



Review

Environmental benefits of conservation buffers in the United States: Evidence, promise, and open questions

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Abstract

Conservation buffers can have a tremendously positive impact on the ecological health of rural landscapes by reducing erosion, improving water quality, increasing biodiversity, and expanding wildlife habitats. Yet, in spite of our knowledge of their value, conservation buffers have not been fully embraced by landowners, or even by policy makers in the United States (US). In this critical review, we examine why conservation buffers remain underutilized in US agroecosystems. We examine the literature on the environmental benefits of buffers, the economic issues related to buffer adoption, and the importance of the aesthetic quality and design of buffers. We propose that many questions related to buffer design and management remain unanswered, and suggest a variety of areas in which future research is necessary to improve buffer functionality and adoption. The implications of this synthesis for designers, planners, scientists, policy makers, and citizens are discussed. Recommendations include: modifying policies to better reflect the preferences of landowners and society, studying buffer systems at the watershed scale using multidisciplinary approaches, and designing buffers that consider aesthetic preferences and regional variation.

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1. Introduction

Evidence suggests conservation buffers can improve millions of kilometers of waterways, dramatically reduce topsoil loss, and increase biodiversity of rural landscapes. By reducing the negative impacts of conventional agricultural practices, buffers have the potential to significantly improve the ecological health of agroecosystems.

Although intensive agriculture may be necessary to sustain the world's growing population, some activities related to agriculture contribute to a decrease in the environmental health of ecosystems at local, regional, and global scales. Consider, for example, that pesticides and fertilizers used in agriculture are now found in water systems throughout the United States (US). Agricultural fertilizers are the major source of nutrient loading in large river watersheds (Ribaudo et al., 2001; Turner and Rabalais, 2003; Schröder et al., 2004)—a problem that is contributing to hypoxia in the Gulf of Mexico (Day et al., 2003). Soil erosion is also a serious problem. Intensive soil disturbance from agriculture contributes to erosion and the loss of valuable topsoil, threatening the future productivity of agricultural landscapes (Zaimes et al., 2004). Soil erosion from conventional farming practices results in a loss of 23 billion tonnes of soil per year from croplands around world (Zapata, 2003), causing adverse economic and environmental impacts on a global scale (Lal, 1998). Finally, the loss of biodiversity in agricultural landscapes threatens ecosystem health. Typical homogenous cropping systems lead to a significant loss in biodiversity of rural landscapes (McLaughlin and Mineau, 1995; Mensing et al., 1998; Day et al., 2003).

Conservation buffers have considerable potential to address these problems. In a number of site-specific studies, and through a variety of mechanisms, buffers have been shown to reduce sedimentation, filter harmful chemicals out of runoff before it enters streams or rivers, and increase biodiversity. Because of the perceived value of buffers, the US Department of Agriculture (USDA) is committed to increasing buffer adoption through the Conservation Reserve Program—the primary program for funding buffers in the US. This program provides farmers with a rental payment and shared establishment costs for retiring land from production for a pre-determined period of time. In fact, the USDA paid more than US\$ 1.6 billion in CRP annual rental and cost-share payments in 2001 and 2002 (Farm Service Agency, 2004), a trend which will certainly continue into the foreseeable future. This figure covers payments for whole-field set-asides, as well as buffers.

But despite the benefit of buffers and considerable governmental support of them, conservation buffers have not been fully embraced by landowners, or even by policy makers. For example, the *National Conservation Buffer Initiative* created by USDA set a goal of installing 3.2 million km of buffers by the end of 2002 and then again for 2003. Yet, only 1.95 and 2.45 million km of

buffers were installed by 2002 and 2003, respectively (Loftus and Kraft, 2003; Berry, 2003), and these buffers were unequally distributed across the US due to the greater CRP rental rates paid to landowners with highly productive soils (Lowrance and Crow, 2002). Questions also remain regarding whether buffers actually provide the environmental benefits that the site-specific studies suggest. That is, there are questions at the watershed scale about the extent to which buffers actually reduce soil erosion, filter chemicals, and increase biodiversity.

In this review, we examine why, in spite of their many benefits, conservation buffers remain underutilized in US agroecosystems. Our efforts are guided by three objectives. The first is to examine the literature in order to develop a clear understanding of our current knowledge about buffers and their value. The second objective is to identify obstacles that may prevent farmers, landowners, and communities from adopting buffers. The third is to pose new questions that must be answered if we hope to remove these obstacles and increase buffer adoption and effectiveness.

2. Background

Before addressing the current status of research on conservation buffers, it is important to understand what conservation buffers are and how they have been used. In this section, we examine the historical conditions that led to the introduction of buffers and the extent to which buffers have been used in the past.

Although the use of the term “conservation buffer” or “agricultural buffer” was not used widely until the 1970s, the concept of retaining uncultivated areas between and within productive fields has been around for centuries. In fact, until the 19th century, agricultural landscapes throughout Europe contained features such as riparian forests, wetlands, and hedges (Vought et al., 1995). In the United States, many natural features also remained in rural landscapes even after much of the land was settled and developed for agriculture. These features existed for a variety of reasons—some occurred naturally and had not yet been removed, while others were created to define property lines and contain livestock (Bennett, 1939). With the intensification of agriculture and introduction of clay drainage tiles in the mid-1800s, however, many of these natural “buffers” were removed and crops were planted in their place (Vought et al., 1995).

