest buffers influence water quality as contaminants are adsorbed onto soil particles, incorporated into plant tissues, or modified by soil organisms.

Effects of riparian forest buffers on sediment, nutrients, and other primary pollutants

Sediment

Sediment refers to soil particles that enter streams, lakes, and other bodies of water from eroding land, including plowed fields, construction sites, logging sites, urban areas, and eroding stream banks (US EPA 1995). Sedimentation of streams can have a pronounced effect on water quality and stream organisms. Sediment can clog and abrade fish gills, suffocate fish eggs and aquatic insect larvae, and cause fish to modify their feeding and reproductive behaviors. Sediment also interferes with recreational activities as it reduces water clarity and fills in waterbodies. In addition to mineral soil particles, eroding sediments may also carry other substances that can cause water quality problems, such as plant and animal wastes, nutrients, pesticides, petroleum products, metals, and other compounds (Clark 1985, Neary et al. 1988).

Riparian vegetation can be very effective at removing sediment. Water quality is improved through the direct removal of sediments from runoff, as well as the nutrients, pesticides, metals, and other contaminants that are often bound to the sediments (Johnston et al. 1984). Studies on forest and grass riparian buffers indicate that both can be efficient sediment traps. For example:

- Researchers in Blacksburg, Virginia found that orchard grass filter strips 30 feet wide removed 84% of the sediment and soluble solids from surface runoff, while grass strips 15 feet wide reduced sediment loads by 70% (Dillaha et al. 1989).
- In the Coastal Plain of Maryland, KY31 fescue filter strips 15 feet wide reduced sediment losses from croplands by two-thirds (Magette et al. 1989).
- In North Carolina, scientists estimated that 84-90% of the sediment that flowed from cultivated agricultural fields was trapped in an adjoining deciduous hardwood riparian area (Cooper et al. 1987). Sand was deposited along the edge of the riparian forest, while silt and clay were deposited further in the forest.
- Along the Little River in Georgia, scientists found that a riparian forest had accumulated

311,600 to 471,900 pounds per acre of sediment annually over the last 100 years (Lowrance et al. 1986).

- Researchers in the Piedmont of North Carolina found that grass and grass-forest filter strips were equally effective in removing sediments, reducing loads from 60-90% (Daniels and Gilliam 1996).

However, researchers have observed that the effectiveness of grass filter strips may decrease over time as the strip becomes inundated with sediment or as the ground becomes saturated with runoff. For example, in an experiment at Virginia Tech, Dillaha et al. (1989) demonstrated that a filter strip which initially removed 90% of the sediment was removing only 5% of the sediment after six trials. Buffers may be most effective at removing large particles such as sand, but may be less effective at removing small clay particles. In Arizona researchers found that sand particles could be removed by grass buffers within a fairly short distance from the field edge (as little as 10 feet), while the removal of silt particles required a buffer of 50 feet (Wilson 1967). Filter strips 300 to 400 feet wide were required to remove clay particles.

Many factors influence the ability of the buffer to remove sediments from land runoff, including the sediment size and loads, slope, the type and density of riparian vegetation, the presence or absence of a surface litter layer, soil structure, subsurface drainage patterns, and the frequency and force of storm events (Osborne and Kovacic 1993). Riparian buffers must be properly constructed and regularly monitored in order to maintain their effectiveness (Dillaha et al. 1989). Probably the most important consideration is the maintenance of shallow sheet flow into and across the buffer. Where concentrated flow paths begin to form or deep sediments begin to accumulate, the buffer can no longer maintain its filtering ability. Maintaining shallow sheet flow into the buffer can be especially troublesome in the Valley and Ridge region of Virginia and some areas of the Piedmont, where slopes are steep and surface flows tend to concentrate.

Nutrients

Nutrients are essential elements for aquatic ecosystems, but in excess amounts, they can lead to many changes in the aquatic environment and reduce the quality of water for human uses (Dupont 1992). Some nutrient inputs into surface waters are entirely natural, such as nutrients contained in plant materials or naturally eroding soils (Clark et al. 1985a). However, most nutrients in surface waters today result from human activities. Lawn and crop fertilizers, sewage, and manure are major sources of nutrients in surface waters (US EPA 1995). Industrial sources and atmospheric deposition also contribute significant amounts of nutrients (Guldin 1989).

Nationwide, agricultural lands are the primary source of nutrient inputs into streams, contributing nearly 70% of the total loads of nitrogen (almost 7 million tons) and phosphorus (3 million tons) each year (Chesters and Schierow 1985). On a per acre basis, intensive livestock operations (such as feedlots) release more nutrients into the environment than any other agricultural activity (Beaulac and Reckhow 1982). Row crops, small grains, and pasture contribute lesser amounts on a per acre basis, but more land is devoted to these uses.

Nutrients can enter surface waters in surface flows (as a dissolved form or attached to soil particles) or in subsurface flows (Gilliam et al. 1997). For example, nitrogen is most commonly transported as dissolved nitrogen through subsurface flows, with peak nitrate levels occurring during the dormant season after crops have been harvested and soil evaporation rates are reduced.

In contrast, phosphorus most often enters the stream attached to soil particles or in organic materials in surface runoff after storm events (Pionke et al. 1995).

Probably the most significant impact of nutrients on streams is *eutrophication*, the excessive growth of algae and other aquatic plants in response to high levels of nutrient enrichment (US EPA 1995). When plant growth becomes excessive, the water body may become depleted of oxygen and choked with large unsightly mats of algae and decaying organic matter, resulting in water with an undesirable color, taste, and odor. Eutrophication can affect the stream's ability to support aquatic and other organisms, interfere with water treatment, and diminish the recreational and aesthetic values of the area. Some algae may also form toxins which are directly harmful to aquatic organisms and humans.

In addition, some forms of nutrients can be directly toxic to humans and other animals (Chen et al. 1994, Evanylo 1994). For example, nitrates can induce methemoglobinemia (a reduction in the oxygen-carrying capacity of the blood) in infants and may be linked to an increased risk of birth defects and stomach cancer in adults (Hall and Risser 1993). Nitrate contaminated water can also be a problem for livestock when it adds to high nitrate concentrations already present in feeds. Chronic nitrate poisoning in cattle has been shown to produce a number of physical ailments, including anorexia, vasodilation, lowered blood pressure, abortion, reduced lactation and other reproductive problems (Johnson et al. 1994a).

Riparian forests have been found to be effective filters for nutrients, including nitrogen, phosphorus, calcium, potassium, sulfur, and magnesium (Lowrance et al. 1984a, 1984b). Because excessive levels of nitrogen and phosphorus are of particular concern in the nation's streams and lakes, the ability of riparian buffers to filter these nutrients has been the focus of much research.

- Nitrogen. Riparian forests have been reported by many scientists to remove nitrogen from agricultural runoff. For example:

- Researchers at the USDA-ARS in Tifton, Georgia, have maintained studies since the early 1980s, where deciduous forest buffers have reduced nitrogen from agricultural runoff by 68% (Lowrance et al. 1984b).
- On the western shore of the Chesapeake Bay in Maryland, scientists estimated a riparian buffer removed 89% of the nitrogen from field runoff, mostly in the first 62 feet of the buffer (Peterjohn and Correll 1984).
- On Maryland's Eastern shore, scientists found riparian buffers removed 53 pounds of nitrogen per acre per year from agricultural runoff (Jordan et al. 1993).
- Recent studies in the Nomini Creek watershed northeast of Richmond, Virginia demonstrated that forested riparian buffers could reduce concentrations of nitrate-nitrogen in runoff from croplands by 48% (Snyder et al. 1995).

Other studies, including research in Iowa, Wisconsin, New England, and New Zealand, have confirmed the role of forested buffers in removing nitrogen and nitrate (NO_3) from agricultural runoff. However, these studies have also shown that not all areas of the buffer function equally in reducing nitrogen levels. For example, researchers in Wisconsin found that nitrogen levels were reduced most in areas of the riparian forest that were frequently flooded; nitrogen levels remained high in drier areas of the buffer (Johnston et al. 1984). Scientists in New England found a similar pattern - where the water table was within 20" of the soil surface, nitrate removal rates were as much as 70% higher than where drier soils occurred (Gold and Groffman 1995). They also found that the nitrate removal capacity of a riparian buffer remains high even during the winter months - in fact, the highest rates of nitrate removal occurred during the dormant season, when there was maximum leaching of nitrate from agricultural fields. Furthermore, their studies showed that the availability of carbon was a limiting factor in nitrate reduction. Likewise, in New Zealand, Cooper (1990) found that where subsurface flows of water moved through organic soils before entering streams, levels of nitrates were reduced by as much as 100%. However, mineral soils located along the same streams exhibited little capacity to decrease nitrogen. These soils showed corresponding low levels of denitrifying bacteria and low levels of available carbon. Recent studies in the Nomini Creek watershed near Richmond, Virginia demonstrated that nitrate reduction is greatest in riparian forests with a high water table and high organic soils (Snyder et al. 1995). Associated laboratory tests showed that denitrification rates were as much as ten times greater in muck soils (16% organic matter) than in soils containing only 1.5% organic matter.

These and other studies support the hypothesis that the primary mechanism for nitrate removal by riparian forests is *denitrification*. Denitrification is a process whereby nitrogen in the form of nitrate (NO_3) is converted to gaseous N_2O and N_2 and released into the atmosphere (Gilliam 1994). In order for denitrification to occur, certain conditions must be present: 1) the water table is close to the soil surface; 2) there are alternating periods of aerobic and anaerobic conditions; 3) there are healthy populations of denitrifying bacteria; and 4) there are sufficient amounts of available organic carbon (Lowrance et al. 1985, 1997). Denitrification offers an important means for the permanent removal of excess nitrogen from the riparian area, because during the process, nitrates are converted to nitrogen gas and released to the atmosphere.

Other mechanisms for nitrate removal include uptake by vegetation and soil microbes and retention in riparian soils (Beare et al.1994, Evanylo 1994). Plants can take up large quantities of nitrogen as they manufacture roots, leaves, and stems. However, much of this is returned to the soil as plant materials decay. For example, scientists in Maryland estimated that deciduous riparian forests took up 69 pounds of nitrogen per acre annually, but returned 55 pounds each year in the litter (Peterjohn and Correll 1984). In North Carolina, researchers estimated that only 3%-6% of the nitrogen passing through an alluvial swamp forest was taken up and stored in woody plant tissues (Brinson et al. 1984). Nevertheless, Correll (1997) has suggested that vegetative uptake is an important mechanism for the removal of nitrate from riparian systems, since vegetation (especially trees) removes nitrates from deep in the ground, converts the nitrate to organic nitrogen in plant tissues, then deposits the plant materials on the surface of the ground where the nitrogen can be mineralized and denitrified. Likewise, soil microbes can take up nutrients and store them until the microbes die, at which time the nutrients are released in a mineralized form that is less biologically available and more readily stored in the soil (Palone and Todd 1997).

Grass buffers may also reduce nitrogen levels from agricultural runoff. For example, scientists in the Piedmont of North Carolina found that both grass and grass/forest riparian buffers reduced total nitrogen by 50% (Daniels and Gilliam 1996). On experimental plots at Blacksburg, Virginia, orchard grass buffers 30 feet wide reduced total nitrogen by 76% (Dillaha et al. 1989). However, scientists in England have found that although both grass and forested buffers can effectively remove nitrogen, forested buffers may be more efficient (Haycock and Pinay 1993). They found that a buffer of poplars adjacent to cereal croplands could remove 100% of the nitrate that entered the buffer, even in the dormant season, compared to a perennial ryegrass buffer which removed only 84%. They attributed the difference to the larger amount of carbon available year-round in the forested buffer. Likewise, a study in central Illinois, comparing the ability of a mixed hardwood riparian forest and a reed canarygrass filter strip to filter nutrients, found that both were effective filters for nitrate-nitrogen, but on an annual basis, grass was less effective than the forest (Osborne and Kovacic 1993). The scientists suggest that this may be associated with the form of carbon available for denitrification in the forested buffer.

Current studies in the Ridge and Valley region of Pennsylvania suggest that neither grass nor forest provides a consistently more favorable environment for denitrification (Schnabel et al. 1995). Rather, it is the presence of certain soil and hydrological conditions which promote denitrification. However, their study confirms the importance of carbon in fueling denitrification processes - denitrification rates increased on both the grass and forested sites when they were amended with additional carbon. Likewise, studies conducted on Virginia's Eastern Shore by the U.S. Geological Survey suggest that the mere presence of forested buffers may not significantly decrease nitrogen loads to streams (Speiran et al. 1998). Soil texture, organic matter content, and groundwater flow paths were the most important factors influencing the fate of nitrogen in this area.

- Phosphorus. Riparian areas can be important sinks for phosphorus; however, they are generally less effective in removing phosphorus than either sediment or nitrogen (Parsons et al. 1994). For example, only half the phosphorus entering a riparian forest in North Carolina was deposited within the forest (Cooper and Gilliam 1987). Richard Lowrance reported only a 30% reduction of phosphorus by a hardwood riparian forest in Georgia (Lowrance et al. 1984b). However, in Maryland, scientists found that deciduous hardwood riparian buffers removed nearly 80% of the phosphorus from agricultural runoff, primarily particulate phosphorus (Peterjohn and Correll 1984). The riparian buffer had little effect on phosphorus in the form of dissolved phosphate.

The primary mechanism for phosphorus removal by riparian buffers is the deposition of phosphorus associated with sediments (Brinson et al. 1984, Walbridge and Struthers 1993). In addition to the settling of particulate phosphorus, dissolved phosphorus may also be removed from runoff waters through adsorption to clay particles, particularly where there are soils containing clays with high levels of aluminum and iron (Cooper and Gilliam 1987). Some have suggested that because clays tend to accumulate in riparian soils, riparian areas play an important role in the removal of dissolved phosphorus (Walbridge and Struthers 1993). However, others have found that soils are limited in their capacity to adsorb large loadings of phosphorus, and in areas where excessive phosphorus enrichment occurs, soils become saturated within a few years (Cooper and Gilliam 1987, Mozaffati and Sims 1994). Unlike nitrogen, phosphorus sorption is reduced in soils with high organic matter (Sharpley et al. 1993, Walbridge and Struthers 1993). Some phosphorus may be taken up and used by vegetation and soil microbes, although like nitrogen, much of this phosphorus is eventually returned to the soil. For example, researchers estimated that less than 3% of the phosphate entering a floodplain forest in eastern North Carolina was taken up and converted to woody tissue, while scientists in Maryland reported a deciduous riparian forest buffer took up 8.8 lb/A/yr phosphorus but returned 7 lb/A/yr as litter (Brinson et al.

1984, Peterjohn and Correll 1984). In some riparian areas, small amounts of phosphorus (0.05-2.14 lb/A/yr) may be stored as peat (Walbridge and Struthers 1993).

Grass buffers may reduce phosphorus levels as well as forested buffers. Researchers in Illinois compared the ability of a mixed hardwood riparian forest and a grass filter strip to reduce phosphorus loads from agricultural runoff (Osborne and Kovacic 1993). They found that while the forest buffer removed more phosphorus initially, the forest buffer also released more phosphorus during the dormant season. On an annual basis, the grass buffer was a more efficient sink for phosphorus than the forest buffer. Studies in the Coastal Plain of North Carolina suggest that grass buffers can reduce phosphorus loads by as much as 50%-70% (Daniels and Gilliam 1996). Studies by Dillaha et al. (1989) at Virginia Tech suggest similar results - orchardgrass buffer strips 30 feet wide removed 89% of the phosphorus from runoff; filter strips 15 feet wide removed 61%. However, his research also suggests that grass buffers may only trap particulate phosphorus temporarily, then release it during later storm events.

Other contaminants

Other contaminants which may reduce water quality include toxins (such as pesticides and metals) and pathogens. The fate of contaminants such as pathogens, pesticides, heavy metals, and other pollutants in riparian areas is not well understood. However, it has been suggested that riparian areas may at least slow the movement of contaminants into surface waters and increase the opportunity for the contaminants to become buried in the sediments, adsorbed onto clays or organic matter, or transformed by microbial and chemical processes (Johnston et al. 1984).

