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GRASS VERSUS TREES: MANAGING RIPARIAN AREAS TO BENEFIT STREAMS OF CENTRAL NORTH AMERICA[1]

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ABSTRACT: Forestation of riparian areas has long been promoted to restore stream ecosystems degraded by agriculture in central North America. Although trees and shrubs in the riparian zone can provide many benefits to streams, grassy or herbaceous riparian vegetation can also provide benefits and may be more appropriate in some situations. Here we review some of the positive and negative implications of grassy versus wooded riparian zones and discuss potential management outcomes. Compared to wooded areas, grassy riparian areas result in stream reaches with different patterns of bank stability, erosion, channel morphology, cover for fish, terrestrial runoff, hydrology, water temperature, organic matter inputs, primary production, aquatic macroinvertebrates, and fish. Of particular relevance in agricultural regions, grassy riparian areas may be more effective in reducing bank erosion and trapping suspended sediments than wooded areas. Maintenance of grassy riparian vegetation usually requires active management (e.g., mowing, burning, herbicide treatments, and grazing), as successional processes will tend ultimately to favor woody vegetation. Riparian agricultural practices that promote a dense, healthy, grassy turf, such as certain types of intensively managed livestock grazing, have potential to restore degraded stream ecosystems.
(KEY TERMS: aquatic ecosystems; erosion, sedimentation; hydrobiology; land use planning; nonpoint source pollution; riparian vegetation; stream restoration; watershed management.)

INTRODUCTION

Many stream ecosystems in central North America have been greatly degraded by intensive agriculture. Efforts to restore these ecosystems often focus on management of the riparian zone, as riparian land-use and vegetation have strong effects on stream environmental quality (Karr and Schlosser, 1978; Schlosser and Karr, 1981; Gregory *et al.*, 1991; Rabeni and Smale, 1995; Naiman and Décamps, 1997). Prescriptions for stream restoration or protection in the United States and Canada commonly emphasize establishment and maintenance of riparian buffer areas of "natural" or "undisturbed" vegetation (Osborne and Kovacic, 1993; Barling and Moore, 1994; Belt and O'Laughlin, 1994; Castelle *et al.*, 1994; Qiu and Prato, 1998). In many cases, natural, undisturbed riparian vegetation is implicitly or explicitly equated with woody vegetation or forest (e.g., USFS, 1990; Gregory *et al.*, 1991; Petersen *et al.*, 1992, Iowa State University, 1996; Isenhart *et al.*, 1997; Montgomery, 1997; Thorn *et al.*, 1997; but see Schueler, 1995, for an exception), even though much of central North America was historically grassland or savannah (Curtis, 1959; Wells, 1970; Axelrod, 1985).

It is very likely that pre-settlement riparian vegetation along small streams within the prairie region of the United States and Canada was predominantly grassy as a result of frequent fires and perhaps grazing by bison (*Bison bison*) and other large herbivores. For example, at Konza Prairie, a 3,487 ha intact prairie remnant in Kansas, small streams had grassy riparian areas, whereas gallery forests lined larger streams (Gurtz *et al.*, 1982). Historical analysis indicated that gallery forests had expanded at Konza by 54 percent since 1939, suggesting that even the larger streams may have had a proportion of their banks in grassy vegetation (Knight *et al.*, 1994). As another example, a visitor to southwestern Wisconsin in 1838, prior to major agricultural development, noted that the local streams and rivers meandered through

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"natural meadow from a quarter of a mile to more than a mile in width" of "high waving grass mingled with the field and meadow flowers" (Smith, 1975:22-23). Interspersed among the meadows and prairies were small groves of riparian shrubs or trees.