At the same time that drainage tiles were increasingly adopted, soil erosion was becoming a problem in areas that had been continuously farmed. Some practices resembling buffers, such as hillside ditches and stonewalls across gullies, were employed to help reduce erosion. But it was not until 1928, with the Buchanan Amendment to the Agricultural Bill for fiscal year 1930, that the issue received public attention. The Buchanan Amendment appropriated

funds to study the causes of soil erosion, determine the potential for infiltration of rainwater by the soil, and establish guidelines for preserving the soil and preventing erosion. The Soil Erosion Service was established in 1933 in the Department of the Interior to create soil and water conservation demonstration projects. The great dust storm of 1934 significantly increased national interest in identifying practices to help reduce the problems of soil erosion from wind and water (Bennett, 1939). In a book entitled *Soil Conservation*, written in 1939, Bennett introduced several soil conservation practices including vegetative control of gullies, vegetative waterways, and contour strip cropping. He also suggested retaining forest areas and planting trees to help control stream bank erosion (Bennett, 1939). In the 1940s and 1950s, windbreaks or shelterbelts gained popularity for reducing wind erosion around farmsteads and fields. During that time, grassed waterways and vegetation along streams and roadsides were also promoted to combat soil erosion (Kohnke and Bertrand, 1959).

Prior to the 1970s, few studies examined the water quality benefits of conservation buffers (Correll, 1997). Since the mid-1970s, however, researchers have demonstrated the ability of buffers to remove nitrates (Osborne and Kovacic, 1993), adhere phosphorus (Lee et al., 2003), trap sediment (Karr and Schlosser, 1978), and remove herbicides (Correll, 1997). The benefits of buffer areas for wildlife habitat, biodiversity, and general ecosystem health continue to be of interest to researchers.

Today, a wide range of functions and designs exist for the different conservation buffers in agricultural settings. Regardless of buffer type, the goal of incorporating conservation buffers into agricultural landscapes is the same—to improve ecosystem health. We know that buffers have the potential to greatly impact the ecology of the farm, as well as the ecological system well beyond the borders of the farm. In the sections below, we examine the environmental, economic, and aesthetic benefits of conservation buffers. Within each section, we identify the disconnects between the current knowledge and the reality of buffers, then suggest questions for future research.

3. Environmental benefits of buffers

Conservation buffers have the potential to reduce the negative impacts of agricultural practices that have resulted in erosion, contamination of streams, decreased biodiversity, and loss or fragmentation of wildlife. Recent research regarding such benefits has resulted in an increasing interest in using conservation buffers to improve the health of agroecosystems. But while many studies have demonstrated that buffers can provide environmental benefits, a number of questions remain unanswered. In this section, we explore this recent research, examine obstacles that have limited the adoption of buffers, and propose questions that should be addressed in future research.

3.1. Current knowledge

Buffers have been used for many years to reduce soil loss by wind and water erosion. Soil erosion is a problem because it reduces the depth of fertile topsoil, creates unwanted gullies in the land, and causes sedimentation of streams. Conservation buffers employ perennial plants to combat this problem. Extensive root systems of perennial plants hold soil in place, allow greater infiltration of water, and trap the sediment entering from cultivated areas. Windbreaks containing woody plants also help minimize soil loss from fields by reducing wind current (Nordstrom and Hotta, 2004). When properly maintained, buffers can remove up to 97% of soil sediment before it enters a stream (Lee et al., 2003; Lowrance et al., 2002). But maintenance here is tremendously important: for buffers to remain effective as sediment sinks, they must be properly maintained. Compaction from farm equipment and livestock should be avoided (Dillaha et al., 1989) and excess sediment must be removed occasionally (Dosskey et al., 2002).

In addition to reducing sedimentation, buffers can also protect water supplies by removing fertilizers and pesticides from field runoff. Many studies have demonstrated the effectiveness of buffers in reducing the concentration of nitrates, phosphorous, and a host of pesticide compounds from water running off cultivated fields. Nitrogen, a harmful pollutant in many water sources, is trapped and assimilated by the plants in buffers. The concentration of nitrate-N can be reduced from between 40 and 94% in a buffer or wetland before entering a stream, though removal rates closer to 50% are more likely with measurements taken on an annual basis (Groffman et al., 1991; Haycock and Pinay, 1993; Osborne and Kovacic, 1993; Kovacic et al., 2000; Lowrance et al., 2002; Stone et al., 2004). Phosphorus runoff is reduced in vegetated buffer strips, but removal rates vary greatly (from 25 to 95%) depending on the percentage of soil-bound versus soluble phosphorus, length of buffer strip, plant cover, and hydrologic conditions (Magette et al., 1989; Vought et al., 1995; Ryszkowski and Jankowiak, 2002; Lee et al., 2003). Buffers can also become saturated, which reduces their effectiveness in removing phosphorus. The ability of buffers to retain pesticides is variable because each pesticide has unique mobility and soil binding properties. Buffers can be tremendously effective in removing pesticides tightly bound to the soil (Radkins et al., 1998), but effectiveness is variable with moderately bound pesticides (USDA, 2000). An extensive review of buffers and their potential for reducing pesticide contamination is provided in the USDA–NRCS publication entitled *Conservation Buffers to Reduce Pesticide Loss* (2000).