- *Pathogens*. Pathogens such as waterborne bacteria, viruses, and protozoa are the source of many diseases infecting humans, livestock, and other animals, including salmonellosis, mastitis, scours, anthrax, tuberculosis, brucellosis, tetanus, and colibaciliosis (Chesters and Schierow 1985, Palmateer 1992). Pathogens can enter streams and lakes through improperly treated sewage, wildlife, stormwater runoff, leaky septic systems, runoff from livestock operations, or as sewage dumped overboard from recreational boats. The 1998 Virginia Water Quality report indicates that bacterial contamination is a major pollutant in the state's streams and estuaries. The primary source of this contamination is livestock operations and municipal sewer overflows.

Once they enter surface waters, disease-causing organisms generally die off fairly quickly; however, when they come in contact with sediments or organic matter, they may become adsorbed onto these materials and can survive for longer periods of time. High nutrient levels and turbidity in the water also increase survivability by providing a source of nutrition and reducing the amount of sunlight which penetrates the water. Many pathogenic viruses and bacteria are not directly harmful to aquatic organisms; however, pathogens can be passed on to humans when contaminated fish and shellfish are ingested (US EPA 1995). Pathogens can also be transmitted to humans, livestock, and other animals through direct contact with contaminated water.

There is little information available on the effect of riparian buffers to reduce contamination by fecal coliform bacteria and other pathogens. However, scientists in Minnesota conducted simulated rainfall tests to measure the ability of various types of vegetation to reduce levels of fecal coliform bacteria and other pollutants in runoff from a cattle feedlot (Young et al. 1980). They found that strips of corn, oats, orchardgrass, and sorghum/sudangrass were all effective in reducing bacterial levels by nearly 70%. They estimated a buffer 118 feet wide would be required to reduce total coliform bacteria to levels acceptable for human recreational use. Others have demonstrated the ability of grass sod filter strips to trap bacteria from dairy cow manure under laboratory conditions (Larsen et al. 1994). They found that even a narrow (2 foot) strip successfully removed 83% of the fecal coliform bacteria, while a 7 foot filter strip removed nearly 95%.

- Toxins. Although many chemicals have toxic effects if present in large amounts, chemicals with adverse and long-term effects are referred to as toxins (US EPA 1995). Once toxins have entered aquatic systems, they may settle out and persist in the sediments for decades. Disruption of the sediments (for example, from boating activity or dredging) may release pollutants into the water for years after they are introduced.

Toxic pollutants can affect aquatic organisms by increasing their susceptibility to disease, interfering with reproduction, and reducing the viability of their young (US EPA 1995). Pollutants can cause behavioral changes (for example, decreased ability to swim) and physiological effects (such as decreased growth or altered blood chemistry) which result in the reduced ability to feed and escape predation (Firehock and Doherty 1995). Because not all organisms are equally affected by environmental toxins, some species may be eliminated from the environment while others survive.

In humans, toxins have been shown to cause disorders of the immune system, reproductive disorders, and developmental and neurological disorders (US EPA 1995). Humans can be exposed to toxins by eating contaminated fish, or drinking or swimming in contaminated water. Toxins of greatest concern in aquatic systems are pesticides, toxic metals, PAHs (polycyclic aromatic hydrocarbons), and PCBs (polychlorinated biphenyls). Limited research suggests that riparian buffers may help mitigate pesticides and metals from runoff.

Pesticides are used extensively throughout the U.S., primarily in agricultural areas. Pesticides also find wide use on utility right-of-ways, golf courses, urban lawns and gardens, and in plant nurseries (Johnson et al. 1994b). Pesticides enter streams through surface runoff, either dissolved in water or attached to soil particles. They may also be discharged into streams from contaminated groundwater or be deposited into surface waters through atmospheric deposition (McConnell et al. 1995).

Although pesticides have the potential to cause significant damage to aquatic communities, pesticide losses from farm fields under typical conditions are generally very low (less than 5% of applied pesticides), and pesticide levels in surface waters are considered extremely low (Baker 1985, Chesters and Schierow 1985, Johnson et al. 1994b). However, contamination of surface waters by pesticides can occur. For example, in north-central Missouri, where an extensive clay pan underlies an agricultural area, widespread contamination of streams has been confirmed (Donald et al. 1995, Blanchard et al. 1995).

Few studies have been made to examine the fate of pesticides in riparian areas. However, where the proper conditions exist, riparian forest buffers have the potential to remove and detoxify pesticides in runoff. Pesticides, like other organic chemicals, are acted upon by various chemical and biological processes in the soil environment (Cook 1996). Probably the most important process is the breakdown of organic chemicals by soil microorganisms (MacKay 1992). For decades, scientists have observed that soil microorganisms adapt to the presence of a pesticide and develop the capacity to metabolize it as an energy source (Fausey et al. 1995). As it is metabolized, the pesticide is broken down to various intermediate compounds, and ultimately carbon dioxide. In addition, most pesticides have a high affinity for clay and organic matter, and may be removed from the soil water as they are bound to soil particles. Once bound, pesticides are often difficult to desorb (Clapp et al. 1995).

Several studies have examined the effectiveness of grass filter strips in reducing pesticide levels in agricultural runoff. Scientists in southern Georgia found that grass filter strips successfully removed as much as 86%-96% of the herbicide trifluralin from agricultural runoff (Rhode et al. 1980). About half of the herbicide was adsorbed onto vegetation or organic matter, while infiltration into the soil accounted for one-third. However, studies on the effect of bromegrass filter strips on the herbicides atrazine, cyanzine, and metolachlor showed that the filter removed only 10%-40% of the herbicide entering the filter strip (Hatfield et al. 1995). Most of this reduction occurred in the upper 2" of the soil surface where high organic matter encouraged rapid infiltration and a high adsorption rate. Likewise, scientists in Iowa found that atrazine adsorption was greatest in soils with high organic matter. In their study, half of the atrazine became irreversibly bound to soil particles, while 10-15% of the atrazine was broken down by soil microorganisms (Moorman et al. 1995). Certain pesticides can be harmful to soil microorganisms. The use of the insecticide aldicarb has been shown to reduce the rate of denitrification in surface soils, presumably because it decreased populations of denitrifying bacteria (Meyer et al. 1994).

Metals may be released into the aquatic environment through industrial processes, mining operations, urban runoff, transportation activities, and application of sewage sludge (US EPA 1995). Trace metals may also be introduced with agricultural pesticides and fertilizer (Clark 1985). Metals pose a particular threat to aquatic environments because they do not degrade and tend to accumulate in the bottom sediments. Metals may also accumulate in plant and animal tissues. In Virginia, portions of the North Fork of the Holston River, the South River, and the South Fork of the Shenandoah River have been closed due to mercury contamination. Metals released from mining operations are the primary pollutants of streams in the western corner of the state.

The fate of metals in riparian areas is not well understood. However, scientists in Virginia have found significant amounts of lead, chromium, copper, nickel, zinc, cadmium, and tin buried in the sediments in the floodplain along the Chickahominy River downstream of Richmond (Hupp et al. 1993). Analysis of the woody tissues of the trees reveal that these compounds are also taken up by the trees. Therefore, sediment deposition and uptake by woody vegetation may help mitigate heavy metals in riparian areas.

Factors affecting the water quality benefits of riparian forest buffers

Riparian forest buffers protect water quality as they filter, dilute, modify, incorporate, or concentrate pollutants (Osborne and Kovacic 1993). The degree to which riparian areas can influence water quality is a function of the area’s hydrology, soils and soil microorganisms, and vegetation.

Hydrology. Probably the most important factor affecting water quality at a particular site is hydrology (Schnabel et al. 1994, Lowrance et al. 1997). Riparian area hydrology is influenced by local geology, topography, soils, and characteristics of the surrounding watershed. Riparian forests will have the most influence where runoff follows direct, shallow flow paths from the uplands to the stream, causing most of the drainage to pass through the riparian area before exiting into the stream. Where deep groundwater flow paths cause drainage to bypass the riparian zone entirely, riparian buffers cannot be as effective. Riparian areas can also influence water quality through their effects on surface waters. In areas where slope is minimal and surface water flows are slow and uniform, riparian areas can be highly effective in slowing the force of stormwaters and reducing the amount of sediment, crop debris, and other particulate materials that reach streams. However, when surface runoff becomes concentrated and runs through the buffer in defined channels, the ability of the buffer to influence surface waters is limited.

Soils. Soils in riparian areas are highly variable, a combination of local soils weathered in place, deposits of sediments during storm events, and the accumulation of organic debris (Lowrance et al. 1985). For example, in southern New England, scientists have observed that riparian soils vary considerably in as little as 30 feet (Gold and Groffman 1995). Features of the soil which influence its water quality functions include the depth to the water table, soil permeability, soil texture, soil chemistry, and organic matter content (US EPA Cheaspeake Bay Program Forestry Work Group 1993). These features affect the way and the rate at which water flows over and through the riparian area, the extent to which groundwater remains in contact with plant roots and with soil particles, and the degree to which soils become anaerobic. Processes such as denitrification require that the soils be anaerobic at least part of the year (Correll 1997). Where organic soils have developed, riparian forests have great potential to enhance water quality. Organic soils are capable of infiltrating large amount of surface runoff, have a high affinity for nitrogen and other contaminants, and are an important source of carbon, needed to fuel microbial processes. In fact, a recent study in the Midwest concluded that the major factor influencing the movement of nutrients and herbicides through the soil was its organic carbon content (USDA-ARS 1995).

Many of the water quality functions of the riparian area are a result of the activity of soil microorganisms (Palone and Todd 1997). Soil microorganisms influence water quality in several ways. Like plants, they take up and convert nutrients to forms which are less biologically available and more readily stored in the soil. Soil microorganisms also utilize and metabolize organic chemicals (such as pesticides) as an energy source, and in the process, transform the chemicals to less toxic compounds. Finally, soil microorganisms are responsible for many chemical reduction reactions which occur in the soil, including denitrification and the reduction of sulphur, iron, and other compounds (Mitsch and Gosselink 1993).

Vegetation. Riparian vegetation affects the filtering ability of the riparian area in several ways. By creating roughness along the surface of the ground, the vegetation decreases water velocity and allows time for water to infiltrate the soil and for sediments to drop out. Sediments are also removed as they are deposited on plant tissues. Riparian plants also loosen the soil, allowing for increased infiltration of runoff. Riparian vegetation and soil microbes also play an important role in removing dissolved pollutants from soil water, as they take up nutrients and other substances and incorporate them into their tissues. Furthermore, riparian vegetation is critical to maintaining high levels of organic carbon in the soil, necessary to fueling denitrification and other biochemical processes. Plants also protect the surface of the soil from wind and water erosion, stabilize streambanks and modify temperature, light, and humidity within the riparian area and the stream itself.

Riparian vegetation: Grass vs. Forest? While there is much debate concerning whether riparian buffers should be revegetated with trees or grasses, research to date does not allow a definitive answer. A number of studies have been made on both types of buffers, but differences in study design and site characteristics do not allow for accurate comparisons between them. Furthermore, studies on grass buffers have generally been made on cool-season pasture grasses rather than native warm-season grasses (warm-season grasses may offer several advantages to cool-season grasses, because they are long-lived, highly productive, and have extensive, deep root systems). However, these studies indicate some general trends:

_ Both grass and forest buffers can reduce levels of nutrients and sediments from surface runoff, and reduce levels of nitrates from subsurface flows. Higher rates of denitrification are often observed in forested buffers, and researchers attribute this to the greater availability of organic carbon and interactions which occur between the forest vegetation and the soil environment (Lowrance et al. 1997, Correll 1997). However, denitrification is also dependent on certain soil and hydrological conditions, which do not exist in all riparian areas.

_ Grass buffers are more quickly established, and in terms of sediment removal, may offer greater stem density to decrease the velocity of water flow and provide greater surface area for sediments to be deposited. Forested buffers, though, offer the advantage that the woody debris and stems may offer greater resistance and are not as easily inundated, especially during heavy floods (US EPA Chesapeake Bay Program Forestry Work Group 1993). However, neither buffer will be effective where the volume and velocity of flood waters and the sediment loads which they carry are large.

_ Neither buffer is particularly effective in reducing concentrations of dissolved phosphorus; however, where flow is shallow and uniform, control of sediment-associated particulate phosphorus can be quite effective.

Whether grass or forest, riparian buffers should be considered as part of a unified land management plan, including sediment and erosion control and nutrient management practices. They will be most effective where vegetation and organic litter are adequate, where subsurface flows of water pass through the plant root zone, and where the presence of moisture, carbon, oxygen, and populations of bacteria encourage denitrification and other biogeochemical processes.

Habitat alteration. Intensive activities in riparian areas can lead to serious losses of stream habitat and water quality. Natural drainage is interrupted as riparian soils become compacted, sedimentation rates increase, solar radiation increases, and stream channels are altered. Examples of habitat alteration include the removal of streamside vegetation, removing woody debris and boulders from streams for boating and shipping, stream channelization, damming, and dredging (US EPA 1995). Streams can also be degraded by activities in the surrounding watershed.

In agricultural areas, riparian areas are often converted to productive crop and grazing lands. Riparian areas are also cleared to increase drainage, reduce competition for moisture and sunlight to crops, to remove sources of noxious weeds, allow easier operation of farm machinery, and to remove habitat for wildlife that may damage crops (Osborne and Kovacic 1993). In these areas, livestock can be particularly damaging where they have access to streams (Kauffman and Krueger 1984, Kasi and Botter 1994). Livestock erode the streambank as they climb in and out of the stream, causing the stream to become wider and shallower. Grazing of the riparian area alters the riparian plant community, compacts and erodes riparian soils, and interferes with wildlife use of the area. Stream water quality is also impaired as stream temperatures increase (as the stream becomes more shallow and vegetation decreases) and manure is deposited or washed into streams, introducing organic matter, nutrients, and pathogenic organisms (Overcash et al. 1983).

In urban areas, streams are often degraded as they are diverted through stormwater systems, as riparian vegetation is removed, and as the watershed becomes covered by roads, parking lots, and buildings. Changes in the vegetative cover in the watershed can cause changes in the amount and timing of water flows in stream channels. Where stormwater once soaked into the ground, it now must flow over hard surfaces, picking up sediments, petroleum products, chemicals, metals, and other pollutants and discharging them directly into storm drains and streams. Increases in the frequency and magnitude of flood events cause damage to stream and riparian plants and animals and cause stream channels to erode their banks and beds. Increases in sediment entering the stream also result in changes in the stream, including a widening and shallowing of the streambed, a loss of aquatic habitat, and a decrease in the streambed “roughness” as pools become filled and the streambank is covered with fine soils. Streams also tend to be warmer in urban areas, due to warmer inputs into the stream and the loss of streamside vegetation.

Suitability of riparian forest buffers for water quality in Virginia

The Commonwealth of Virginia crosses three primary physiographic regions - the Coastal Plain to the east, the Piedmont of central Virginia, and the mountains to the west. Variations in soils, topography, and hydrology in each of these regions influence the capacity of riparian forest buffers to influence water quality.

Coastal Plain. Virginia’s Coastal Plain is an area consisting of deep deposits of sand, gravel, fossil shells, and clay. Much of the Coastal Plain is underlain by a confining layer (aquitard) which restricts movement of groundwater downward. When groundwater reaches the confining layer, it begins to move laterally, until it exits into a stream or other surface waters. Streams within the Coastal Plain region are typically low-gradient, low velocity streams that in their natural condition are relatively clear, dark with humic acids, and low in pH, dissolved solids, and dissolved oxygen and nutrients (Kuenzler 1988). Due to the shallow aquifer, water tables are high, and the floodplain is often inundated for months during the winter and spring. Of all the physiographic regions, streams in the Coastal Plain often benefit significantly from the presence of riparian forest buffers. Here, flat, gentle topography means that storm waters flow relatively slowly across the surface of the land, which allows time for sediments to be removed by riparian vegetation. More importantly, most water enters streams through shallow surface aquifers, moving through the root zone of the riparian buffer where nutrient removal is very high. However, even within the Coastal Plain, variability in soils, topography, groundwater flow patterns and land uses can influence the movement of nonpoint source pollution to streams (Staver and Brinsfield 1994, Speiran et al. 1998). For example, in well-drained upland areas, the water table is much deeper and rainwater is more likely to bypass riparian vegetation and enter streams through the stream bottom. Here, there is little chance for nitrate removal from the root zone, although deep-rooted trees immediately adjacent to small streams may intercept deeper groundwater before it enters the stream. These trees may also provide an important source of carbon for denitrification in and around the stream channel. Other areas of the Coastal Plain where riparian buffers have less impact on water quality are tidally-influenced streams, where lands have been ditched to promote drainage of agricultural fields, and areas of the Bay that are bordered by tall cliffs.