The functions and benefits of wooded riparian zones to stream ecosystems are well studied by ecologists, but the role and value of grassy or herbaceous riparian vegetation are not (Hynes, 1970; Wiley *et al.*, 1990; Osborne and Kovacic, 1993). A small but increasing body of scientific literature has documented specific cases and types of stream degradation where maintenance of open grassy riparian zones provided benefits equal to or greater than those achieved with riparian forests (White and Brynildson, 1967; Hunt, 1979; Peterson, 1993; Davies-Colley, 1997; Trimble, 1997). Additionally, civil and agricultural engineers have for many years used grassy vegetation in riparian areas of semi-natural channels such as floodways and drainage ditches to help manage flood flows, stabilize banks, and filter polluted terrestrial runoff (USACOE, 1991; NRCS, 1997a). However, the management implication that non-wooded riparian areas might be equally or more appropriate in some natural settings is controversial among aquatic scientists and resource managers (Montgomery, 1997).

In this paper we review the positive and negative implications of grassy versus wooded riparian zones for the protection and restoration of stream ecosystems. Our emphasis is on small streams in central North America. We consider effects of riparian vegetation on both inputs to the stream from adjacent uplands and banks and processes within the stream channel. We briefly summarize the scientific literature on the theoretical and observed effects of woody versus grassy riparian vegetation on stream ecosystems. We identify topics for which more research is needed and discuss management implications.

FOCUS OF THE REVIEW

Our main focus is on the effects of different types of riparian vegetation on small streams in the grassland/savannah region of central North America. This region extends roughly from the eastern edge of the Rocky Mountains in the west to western Indiana, Illinois, and southern Wisconsin in the east, and from southern Alberta, Saskatchewan, and Manitoba in the north, to central Texas in the south (Curtis, 1959; Steinauer and Collins, 1996). Before European settlement, small streams in this region primarily flowed through open grasslands and savannah, although riparian gallery forests were present in some areas (Smith, 1975; Gurtz *et al.*, 1982; Menzel *et al.*, 1984; Knight *et al.*, 1994). We emphasize small streams (drainage areas less than 250 km^2 and widths typically less than 10 m) with natural channels (i.e., no channelized, with limited or no bank or channel armoring) because the influence of riparian vegetation is readily observed and has been relatively well studied in these ecosystems. That is not to imply, however, that riparian vegetation does not play an important role in other types of fluvial ecosystems, and, as appropriate, we include in our review relevant studies from heavily modified streams and larger rivers as well as data from outside of central North America.

We broadly define "wooded" and "grassy" riparian vegetation. Woody vegetation includes both shrubs and trees, but they must occur at a density that provides at least 75 percent canopy closure at a height of more than 2 m for the riparian zone to be considered wooded. Based on this definition, wooded riparian zones will shade most of the stream bank and channel during summer months. "Grassy" vegetation encompasses grass, forb, and herbaceous species that do not exceed 2 m in height. Grassy vegetation must cover more than 75 percent of the ground in dense growths with no more than a few widely scattered trees or shrubs present for the riparian zone to be considered grassy. Grassy riparian zones can consist of either managed (i.e., lawn, pasture) or unmanaged (i.e., prairie, meadow) vegetation. Unfortunately, many studies on riparian vegetation or buffers provide only limited information on vegetation characteristics.

PROS AND CONS OF WOODY VERSUS GRASSY RIPARIAN AREAS AND STREAMBANKS

Riparian vegetation influences many aspects of stream ecosystems. Here we compare and contrast effects of grassy and woody vegetation on selected aspects of particular interest to water resources management in central North America.

Bank and Channel Habitat

Bank Stability, Channel Morphology, and Erosion. Bank erosion is a natural and fundamental process in the development and maintenance of stream channel morphology (Leopold *et al.*, 1964). However, many types of human modification of stream watersheds, riparian zones, and channels can destabilize stream banks (Hupp, 1992). Destabilized banks have high rates of erosion, leading to undesirable changes in channel morphology, excessive instream sedimentation, and loss of habitat for many aquatic organisms, particularly fish (Gregory, 1992; Naiman and Décamps, 1997). Management of riparian vegetation is commonly used to stabilize banks, recreate habitat, restore natural channel morphology, and reduce erosion (Osborne and Kovacic, 1993; Barling and Moore, 1994; Belt and O'Laughlin, 1994; Castelle *et al.*, 1994).