Buffers also provide indirect environmental benefits such as increasing the biodiversity of flora and fauna and providing habitat for wildlife. Vegetation in riparian areas can help regulate light and temperatures, allowing wildlife access to food and water and creating a wide variety of habitats—all contributing to ecological diversity (Naiman

et al., 1993). Buffers planted with a variety of species will further increase the benefits to wildlife (Schultz et al., 1997), and buffers containing woody vegetation are likely to exhibit greater species richness than grassy buffers (Freemark et al., 2002; Paine and Ribic, 2002; Boutin et al., 2003). In addition to improving the ecological conditions for terrestrial species, riparian buffers, particularly those containing trees, can also contribute to the health of aquatic species by cooling stream waters, providing food and habitat, and increasing the dissolved oxygen in water (Davis, 2000).

Conservation buffers can also promote wildlife health by providing corridors that connect wildlife habitats and allow safe movement between fragmented patches of natural areas (Henry et al., 1999; Schuller et al., 2000). Fig. 1 shows the structure and relationships of patches, corridors, and matrices as defined by buffers and cropland. This figure demonstrates how buffers can effectively work as corridors to connect patches or other corridors in the matrix of agricultural land (Grillmayer, 2002). In order to use buffers as corridors, their length and width must allow movement of desired species from one location to another (Ma et al., 2002; Schultz et al., 1997; van Dorp et al., 1997). The success of buffers as corridors supporting the dispersal of organisms depends on their location in connecting key natural areas (Schuller et al., 2000).

In sum, considerable research demonstrates that buffers can be effective in promoting environmental quality in and beyond agricultural landscapes. Buffers remove sediment from surface runoff and reduce concentrations of nitrogen, phosphorus, and a host of herbicidal compounds. Research suggests that, because buffers improve biodiversity and provide habitat for wildlife, the general ecological health of

agricultural landscapes improves in areas that contain buffers. Still, there is much that we do not yet fully understand about the environmental benefits of buffers, and this lack of knowledge has created important obstacles to the effectiveness of buffers.

3.2. Obstacles and future research

Buffers have been shown to provide environmental benefits in site-specific studies. We know little, however, about how this research relates to other spatial scales. In fact, our understanding of the impact of buffers on overall water quality in the US is extremely limited. We can begin to address these issues by asking questions such as how, for instance, the addition of buffers impacts the ecological health of an entire watershed. To what extent will pollutant concentrations be reduced if a high percent of landowners in a particular watershed add buffers in sensitive areas? Watershed-scale approaches to buffer design and management can also provide new information on the optimal placement of buffers. For example, if buffers are to function as corridors, they should probably be located in areas where they connect with other wildlife habitats. To what extent are buffers placed adjacent to ditches, rivers, and streams more effective than buffers placed within fields?

Effective models for buffer systems are needed in order to understand the environmental benefits at the watershed scale. The Soil and Water Assessment Tool (SWAT) is one model created by researchers with the USDA that focuses primarily on water and soil quality. We need, however, to develop models that will address other environmental issues such as connectivity and biodiversity, at the landscape scale. What is the contribution of buffers to landscape biodiversity? What is the pattern of species habitation within buffers and the surrounding land?

Buffers have also been shown to provide environmental benefits in short-term studies. We know little, however, about how these studies relate to other temporal scales. We must learn about the long-term impacts of buffers on the environment, since long-term management approaches may be critical to the ultimate success of buffers. For example, we need to provide landowners with more information on the potential saturation of buffers by sediment and phosphorus. To what extent do various management practices reduce or prolong the time to reach saturation? After new buffers are installed, how long does it take to begin to see the ecological benefits of buffers? Large-scale and long-term approaches to buffer research and watershed management offer tremendous opportunities to learn a great deal about the best approaches for optimizing the environmental benefits of buffers.

More research is also needed to understand how buffers should be modified to function effectively in different agricultural regions. In the flat plains of the Midwestern US, for example, water from tile drains often enters directly into a ditch or stream, bypassing the buffers along the edge. Are

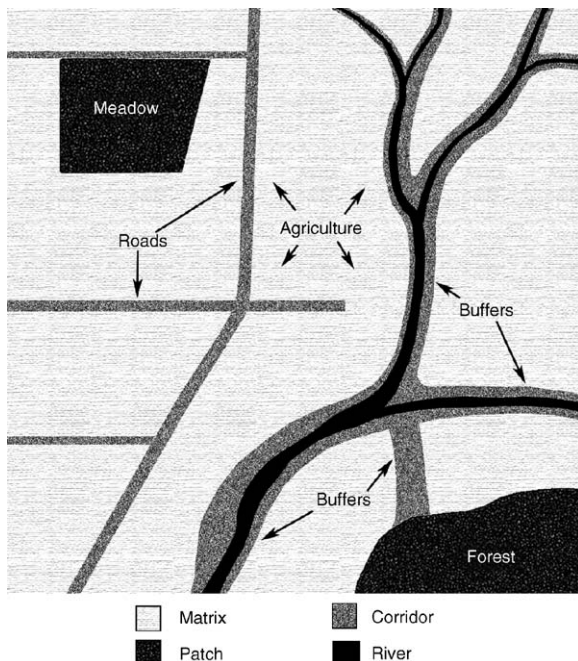


Fig. 1. Plan view of different types of landscape structure in a rural setting.