Piedmont. The Piedmont region is located in central Virginia, an area characterized by rolling hills and underlain by a complex of igneous and metamorphic rocks (Lowrance et al. 1997). The geology and soils of the Piedmont region is quite variable. In much of the Virginia Piedmont, water flows to streams through shallow groundwater, providing ideal conditions for riparian buffers to remove contaminants from subsurface flows before they enter streams. In other areas of the Piedmont, deeper soils result in flow patterns which may cause drainage to bypass the forest buffer altogether and seep into the stream from underneath the stream bed. These areas offer little opportunity for the removal of nutrients or other contaminants from subsurface flows. However, areas with very gentle slopes offer a good opportunity for the removal by riparian buffers of sediment and sediment-borne nutrients and contaminants from surface flows. Sediment control in areas with steeper slopes will depend to a large degree on how effectively the runoff is controlled and spread out before the water reaches the buffer. Where runoff is rapid and forms channels, water will flow quickly through the buffer, offering little time for infiltration.

Mountains. Western Virginia is dominated by mountains. The eastern-most band of mountains, the Blue Ridge, are underlain with hard granite, quartzites, and greenstone which originated as ancient lava flows. Just west of the Blue Ridge lie the Appalachian Mountains and the Cumberland Plateau, where erosion resistant quartzites and sandstones lie along the ridges, with softer limestones and shales in the lower valleys (VA DEQ/DCR 1998).

In the mountains, small, steep stream channels drain the ridges, eventually joining large streams that flow through valley bottoms. Subsurface water movement in this area is complicated and not well understood. In areas underlain by limestone bedrock, water may flow quickly through cracks and cavernous openings to deep aquifers, then travel many miles before it is released into surface waters. Where bedrock is harder and resistant to weathering, groundwater is more likely to move toward the stream closer to the surface, providing a greater opportunity to come in contact with the root zone of vegetation. Therefore, the degree to which riparian buffers may protect streams from contamination in this region is highly variable (Lowrance et al. 1997). Along valley floodplains and around seeps and springs where groundwater discharge occurs, forested buffers will have their greatest influence on stream water quality. In other areas, their effects may be minimal. However, streamside buffers continue to play a very important role in controlling stream temperatures and providing food and habitat to aquatic ecosystems throughout the mountain region.

Riparian forest buffers and water quality - additional considerations

The benefits of riparian buffers in improving water quality have been documented and can provide economic benefits to communities (for example, from reduced water treatment costs). However, some researchers point out that where water quality is the primary management objective, other Best Management Practices may be equally, or more, effective than riparian forest buffers. For example, in Indiana, Pritchard et al. (1993) predicted that buffering a small watershed entirely with forested buffers would remove 442 acres of land from production and reduce sediment loadings in the watershed from 1560 tons per year to 1141 tons per year (a reduction of 27%), at a cost of $91 per ton. However, removing 442 acres of the most erodible land in the watershed would reduce sedimentation by 31% (to 1074 tons per year) at a cost of $78 per ton. In Idaho, researchers predicted that protecting 100% of the riparian areas in forest would reduce erosion by 47% and other pollutants by 61%. However, using other conservation measures could reduce erosion by 77% and other pollutants by 80%, although at a higher cost to farmers. (Prato and Shi 1990). It should be noted, though, that both studies were based on predicted (not actual) values and did not consider the value of the other important benefits that riparian forest buffers can provide.

The long-term effectiveness of the riparian forest buffer in assimilating and permanently storing sediments, nutrients and other contaminants is not well understood (Brinson et al. 1984). Denitrification offers the most permanent removal of nitrogen, as it is released into the atmosphere. In some areas, sediment deposition can serve as an important sink for sediments and sediment-attached nutrients, metals, pesticides and other compounds. However, riparian areas have a limited storage capacity for these materials and sediments, phosphorus and other materials may be eroded or solubilized into suspension again (Johnston et al. 1984). Nutrients may also be taken up and incorporated into woody biomass. Several scientists have recommended periodic harvest of riparian vegetation to maintain nutrient uptake, although studies monitoring the impact of harvest on nutrient levels are generally lacking (Lowrance et al. 1985).

Others question whether it is the presence of forested buffers specifically but the presence of forest in general that contributes to improved water quality. For example, Omernick et al. (1981) compared 80 watersheds with varying amounts of forested and agricultural land. They found that nutrient concentrations in streams could be predicted by the percent land cover in forest or agriculture, but there was no significant relationship between the proximity of the forest to the stream. Their study suggests that as the amount of forest cover decreased from more than 75% to less than 25% of the watershed, there was a corresponding increase in nitrogen and phosphorus concentrations in streams, regardless of whether the forest was located adjacent to or away from the stream itself.

Chapter 3

Plant and Animal Communities

Riparian areas in the eastern United States are among the most productive biological systems in the world and support distinctive communities of plants and animals (Dickson and Warren 1994). Streams play a major role in shaping the riparian area and in creating habitat for plants and animals (Murray and Stauffer 1995). As streams shift over time, they constantly reshape the riparian area, creating new channels, sandbars, undercut banks, oxbows and floodplain pools. Streams also transport sediments, nutrients, organic matter, plant seeds, and animal life from upstream reaches and adjacent floodplains (Wigley and Roberts 1997, Nilsson et al. 1994).

Riparian plant communities

The riparian area supports one of the most diverse and productive of all plant communities. Variable topography, hydrology, and soils result in a wide range of physical habitats within close proximity, each supporting distinct plant species. The regular movement of nutrients, sediment, organic matter, and living organisms between the stream, the uplands, and the floodplain contribute to a diverse and productive plant community (Gregory et al. 1991, Nilsson et al. 1994).

Disturbance, both chronic (occurring monthly to yearly) and episodic (in terms of decades or centuries), is common to the riparian area, resulting from floods, fire, wind, and pests (Gregory et al. 1991, Bohlen and King 1996). These disturbances can produce large-scale changes in the plant community, or small cleared areas scattered about the floodplain. As a result, young growth and mature vegetation is often found growing close together.

Readily available water and productive soils support greater plant biomass than is often found in upland areas, creating forests with a complex vertical structure (LaRue et al. 1995). Within the riparian forest is a multi-layered canopy of large trees, an understory of vines, shrubs and small trees, and herbaceous vegetation on the forest floor. Snags and downed logs and limbs provide other important elements to the forest. The dense vegetation and the presence of surface water provides a protective environment and helps moderate temperature extremes within the riparian area.

Adding to their complexity, riparian areas support large amounts of “edge” habitat, both along the stream and where they border adjacent uplands (Gregory et al. 1991, LaRue et al. 1995). As a result, riparian areas support a variety of species common to upland areas, wetlands, and aquatic environments. This variety within riparian forests can contribute significantly to landscape diversity, particularly in areas generally lacking forest cover.

Recent studies have documented the biological diversity of mid-Atlantic riparian areas. Hedman and Van Lear (1995) examined the vegetative characteristics of Southern Appalachian riparian forests and recorded the species composition of riparian forests in various stages of succession. They identified the increasing abundance of rhododendron as a problem for future regeneration. Along the Susquehanna River valley of southeastern Pennsylvania and northeastern Maryland, Bratton et al. (1994) documented the importance of riparian areas in maintaining populations of mesic forest floor herbs in the Susquehanna River valley. They recommend the preservation of a “key number of locations with key microhabitats”, particularly “the mouths and banks of the larger creeks, minor tributaries on high base rock, and the more extensive areas of the floodplain”.

Buffer design considerations

When restoring riparian plant communities, it is important to keep in mind the variety of soils and hydrological conditions found in the area, as well as the role of the plant community in maintaining water quality and wildlife habitats. That is why native species are often recommended for the riparian area. Native species are well adapted to the riparian environment and can satisfy a variety of wildlife needs. A list of recommended species is provided in Chapter 7 of this publication. In addition, a list of native plant species is available from the Virginia Department of Conservation and Recreation, Division of Natural Heritage.

Riparian animal communities

Because of their complex structure, diverse and productive plant communities, and close proximity to water, riparian areas provide critical habitat for many species of wildlife (Nilsson et al. 1994, Wigley and Roberts 1997). These may be permanent residents of the riparian area or occasional visitors who use the area for food, water, or temporary shelter.

Components of the riparian ecosystem.

Forested riparian buffers benefit wildlife in many ways, by providing food and foraging sites, water, reproductive habitat, escape cover, protection from wind and adverse weather, and travel corridors.

- Food. Food availability varies with the type of vegetation in the riparian area, but includes fruits, mast, seeds, foliage, twigs, buds, and insects and other invertebrates. Trees and shrubs produce a variety of foods that are eaten by many animals, and may be especially important sources of nutrition during the winter months. Grasses and herbaceous vegetation provide seeds and forage both within the riparian area and along the forest border.

- Water. The stream environment provides moving waters for many animals to drink, feed, swim, and reproduce. Water is also available on moist vegetation and in shallow wetland pools and backwaters common to many riparian areas. These areas, both permanent and temporary, are especially important for amphibians and macroinvertebrates (Clark 1978).

- Cover. Riparian areas provide a sheltered environment for many species of animals to feed, rest, and reproduce. Animals use these to seek shelter from extremes of weather and to escape predators and human activity (Compton et al. 1988, Johnson and Beck 1988). Riparian areas may also provide important travel corridors for some species, and are frequently used as stopover points for migratory birds.

Factors which influence wildlife use of riparian buffers.

Due to their diverse and productive plant communities and close proximity to water, riparian areas support many species of wildlife. However, the importance of riparian areas to wildlife depends on the species of concern, the characteristics of the riparian area, and the type of land use in which the riparian area occurs.

- Landscape setting. In areas of intensive agriculture, forested riparian areas can provide important ‘islands’ of wildlife habitat. Here, species that depend on trees and forests for their survival can live and reproduce. Areas adjacent to riparian forests offer supplementary habitat by providing additional foods, nesting and roosting sites, and cover. Riparian forest buffers are also important habitats in urban areas, where in some places, they are among the only remaining natural areas available to wildlife.

Riparian areas are also important to wildlife in forested landscapes. Today, most forest harvests incorporate the use of Best Management Practices and maintain Streamside Management Zones (SMZs) during forest harvest operations. Many studies have been made on the importance of SMZs to wildlife, particularly after clearcuts, and indicate that they are important for maintaining wildlife in the area (Darveau 1996).

Activities within the immediate vicinity, as well as upstream and downstream from the buffer will also influence wildlife use of the area. These include the presence of industrial operations, urban development, pollution, recreational activities, roads, and other uses.

- Vegetative characteristics of the buffer. The type of vegetation growing in the buffer affects its usefulness to wildlife through the availability of food and foraging sites, nesting sites, and other habitat needs (Johnson and Beck 1988). The more diverse the habitat, the greater its utility to many species of animals. For example, in Iowa, biologists found a greater abundance and greater number (50) of species of birds in woodland edges around cornfields, compared with grass/herbaceous edges (23 species) (Best et al. 1990). In Charlotte County Virginia, wildlife biologists studied bird communities along channelized streams where all the woody vegetation had been removed from the streambank (Ferguson et al. 1975). As shrubs and trees begin to regenerate the site, there was a corresponding increase in bird species diversity and density.

Complex habitats support more animals because animals partition their habitat very precisely, feeding and nesting only in certain sites within the environment. For example, the presence of small mammals in riparian areas of the Pacific Northwest has been correlated with very specific habitat features: certain species occur on sites with low cover, while others prefer overgrown thickets; some prefer deciduous or evergreen cover; and still others are correlated with the abundance of snags and decayed logs (Doyle 1990). Other small mammals are associated more with the presence of a particular prey base than to specific vegetation, while burrowing mammals prefer areas of high organic soils. Likewise, researchers have documented distinct habitat preferences among reptiles and amphibians in Kentucky (Pais et al. 1988).

Animals respond to the type (species) of vegetation present, as well as the conditions created by the vegetation: moderated temperatures, high humidity, moist loose soils, diversity of canopy layers, and availability of nesting and denning sites. Therefore, animals find riparian areas useful not only because of the presence of water, but the variety of habitats created in this environment.

- Wildlife species of concern. Wildlife use of riparian areas will also vary depending on an animal's specific requirements for food, water, cover, and territory. For example, some species of wildlife will not live in buffers unless they are very wide (300 feet or more), although they may make use of riparian areas as stopover points for migration or for resting or feeding grounds. Others will thrive in much narrower buffers and along the buffer edge. In some cases, wildlife found in riparian areas are not necessarily riparian-dependent species, rather, they may be utilizing the area because in many cases, it offers the only available forest habitat.

<u>Large mammals</u>. Mature riparian forests can provide refuge for large animals, particularly when large tracts of forest are otherwise lacking. In south Florida, for example, the cougar is occasionally found in remnant bottomland stands (Dickson and Warren 1994). Black bears may also be found in riparian areas, particularly where there is brushy cover for hiding and mature hardwoods for denning and mast production (Oli et al. 1997). White-tailed deer also make use of the area for forage and cover (Compton et al. 1988, Dickson and Warren 1994). Other mammals commonly associated with riparian forests are beaver, mink, muskrat, river otter, and racoon.

However, in order for the riparian area to be useful for animals with large territorial requirements, it must be large or connect to other large tracts of contiguous forest. Mammals that use the riparian area for only part of their needs (such as white-tailed deer) and animals with smaller space requirements can make use of smaller riparian areas.

***Small mammals*.** Doyle (1990) examined the use of riparian areas by small mammals in the Pacific Northwest, and found that riparian areas had more small mammals (shrews, mice, voles, chipmunk, northern flying squirrel, and ermine) than adjacent uplands, and that many species from the riparian area weighed more and included a greater number of adults in breeding condition. He suggested that riparian areas provide superior habitat for small animals because of: greater availability of water, forage, and invertebrates; loose, friable soils which facilitate burrowing; and more stable temperatures. In the Southeast, researchers found that hardwood SMZs were important components of gray squirrel habitats in pine and mixed pine-hardwood stands (Fischer and Holler 1991). The availability of mast, cavities for nesting, diversity of trees, tree canopy development, and distance to water and cultivated crops were also important habitat features.

However, in agricultural areas of Iowa, researchers found that small mammals (mice, shrews, voles, eastern chipmunks, and ground squirrels) preferred grazed, grassy riparian areas to upland or floodplain deciduous forests because of the greater variety of food and cover in the grazed areas (Geier and Best 1980). Within the wooded areas themselves, small mammal numbers were positively related to the presence of woody debris (logs and stumps).

Studies that have attempted to determine optimal riparian buffer widths for small mammals have produced conflicting results. Dickson and Williamson (1988) assessed the use of hardwood SMZs by small mammals in forest clearcuts and found that there were significantly more small mammals in narrow SMZs (<82 feet) than in wider SMZs. They attributed this to dense, brushy vegetation, abundant seeds and forage, and dense logging slash found in the narrow zones. Tappe et al. (1994), however, found that the width of hardwood SMZs had little effect on small mammal abundance, richness, or diversity in managed pine stands of the Ouachita mountains of Arkansas. Rather, it was the structure of adjacent pine stands which determined the presence of small mammals - SMZs along young pine plantations had the greatest abundance of small mammals, while SMZs in closed canopy plantations had the lowest number.