For high (> 1 m), steep (> 45° angle with stream), eroding banks, woody vegetation is normally more practical than grassy vegetation for stabilization (Hupp, 1992; Isenhart *et al.*, 1997; Watson *et al.*, 1997; Burckhardt and Todd, 1998). Plantings of willows (*Salix* species) from 0.5 to 2 m in height have proven highly beneficial in many instances (Lyons and Courtney, 1990; Watson *et al.*, 1997), although willow effectiveness is often enhanced when plantings are coupled with mechanical bank sloping or placement of rock rip-rap along the toe of the bank (e.g., Shields *et al.*, 1997). The willows develop a thick root system that binds together bank soils, and their dense, bushy branches slow water velocities, reduce bank scouring, trap suspended sediment particles to rebuild the bank, and armor it from damage from drifting debris and ice (Lyons and Courtney, 1990; Isenhart *et al.*, 1997). However, willow trunks and branches can induce turbulence and cause local erosion during high stream flows. Willows are also relatively short-lived, and additional vegetation management may be needed as they die and decay.

Where banks are lower and less steep, grassy vegetation may be superior to woody vegetation in preventing erosion (Davies-Colley, 1997; Trimble, 1997). In many instances shading from woody vegetation reduces or eliminates understory vegetation, leading to unprotected bare soil that is susceptible to erosion (White and Brynildson, 1967; Hunt, 1979; Peterson, 1993). When large streambank trees fall across the channel, their branches may gouge out the bank on the opposite shore and leave an unstable area where their root mass was (White and Brynildson, 1967; Shields and Gray, 1992). The voids left by the root masses of fallen trees cause turbulence and local erosion (Thorne, 1990; Trimble, 1994). Large woody debris in the channel can focus stream flows into the bank, further promoting local erosion and bank instability (Gregory and Davis, 1992; Gurnell and Gregory, 1995; Keller and McDonald, 1995; Shields and Gippel, 1995; Trimble, 1997), although in many instances large woody debris armors the stream bank from scouring flows (Keller and Swanson, 1979). A "plume" of large woody debris often extends downstream of wooded riparian zones, such that some of the bank and channel effects of wooded riparian zones may extend well beyond the actual extent of the woody vegetation (Trimble, 1997). In contrast, grassy riparian areas generally have a well-developed turf and a dense root system that is excellent at preventing erosion (White and Brynildson, 1967; Murgatroyd and Ternan, 1983; Clary and Webster, 1990; Peterson, 1993; Dunaway *et al.*, 1994). No trees are present to fall and damage the banks or to produce large woody debris in the channel.

Grassy and wooded riparian areas produce very different channel morphologies. Comparisons of adjacent stream reaches or of the same reach over time have revealed that stream channels tend to be significantly narrower in grassy than in wooded riparian vegetation (White and Brynildson, 1967, Zimmerman *et al.*, 1967; Hunt, 1979; Clary and Webster, 1990; Peterson, 1993; Sweeney, 1993; Dunaway *et al.*, 1994; Davies-Colley, 1997; Trimble, 1997). In some instances, grassy channels are also deeper (White and Brynildson, 1967; Peterson, 1993; Sweeney, 1993). Wooded zones tend to have fewer pools, more fine sediment on the channel bottom, and more variation in bottom substrates, water velocity, and channel dimensions than grassy zones (Keller and Swanson, 1979; Shields and Smith, 1992; Peterson, 1993; Sweeney, 1993; Trimble, 1997). Undercut banks, favored by many species of fish, are more likely in grassy riparian areas (Hunt, 1979, 1993; Peterson, 1993).

Grassy areas have narrower channels because of their tendency to "build" stable stream banks by trapping and storing suspended sediments and their tendency to have less bank erosion than wooded areas. Trimble (1997) estimated that grassy reaches of a southwestern Wisconsin stream stored 2,100 to 8,800 m^3 km^{-1} more sediment than comparable forested reaches. Several authors have cautioned that as grassy banks revert to wooded banks through vegetation succession, large amounts of sediment could be released into the stream channel (Murgatroyd and Ternan, 1983; Smith, 1992; Davies-Colley, 1997; Trimble, 1997).