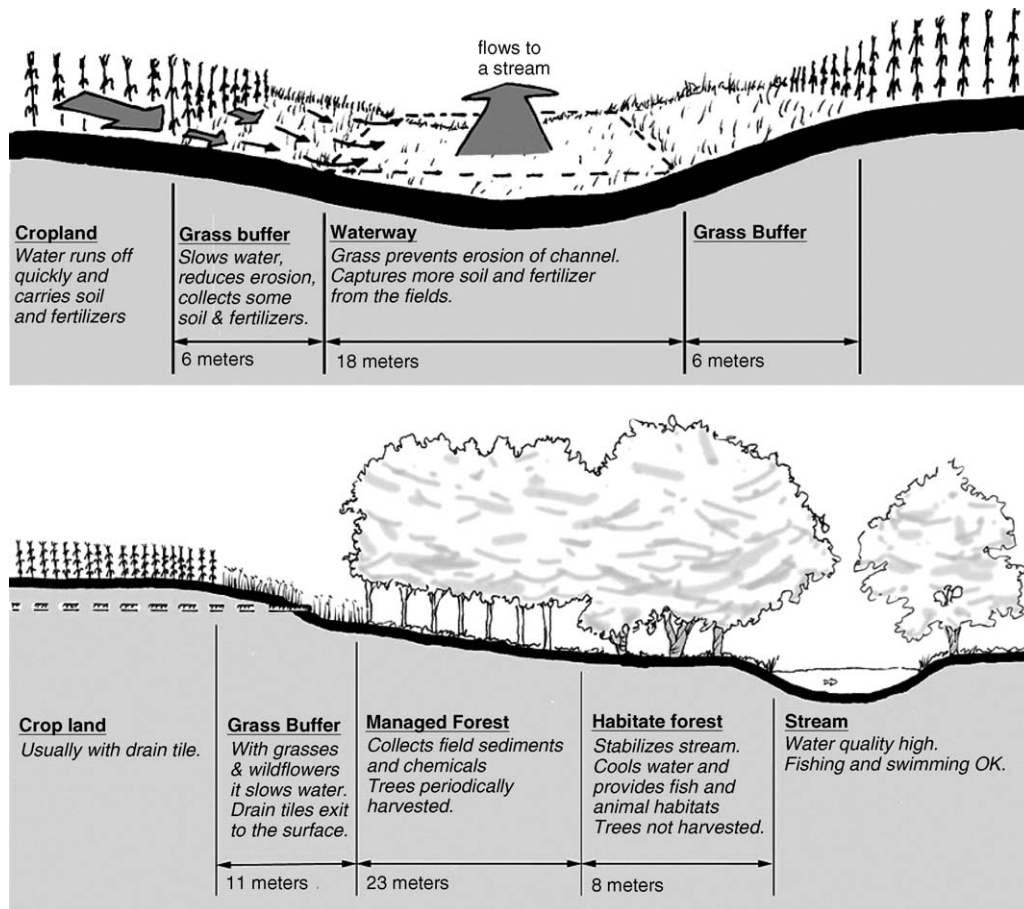


Fig. 2. Design alternatives for grass and treed buffers (Anderson, 2001).

wetlands the best approach to treating the water from tile drains? Is saturation a problem in wetlands? In hilly regions, contour buffers placed on sloped areas could be more effective. How could buffer design be modified depending on regional variation? What vegetation would be most appropriate for each region?

Clearly, more research is needed in order for us to have a comprehensive understanding of the environmental costs and benefits of buffers at various scales. Until we have such an understanding, our capacity to promote buffers will surely be constrained.

4. Social and economic context

To understand the best approaches for increasing the use and effectiveness of conservation buffers, we must consider their social and economic implications. Although most conservation practices provide benefits to both the landowner and the public, they also result in some costs. The costs and benefits, however, may not be shared equally by landowners and the public (Lynch and Brown, 2000). What do we know about the impact of costs and benefits of buffers on their adoption? What are the major motivations for

landowners to change land use patterns to include buffers? How do local and federal policies influence the acceptance and adoption of buffers?