***Reptiles and amphibians*.** Rudolph and Dickson (1990) evaluated populations of reptiles and amphibians in SMZs of various widths in eastern Texas and found a wide variety of reptiles and amphibians used SMZs greater than 98 feet wide but were scarce in SMZs less than 82 feet wide. However, there were significant differences in the vegetative structure of the SMZs. Narrow SMZs had dense shrub and herbaceous vegetation, while wider SMZs had a well developed overstory and midstory canopy, sparse understory vegetation, and abundant leaf litter.

In New England, researchers found a greater abundance of reptiles and amphibians in streamside forests than upland forests in three different forest cover types: red maple, balsam fir, and northern hardwoods (DeGraaf and Rudis 1990). In addition, the greatest differences in species abundance and diversity occurred between the coniferous and deciduous forest types, with both hardwood types supporting more species.

***Birds*.** A number of studies have examined the use of riparian areas by birds, both in agricultural and in forested landscapes.

Studies of bird communities in areas of intensive agriculture suggest that riparian areas, shelterbelts, and small woodlots are very important habitats for birds. For example, Croonquist and Brooks (1991) evaluated bird use of riparian areas in Central Pennsylvania and observed that even very narrow riparian strips (7 feet) significantly increased the number of birds in the area. However, “area-sensitive species” were not found unless a corridor of at least 82 feet occurred on both sides of the stream. They recommended a 410-foot buffer of natural vegetation to “support the full complement of bird communities in the area”, although they suggested that protecting at least 82 feet of riparian habitat would provide dispersal and breeding opportunities for many birds. Keller et al. (1993) evaluated bird use of riparian forest buffers in agricultural areas of the coastal plain of Maryland and Delaware. They found “the presence of even a narrow riparian forest dramatically enhances an area’s ability to support songbirds compared to a stand surrounded only by agricultural fields or herbaceous riparian vegetation”. Riparian forests less than 328 feet wide were dominated by short-distance migrants, while forest buffers wider than 328 feet had more neotropical migrant species, and these continued to increase in numbers but much more gradually in forests wider than 656 feet. The number of resident species was not related to the width of the riparian forest. Stauffer and Best (1980) studied bird use of riparian forest buffers surrounded by row crops and hay fields in Iowa, and found that riparian woodlands supported higher densities of birds than either upland woodland or herbaceous buffers. Bird species richness increased with increasing buffer width. However, species gains were also associated with other habitat features, such as snag size, number of canopy layers, sapling/tree size, and the species richness of the vegetation.

Studies conducted in Virginia, Kentucky, Georgia, Arkansas, Texas, and Canada on bird use of SMZs in managed forests all support the practice of leaving hardwood corridors along streams during forest harvest operations (Holbrook et al. 1987, Triquet et al. 1990, Tappe et al. 1994, Darveau et al. 1995, Dickson et al. 1995, Hodges and Krementz 1996). However, their recommendations for SMZ width ranged from 98 to 328 feet, depending largely on the species of interest. For example, narrow buffers (<82 feet) are used primarily by “edge” species and those associated with young, brushy, or open stands, such as yellow-breasted chat, indigo bunting, orchard oriole, eastern kingbird, common yellowthroat, blue grosbeak, and prairie warbler. Wider buffers (>164 feet) begin to attract birds that commonly breed in mature forests, such as yellow-billed cuckoo, Acadian flycatcher, tufted titmouse, Carolina wren, red-eyed vireo, and others. Recommendations for buffers 300 feet or larger were targeted to "area-sensitive" forest interior dwelling birds.

Recently, two studies have examined bird use of riparian areas in contiguous forests of the mid-Atlantic (Croonquist and Brooks 1993, Murray and Stauffer 1995). They found no significant difference in species diversity or abundance of birds between riparian areas and upland forests. However, Murray and Stauffer (1995) found that in southwest Virginia, two species -- the Acadian flycatcher and the Louisiana waterthrush -- showed a strong association with streams and may be considered riparian-dependent species.

Two issues of controversy - the desirability of edge habitat, and the importance of wildlife corridors

Due to their long, linear nature, riparian areas create abundant edge habitat, an area considered to be highly productive for many wildlife species. However, not all wildlife is suited to edge habitat, and the deliberate construction of large amounts of edge has been contested by some wildlife biologists. They are concerned that an abundance of edge may cause reproductive failure, restriction of range, loss of genetic variability, and mortality for species that have very specific habitat requirements (Harris 1988, Wigley and Roberts 1997). In urban areas, edge effects may be more pronounced (Adams and Dove 1989). Buffers surrounded by commercial, residential, and industrial development frequently hold a large number of predators, such as brown-headed cowbirds, raccoons, and domestic animals, as well as exotic plant species.

Riparian forest buffers have also been promoted because they can serve as corridors for wildlife movement. The presence of corridors are believed to be especially important to reptiles, amphibians, less mobile birds and small mammals, and for young as they establish new territory (Clark 1978, Machtans et al. 1996). However, some scientists have suggested that corridors actually hinder native wildlife populations because they can enhance the spread of contagious diseases, fires, predators, and exotic species, and may promote the movement of generalist species at the expense of area-sensitive species. There is also debate about whether the corridor is necessary to maintain genetic diversity within a population.

Buffer design considerations

When designing riparian buffers with wildlife in mind, it is important to consider their primary purpose - are they intended as habitats for a particular species, a group of species, corridors for movement, or some other purpose? Consider too, activities on adjoining lands that may impact wildlife use of the buffer, as well as features that could increase their value as wildlife habitat (such as the close association with large tracts of forest, the presence of caves, springs, etc.). When revegetating riparian areas, select plants which will be most valuable to wildlife, including mast-producing species and trees commonly used for nesting and dens.

Table 3.1. Wildlife which prefer riparian area habitat

Amphibians	
Dusky salamander	*Desmognathus fuscus*
Jefferson salamander	*Ambystoma jeffersonianum*
Spring salamander	*Gyrinophilus porphyritcus*
Two-lined salamander	*Eurycea bislineata*
Mudpuppy	*Necturus maculosus*
Green frog	*Rana clamitans melanota*
Reptiles	
Ribbon snake	*Thamnophis sauritus*
Worm snake	*Carphophis amoenus*
Map turtle	*Graptemys geographica*
Eastern spiny softshell	*Trionyx spiniferus*
Birds	
Alder flycatcher	*Empidonax alnorum*
Barred owl	*Strix varia*
Belted kingfisher	*Cergle alcyon*
Cerulean warbler	*Dendroica cerulea*
Common yellowthroat	*Geothlypis trichas*
Eastern screech owl	*Otus asio*
Eastern wood-pewee	*Contopus virens*
Gray catbird	*Dumetella carolinesis*
Louisiana waterthrush	*Seiurus motacilla*
Northern waterthrush	*Seiurus noveboracensis*
Prothonotary warbler	*Protonotaria citrea*
Red-shouldered hawk	*Buteo lineatus*
Red-bellied woodpecker	*Melanerpes carolinus*
Rough-winged swallow	*Stelgidopterx serripennis*
Song sparrow	*Melospiza melodia*
Tufted titmouse	*Parus bicolor*
Veery	*Catharus fuscenscens*
Wood duck	*Aix sponsa*
Yellow warbler	*Dendroica petechia*
Yellow-breasted chat	*Icteria virens*
Mammals	
Beaver	*Castor canadensis*
Big brown bat	*Eptesicus fuscus*
Keen's myotis	*Myotis keenii*
Little brown myotis	*Myotis lucifugus*
Mink	*Mustela vison*
Northern short-tailed shrew	*Blarina brevicaude*
River otter	*Procyon lotor*
Racoon	*Lutra canadensis*
Silver-haired bat	*Lasionycteris noctivagans*
Water shrew	*Sorex palustris*

From: DeGraaf, R.M., M. Yamasaki, W.B. Leak, and J.W. Lanier. 1992. New England wildlife: management of forested habitats. USDA Forest Service GTR-NE-144.

Aquatic communities

At one time, much of eastern North America was predominately forested, and its stream communities evolved in this environment (Sweeney 1993). Removal of the forest has affected the stream environment in many ways, including loss of food, habitat, and water quality. The creation of forested buffers around streams can help restore these habitats.

Components of the aquatic community

Riparian forests influence the aquatic community through their effects on food availability, habitat structure, stream flow, light and temperature, and water chemistry. These factors determine the productivity and variety of plants, microorganisms, invertebrates, and fish found in the stream.

- Food. Riparian forests provide food to stream organisms in the form of twigs, branches, bark, leaves, nuts, fruits, flowers, and insects falling from the forest cover. Streamside forests also influence the stream's microbial community by modifying the levels of nutrients and dissolved organic matter leaching from the surrounding land (Sweeney 1993). In the eastern forest, small headwater streams receive as much as 60% to 99% of their organic food base from the surrounding forest (Cummins 1974, Minshall 1978). Deciduous forests contribute very large amounts of debris into the stream, mostly during autumn leaf fall and as buds burst and flowers are produced in the spring (Moss 1988). The organic debris may be captured near its origin or carried downstream. This organic material is slowly broken down by aquatic microorganisms and stream invertebrates, which form the base of the food chain for other aquatic organisms and fish.

The distribution and abundance of aquatic organisms in streams is closely tied to the timing and type of inputs from the surrounding forest (Cummins et al. 1989). Aquatic invertebrates are most abundant in late spring and early summer, decrease in late summer, and increase again in late fall. In turn, fish pattern their reproduction and growth around the availability of aquatic invertebrates (Dickson and Warren 1994). When streamside vegetation is altered, the invertebrate community changes, which in turn affects the types of fish present (Karr and Schlosser 1978).

The environment of mid-order streams is very different than that of lower order streams. As the stream deepens and widens, sunlight penetrates the forest canopy and filamentous green algae and rooted aquatic plants become more common (Cummins 1974). These begin to replace organic debris as the food source for aquatic microorganisms and invertebrates. However, the interaction between the riparian area and the stream remains. Small fish still find refuge along the margins of streams and depend on insects and plant materials from the surrounding forests for food (Manci 1989). During flood events, organic debris is washed from the riparian area into the stream, providing an important surge of nutrients and dissolved carbon for plant growth. The productivity of mid-order streams is also influenced by the quality of the water, nutrients, and organic matter that they receive from upstream reaches. Although woody debris plays a lesser role in the main stream channel, it is still found in the riparian area and along river banks, providing large stable substrate for invertebrate communities and a source of food, habitat and cover for fish (Wallace and Benke 1984).

Much of the world’s freshwater fish production occurs in large rivers (Gregory et al. 1991). In large rivers and lakes, planktonic algae becomes the dominant food source, with seasonal inputs of forest litter less important (Welsch 1991). However, the connection with the surrounding riparian area is of equal, if not greater importance in supporting fisheries (Ahle and Jobsis 1994). During periods of high flow, rivers expand into the adjoining riparian floodplain, picking up large amounts of organic matter, nutrients, small organisms, and plant debris. Once flood waters return to their channel, this nutrient-enriched water increases the growth of aquatic plants and microorganisms. At the same time, flooding allows fish to migrate from the stream channel to feed and spawn in the floodplain. Because of the increase in available food and the expansion of the physical habitat, fish experience accelerated growth and improved condition during high water periods. Floodplain areas may also provide permanent habitat for some fish in isolated pools, oxbows and small backwater channels.

- Shelter. Through their life cycle, fish require different types of habitat. Recently hatched fish require shallow, protected areas that adult fish cannot enter and that have overhead cover for protection from predators. As juveniles, fish require shallow pools for feeding and the cover of boulders, brush, or vegetation. Adult fish require larger pools for feeding and security cover. Habitat for nesting is found in shallow areas not prone to washing out during storms or being buried by silt.

Trees increase the diversity of stream habitats when they fall into or drop limbs and other debris into streams. Large woody debris is important to stream communities because it can slow the force of stormwaters, trap leaves, twigs, seeds, and other important food items, supply cover, and create various small habitats such as deep pools and still backwaters. Logs provide escape cover for fish, an area for invertebrates to colonize, and resting and sunning areas for reptiles, amphibians, birds and mammals. Fish also find habitat in overhanging roots and streamside vegetation.

In his study of a small Appalachian stream, Minshall (1968) found the maximum diversity of aquatic species in streams bordered by mature woodlands. Species diversity decreased where forest cover was removed, in deep pools and in areas with sand-mud bottoms. Likewise, biologists at Virginia Tech found higher densities of brook trout, rainbow trout, and brown trout in southern Appalachian mountains streams with an abundance of large woody debris than in streams with less and smaller woody debris (Flebbe and Dolloff 1995). Statewide stream surveys in Minnesota showed that most fish species preferred habitat formed from woody debris for at least some of their activities (Aadlund 1996). Areas of the Mississippi and Illinois Rivers in western Illinois bordered by riparian forests have been found to support nearly three times the fish (by weight) as areas where riparian vegetation is lacking (Roseboom and Russell 1985). These river segments also have greater variety of habitats (pools, riffles), more in-stream cover (snags and tree roots), and greater bank stability.

Like fish, aquatic invertebrates also require a variety of habitats. They may live on either inorganic (sand, gravel, cobble) or organic (leaves, woody debris, tree roots) substrates. In the Piedmont area of southeastern Pennsylvania, Sweeney (1993) found that forested streams support larger benthic (bottom-dwelling) populations because forested streams are wider and they provide areas for benthic invertebrates to reproduce on roots and woody debris. The presence of large woody debris has been found to be an especially important substrate for aquatic invertebrates in the sandy bottom streams and rivers of the southeastern coastal plain. In the Satilla River, GA, Benke et al. (1985) found that invertebrate diversity, biomass, and production were all considerably higher on snag surfaces than in either sandy or muddy substrates. Snags represented only 4% of habitat surface in the river, yet supported 60% of total invertebrate biomass. In addition, four of the eight major fish species obtained at least 60% of their diet by feeding around snags. The scientists predicted that if snags were removed from the river, sunfish production would be reduced by as much as 70%, with a corresponding shift in the fish community to one dominated by suckers and small fish.

- Stream flow. Water velocity, depth and seasonal flow patterns are important factors that influence species distribution and life cycle activities of stream organisms. For example, in southern river swamps, dropping water levels induce dormancy in some aquatic salamanders and snakes, while rising water levels initiate breeding activity in certain fish (Clark 1978). Stream velocity also affects oxygen levels in streams, the retention of organic materials, and the ability of aquatic organisms to move up and down the stream. Loss of forest vegetation can affect streams and aquatic communities by increasing the intensity and frequency of flood events and the degree and duration of low flow conditions during droughts.

- Light and temperature. The presence of a forest canopy over small streams greatly affects the intensity of light reaching the surface of the stream (Sweeney 1993). Light intensity in a shaded area of a stream can be as much as 30% to 60% less than that of unshaded areas, depending on the season. The degree and seasonal pattern of light is important to the stream environment because it affects the production of algae and other aquatic plants.

The amount of sunlight reaching the stream also affects stream temperature. Temperature is a critical influence in aquatic ecosystems, affecting both the physical and biological characteristics of the stream. Higher stream temperatures can reduce the stream's oxygen- carrying capacity, increase rates of organic decomposition, and influence the rate at which nutrients are released from suspended sediments (Brown and Krygier 1967, Sweeney 1992). Slight increases in temperature can produce substantial increases in the amount of phosphorus released into the water, and temperature increases of as little as 9°F can produce heavy growth of filamentous algae (Cummins 1974). Warm temperatures also encourage the growth of parasitic bacteria (Brown and Krygier 1970). When water temperatures increase 6°F to 9°F, it may become impossible for species who require lower temperatures to continue living in the stream, resulting in a shift in community structure to species that can tolerate the increased temperatures (Karr and Schlosser 1978). Minshall (1978) found that both species diversity and total numbers of benthic organisms decreased significantly as forest cover was removed from stream banks, primarily as a result of increasing water temperatures. Temperature affects benthic organisms by influencing respiration, feeding, growth rates, adult size, fecundity, and timing of reproduction (Cummins 1974, Sweeney 1992). McCormick et al (1972) found that the optimal range of temperatures for growth and survival of young brook trout lies between 54 and 60°F. Trout may exist in warmer waters; however, physiological stress can reduce their resistance to predation and disease and inhibit feeding and reproduction (Swift and Messer 1971).