Cover for Fish. Sufficient shelter and hiding areas, termed "cover," are critical for fish production in streams, and enhancement of instream and bankside cover through riparian vegetation management is an important fisheries management activity (Lyons and Courtney, 1990; Hunter, 1991; Hunt, 1993). Wooded and grassy riparian areas produce very different types of cover. In wooded stream reaches, large woody debris provide extensive and excellent cover for a wide range of warmwater and coldwater fishes, as do the rootwads of trees on the streambank (e.g., Bryant, 1983; Angermeier and Karr, 1984; McClendon and Rabeni, 1987; Sedell *et al.*, 1988; Hunter, 1991; Sundbaum and Näslund, 1998). Woody debris are routinely added to streams in the form of half-logs and other wooden habitat structures to improve fisheries

(Lyons and Courtney, 1990; Hunt, 1993). However, wooded areas that are dominated by shrubs tend to produce very little large woody debris and few stable rootwads, although low branches may provide some overhanging cover (White and Brynildson,1967; Hunt,1979).

Grassy riparian areas have cover primarily in the form of overhanging vegetation, undercut banks, and aquatic macrophytes (Hunt, 1979, 1985, 1993; Peterson, 1993). Undercut banks are particularly important habitat for brown trout (*Salmo trutta*) (Thorn, 1992; Thorn and Anderson, 1993).

Water Quality and Quantity

Terrestrial Runoff. Surface runoff and subsurface inputs from terrestrial areas are major sources of water, sediments, nutrients, and, in some cases, toxic substances for streams. Riparian vegetation has a strong influence on the rate, amount, and type of water, sediments, and nutrients reaching the stream from the surrounding uplands (Hynes, 1970; Cooper *et al.*, 1987; Naiman and Décamps, 1997). Probably the most common reason for the development of vegetated buffer strips in agricultural areas is to slow and filter terrestrial inputs of water and thus improve stream water quality (Osborne and Kovacic, 1993; Barling and Moore, 1994; Lowrance *et al.*, 1997).

Wooded riparian soils have particularly good water infiltration capabilities (Cooper *et al.*, 1987; Osborne and Kovacic, 1993; Barling and Moore, 1994; Belt and O'Laughlin, 1994; Castelle *et al.*, 1994; Daniels and Gilliam, 1996; Lowrance *et al.*, 1997; Snyder *et al.*, 1998). Infiltrated runoff waters drop their sediment loads, along with any adsorbed nutrients and toxins. Dissolved chemicals in the infiltrated water can then be taken up by trees and shrubs or associated microbes (Fail *et al.*, 1986; Hill, 1996). The thickness and characteristics of the forest floor "duff" (decaying leaves and twigs) layer is particularly important in slowing and modifying terrestrial runoff (France, 1997).

Wooded riparian areas are generally better than grassy areas in assimilating nitrogen from terrestrial runoff, except when nitrogen-fixing shrubs such as alders (*Alnus* species) are present, in which case wooded riparian areas may become a source of nitrogen to the stream (Petersen *et al.*, 1992; Haycock and Pinay, 1993; Osborne and Kovacic, 1993; Vought *et al.*, 1994). Nitrogen in terrestrial runoff is usually highly soluble and readily enters the ground water (Wenger, 1999). The deeper root systems of tree and shrubs allow them to take up nitrogen from a greater volume of subsurface waters (Hill, 1996; Isenhart *et al.*, 1997). However, the actual amount of nitrogen removed from the runoff depends on many factors, including soil characteristics, depth to ground water, riparian slope, width and type of vegetation, and season; and there are instances where grassy vegetation has been found to remove more nitrogen than woody vegetation (Haycock and Pinay, 1993; Hill, 1996; Correll *et al.*, 1997; Wenger, 1999). Furthermore, once the nitrogen has been removed from the runoff, the extent to which it leaves the riparian zone and enters the atmosphere via denitrification is also a function of many specific site characteristics, and it is difficult to generalize about the relative rates of denitrification for woody versus grassy vegetation (Osborne and Kovacic, 1993; Wenger, 1999).