4.1. Current knowledge

Conservation buffers provide a number of benefits to society. Because they are effective in removing sediment and pollutants from runoff, buffers help improve water quality in areas near farms and downstream. Poor water quality can result in direct health risks to those drinking the water and in greater treatment costs for urban residents. An increase in the use of buffers for erosion control would also reduce the costs of trenching streams to removed sediment (Schultz et al., 1997). Buffers can even reduce the severity of flooding by slowing water flow, increasing infiltration of water into soils (Schultz et al., 1997), and in the case of wetlands, providing a holding area for flood water (Shultz and Leitch, 2003). Recent research suggests tree buffers have the potential to mitigate the problem of livestock odor—a serious and contentious issue in some rural areas (Tyndall and Colletti, 2001). In addition, buffers can provide recreational opportunities, particularly when they are located on public property (Schoeneberger et al., 2001).

Buffers can even improve the visual quality of rural areas, especially in flat, open landscapes of the Midwestern US. This improved visual quality might result in greater tourism in certain areas where the rural landscape already has significant visual appeal.

Although a primary focus of buffers has been the benefits for society, individual farmers and landowners also benefit from buffers. Buffers often improve crop yields by minimizing soil loss and reducing wind velocity over crops near a windbreak (Henry et al., 1999; Pimentel et al., 1995). Conservation buffers can also increase land values because they improve the aesthetic quality of the farm (Henry et al., 1999) and increase nearby wildlife (Bastian et al., 2002). Landowners can profit from the products of buffer vegetation including hay from grasses and legumes, saw timber from hardwood trees, and nuts or berries from various fruiting species (Schoeneberger et al., 2001). In fact, some farmers even profit from the recreational opportunities buffers provide—charging a fee for hunting, fishing, or other activities that are available in buffer areas (Schultz et al., 1997). Farmers can also benefit financially from state and federal incentives programs designed to promote the development and maintenance of buffers.

Although the public benefits of planting and maintaining conservation buffers are well established, the decision to set land aside, plant buffers, and continue to maintain the buffers lies primarily in the hands of individual landowners or farmers. To date, buffers have not been widely adopted by growers in many parts of the US for a number of different reasons. Obviously, buffers result in some cost to the landowner. Farming is a tremendously competitive occupation, and many farmers feel forced to make management decisions based on short-term profitability, rather than long-term sustainability. The most obvious cost of buffers results from the lost profit when land is taken out of production and established as a natural area. There is also a direct cost in establishing a buffer, which can range greatly depending on the type of buffer and methods used. For example, the cost of plant material for an edge-of-field buffer is considerably less than the cost of renting or hiring large land-moving equipment necessary to create or restore a wetland (Shultz and Leitch, 2003). Buffer maintenance (e.g., weed control, mowing, and removal of accumulated sediment) also results in costs to the farmer or landowner. Buffers have some potential to reduce crop yields because they harbor pests and shade crops, although these losses are typically quite low. The costs incurred from the establishment and maintenance of buffers will have an important impact on the willingness of landowners and farmers to change the land use patterns.

As we mentioned above, public policies play a role in the adoption of conservation buffers. A recent study by Nassauer et al. (2002) demonstrated significant differences in projected land use based on policies that emphasized agricultural production, water quality, or biodiversity. Policies related to conservation buffers are subject to the same influences. Incentive programs such as the Conservation Reserve

Program can drastically alter adoption rates of new agricultural practices (Lant et al., 2001). Public subsidies may be necessary to reduce costs incurred by landowners in establishing and maintaining buffers, in order to increase their adoption (Bastian et al., 2002). Participation in government programs is driven to a considerable degree by land values, crop prices, and rental rates for enrollment (Lant et al., 1995; Purvis et al., 1989). Some farmers, however, are unwilling to participate for reasons beyond economics: they do not want to give up control, work with the federal government, or lose the flexibility of land use (Lant et al., 2001).

In sum, social, economic, and public policy issues all have an impact on the adoption of conservation buffers. While society benefits from increased adoption of buffers, the costs are not evenly distributed: farmers and landowners too often find the costs associated with setting aside land and building and maintaining conservation buffers to be too high. The lack of widespread use of buffers on farms and the heavy reliance on incentive programs suggest the costs still outweigh the benefits for many landowners. Our current knowledge of the economic factors related to buffers has not yet resulted in a major change in land use. Obviously, a number of obstacles must be addressed before the social and economic benefits of buffers are fully realized.

4.2. *Obstacles and future research*

Some of the greatest obstacles to optimizing buffer effectiveness and adoption are related to the structure and function of government incentive programs. In spite of the economic incentives these programs provide, conservation buffers have been adopted at levels that too often fall short of local and federal goals. One serious obstacle that is worthy of future research concerns the lack of coordination between and within agencies. How can these programs be reformed to improve coordination, and thus stimulate enrollment and optimize the effectiveness of public investments in buffers? Should more public funds be spent to increase the economic incentives for buffer adoption or to provide more education on the programs? To what extent might farmers support redirecting crop subsidies to support land being taken out of production and planted as buffers? Would such policy changes increase adoption rates?

Another serious obstacle within the incentives programs is that the goals are often unclear or seem, to farmers at least, to be inappropriate. For example, incentive programs place greater emphasis on the development of new buffer areas (Heimlich et al., 1998; Lowrance and Crow, 2002), rather than preserving existing natural riparian buffers or wetlands that often provide greater environmental benefits and plant diversity (Galatowitsch and van der Valk, 1996). Would goals including existing buffer areas allow for greater environmental benefits, as well as greater connectedness between buffers? Would such policy changes increase adoption rates?