Removal of streamside vegetation can cause increases in daily and seasonal temperature variation and maximum summer temperatures. For example, scientists in North Carolina found that as mature hardwood forest cover was removed from streams in the Appalachian mountains, stream temperatures increased from the normal 66°F to 73°F or more (Swift and Messer 1971). Scientists at the Stroud Water Research Laboratory, in Pennsylvania have estimated that deforestation in southeastern Pennsylvania can result in a 4°F to 9°F warming of small streams, the equivalent to moving the stream 425 miles south (Sweeney 1992). Small shallow streams are especially vulnerable to increases in stream temperatures, due to their small volume (Brown and Krygier 1970). However, these streams will most quickly respond when shading is restored (Karr and Schlosser 1978).

- ***Water chemistry.*** The quality of water strongly affects the richness and abundance of aquatic organisms (Clark 1978). Extremely high or low nutrient or pH levels, low dissolved oxygen concentration, high sediment loads, or high toxic chemical content adversely affect the stream environment.

Sedimentation is considered a major factor in the decline of fisheries in the United States (Karr and Schlosser 1978). Sedimentation affects aquatic life by decreasing light penetration, reducing dissolved oxygen levels, and by introducing toxins into the stream (Chen et al. 1994). This in turn reduces the food base, impairs fish feeding due to reduced hunting success and reduces reproductive success (by covering spawning grounds and eggs, preventing the emergence of newly hatched fry, limiting the availability of oxygen to incubating eggs, and reducing water flow and removal of wastes) (Karr and Schlosser 1978). Very high levels of sedimentation can cause direct mortality to fish by clogging their gills and by preventing normal water circulation and aeration of the blood. Sediment deposits also affect the survival of insect larvae through the reduction of food, loss of habitat, and by smothering and sand abrasion (Chutter 1969).

Nutrient enrichment is also a serious problem in the nation's streams and lakes, affecting aquatic communities through direct toxic effects and by inducing excessive growth of algae and other aquatic plants. Riparian forest buffers can protect stream water quality as they reduce the amount of sediment, nutrients and other contaminants that enters the stream.

Stream restoration

Stream ecologists have observed that the recovery of streams is controlled by the rate of recovery of the surrounding terrestrial environment (Cummins 1974, Haefner and Wallace 1981). Many types of riparian buffers, including grasses, shrubs, and trees, may improve water quality of streams by reducing the amount of sediment and nutrients that flow into the stream. However, the type of vegetation that is established alongside the stream will also influence the aquatic community through its effects on temperature, habitat, and food resources. Therefore, native hardwood species are often recommended for revegetating riparian areas (Sweeney 1993). Trees that are especially beneficial to the aquatic community are those with strong root systems that tend to grow over water, are long-lived, grow tall, and provide a large, dense crown for shading (Higgins 1996).

Table 3.2. Habitat Requirements of Major Fish Families

Family	Oxygen	Temperature	pH	Turbidity Tolerance
Carp	>0.5 ppm	70-90^0 F	7.5-9.0	High
Catfish	>4.0 ppm	70-90^0 F	7.5-9.0	High
Sunfish	>5.0 ppm	73-80^0 F	7.5-8.5	Low-moderate
Bass	>5.0 ppm	73-80^0 F	7.5-8.5	Low-moderate
Trout	>5.0 ppm	50-60^0 F	6.0-8.0	Low

From: Palone, R.S. and A.H. Todd (eds.).1997.Chesapeake Bay riparian handbook: A guide for establishing and maintaining riparian forest buffers. USDA Forest Service NA-TP-02-97.

Chapter 4

Benefits to Communities and Landowners

Aesthetic and cultural benefits

For much of human history, river and stream valleys have been the focus of exploration and settlement, and the place of economic and social activity (Emerson 1996). Early transportation networks were based almost entirely on river systems. As a result, riparian areas are rich in historic, archeological and other cultural features.

Riparian areas also have rich aesthetic appeal. Litton (1977) suggests that water in the landscape tends to draw people because of its "visibility, movement, reflections and color, its consequent contrasts to adjacent earth surfaces". He suggests that the aesthetic appeal of a stream or river is a function of topography, relief, stream form, vegetation types and arrangement, the water variability and pattern of the water, and human use and impacts. Other features, such as the presence of rapids, can increase the appeal of the stream as well (Kuska 1977). Streams that are more sinuous are often more interesting, because a hidden view contributes to a sense of "mystery" to the experience. The presence of a large, open scenic vista as well as the 'local' view also contribute to the total picture (Leopold 1969, Brown and Daniel 1991). However, the presence of litter, man-made features (utilities, roads, dams, etc.), and evidence of poor water quality (discoloration, turbidity, odor, algae) can distract from the aesthetic appeal (Leopold 1969, Hoover et al. 1985).

Streamside vegetation adds to the area's beauty (Higgins 1996). Although each individual has different scenic preferences, most people enjoy viewing old, tall, large-diameter trees. A variety of textures and colors are also desirable characteristics. Many of the participants in Maryland's Buffer Incentive Program considered aesthetic factors critical or somewhat important in their decision to install riparian forest buffers (Hagan 1996). Some enjoyed the privacy provided, while others just "liked trees". One landowner noted that the buffer provided a "great source of satisfaction and beauty".

Recreational benefits

In recent decades, interest in and use of riparian areas for recreational enjoyment has greatly expanded (Pigrim 1983, Pawelko et al. 1995). Not only have stream corridors attracted more users, there is a greater diversity of recreational activities occurring within these environments. Today we find people engaged in traditional uses, such as trapping, hunting, and sportfishing, and others who are rafting, kayaking, motorboating, hiking, biking, or simply observing nature.

The importance of streams and riparian areas in providing recreational opportunities is reflected in a survey of visitors to the Delaware River Valley (Pawelko et al.1995). Recreationists were drawn to the area for its clean water, exceptional fisheries, wildlife, and historic and cultural resources. Many visitors, even first time users, shared a concern for and attachment to the river valley. Their comments reflected feelings of possessiveness (for example, "my river"), gravitation to water ("I never get tired of seeing it"), protectiveness ("I would like to see the river remain unpolluted"), or cultural identification with the area ("It's being able to know firsthand what it was like for the pioneers"). Some had developed a tradition of visiting the area with family or friends ("My family comes here every year"). Others came to participate in specific activities

("I'm a kayaker"). Almost unanimously, their comments reflected the sense that the river provided them an important source of mental and physical refreshment.

Residents of Alabama reported that they visited river environments to drive for pleasure along the stream, picnic or fish (Clonts and Malone 1990). Other reasons for visiting were to observe or photograph nature, swim, hike, camp, canoe, hunt, boat, or raft. These individuals indicated they were willing to pay nearly $57 per year per household to protect the state's rivers in their natural condition. Although economists warn that these types of surveys can often overstate the amount individuals would actually pay, this study suggests that Alabama's citizens recognize stream environments as an important natural area. The most important reasons reported for preserving the rivers were to protect fish and wildlife habitat, water quality, air quality, and scenery. They also wished to protect rivers for future generations, just for the satisfaction of knowing rivers exist and are protected, and to preserve the option to use the rivers in the future.

Riparian areas in urban centers can be especially important places where residents can escape from the activity in the city and engage in recreational activities. A 1995 survey of Marylanders found that nearly 77% felt that it was important to them to have natural areas close to where they live and work. Almost half said they would be inclined to move if existing open space in their community were lost (Palone and Todd 1997).

Economic benefits of wildland recreation

Recreational use of riparian areas can also be a potential source of income for landowners and communities. A 1996 survey of Virginians found that 44% of the population participates in some form of wildlife-related recreation, such as hunting, fishing, or wildlife-watching (US Fish & Wildlife/Bureau of the Census 1996). Recreational fishing contributed almost $821 million to the state's economy; while hunters contributed another $519 million (Table 4.1). In addition, Virginians spent almost $698 million observing, feeding, and photographing wildlife. In Maryland, it is estimated that waterfowl hunting alone generates almost 160 jobs and $3.5 million per year (Lynch 1997). Access for waterfowl hunting generally runs about $3 to $5 per acre for an annual lease, or as much as $80 fee for a single day (Palone and Todd 1997). Professional guides can earn between $7000 to $30,000 during the winter season.

Table 4.1. Percent of Residents Participating in Wildlife-Associated Recreation and Revenues Generated

	Virginia	Mid-Atlantic Region	Nationwide
Fishing	13% $821 million	12%	13% $37.8 billion
Hunting	3% $519 million	5%	7% $20.6 billion
Wildlife-watching	37% $698 million	27%	31% $29.2 billion

From: U.S. Fish & Wildlife and U.S. Bureau of the Census. 1996 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation. USF&WL FHW/96 NAT.

Recreational boating, canoeing, and floating are other popular stream activities. A study of whitewater boaters on the Upper Youghiogheny River of western Maryland found that in 1988 they contributed nearly $1.2 million dollars to local economies and another $1 million in neighboring states (Gitelson and Graefe 1990). This included dollars paid to local rafting companies, lodging, food and beverages, entertainment, souvenirs, boating equipment, and auto-related items.

Pollution of streams by sediment, nutrients, and other pollutants has a variety of impacts on recreation, including destruction of fish habitat, siltation and eutrophication of waterways, and closing of swimming areas (Ribaudo 1986). The 1994 EPA National Water Quality Inventory Report to Congress identified 374 sites in 22 states where recreation was restricted due to poor water quality, with bacterial contamination cited as the most common cause of these restrictions. (US EPA 1995).

Impact of recreation on riparian areas

The construction of riparian forest buffers along streams and lakes can increase the aesthetic beauty of the area, improve water quality for swimming and boating, and enhance the area's fisheries and recreational opportunities.

However, if recreation occurs without proper management, the aesthetics and many of the benefits the riparian area provides may be lost. Heavily used areas may experience soil compaction, reduction in soil organic matter and soil moisture, increasing rates of erosion, injury and mortality to riparian vegetation, disturbance to riparian animals, alteration of stream habitats and water quality problems (including increases in fecal coliform bacteria, and other contaminants such as motor oil, cleaning detergent, and garbage) (Wall and Wright 1977, Clark et al. 1985b, Pigrim 1983, Harris et al. 1990).

Along the Grand Canyon, problems caused by river recreationists include fire, littering, trampling of vegetation, and human waste disposal (Aitchison et al. 1977). In addition, nuisance insects, and introduction of certain lizards, exotic birds, and mammals into remote areas has occurred. Researchers in California found that placing campgrounds in riparian areas reduced vegetation density, deadwood, soil litter depth, and resulted in changes in the avian community (Blakesley and Reese 1988).

As riparian areas become more popular, there is also the likelihood that conflicts may develop among users (Pigrim 1983). For example, there may be incompatibility between new visitors and traditional uses of the site, or between different types of recreational activities (for example, water skiing and fishing). Conflicts can also develop between recreational uses and other uses of the stream, for reservoirs, power generation, industrial purposes, navigation, and waste disposal. Some of these are compatible with recreation, while others are incompatible or may detract from the recreational experience. Sometimes, conflicts can also arise between river users and property owners whose land is adjacent to recreation streams.

Homeowners are often attracted to riparian areas not only for the recreational benefits, but also for the water view they can provide. In fact, this desire for a water view can hinder efforts to install riparian forest buffers in developed areas. As one landowner observed "Why have waterfront property if you can't have the view?" (Hagan 1996). Along shorelines where high land values and tax liabilities are in effect, giving land over to environmental uses may be difficult to accomplish. A study in New England estimated the per acre cost of development rights were as much as 53% higher on parcels that had a panoramic view of the water than on parcels which had no water view (Wichelns and Kline 1993).

Community benefits

Besides providing recreational and aesthetic value, people also benefit from the water quality benefits that riparian areas provide. Although riparian forest buffers cannot begin to mitigate all of the impacts of polluted waters, they can play an important role in reducing the amount of sediment, nutrients, and other contaminants that reach streams and lakes. As a result, communities may benefit from reduced costs of water treatment, water storage, and dredging (Holmes 1988, Ribaudo 1986). In addition, riparian buffers can reduce flood damage to communities and croplands and maintenance to drainage ditches and irrigation canals (Clark 1985, Park and Dyer 1986). Buffers can also benefit groundwater supplies, as well as commercial fisheries and agriculture.

Water treatment and storage costs

Communities across the nation spend millions of dollars each year to treat contaminated waters (Clark et al. 1985a). As nutrients, sediments, and other contaminants move off the land and into streams, the costs of treating municipal water supplies increase as sediment basins must be built, filters cleaned more frequently, and chemical coagulants and disinfectants are added. Water which is turbid may also have serious taste and odor problems. In 1991, the costs of treating contaminated water was estimated to be $10 to $15 per month for a family of three (Welsch 1991). Communities such as Washington, DC spend as much as $3 to $5 per pound to remove nitrogen from wastewaters (Palone and Todd 1997). In the right location, forested buffers can remove as much as 21 pounds of nitrogen per acre per year, along with about 4 pounds of phosphorus per acre per year from upland runoff.

Many studies show the public has an interest in maintaining clean water supplies and are willing to pay for programs which will improve water quality. For example:

- A nationwide survey conducted during the early 1990s found that individuals were willing to pay on average $275 to $366 per household per year to improve water quality to a "swimmable" level (Carson and Mitchell 1993).
- Residents of Georgia expressed a willingness to pay $5.49 to $7.38 per month to improve the quality of their drinking water in their state, even though most rated their water quality currently as very safe, safe, or fair (Jordan and Elnagheeb 1993).
- Another survey of Georgia residents found they were willing to pay $641 annually per household for a program that would protect groundwater supplies (Sun et al. 1992).
- Citizens of Dover, New Hampshire were willing to pay $40 per household annually for a groundwater protection plan (Schultz and Lindsay 1990).
- A survey of citizens from Indiana, Nebraska, Pennsylvania, and Washington indicated a willingness to pay nearly $55 per month to remove all nitrates from their water supplies (Crutchfield et al. 1997).

Contaminants can also cause problems for industrial users. Contaminated water can increase industrial expenses as they cause steam electric power plants to operate less efficiently, clog cooling equipment, corrode pipes, and increase the rate at which pumps and other equipment wear out. Ribaudo (1986) estimated that suspended sediment and algae cost steam electric power plants and other water cooling facilities $24 million annually (1983 dollars) in maintenance costs.

Sedimentation of streams and lakes also increase the rate at which lakes and reservoirs are filled, costing communities millions of dollars to create new facilities and to maintain existing reservoirs. In 1985 (a), Clark et al. estimated that 1.4 to 1.5 million acre-feet of reservoir and lake capacity is permanently filled each year with sediment. In addition, nearly a million acre feet of additional storage capacity, at a cost of $300 to $700 per acre-foot, must be built to capture and store sediment (Clark et al. 1985a). Nationwide, sedimentation of water storage facilities costs communities nearly $1.1 billion annually (1983 dollars) (Ribaudo 1986).

Navigational impacts

Sedimentation of harbors and navigational waterways reduces their capacity to handle commercial ships and often means dredging is required to keep the channels navigable. For example, each year, Baltimore Harbor alone spends almost $10 to $11.5 million to dredge sediments (Palone and Todd 1997). Besides the expense, dredging can create water quality problems by creating turbidity and stirring up heavy metals and other contaminants from the bottom. There is also the problem of where to deposit the dredged material. Dirty waters have also been linked to shipping accidents and shipping delays and cause damage to ship engines and propellers.

Flood damages

Damages caused by floods costs communities millions of dollars each year. The Roanoke Valley of Virginia has had nearly $200 million in flood damages to more than 12,000 homes and 1,000 businesses since 1975 (USA Today, March 24, 1998). Recently, a regional flood control plan has identified 130 projects, expected to cost $61 million, which are needed to reduce flood damages. In addition, $60 million will be required to floodproof or relocate structures out of flood-prone areas. Annual flood damages in the U.S. in 1986 were estimated at $887 million per year (1983 dollars) (Ribaudo 1986).