The infiltration and filtering functions of riparian areas can be saturated and overwhelmed by high volumes of terrestrial runoff water and nutrients (Omernik *et al.*, 1981; Barling and Moore, 1994; Daniels and Gilliam, 1996). In agricultural landscapes, field tile drains can allow runoff to bypass the vegetated riparian zone, but the deeper root systems of trees and shrubs are more likely than grassy vegetation to break or clog these drains (Petersen *et al.*, 1992; Osborne and Kovacic, 1993).

Grassy vegetation also has a strong influence on runoff from terrestrial areas. Grassy riparian areas have good water infiltration capacity, although not quite as good as woody vegetation (Trimble and Mendel, 1995). Sediment trapping capacities are roughly similar for the two types of vegetation, although many site-specific and vegetation-specific factors strongly influence trapping efficiency (Parsons *et al.*, 1994; Daniels and Gilliam, 1996; Wenger, 1999). Grassy riparian zones are usually better than wooded zones at assimilating phosphorus, which tends to be concentrated in surface and shallow subsurface runoff (Osborne and Kovacic, 1993; Parsons *et al.*, 1994; but see Vought *et al.*, 1994). Once assimilated into riparian zone vegetation, phosphorus remains unless physically removed. When phosphorus inputs from terrestrial runoff are heavy, the riparian zone can be overwhelmed and saturated, and the phosphorus retention rate will decline accordingly (Daniels and Gilliam, 1996; Wenger, 1999). However, regular mowing or managed livestock grazing that takes substantial plant biomass from the riparian zone can be used to directly remove phosphorus and increase the nutrient assimilative capacity of grassy vegetation (Osborne and Kovacic, 1993).

Both woody and grassy riparian vegetation can filter toxins such as organic wastes, pesticides, heavy metals, and hydrocarbons from terrestrial runoff (Wenger, 1999). However, only a few studies have looked at this topic in detail, and there are insufficient data to determine the relative effectiveness of woody versus grassy vegetation for removing toxic substances.

Hydrology. Riparian vegetation can have a major effect on stream flow patterns, in part by slowing or reducing terrestrial surface runoff to the stream, but also by directly modifying flood and base flows in the stream channel (Naiman and Décamps, 1997). This function of vegetation is particularly important in watersheds where agricultural or urban land-use practices have increased the magnitude and frequency of floods and decreased base flows (Dunne and Leopold, 1978).

Woody vegetation can directly influence stream hydrology. Wooded riparian zones with large amounts of woody debris on the bank or in the channel promote debris dams that slow flood flows, raising the stream stage and spreading flood waters further out into the floodplain (Keller and Swanson, 1979; Gregory, 1992; Shields and Smith, 1992). This can increase localized flooding, but may dampen downstream flood peaks (Castelle *et al.*, 1994). At the other extreme, wooded riparian zones may reduce summer low flows in the stream channel, relative to grassy riparian zones. Generally, shrubs and trees require more water for maintenance and growth than do grassy or herbaceous vegetation, and are more likely to lower the local water table, which largely determines baseflows (Dunne and Leopold, 1978; Trimble *et al.*, 1987). Greater water use by trees results in drier soils, which lowers erosion potential owing to bank sloughing and slumping (Thorne, 1990).

Grassy vegetation has less direct influence on stream flows than woody vegetation. Grassy areas are less likely to result in debris dams that exacerbate local flooding. Grassy vegetation uses less water and has less potential to reduce summer baseflows.

Water Temperature. Water temperature has a major influence on stream water quality and biota (Schlosser and Karr, 1978; Winger, 1981; Sweeney, 1993; Lyons *et al.*, 1996; Hawkins *et al.*, 1997). In many areas, "coldwater" streams are especially valued for the salmonid fisheries that they support, and maintenance of relatively low summer water temperatures is a major management concern.