It is likely that another obstacle to buffer adoption is related to the lack of information regarding buffer management. Although there is a wealth of information available regarding how to establish a buffer, precious little information exists regarding how to manage buffers once they are installed. In addition, landowners need specific information about opportunities to make money from the materials they plant in their buffers. Researchers have begun to investigate income-producing products of buffer plantings such as saw timber, hay, or prairie grass seed (Riddell-Black et al., 1997; Schultz et al., 1997), but more work in this area is needed. Under what conditions do these buffer products (buffer crops) provide a positive return on investment? What are the future market trends for the various products that can be harvested from buffers?

Land ownership may be a critical obstacle to the adoption of buffers. Currently, the vast majority of land around streams and rivers in rural areas is privately owned, and thus the decision about the development of buffers lies exclusively on landowners. But there are emerging mechanisms through which public trusts or non-profit organizations can purchase the land in these sensitive areas to allow the establishment of buffers and corridors that benefit the entire community. Under what conditions are landowners willing to sell their less productive land (e.g., land in floodplains)? How would the cost of purchasing the land compare with the cost of incentive programs? Who would maintain the land established in buffers? Under what conditions do public-private partnerships established to maintain agricultural buffers work best?

There are a variety of social and economic factors that obstruct buffer adoption: the structure of buffer incentives programs, poorly specified goals, lack of maintenance information, and perhaps even private ownership of land that might best be planted as buffers. We must focus research efforts in these areas in order to find ways of overcoming these obstacles.

5. Buffer aesthetics and design

To understand the best approaches for increasing the use and effectiveness of conservation buffers, we must also consider their aesthetic characteristics. Our review of the literature suggests that the design and aesthetic characteristics of landscape buffers have too often been ignored. Buffers impact the visual quality of the countryside by introducing variability into what is often a homogenous landscape where monoculture crops dominate. There are reasons to believe that the addition of buffers, particularly those containing trees, could have a profoundly positive impact on the visual quality of some agricultural landscapes. In this section, we examine research on landscape preferences, explore the extent to which current buffer designs match these preferences, and suggest new research opportunities that might ultimately help increase buffer adoption rates.

5.1. Current knowledge

Thirty years of research on preferences for various landscape features provides insights regarding the aesthetic qualities of conservation buffers. Methodology for this research has most often relied on responses from various participant groups to photo-questionnaires including images or photo-simulations of the landscape features in question. The short summary is that, on the whole, people prefer natural spaces to built ones (Kaplan and Kaplan, 1989), and settings with trees over settings without trees (Kaplan and Kaplan, 1989; Wolf, 2003; Kent and Elliot, 1995; Kuo et al., 1998). In rural settings, the highest preference ratings are often given to scenes that include an open area such as a meadow, bordered by trees (Clay and Daniel, 2000; Sullivan, 1994; Ryan, 2002).

Landscape preferences can vary by stakeholder group. For example, preferences for the management of agricultural land have been shown to differ among farmers, landowners, or non-farm residents. While non-farm residents prefer more naturalized settings in rural areas, farmers often prefer less naturalized, more manicured settings (Ryan, 1998). Nassauer (1989) suggests that, for a rural landscape to be considered attractive, it must demonstrate both neatness and stewardship—a management approach that could align the preferences of farmers and non-farm residents. Nassauer (1997) has found that individuals prefer rural landscapes that demonstrate some form of neatness or care, even when the goal of the landscape is ecological health. She proposes the inclusion of “frames around ecosystems” that receive greater management and care than the ecosystem itself (Nassauer, 1995, 2002). Farmers and rural landowners may be particularly sensitive to the need for a “clean or neat” look associated with conservation buffers, since the appearance of a farm is often taken as a measure of the work ethic of the farmer. These findings suggest that conservation buffers should be designed and managed so that they convey a sense of stewardship; that is, so they have some visible signs of care.

A small body of research examines individual's reactions to conservation buffers. Sullivan et al. (2004) measured approval of different buffer types by three stakeholder groups: farmers, residents, and academics. Each study participant rated computer-simulated images of three buffer conditions (no buffer, basic buffer, and extensive buffer) for each of six buffer types, where the basic buffers were designed with standard widths recommended in the US Conservation Reserve Program and extensive buffers were designed with widths greater than recommended by the program. Approval for basic buffers was over three times that of the no buffer conditions and even greater for extensive buffers. Farmers, academics, and residents agreed on their approval for the basic buffers over no buffers, but differed with respect to the extensive buffers. The finding that farmers approved of conservation buffers appears to contrast with results from Dvorak (1994) who showed that

most farmers preferred clean management practices to conservation practices for their field margins. Taken together, however, these results reinforce Nassauer's findings (1995, 2002) and suggest that buffers with a managed edge are most acceptable to farmers, landowners, and other rural residents.