Riparian forest buffers play an important role in flood control, as they provide a natural basin where floodwaters may spread out horizontally (Lowrance et al. 1985). Within the riparian area, the vegetation slows the speed at which stormwaters move through the floodplain, reducing the water's erosive potential, and capturing materials carried by the floodwaters (Gregory et al. 1991). Forests break the force of rain in their crown, generate porous organic soils, and drop organic material onto the forest floor - all of which increases their capacity to store water. Along the stream itself, vegetation helps to stabilize the bank by protecting soils and reducing streambank scouring (Karr and Schlosser 1978). Restoring forests along smaller stream means more storm flow is captured and retained higher in the watershed.

The loss of riparian vegetation from the floodplain results in an increase in the volume and velocity of floodwaters as they move downstream, since the reduced vegetation and woody debris creates less resistance to water flow (Osborne and Kovacic 1993). Sedimentation of streams also contributes to flood damages by filling in streambeds and increasing the frequency and depth of flooding, by increasing the volume of flood waters, and because of the additional damage caused by the sediment itself during flood events. Nearly half of all flood damages are to agriculture, when crops and livestock are destroyed and soil is washed away (Guldin 1989).

Severe floods in Virginia in 1994-95 resulted in more than $10 million in damages. In areas where forested buffers existed, damage to river banks and adjacent farmlands was reduced (Palone and Todd 1997).

Groundwater

Safe, dependable supplies of groundwater are important to people as well as stream systems. In the U.S., groundwater is used for public and domestic water supplies, irrigation, livestock watering, mining, commercial uses, and thermoelectrical cooling systems (US EPA 1995). Nearly 34% of Virginia's citizens depend on groundwater for drinking water, including 70% of those who have private wells (VA DEQ/DCR 1998).

There is a close association between surface and groundwaters. Groundwater is replenished or "recharged" by percolation of precipitation through the soil and by seepage from stream channels (Guldin 1989). Water also moves from groundwater into the stream. Therefore, polluted surface waters can contaminate groundwater, and vice versa. In some streams, as much as 40% of the annual streamflow and nearly all the flow during dry periods is provided by groundwater. This continuous flow of water is critical to maintaining adequate stream water levels and temperatures to support aquatic life. Removal of vegetation on riparian lands can result in loss of groundwater recharge and increase the frequency, duration, and severity of low flow conditions in streams.

Commercial Fisheries

In 1991, over 9 billion pounds of fish and shellfish with a value of over $3 billion were harvested by commercial fishermen (US EPA 1995). It is estimated that nearly three-quarters of commercially valuable fish and shellfish depend directly or indirectly on coastal estuaries and river basins for spawning grounds or nurseries. When sediment and other pollutants accumulate in these waters, they can destroy habitat for the organisms that live and spawn there. Ribaudo (1986) estimated that damages to marine fisheries due to man-made pollutants was over $1 billion, and damages to commercial freshwater fisheries were another $150 million per year.

Additional benefits

Besides protecting streams and water supplies, riparian forest buffers provide additional benefits to communities. Trees help clean the air as they trap and filter air pollutants during the process of evapotranspiration. For example, in 1991, the city of Chicago estimated that trees removed 17 tons of carbon monoxide, 98 tons of nitrogen dioxide and 210 tons of ozone from the atmosphere (Palone and Todd 1997). Urban trees also reduce heating and cooling costs for communities by buffering winds, providing shade, and cooling the air. Studies on the home heating benefits of shelterbelts in Canada suggest that tree plantings can result in as much as a 15-30% savings in home heating costs, depending on weather conditions and house construction (Kort 1995). The value of cooling costs ranged from $15 to $20 per year in Minneapolis to $85 to $170 in Phoenix.

Benefits to landowners

Agriculture

Damages to agriculture due to water pollution include contamination of water for livestock, irrigation, and personal use, as well as increased flooding, silting of bottomlands, and filling of drainage ditches and sediment ponds due to siltation.

Livestock operations, in particular, benefit from safe sources of drinking water for their animals. For example, high levels of sulfates in drinking water can contribute to decreased egg production in chickens (Veenhuizen and Shurson 1992). Many species of animals are susceptible to nitrate or nitrate poisoning, especially cattle (Johnson et al. 1994a). Excessive consumption of nitrates has been associated with abortions and other reproductive problems, because it reduces the transfer of oxygen to the fetus. Nitrate poisoning can also cause anorexia, lowered blood pressure, and reduced lactation. Livestock may also be affected by a variety of pathogenic organisms that are transmitted from manure-contaminated waters (Overcash et al. 1983, Palmateer 1992). These include organisms that cause scours, mastitis, salmonellosis, leptospirosis, brucellosis, listeriosis, tetnas, staphloccus, tuberculosis, bronchitis, and other diseases. A survey of farmers who participated in Pennsylvania’s stream fencing program reported that the health of their herd improved when the livestock were no longer allowed in the stream (Kasi and Botter 1994). The animals were also less prone to injury, as they were no longer climbing up and down streambanks.

Forested buffers may also provide a farm windbreak. The shelter of trees can reduce loss of soil from wind erosion, and reduce heating and cooling costs to farm buildings and homes (Kort 1995). Livestock benefit from shade and winter cover, which help to maintain milk production and weight gain during extreme weather (Dronen 1988).

Income opportunities

Riparian areas can yield many valuable products, including wood products, foods, floral products, aromatics, pharmaceuticals, and weaving and dying materials. Landowners may also develop recreational enterprises in these areas.

Wood products. Forested buffers may be used to produce fuelwood, sawtimber, and other wood products (Walbridge 1993, Schultz et al. 1994). Because of high soil moisture and nutrient availability, these areas are often highly productive sites for growing trees, and particularly in the southeast, valuable hardwood sawlogs. Riparian areas can also produce fuelwood to fuel grain driers, space heaters, and small electric generators.

Researchers in Iowa have suggested an innovative design for producing fuelwood in riparian areas based on the 3-zone buffer system proposed by Welsch (Schultz et al. 1994). They suggest using specially selected fast-growing tree species (hybrid poplar, green ash, silver maple, black walnut, ninebark, red osier dogwood) that are grown as short-rotation woody crop systems to produce biomass for energy in 5-8 years and timber products in 15-20 years (except black walnut, which is grown on a 45-55 year rotation). These particular species were selected because they grow rapidly, reproduce vegetatively by stump or root sprouts, and develop large root systems required for rapid nutrient uptake and soil stabilization. These trees are combined with native shrubs and grasses to enhance wildlife habitat.

Also in Iowa, Louis Licht (1992) has proposed planting an "ecolotree buffer", of closely spaced (l ft apart in rows 40" apart) hybrid poplars for fuelwood production. Hybrid poplars were suggested because they grow very fast in densely planted buffers (producing over 20,000 pounds of wood per year); they coppice easily (producing 2 to 16 new shoots from a harvested stump); they produce roots that grow deep within riparian soils; they are easily cloned from stem cuttings; and they are phreatophytic, capable of surviving root and stem submergence. Preliminary results from his research indicate that the trees grow to almost 18 feet high in 2 ½ years, while they reduce nitrate-nitrogen concentrations in shallow groundwater by nearly 90%.

Other crops. Riparian areas can be used to produce other crops such as aromatics, botanicals, pharmaceuticals, cooking wood (such as apple, cherry, and alder), weaving and dying materials, decorative cones, mushrooms, nuts, fruits, honey, maple syrup, and pinestraw. Cut flowers, including cut ornamental grasses, cut grains, cut wildflowers and weeds, and shrubs which produce berries, have unusual or colored bark, or have flowering stems for forcing can be grown in some areas (Kelly 1991).

One large Virginia grower produces a wide assortment of woody stems and flowers for sale to the Washington, DC area (Jenkins 1991). These include cut woody stems for forcing (pussy willow, flowering quince, forsythia, plum, cherry, peach and crabapple), woody ornamentals for flower production (Bradford pear, Japanese cherry, redbud, spirea, dogwood, mock orange, viburnum, hydrangea, lilac, and weigela), berries (pyracantha, nandina, bittersweet, and deciduous holly), plants with interesting twigs (euonymous, and red twig dogwood), and evergreen foliage (privet, holly, pine, spruce, boxwood, and magnolia).

Commercial markets also exist for Baby's breath, cattails, mosses, galax, grapevines, witch hazel, corkscrew willow, fantail willow, and birch. In the upper Midwest, sapling-size birch, ironwood, and alder trees are harvested for ornamental purposes (Eisel 1988). Grasses (including love grass, plume grass, Indian grass, fountain grass, reed grass, grama grass and switch grass) and weeds (such as Queen Anne's Lace, wormwood, teasel, goldenrod, wild yarrow, and milkweed) have commercial potential as well (Meyer 1988, Weiler 1988).

Researchers in Indiana have suggested a plan for farm windbreaks that may be applicable to the riparian buffer and would provide income for the farm owner (Miller et al. 1994). They suggest a strip of trees and shrubs (in the riparian area, this would be adjacent to the stream), bordered by a strip of perennial livestock forage to be cropped for hay. They suggest shrubs which may be sold as floral crops or landscape stock (corkscrew willow, pussy willow, yellow twig dogwood, red osier dogwood, forsythia, redbud, sea buckthorn, witch hazel), shrubs for fruit production (hazelnut, elderberry, Nanking cherry) grapes (for fruit and wreaths), trees for fruit production (persimmon, Chinese chestnut, apples, and pears), Christmas trees, hardwoods for fenceposts and firewood, balled and burlap landscape stock, and trees for timber production (green ash, black walnut and northern red oak). They found that branches from the shrubs could be harvested within two years of planting, and they resprouted to grow a new crop quickly. Gross returns in excess of $33,580 per acre were anticipated from the sale of pussy willow branches. However, the researchers point out that the timing of planting and removal must be staggered to assure that an effective buffer remains in place.

Kort (1995) has suggested the use of income producing trees and shrubs for shelterbelt plantings in the Great Plains States and the Canadian Prairie Provinces. He suggests the use of box elder for the production of syrup and saskatoon berry for fruit production. Choke cherries, highbush cranberry, buffaloberry and sea-buckthorn were also being investigated as species with commercial potential. He estimates that 55-year old shelterbelts in southern Manitoba should yield 3211 board feet of green ash per half mile and 4953 board feet of American elm per half mile, for a combined value of $3464 of hardwood per half mile.

There are two obvious concerns about developing alternative income crops in riparian areas. The first, from the growers perspective, is finding a way to reasonably incorporate them into ongoing farm operations, and marketing the products once harvested. Markets for these types of products are highly variable, and landowners may have work to establish markets with local retailers, such as grocery stores, florist shops, and craft stores to establish a local buyer. Facilities and costs for harvesting, packaging, storage, handling, and shipping must be considered. From the environmental perspective, there may concerns about the loss of native plant diversity and the impacts of harvest activities on the functioning of the buffer.

Recreation. Landowners may derive income from the leasing of hunting and fishing rights to their property, or from developing other recreational opportunities such as wildlife observation/photography areas or swimming/boating areas. On the Eastern Shore of Maryland, hunters and professional guides paid an average of $10, 000 per farm in 1988 to lease lands with access to waterfowl (Lynch 1997). Many farmers work as part-time hunting guides during the winter season, reporting incomes between $7,000 to $30,000 for their services. Hunters also purchased food, lodging, equipment, clothing, and other items. Some farms earn additional income by offering shoot and release of pen-raised birds, sporting clays, services to clean game, and similar enterprises.

Chapter 5

Planning, Establishment, and Maintenance

Riparian forest buffers can provide many ecological and societal benefits. However, it is important to recognize that all not buffers will provide all benefits equally. Every situation presents different problems and opportunities and requires different solutions. Therefore, careful planning and design of the riparian forest buffer are needed to maximize the benefits the buffer can provide.

Objectives

The first step in designing the buffer is to clearly define what the buffer is expected to accomplish. Consider questions such as: Are there water quality problems that need to be addressed? Is flood control an issue? Are fisheries a concern? Is wildlife a primary objective, and if so, what are the species of interest? What are the landowner's personal interests in restoring the buffer? Do they include aesthetic and recreational benefits? It is important as well to consider how the placement of the buffer will affect the management of the land. For example, stream crossings may be required to maintain access to all of the property, and fencing livestock out of streams will mean that alternate watering sites must be established. Finally, determine if there are any financial, personal, or time constraints that will make buffer establishment and future maintenance difficult. Remember, the restoration of riparian forest buffers is a long-term process requiring the ongoing commitment and involvement of the landowner.

> "River restoration is a multi-disciplinary art that involves some knowledge and experience in hydrology, geology, soil science, aquatic habitats, civil engineering, forestry, and horticulture."
>
> Deborah G. Mills
> Virginia Department of Conservation and Recreation

Site assessment

Next, evaluate the site and determine if site conditions can reasonably be expected to produce the desired benefits. The evaluation should take a look at stream conditions upstream and downstream as well as in the immediate area (Palone and Todd 1997, Firehock and Doherty 1995, Hoffman et al. 1998).

Watershed. To understand the forces affecting a particular stream segment, it is important to look not only at what happens within the stream and on its banks, but within the entire watershed. The stream will be influenced by many factors, including watershed size, geology, hydrology, soils, and vegetation. However, one of the most important influences on the stream is the way the land is used. For example, streams which flow through urban areas are subject to high pollution loads and increased volume and velocity of stormwater flows. Agricultural activities can contribute to high loads of sediments and nutrients and damage to streambanks from livestock grazing. Industrial activities, mining, dams, and wastewater treatment facilities can have a significant impact on discharge and nutrient and sediment loads.

Aerial photographs, soil survey maps, topographic maps, State geological maps and land use maps can each provide useful information on a watershed level. Attempt to identify: 1) Where is the stream located in the watershed? Is it a headwater stream, a mid-order stream, or a major stream artery? 2) How is the riparian area linked hydrologically with the uplands and with the stream? 3) What is the most important water quality problem in the watershed? Where and when does the maximum discharge of pollutants occur? 4) What fish and wildlife species are found in the area and how might they be influenced by the buffer? 5) What will be the impact of placing a buffer at this particular location? Will watershed landuses override the ability of the buffer to produce the expected benefits? (Schnabel et al. 1994, King et al. 1997).

Sometimes, watershed impacts can result in severely degraded, unstable stream systems (Firehock and Doherty 1995). This is particularly true when the watershed is undergoing a great deal of change, for example, when forest or agricultural lands are being converted to urban uses. When this is the case, attempts to repair streams are likely to be unsuccessful unless the source of the problem can be addressed.

Riparian area. Next, the evaluation should focus on the condition of the riparian area, including the site's hydrology, soils, and vegetation (Myers 1989, Hoffman et al. 1998).

Riparian area hydrology can be difficult to evaluate, however the lay of the land, the steepness of slopes, and observations of soil conditions during the wet season can provide valuable clues. If soils are saturated, this is a good indication that groundwater flows close to the surface. If the area is well drained, groundwater flows are deeper. The absence or presence of wetlands and observations of sediment deposits and erosion patterns also provide useful information (Palone and Todd 1997). The width of the floodplain, and flood frequency, duration, and season are other important hydrological features.

Soil survey maps provide good information on the character and types of soils found in the riparian area. However, riparian area soils can be highly variable, even within short distances (Myers 1989). Therefore, soils should be sampled at intervals to determine soil type, texture, pH, presence of mottles and/or a clay layer and other attributes.

Existing riparian vegetation can be a good indication of which species will grow well on the site. The vegetation can also provide valuable clues to the area's soils and hydrology. Species, age, and density of the vegetation as well as presence of exotic invasive species should be noted. The presence of wildlife and wildlife habitat, cultural resources, and human disturbance should also be recorded.

Stream. Before the riparian forest is reestablished, it is important to evaluate the condition of the stream and its channel. Although it is natural for streams to shift their course over time, activities on the land can accelerate the process dramatically and result in an unstable stream system with rapidly eroding banks. When this occurs, it is necessary to stabilize the channel before attempting to restore riparian vegetation. If the erosion is especially severe, the source of the problem on the land must be first addressed or the restoration is likely to be unsuccessful.