Shading from woody riparian vegetation is particularly valuable in reducing temperature fluctuations and extremes (Karr and Schlosser, 1978; Barton *et al.*, 1985; Sweeney, 1993; Belt and O'Laughlin, 1994; Castelle *et al.*, 1994; Hetrick *et al.*, 1998). Both the length and width of the wooded riparian area are important in temperature control (Barton *et al.*, 1985; Wehrly *et al.*, 1998). Loss of forested stream banks to clear-cutting, row-crop agriculture, or urbanization has led to warmer and more variable summer temperatures, which in turn has altered stream biological communities (Burton and Likens, 1973; Barton *et al.*, 1985; Sweeney, 1993; Hetrick *et al.*, 1998). However, no studies have specifically compared summer stream temperatures between wooded and well-established grassy riparian zones. We speculate that in grassy stream reaches the narrower stream channel, greater extent of undercut banks, and greater amount of grasses overhanging the channel relative to comparable wooded reaches might lead to lower summer water temperatures than predicted from existing studies of the relation between riparian land-use and stream thermal regimes.

Organic Matter and Primary Production. Riparian vegetation influences instream primary production directly through blocking of sunlight and inputs of organic matter from the vegetation itself, and indirectly through filtering of terrestrial runoff and modification of channel morphology and temperature (Karr and Schlosser, 1978; Vannote *et al.*, 1980; Gregory *et al.*, 1991; Sweeney, 1993). The amount of primary production and the type, quality, and availability of organic matter in turn influence water quality and biota. Stream eutrophication and excessive aquatic plant growth are major management concerns in many agricultural watersheds (Schlosser and Karr, 1981; Wiley *et al.*, 1990; Bunn *et al.*, 1998).

Woody riparian vegetation dramatically affects primary production and organic matter inputs (Vannote *et al.*, 1980; Gregory *et al.*, 1991; Sweeney, 1993; Hetrick *et al.*, 1998). In small agricultural streams, shading from the riparian forest canopy is often the most important factor limiting aquatic photosynthesis (Karr and Schlosser, 1978; Schlosser and Karr, 1981; Sweeney, 1993). Shaded channels tend to have little algae and few macrophytes. Riparian trees and shrubs drop large amounts of coarse organic material (i.e., seeds, leaves, twigs, and branches) into the stream, with a major pulse of leaves during the fall (Vannote *et al.*, 1980). Large woody debris in the stream channel help retain this organic matter within the stream reach where it can be used by micro and macro-organisms (Gregory *et al.*, 1991). The relative lack of autochthonous (within-stream) production coupled with major allochthonous (outside stream) organic inputs results in a very different assemblage of microorganisms and macroinvertebrates (see next section) relative to unwooded stream reaches (Sweeney, 1993).

Patterns of primary production and organic matter inputs are substantially different in streams with grassy riparian areas. Grassy riparian areas tend to shade the stream channel less than do wooded areas

(Hunt, 1979; Sweeney, 1993). Algae and macrophyte densities are generally higher in grassy areas, resulting in greater overall primary production (Schlosser and Karr, 1981). In low-nutrient, sand-bed streams, increased macrophyte density provides more fish cover and more macroinvertebrate production and is considered beneficial (Hunt, 1979, 1985). In agricultural streams with higher nutrient inputs, macrophytes and algae will often reach nuisance levels in grassy reaches, depleting dissolved oxygen levels at night and impeding water flow. This leads to declines in desirable fish and invertebrate populations (Schlosser and Karr, 1981; Wiley *et al.*, 1990; Greb and Graczyk, 1993; Bunn *et al.*, 1998).

On a per-unit-area basis, grassy riparian zones have more limited organic matter inputs to streams than woody zones, the organic matter is finer in size, and there is not a dramatic fall pulse in inputs (Wiley *et al.*, 1990). Compared to wooded reaches, grassy reaches have relatively high autochthonous production and low allochthonous inputs, and a different fauna is the result (Sweeney, 1993).

Biota

Aquatic Macroinvertebrates. Macroinvertebrates, especially insects, are among the most diverse and important components of the non-microscopic fauna of a stream. They are important in organic matter processing and energy flow from primary producers to consumer organisms, and are major sources of food for fish (Cummins, 1974; Gregory *et al.*, 1991). Macroinvertebrates are also useful indicators of overall stream ecosystem quality (Rosenberg and Resh, 1993). Riparian vegetation has strong effects on macroinvertebrate assemblages, especially though its influence on habitat conditions, primary production, and organic matter (Hynes, 1970; Vannote *et al.*, 1980; Gregory *et al.*, 1991; Sweeney, 1993; Richards *et al.*, 1993, 1996, 1997; Storey and Cowley, 1997).