To what extent, then, does buffer design reflect these preferences? Evidence indicates that, at least in the case of riparian buffers, the designs fit these preferences quite well. In a key USDA publication entitled *Riparian Forest Buffers: Function and Design for Protection and Enhancement of Water Resources*, Welsch (1991) introduced a riparian buffer design consisting of three zones. The design included a 6-m grass buffer for runoff control located next to cropland, followed by an 18-m managed forest for filtration and plant uptake, and finally a 5-m undisturbed forest located closest to the stream. Another design for a riparian buffer system containing perennial grass, two rows of shrubs, and four or five rows of trees was proposed by Schultz et al. (1995). Both designs address the functional qualities of riparian buffers and, based on the preference research, would certainly improve the visual quality of many agricultural landscapes—at least in the Midwestern US. The combination of open and treed areas, with a managed edge (Fig. 2), results in a design that should be highly preferred by a wide variety of individuals.

The selection of specific plant species is an emerging area of research related to buffer design. A number of previous efforts to establish healthy conservation buffers have been unsuccessful because the selected plants were inappropriate for the particular site—the plants did not survive, they did not optimize the functionality of the buffer, or they became invasive, threatening the ecological balance of the system. Researchers have begun to explore effects of plant populations on buffer areas to determine which species survive the best and which species provide the greatest ecological benefits. The important initial work in this area is being led by Susan Galatowitsch and her colleagues who have been studying species diversity and the establishment of various native plants in restored areas such as wetlands (Perry and Galatowitsch, 2003; Mayer and Galatowitsch, 2001; Budelsky and Galatowitsch, 1999, 2000). Galatowitsch's laboratory has demonstrated the importance of selecting appropriate plants for particular sites. When appropriate plants are selected, success rates increase dramatically.

In sum, converging evidence suggests that the addition of conservation buffers will improve the visual quality of many agricultural landscapes—especially landscapes that contain few trees and are planted with row-crops. We also know that different approaches to the design and management of the buffers can have a considerable impact on the visual quality and establishment of buffers. Still, there are a number of important obstacles that, once addressed, may lead to greater adoption and effectiveness of conservation buffers.

5.2. Obstacles and future research

Although preferences for landscape features have been studied extensively, we know little about the *relationships* among ecological health, economic potential, and landscape preference. Although Nassauer's work begins to address these relationships, it is still unclear how highly productive landscapes can meet goals of ecological health and human preference. Two questions are pressing: to what extent can the design of buffers be used to harmonize environmental and economic issues? How can the design and management of buffers better address social and environmental concerns without creating an economic hardship on the farmer or landowner?

Regional variation in landscapes and thus in the experiences of individuals is likely to influence preferences for conservation buffers. Although much of the agricultural land of the Midwestern US consists of homogenous row-crop agriculture, other agricultural settings contain much greater diversity in crops and landscape. These conditions suggest several research questions: to what extent do individuals living in areas with greater landscape diversity consider conservation buffers to be an improvement in visual quality? What qualities of buffers appeal to farmers and landowners in different regions? Do farmers and landowners living in regions with more landscape diversity prefer the same level of "neatness" for the edges of conservation buffers?

Species composition of buffers is another important area of research that may impact the environmental benefits, as well as the aesthetic quality of buffers. Traditionally, vegetative species in buffers have been selected based on their ability to establish quickly and reduce runoff velocity, but little attention has been given to the role these species play in ecosystem health and visual quality of an area. Our lack of knowledge in this area offers several research opportunities: which species should be used in buffers to provide the extensive root systems needed for erosion control, and also improve biodiversity? How do the benefits of native species compare with the standard non-native buffer species for overall environmental benefits? To what extent would the addition of trees to non-riparian buffers improve the visual quality of the farm and the entire rural landscape? Should conservation programs include more incentives to plant trees in all buffers?

As with social and economic issues, land ownership presents an important obstacle for the buffer aesthetics and design. Although landowners who live on the farm may appreciate the improved visual quality provided by buffers, a growing number of farms are owned by individuals who live elsewhere. Absentee landlords (land owners who do not live in the community where the land exists) are not likely to be highly influenced by aesthetics. Thus, we wonder, are economic incentives the only way to appeal to the growing group of absentee landlords? Should efforts to improve the visual quality of buffers focus on the preferences of the farmer, the landowner, or the public?

An important obstacle in buffer adoption is our lack of understanding about the importance of buffer aesthetics and design. Previous research suggests that the addition of buffers would improve the visual quality of many rural landscapes. But very little work has tested this assumption in the context of other important environmental and economic goals. We need additional research that explores the interrelatedness of these various concerns.

6. Implications

This review of conservation buffers demonstrates that, although buffers have the potential to improve the environmental health and visual quality of agricultural landscapes, a number of obstacles must be overcome before they are more widely adopted. Future research efforts focusing on environmental benefits, social and economic issues, and aesthetics and design of buffers offer opportunities to remove these obstacles. In spite of all that we still need to learn, this review suggests a number of important implications for designers, planners, scientists, policy makers, and citizens.