To judge whether the stream is stable or undergoing rapid change, some basic observations are needed. First, observe the shape of the stream channel. Straight streams are extremely rare in nature, and are usually an indication that the stream has been channelized. Over time, channelized streams will move about as they try to regain their natural course. Channel width, depth, and slope are other important channel features.

One commonly used system of evaluating stream stability was developed by David Rosgen (1994). The Rosgen classification is based on the principal that the shape of the stream channel is directly influenced by the stream velocity and discharge; sediment load and size; channel width, depth and slope; and type of bed material. A change in any one of these variables results in a series of adjustments in all of the others, and ultimately a change in the pattern of the stream itself. For example, in response to increased bank erosion, the stream may become wider and more shallow, become less sinuous, increase the slope of the river bed downstream, and/or form sandbars. If these variables are measured and understood, they can be used to predict the response of the stream to disturbance, its potential for recovery, and to select the best design for long-term stability.

Besides the stream channel, observe the streambank. Streambanks that are well vegetated and showing little erosion usually are stable. Overly steep banks, frequent tree fall, poor bank vegetation, and widening of the stream channel are indicators of less stable conditions. Then, look within the stream. Healthy streams usually have a combination of pools (deep sections outside of bends and below large rocks and woody debris), riffles (shallow areas where water bubbles over rocks), and runs (straight sections). The presence of overhanging trees, large woody debris within the stream, and aquatic vegetation are also important habitat features. Finally, make observations on water quality (color, odor, presence of algae, etc.) and the composition of invertebrate and fish communities (Myers 1989, Hoffman et al. 1998).

Key components of site assessment are summarized in Table 5.1.

Table 5.1. Site Assessment Checklist
Watershed Considerations Hydrology Geology Topography Watershed size Intensity and type of landuse Sediment and nutrient loadings
Site Considerations - Riparian Area Hydrology (depth to the water table, presence of wetlands, flow paths) Width of 50 and 100 year floodplain Soil characteristics (texture, color, permeability, erodibility, hydrologic group) Slope Riparian vegetation Wildlife resources Cultural resources Human disturbance
Site Considerations - Stream Stream order/size Flood frequency Water velocity Channel shape, width, depth, slope

Streambank stability
Presence of pools, riffles, runs
Presence of in-stream habitat structures (e.g., woody debris)
Channel substrate
Water quality (color, odor, presence of algae, etc.)
Aquatic community

Design

Three-zone riparian forest buffer system. In 1991, the U.S. Department of Agriculture developed guidelines for restoring riparian forest buffers (Welsch 1991). They proposed a "three-zone approach" to restoring and maintaining forest buffers, with each zone providing some specific function. Nearest to the stream is a zone of undisturbed forest managed to stabilize streambanks, provide shade, moderate stream temperatures, and provide large woody debris to the stream (Zone 1). Adjacent to Zone 1 lies an area of managed forest (Zone 2). The purpose of Zone 2 is to provide water quality benefits through vegetative uptake and biogeochemical processes in the soil. Native deciduous trees are suggested for planting in Zones 1 and 2, to maximize habitat value for fish and wildlife and water quality benefits. As the stand matures, selective timber harvesting and timber stand improvements are necessary in Zone 2 to promote vigorous growth of the trees. Zone 3 is an area of dense grass that lies between the forest buffer and adjoining landuses. The purpose of Zone 3 is to slow and spread concentrated flows of water coming from the land, in order to promote the release of suspended sediments and the infiltration of surface runoff into the ground. Native warm season grasses are often suggested for planting in Zone 3, because of their tall, stiff stems and their deep root systems (Schultz et al. 1995).

Width. One of the first questions most landowners ask is - how wide does the buffer need to be? Unfortunately, there is no one single "ideal" buffer width. The proper buffer width depends both on site characteristics and what benefits are expected from the buffer. In the Chesapeake Bay region, a buffer of 35 feet on each side of the stream is generally suggested to benefit the aquatic community, with the buffer expanding to 75 to 100 feet per side to produce water quality and wildlife benefits (Palone and Todd 1997). Other researchers have suggested different "rules-of-thumb" for determining the proper buffer width. For example, E.S. Verry, a hydrologist with the U.S. Forest Service in Minnesota, suggests that a proper width for riparian management is "the active 50-year floodplain plus the terrace slopes", or approximately ten times the stream "bankfull" width plus 50 feet on either side (Verry 1996). In the Pacific Northwest, a team of scientists known as the Federal Ecosystem Management Assessment Team (FEMAT) recommends buffer widths (per side) equal to the height of a "site-potential tree", or the average maximum possible tree height for that site (the average "site-potential tree" in the eastern U.S. is 110 ft.) (O'Laughlin and Belt 1995). Many buffer functions (for example, providing shade, leaf litter, large woody debris, and stabilizing streambanks) are met with a buffer width of one site-potential tree height. Others, including wildlife and water quality benefits, require a wider buffer.

Stream size and stream order can also influence the size of the buffer needed. Headwater streams may not require the same degree of buffering as larger streams to provide the same benefit (Palone and Todd 1997). Buffer widths should also take into account the goals of the landowner and the desired functions (Table 5.2).

Table 5.2. Range of minimum widths for meeting specific buffer objectives

Objective	Buffer width (feet)	Considerations
Water quality		
Nutrient removal	15-200	Depends on hydrology, soils, loadings.
Sediment control	30-300	Depends on slope, soil type, sediment loadings.
Streambank stabilization	25-55	Choose deep rooted species that readily resprout.
Flood control	25-200	Depends on stream order, flood patterns. Select sturdy flood tolerant species.
Wildlife habitat	25-300	Depends on species of concern. Select native species for revegetation, particularly those which provide high value for food and shelter.
Aquatic habitat	60-110	Select native species for seasonal inputs of leaf litter and inputs of large woody debris.
Water temperature moderation	50-110	Depends on stream size and aspect, and the height, density, and crown size of the vegetation.

- ***Water quality.*** The design of riparian forest buffers to improve water quality is complicated by the need to control three different types of pollutants at the same time - sediment-adsorbed pollutants in surface runoff, dissolved pollutants in surface runoff, and dissolved pollutants in groundwater (Palone and Todd 1997). The design must also take into account the area's hydrology, soils, and pollutant loadings.

Buffers of 50 to 100 feet are generally recommended to trap sediments, with the buffer expanding where there are high sediment loads or steep slopes (as a rule of thumb, the buffer should expand about 5 feet for every 1% increase in slope) (Palone and Todd 1997). On flat sandy soils where sediment loads are low, narrower buffers may be effective (Magette et al. 1989). However, only very wide buffers will be effective in trapping small clay particles. For example, researchers in Arizona found that grass buffers could trap most sand from shallow surface runoff within about 10 feet and trap most silt within 50 feet, but as much as 300 to 400 feet of buffer was required to trap small clay particles (Wilson 1967). Similar observations were made by others in a riparian forest in North Carolina (Cooper et al. 1987).

The ability of the buffer to remove dissolved pollutants, such as nitrate, is highly variable and tied to the site's soils and hydrology. For example, when Phillips (1989) examined the buffering capacity of various riparian soils in North Carolina, he found that a buffer width of anywhere from 16 to 300 feet would be required to remove nitrates from the field drainage. Most frequently, widths of 35 to 125 feet are recommended to remove dissolved pollutants, depending on loads and site conditions (Palone and Todd 1997).

As a general guideline for restoring riparian buffers to meet water quality functions, David Welsch of the U.S. Forest Service Northeast Area recommends a width of 75 feet per side based on the “three-zone system” (Zone 1 - 15 feet, Zone 2 - 60 feet, and Zone 3 - 20 feet) (Welsch 1991). However, he suggests that the buffer should expand: 1) where frequent flooding occurs (soils of Hydrologic Groups C and D); 2) where certain soil types are present, for example very shallow or erodible soils (Soil Capability Class IIIe/s, IVe/s - increase the combined width of zones 1 and 2 to 100 feet, Soil Capability Class Vie/s, VIIe/s and VIII - increase to 150 feet); and 3) on steep slopes (increase width to one-third of the distance from the stream to the top of the slope). The U.S. Department of Agriculture Natural Resources Conservation Service recommends a minimum buffer width of at least 30% of the geomorphic floodplain, or at least 15 feet for Zone 1 and 20 feet for Zone 2 on all streams.

Dillaha and Hayes (1991) of Virginia Tech have recommended delineating “subwatersheds” (drainage areas) within the area to be protected and designing buffers to fit each.

- ***Bank stabilization.*** Where erosion is moderate, widths of 25 feet to 55 feet are recommended to stabilize and maintain streambanks (O’Laughlin and Belt 1995, Palone and Todd 1997). Along unstable streams, buffer width may be expanded to provide for future adjustments in the stream channel. If erosion is excessive, efforts should first be made to correct or moderate the problem at the source.

- ***Flood control.*** Along small streams, a narrow band of trees may be all that is necessary to provide moderation of flood waters. On large streams, wide buffers of sturdy flood-tolerant trees extending throughout the floodplain are recommended (Dosskey et al. 1997).

- ***Wildlife.*** The choice of a buffer width for wildlife depends on the species of interest. Some animals, particularly “edge species”, may require only narrow buffers (25 feet or less) to meet their needs, while others like large mammals and certain birds require a buffer of 100 to 300 feet (Croonquist and Brooks 1991, Keller et al. 1993). Forested areas as wide as 600 feet have been recommended where there are heron rookeries, bald eagles, or cavity-nesting birds (USDA NRCS 1996c). When managing for wildlife, the needs of the animal for food, shelter and certain environmental conditions (for example, cool moist environments for certain amphibians) will be as important as a creating a particular buffer width. Features such as snags, trees with large cavities, and mast-producing trees should be incorporated in the buffer plan.

- ***Aquatics.*** Important considerations for aquatic communities include inputs of food and structural elements (limbs, logs, overhanging roots) to provide shade and cover. To provide shade and temperature control for cold water fish, a buffer of 80 to 110 feet is recommended, although along small streams, a buffer of only 50 feet may be adequate (Dosskey et al. 1997, O’Laughlin and Belt 1995, Palone and Todd 1997). The level of shading will be influenced by the vegetation height, density, crown size, as well as stream size and aspect (Quigley 1981).

To incorporate sufficient large woody debris into the stream, buffers of 60 to 110 feet are recommended. The choice of trees and shrubs which are native to the riparian area can be as important as a particular buffer width in restoring aquatic communities, because the life cycles of many aquatic organisms are linked to seasonal inputs of particular species from the terrestrial environment.

- ***Recreation and aesthetics.*** The width of the buffer may be expanded to accommodate recreational activities. In these areas, the choice of aesthetically pleasing trees, for example those with showy flowers, fruit, color, or interesting texture and form may be a consideration.

- ***Marketable products.*** Landowners who wish to harvest a marketable product from the buffer must choose the appropriate species for planting. Depending on the product, the buffer width may need to expand in order for the operation to be economically viable.

Restoration

Restoration of the riparian forest buffer includes stabilizing the stream channel, preparing the site, planting the vegetation, and regular maintenance.

Stabilize the streambank. Where the stream channel is unstable the streambank must be stabilized before planting vegetation (USDA NRCS 1992). Channel stabilization may include a combination of structural techniques (“hard engineering”) and vegetative techniques (“soft” or “bio” engineering). Vegetative techniques are usually the best choice, due to their low expense, their more natural appearance, and the additional benefits provided to fish and wildlife (Firehock and Doherty 1995). Structural techniques may be required in some situations, for example, to protect important resources such as roads and buildings. Examples of structural repairs are riprap and concrete box structures. Examples of vegetative techniques are live stakes, tree revetments, live fascines, and brush layers and mattresses. Sometimes, boulders, logs, sandbags, or gabions (rock-filled wire cages) are used with the vegetation to provide additional stability.

Designing a successful streambank stabilization project requires experience and a good understanding of the stream and site hydrology. In addition, local, state, and federal permits are required for work in and along all surface waters (including lakes, streams, springs and wetlands) and within the 100 year floodplain. This includes, for example, construction of stream crossings and impoundments, installation of riprap and other materials, and any activities which will modify the stream channel. Therefore, it is important that you contact your local Soil & Water Conservation District for assistance in planning the project and to secure necessary permits before the work begins.

- ***Riprap.*** Rock riprap is a method of placing stones along the streambank to stabilize the soil. Sometimes, riprap is used to secure the base of the streambank while establishing vegetative cuttings. One disadvantage to using riprap is its unnatural appearance. Riprap can also raise the temperature of the stream as the rock absorbs solar radiation. Habitat benefits can be increased by placing plants between the rocks.

- ***Gabions.*** Gabions are rock-filled wire cages buried into the streambank used to stabilize erosion. Gabions are especially useful for protecting banks that have been scoured or undercut. Vegetation can be planted into the bank around the gabion to improve the effectiveness and the appearance of the structure.

- ***Live Cribwall.*** A live cribwall is a rectangular structure constructed of logs, rocks, and woody cuttings, and filled with soil and layers of live branch cuttings. The cribwall is built into the streambank to protect eroding banks and is a technique which is very effective on fast flowing streams. The cribwall provides long-term bank stability once the woody cuttings take root and grow. Cribwalls are not recommended where the bed is severely undercut, in rocky terrain, or on narrow reaches where banks are high on both sides.

- ***Bank revetments.*** Bank revetments are created to protect streambanks from erosion and to provide overhead cover and shade for fish. One type of bank revetment is a tree revetment. Tree revetments are simple to construct and are made by anchoring cut trees along a streambank with wire cable. Eastern red cedar trees are commonly used and work very well because of their dense branches. Tree revetments are most appropriate on small to medium banks (less than 12 feet high) that are experiencing moderate erosion. Other types of revetments may be created using boulders, root wads, and logs.

- ***Live Stakes.*** Live stakes are woody plant cuttings that will root quickly when placed in the soil. Once established, they provide vegetative cover and result in a very effective barrier to erosion. Live stakes can be very economical and require minimum labor to install. Alone, they are most effective as a preventive measure before severe erosion problems develop. Live stakes may also be used to stabilize areas between other bioengineering techniques. Willow is the most commonly used material for live stakes, although other species may also be used. Table 5.3 lists trees and shrubs which are suitable for use as live stakes.

- Live Fascines (wattling bundles). Live fascines are long (15 to 20 feet) bundles of live branch cuttings bound together with baling twine. Fascines are placed into trenches in the streambank, secured with stakes, and partially covered with soil. Fascines may be constructed from cuttings of materials that are on site, such as willow, shrub dogwoods, or other species which readily sprout from cuttings. Fascines offer immediate protection for the bank and provide additional stability once the cuttings take root. Fascines are particularly useful on steep, rocky slopes where digging is difficult.

- ***Branchpacking.*** Branchpacking involves alternating layers of live branches and soil into a washed out streambank. Branchpacks may be used both underwater and above fast moving water. Branchpacks form a very effective barrier that redirects water away from bank. They are often used for revegetating holes scoured in streambanks.

Table 5.3. Plants suitable for use as unrooted hardwood cuttings

Species	Region	Tolerance to Flooding	Tolerance to Drought	Tolerance to Deposition	Tolerance to Shade	Rooting ability	Habitat value	Form
Box elder *Acer negundo*	C P M	H	H	H	L	L	H	small tree
Groundsel bush *Baccharis halimifolia*	C P	M	M	H	L		M	large shrub
Silky dogwood *Cornus amomum*	P M	L	M	L	M	H	H	small shrub
Red osier dogwood *Cornus stolonifera*	P M	L	M	H	M	H	H	med. shrub
Gray dogwood *Cornus racemosa*	P M	M	H	M	M	H	H	med. shrub
Hawthorn *Crataegus spp.*	C P M	M	H	L	L	L	M	small tree
Eastern cottonwood *Populus deltoides*	C P M	M	M	H	L	H	M	large tree
Sandbar willow *Salix interior*	C P M	H	L	H	L	L	M	large shrub
Black willow *Salix nigra*	C P M	H	H	H	L	H	M	small tree
Streamco willow *Salix purpurea*	C P M	H	M	H	L	H	H	med. shrub
Bankers willow *Salix x cotteri*	P M	H	M	H	L	H	M	small shrub
American elderberry *Sambucus canadensis*	P M	H	M	M	M	M	H	med. shrub
Arrowwood viburnum *Viburnum dentatum*	C P M	M	M	M	M	M	M	med. shrub
Nannyberry viburnum *Viburnum lentago*	C P M	M	M	L	M	L	M	large shrub

Region: C=Coastal Plain, P=Piedmont, M=Mountains
Tolerance, Habitat value, Rooting ability: L=Low, M=Medium, H=High

From: USDA Natural Resources Conservation Service. 1992. National Engineering Handbook, Part 650 - Engineering Field Handbook Chapter 18.