Macroinvertebrate assemblages in wooded stream reaches tend to be very different from those in grassy reaches (Sweeney, 1993). The relatively high amount of coarse organic matter in wooded reaches promotes the abundance of shredders, which feed on large organic particles (feeding groups based on Cummins and Merritt, 1984), and the detritus trapped by large woody debris favors populations of some detritivores (Gregory *et al.*, 1991; Sweeney, 1993). In sand-bottomed streams, woody debris from riparian vegetation is the key site for primary and secondary production, and woody debris have a much higher biomass and diversity of macroinvertebrates than the sand substrate (Wallace and Benke, 1984; Benke *et al.*, 1985).

In open or grassy riparian areas, relatively high primary production promotes the abundance of grazers, collector-gatherers, and other herbivores. On a per-unit-area basis, total macroinvertebrate biomass and production are greater in open reaches than forested reaches (Gregory *et al.*, 1991; Sweeney, 1993). However, Sweeney (1993) argued that total macroinvertebrate biomass might actually be higher in some wooded areas because of the much greater bottom area (wider channel) and surface area of woody debris available as habitat. In studies of historically forested streams, Sweeney (1993) and Davies-Colley (1997) considered the narrowing of the stream channel that occurred when a forested reach was converted to grassy vegetation as a loss of macroinvertebrate habitat.

Macroinvertebrate communities are particularly strongly influenced by stream substrate and velocity patterns, which are in turn influenced by riparian vegetation. It seems logical that the habitat differences documented between woody and grassy stream channels in the amounts of pools, fine sediment on the channel bottom, and variation in bottom substrates, water velocity, and channel dimensions would contribute to major differences in macroinvertebrate communities. However, to our knowledge, no one has studied the influence of these habitat characteristics on macroinvertebrate communities in grassy riparian areas.

Fish. Fish play a key ecological role in streams, support economically and socially important fisheries, and are good indicators of overall stream condition (Karr, 1981; Matthews and Heins, 1987; Fausch *et al.*, 1990). Consequently they are a major focus of stream management activities (Kohler and Hubert, 1993). Riparian vegetation appears to strongly influence fish assemblages, although available information is largely limited to coldwater streams and salmonid fishes (Gregory *et al.*, 1991; Rabeni, 1993; but see Collares-Pereira *et al.*, 1995, and Rabeni and Smale, 1995).

Wooded riparian areas are generally considered best for stream fishes (e.g., Thorn *et al.*, 1997), but supporting data come largely from historically forested areas, particularly western North America (e.g., Hawkins *et al.*, 1983; Murphy *et al.*, 1986; Platts and Nelson, 1989; but see Angermeier and Karr, 1984; Barton *et al.*, 1985). Most studies emphasize the benefits to fish from the large woody debris and temperature control derived from wooded riparian zones (Schlosser, 1991).

A handful of studies have documented benefits of grassy riparian zones for salmonid fishes. Peterson (1993) found significantly more brook trout (*Salvelinus fontinalis*) in streams adjacent to short grassy riparian areas (~30 m-long electric transmission right-of-ways) than in nearby heavily wooded reaches in a forested region of New York. Slawski (1997) found more adult brook trout in a grassy riparian area than in a nearby wooded riparian in a small southeastern Wisconsin stream. However, the highest abundances of brook trout were in a wetland zone with a mix of woody and grassy riparian vegetation. Hunt (1979, 1985) reported greater brown and brook trout abundance and biomass in reaches of two out of three forested Wisconsin streams where dense stream bank shrubs were removed and replaced with grassy vegetation. As a result of Hunt's studies, stream bank "debrushing" has become a common fisheries management practice along Wisconsin trout streams (Hunt, 1993). Data in Hunt (1988) suggest that debrushing may benefit brown trout more than brook trout.