For designers, the sum of this information suggests that if more attention were paid to the design of conservation buffers, more farmers would be willing plant buffers. Individuals designing conservation buffers can manipulate the size, shape, and placement of buffers, as well as the selection of plants and other features that will improve not only the visual quality of the buffer, but also its functionality. For example, elements such as trees can help define separate areas in a field and increase the richness of the setting, while at the same time improving the functionality of the buffers by reducing wind erosion and chemical drift. Designers should also consider incorporating a clean or manicured edge to buffers that inherently have a more natural look than the rest of an agricultural field. Buffers designed with a focus on the aesthetic preferences of landowners and local residents are likely to be accepted and supported to a greater extent than standard buffers.

There are a number of implications of this review for planners. The recent increase in the availability and utility of geographic information systems (GIS) and other mapping technologies allows planners to respond to the landscape by selectively placing features such as buffers where they will be most efficient, such as sloped areas or in riparian

corridors (Bentrup and Leininger, 2002). Such technology also allows *watershed-scale planning* of buffer systems instead of dealing only with individual farms (Lowrance and Crow, 2002; Ryszkowski and Jankowiak, 2002; Sliva and Williams, 2001). By working at the watershed scale, buffer systems could be made more efficient and interconnected, improving the ecological health of the entire area (Franklin, 1992). This watershed-scale approach to buffer design is likely to have a profoundly positive effect on a range of environmental and social factors. See, for instance, Table 1, which compares possible goals for farm scale and watershed-scale designs. In a watershed-scale approach, agriculture could be studied as part of an ecosystem, beyond the evaluation of individual sets of crops (Baudry et al., 2000). Many land planners and landscape architects have the training and tools to coordinate activities on this larger scale.

This review has implications for a variety of scientists: from scientists who study relationships between environment and behavior, to ecologists and agronomists. Clearly, there is a need for scientists to better understand the ways in which the environmental benefits of buffers interact with economic factors and stakeholder preferences. Greater interaction among scientists and experts in disciplines such as landscape architecture and planning can produce results that will not be realized through small site-specific field experiments. For example, sociologists might provide insight into methods for improving communication between landowners and scientists in conducting experiments at the scale of a watershed, a process that will lead to improved approaches for management of watersheds (Rhoads et al., 1999). The work here also suggests opportunities for ecologists who might redirect their focus from wilderness landscapes toward the tremendously large land area covered by agricultural landscapes.

The implications for policy makers are complex, but equally as important. Policy makers must balance a variety of issues in their attempts to promote economic well-being and environmental health. This review suggests that a greater emphasis on visual quality of buffers might increase public support for programs that seek to establish and maintain buffers. Incentives could be provided to increase tree planting in non-riparian buffers—an approach that would improve both visual quality and buffer functioning. Policy makers may also reconsider the best approaches for taking land out of production. For example, it may make more long-term economic sense to purchase land for buffers

Table 1
Potential design goals for conservation buffers at the farm scale and the landscape scale

	Design factors		
	Environmental	Social/economic	Aesthetic
Watershed-scale design	Achieve connectedness for wildlife at streams Improve water quality for aquatic life and consumption	Encourage recreational opportunities Reduce flooding potential	Maximize scenic quality of the area Encourage agrotourism
Farm-scale design	Reduce loss of valuable topsoil Provide wildlife habitat and biodiversity	Profit from products of buffer plantings Profit from recreational opportunities	Increase land values Improve views on farmstead

instead of renting land in perpetuity, particularly in the most sensitive or visible areas.

There are far-reaching implications from this review for citizens, landowners, and farmers. Any design, even one for a utilitarian agricultural landscape, has meaning. Planting agricultural buffers on a farmstead offers the opportunity to express an appreciation for the ecological health of the environment and community. Nassauer (2002) suggests that designing landscapes “in harmony with nature” will add a level of meaning beyond using the land only for production. An increase in the adoption of conservation buffers might start a trend toward greater appreciation of ecological health and biodiversity in rural areas. Currently, greater efforts are needed to engage landowners and the public in opportunities to provide ecological health benefits by increasing the use of buffers. These efforts might include opportunities to incorporate buffers on public land, such as university research farms, where the public could be engaged in conservation design and management.

7. Conclusion

There has been considerable progress over the past 30 years toward understanding conservation buffers and their role in promoting ecosystem health. In this review, we have explored the vast literature on the many environmental benefits of buffers, the social and economic issues related to buffer adoption, and the importance of the aesthetic quality of buffers. Yet, in spite of our increasing knowledge of their value, most efforts to significantly improve environmental health through the use of conservation buffers have been limited by a number of obstacles that thwart an increase in buffer adoption. These obstacles include a lack of watershed-scale research on the impacts of buffers, a need for more clearly defined and targeted goals for buffers, a lack of cooperation between scientific disciplines and agencies, an absence of accountability from landowners for the public investment in buffers, and limited attention to the aesthetic quality of buffers. Even with new knowledge in these areas, the addition of buffers will not solve all of the environmental problems related to agriculture. In fact, a reform of the entire US agricultural system to promote greater diversity in cropping systems and to incorporate agroecology approaches may be necessary to improve environmental health on a global scale. We need to continue challenging the conventional approaches and provide viable alternatives, in order to create a more sustainable agricultural system that can ensure food availability for centuries to come.

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