- ***Brush mattress.*** A brush mattress is a blanket of long branch cuttings wired together and secured to the streambank with stakes (Hoffman et al. 1998). The brush mattress forms a complete cover for the bank and provides protection immediately after it is established. Brush mattresses can be very effective at capturing sediment and rebuilding an eroding bank. Once the plants take root, they provide long-term erosion control and dense plant growth. The disadvantage to this technique is that it requires a great deal of live material and is time-consuming to install.

- ***Lunker structure.*** Lunker structures are crib-like structures made of oak planks and blocks held in place with reinforcing rods. Lunker structures are commonly used in trout streams as well as small warm water streams to provide bank stabilization and instream cover for fish.

- ***Log-spur bank feature.*** The log spur bank feature is constructed by partially burying the top of a large cut tree in the stream channel with the lower branches pointing into the current. The lower half of the tree lies on the bottom of the stream and is anchored by boulders along the stream bottom. Log-spur bank features are designed to stabilize the stream channel and provide in-stream habitat for aquatic organisms.

- ***Deflectors.*** Deflectors are triangular, rock-filled structures used to divert the flow of water in the stream channel. They may be used to narrow a stream channel, increase flow velocity, divert water from a bank, or to create pools. Deflectors are commonly made of a log triangle that is secured to the stream bottom with steel pins. Deflectors are best suited for low-gradient streams where water levels are fairly stable.

Prepare the site. Once the streambank has been stabilized, vegetation can be planted in the riparian area. But first, some sort of site preparation is usually required. The degree of site preparation necessary will depend on the type of vegetation already found on the site, including the presence of invasive exotic weeds. Where livestock have access to the riparian zone, they should be fenced away before the area is revegetated. Fencing livestock from the stream will help stabilize streambanks, reduce bank erosion, and eliminate grazing on newly established vegetation. Where stream watering or crossing sites are necessary for livestock, select locations where there are smooth, low slopes and hard bottoms. Stone can be spread on entrance ramps to minimize streambank damage, and swinging flood gates can be erected across the stream to restrict livestock movement upstream and downstream.

In areas where invasive weeds are a problem, it is important to control them as much as possible before the vegetation is planted (Palone and Todd 1997). Where the problem is severe, this can require as much as a year of consecutive treatments. Weeds which can cause problems in riparian areas are phragmites (common reed), oriental bittersweet, Japanese honeysuckle, kudzu, porcelain berry, mile-a-minute vine, trumpet creeper vine, Japanese bamboo, privet, multiflora rose, Tree-of-Heaven, and Norway maple. Invasive weeds may be controlled by either mechanical or chemical means. Examples of mechanical control are mowing multiple times over the growing season to exhaust root systems, ripping them out with a tractor, or girdling the plants. However, these weeds can be very difficult to control with mechanical methods. Therefore, herbicides are recommended in areas where they can be safely applied. The only herbicide listed for direct application to aquatic areas is Rodeo[R], which is used in many areas for control of phragmites. Other herbicides may be applied in the riparian area away from the stream itself (note: see the herbicide label for precautions when applying near aquatic systems).

Herbicides acceptable for use in riparian areas are listed in Table 5.4; contact the Virginia Department of Forestry for additional recommendations (Palone and Todd 1997).

Once weeds are controlled, the ground should be prepared for tree planting. If the ground is currently in pasture, the area should be plowed and disked (up to three feet from the stream) and sprayed with an herbicide to control weeds. A cover crop (such as annual rye or field bromegrass or a mixture of switchgrass, deertongue, eastern gamagrass, and smartweed in wet areas) should be planted to stabilize the soil. If vines are a problem in the area, legumes such as lespedeza and birds-foot trefoil are suggested as a cover crop.

On certain sites, for example where erosion is likely, a herbicide application is recommended to prepare the site instead of tillage. The herbicide should be applied in a four foot diameter circle where tree or shrub seedlings will be planted (Palone and Todd 1997).

If the riparian area already has established shrubs and trees of desirable species, the area should be surveyed to determine its condition. Sometimes, some type of timber stand improvement is necessary to release the trees from competition or to remove less desirable vegetation. This may be accomplished by cutting, girdling, or injecting the undesirable plants with a herbicide. One of the best times to treat the site is just after it has leafed out in the spring (usually around late May). At this time, root reserves are at their lowest, reducing their ability to resprout (Palone and Todd 1997).

Table 5.4. Herbicides for Invasive Plant Control

Herbicide	Trade Name	Target Species
2,4-D	2,4-D	All species, especially herbaceous vegetation
2,4-D + Picloram	Pathway[R]	Herbaceous vegetation Beech, holly, maple, dogwood resistant.
Dicamba	Banvel[R]	Tree-of-heaven Sumac Kudzu Honeysuckle Poison ivy
Fosamine	Krenite[R]	Multiflora rose Tree-of-Heaven Woody plants with terminal buds.
Gluphosinate	Finale[R]	Warm season grasses Nut sedge Other herbaceous plants
Glyphosate	Accord[R] Compadre[R] Rodeo[R] Roundup[R]	Sod Tree-of-heaven Sumac Poor control of vines, roses, greenbriar, maple, holly, redbud, elm, hickory, and blackgum.
Hexazinone	Velpar L[R]	Woody species Huckleberry resistant.
Imazapyr	Arsenal[R] Chopper[R]	Turf grasses Blackberry, pine, locust, hickory, and elm are resistant.
	Arsenal[R] + glyphosate	Japanese bamboo Phragmites Locust is resistant.
Metsulfuron	Escort[R]	Turf grasses Sumac Tree-of-Heaven Kudzu, multiflora rose, and blackberry are resistant.
Metsulfuron + Triclopyr	Escort[R] + Garlon[R]	Oriental bittersweet Porcelain berry Poison ivy Wild grape Blackberry Multiflora rose
Metsulfuron + Imazapyr	Escort[R] + Arsenal[R]	Greenbrier Honeysuckle

		Multiflora rose Blackberries Kudzu
Sulfometuron	Oust[R]	Turf grasses. Poor control of broomsedge and wire grass.
	Oust[R] + Glyphosate	Turf grasses
Triclopyr	Pathfinder II[R] Garlon[R]	Wild grape Poison Ivy Cherry and maple resistant.
From: Palone, R.S. and A.H. Todd (eds.).1997.Chesapeake Bay riparian handbook: A guide for establishing and maintaining riparian forest buffers. USDA Forest Service NA-TP-02-97. Virginia Department of Forestry. 1999. Herbicide Use Sheets - Program Year 1999. http://state.vipnet.org/dof/herbuse.htm. Virginia Department of Forestry, Charlottesville, VA.		

Establish vegetation. Naturally vegetated riparian areas are among the most productive and diverse of all plant communities. However lush, this vegetation is well adapted to an environment which sees wide fluctuations in water levels and regular disturbance. Therefore, it is important to carefully select the proper species when revegetating riparian areas. One of the most important considerations is the riparian area hydrology, particularly the depth to the water table and the frequency, season and duration of flooding (McKevlin 1992). Soil characteristics, including soil type, texture, structure, and pH are also important considerations. Keep in mind that soils and hydrology can be highly variable within the same floodplain.

Trees selected for planting along the streambank should be selected for their ability to withstand frequent disturbance and flooded conditions. These trees are also important to provide bank stability, a dense canopy for shade, and food for aquatic organisms. Fast growing native species that are easily established, such as river birch, black willow, maples (especially silver maple and box elder), cottonwood, green ash and sycamore, are good choices here (Hupp 1992, Palone and Todd 1997). Further back from the streambank, a wider variety of trees is recommended. Sweetgum, elm, hackberry and water tolerant oaks and hickories can be added to the mix. Clumps of pine or other evergreen trees can be mixed in with the hardwoods. The pines will grow quickly and help break the wind, providing some protection for the hardwoods and cover for wildlife until the hardwood stand is established. Shrubs can be placed among the trees or along the forest edge.

The objectives of the landowner also play an important part in the selection of vegetation. For example, some species are particularly valuable for wildlife, others provide more valuable commercial products, and some have special aesthetic appeal. Table 5.5 lists trees and shrubs appropriate for planting in riparian areas. They may be purchased from the Virginia Division of Forestry, mail-order nurseries, and local sources.

Trees may be regenerated from seed or by planting tree seedlings (McKevlin 1992). In some cases, the stand will successfully regenerate on its own through natural succession. However, in areas that have been heavily grazed or where invasive exotic species are a problem, natural succession does not always result in a good stand of preferred species. In many cases, it will be necessary or desirable to restore the site by planting tree seedlings or through direct seeding. For most species, planting bare root tree seedlings usually provides better results (McKevlin 1992). Trees should be planted at 200-500 trees per acre depending on competition from other vegetation. Understory shrubs can be planted between the trees, spaced 5 to 8 feet apart. Direct seeding of species with large seeds (such as walnut, hickory, and oak) is an option, although rarely used. Seeds should be planted 2" deep at a rate of 1500 per acre (approximately 3' x 10' spacing) (McKevlin 1992). Regeneration may be more successful where trees or seeds are protected by tree shelters. In urban environments, the use of larger balled and burlap trees or containerized stock is appropriate. Recommended spacing for these trees is 16' apart, or 200 trees per acre (Palone and Todd 1997).

Native warm season grasses, such as switchgrass are often recommended for the portion of the buffer planted to grass (Zone 3). Warm season grasses are preferred due to their large root systems, high above-ground productivity, value to wildlife, and low maintenance (Schultz et al. 1995). For a list of warm-season grasses, see Table 5.6. Where sediment loads are low (less than 1000 lb/acre/year), herbaceous forbs and shrubs can be included in Zone 3 (Palone and Todd 1997).

Warm season grasses can be established by plowing, disking, and cultipacking the area to create a firm seedbed (Capel 1992). The seed can then be drilled into the soil (1/4" deep) with a grain drill (using the alfalfa seed box) or broadcast with a cyclone spreader, followed by cultipaking to tamp down the seed. Chaffy seeds or seeds with wings (for example, Bluestem and Indiangrass) are usually best broadcast because they tend to clog the drill. Warm season grasses should be planted when the soil is >60^{o}F (April to June in the Coastal Plain, May to early July in other parts of the state), if possible, just prior to a good rain (Wolf and Fiske 1995). Nitrogen fertilizer is not recommended at seeding; phosphorus, potassium, and lime should only be applied if recommended by the soil test. Grass seed should be purchased on a Pure Live Seed (PLS) basis rather than by bulk weight (Pure Live Seed accounts for debris and germination efficiency). A high Pure Live Seed is an indication of overall seed quality.

Maintenance

The riparian buffer will require ongoing maintenance throughout its life. It is important that the landowner walk the area on a regular basis, watching for damage to fences, the formation of gullies, weed problems, wildlife damage, insect and disease problems, and bank erosion and wash-outs in the stream.

In the early stages of buffer establishment, competition for light and nutrients by weeds can cause mortality and substantially reduce seedling growth. Weeds should be controlled by mowing, mulching, or herbicides. If it occurs on a regular basis, mowing can effectively control weeds. However, mowing often damages tree seedlings and where weeds are thick, does not eliminate the competition for moisture. Mowing also requires a more regular spacing of plants. Mulches or weed control fabrics can be used as an alternative to mowing, and provide the additional benefit of protecting trees from moisture stress in drought-prone areas. Herbicides probably offer the best competition control and result in more rapid establishment of the forest buffer. Tree shelters can increase survival of tree seedlings and offer the advantage of protecting the seedlings during mowing or spraying. However, tree shelters are expensive, at a cost of nearly $3 each.

Once the stand has become established, periodic thinning and timber stand improvements should occur in order to maintain vigorous growth and to maximize nutrient uptake (Palone and Todd 1997). At maturity, selective harvest of trees is recommended to sustain this growth and to remove nutrients sequestered in tree stems and branches. Care should be taken during harvest to protect the forest floor from disturbance and compaction and to preserve surface and subsurface water flows (Nutter and Gaskin 1988). This is best accomplished by following forestry Best Management Practices (BMPs). Suggested BMPs for logging in riparian areas are described in the "Forestry Best Management Practices Guide for Virginia", issued by the Virginia Department of Forestry (VA DOF 1997b). Best Management Practices which apply in streamside areas include:

- Harvesting should remove no more than 50% of the crown cover and should be limited to cable or winch systems.
- Log decks, sawmill sites, and drainage structures should not be constructed inside the riparian area.
- Stream crossings should be avoided wherever possible. If a stream crossing is necessary, a temporary bridge, culvert, or ford should be installed. A permit is required to construct a stream crossing over a stream which drains more than a 3000 acre area.
- Any wetlands, bogs, or seeps found in the riparian area should receive special protection. Trees should be felled away from the seeps and wetlands, and should not be skidded through the area. The movement or entry of equipment into these areas should be avoided wherever possible. Be aware that additional federal, state, and/or local regulations may apply to activities in wetland areas; therefore the local office of the U.S. Army Corps of Engineers should be contacted before initiating any activity in the wetland area.

Consultation with the Virginia Department of Forestry is highly recommended to plan a successful harvest of trees. By law, they *must* be notified that a harvest will occur at least three days before logging begins.

Where warm-season grasses are incorporated into the buffer plan, they will also require regular maintenance (Dillaha and Hayes 1991, Capel 1992). Warm season grasses have few insect or disease problems and do not require fertilizer unless the landowner would like to increase production for hay. However, these grasses are slow to establish and spend much of the first two years developing deep root systems. During this time, the stand will require regular mowing or herbicide application to control broadleaf weeds. Usually by the end of the second growing season, the grasses are established and can maintain themselves with few inputs. Once established, warm season grasses benefit from periodic controlled burns about every 3 to 4 years to recycle nutrients, stimulate new growth, and to kill back woody plants and other species.

Often, a berm of sediment may build up along the buffer edge, preventing field runoff from flowing across the buffer and causing it to flow parallel to the buffer. Where this occurs, accumulated sediments should be removed and the area regraded and reseeded. This should occur when sediments have accumulated more than about 6" (about every 10 years in areas of moderate erosion).

How long to recovery?

Once a forested riparian buffer is established, it may be just a few years before it begins to provide its desired functions. For example, in Iowa researchers found that a newly established buffer was trapping 80-90% of sediments and up to 90% of nitrates and atrazine from field runoff by the fourth growing season (Schultz et al. 1995) In the southeastern Coastal Plain, researchers have observed that where high organic matter soils and anoxic sediments are present, buffers will begin to have a major impact on nitrate in five to ten years (Lowrance et al. 1997). In other areas, 15 to 20 years may be required before buffers will begin to control nitrate loads. Wildlife use of the area will change over the life of the buffer. In Virginia, wildlife biologists observed significant use of streamside areas by birds within 5 to 9 years after they had been cleared and allowed to revegetate naturally (Ferguson et al 1975). They expected that bird species diversity would continue to increase as the stand matured and became more structurally complex. With slow-growing species, though, it may be decades before other benefits, such as stream cooling and inputs of large woody debris for aquatic communities, are realized.

Additional resources

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1-800-284-4952

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Permits

Virginia Marine Resources Commission Habitat Management Division. Local, state, federal joint permit application. Published jointly by the U.S. Army Corps of Engineers, Virginia Marine Resources Commission, Virginia Department of Environmental Quality and local wetlands boards. P.O. Box 756. Newport News, VA 23607. (804) 247-2255.