Riparian vegetation also influences the occurrence of beaver (*Castor canadensis*), a mammal which has a major influence on streams and their fish communities through construction of dams, ponds, and bank burrows (Naiman *et al.*, 1988; Schlosser, 1995). Wooded riparian areas are more conducive to beaver activity than grassy areas, especially if they are dominated by shrubs and small trees (Naiman *et al.*, 1988). The effects of beaver on stream trout fisheries in Wisconsin are generally perceived to be negative (Hunt, 1993). They include flooding, siltation of stream habitat, and summer temperature increases. Consequently, fisheries managers often attempt to remove beaver and their dams from trout streams. Although direct habitat effects within beaver impoundments are obvious, surprisingly little quantitative documentation exists for negative impacts of beaver outside of impounded areas (Avery, 1992; McRae and Edwards, 1994; Butler, 1995). Schlosser (1995) concluded that beaver ponds were essential to the persistence of several small minnow species (Cyprinidae) in a northern Minnesota stream.

Riparian vegetation determines the ease with which people can fish in small streams. In the spring, when grassy vegetation is low, woody riparian areas may be more difficult for fishing than grassy areas, at least for methods that require casting, such as fly fishing. By summer, grassy vegetation in unmanaged riparian zones may be tall enough to hamper fishing. Densely vegetated riparian zones could conceivably act as refuge areas for fish in heavily fished streams. A mosaic of grassy and wooded areas along a stream might be best for maintaining fisheries.

MANAGEMENT IMPLICATIONS

Research Needs

Much more needs to be learned about the relative function and value of grassy riparian areas (see also Osborne and Kovacic, 1993). Grassy vegetation topics especially worthy of additional attention include bank erosion and channel morphology, filtering of toxins from terrestrial runoff, baseflows, water temperature, fish habitat, and macroinvertebrate and fish communities. Studies of grassy vegetation effects should encompass a broad range of climates, grassy vegetation types, stream gradients, water temperature regimes, and soils.

Wooded riparian areas are comparatively well-studied, but for many aspects of stream management it is difficult to determine the relative advantages and disadvantages of woody versus grassy vegetation. Most studies on wooded riparian areas come from historically forested regions of North America, and results from these studies may not necessarily be completely applicable to grassland regions (e.g., Wiley *et al.*, 1990). Further, the benefits of woody vegetation typically have been assessed in comparison with major human modifications of the riparian zone, such as clear-cutting of trees, intensive row crop agriculture, livestock overgrazing, or urban development, rather than grassy vegetation. More studies on woody riparian vegetation are needed for the streams of central North America, particularly studies that consider different types of woody vegetation (e.g., shrubs, mature hardwoods) in comparison with different types of grassy vegetation (e.g., meadow, well-managed pasture).

Grassy Vegetation in Riparian Management

Our review suggests that grassy riparian vegetation may be equal to or better than woody vegetation for achieving certain stream management goals (Table 1). Of particular interest in agricultural watersheds is what seems to be the generally superior ability of grassy vegetation to prevent bank erosion and trap suspended sediments from the stream.

Although grassy riparian vegetation has certain benefits, we urge great caution before replacing existing woody riparian vegetation with grassy vegetation, especially in historically forested watersheds. Advantages and disadvantages of each vegetation type need to be considered collectively when developing management goals and strategies for the riparian zone of a stream. In most cases, we believe that the benefits of

TABLE 1. Relative Benefits of Grassy Versus Woody Riparian Vegetation for Small Streams in Grassland/Savannah Areas of Central North America.

Management Aspect	Grassy Vegetation	Woody Vegetation
Bank Stability, Channel Morphology, and Erosion	Less bank erosion; greater trapping of suspended sediment; narrower channels, more undercut banks and pools	Better stabilization of severely eroding banks; wider channels, more diverse substrates
Cover for Fish	More undercut banks, overhanging vegetation, aquatic macrophytes	More large woody debris
Terrestrial Runoff and Subsurface Inputs	Better assimilation of phosphorus	Better assimilation of nitrogen; uptake of nutrients from deeper subsurface waters
Hydrology	Less local flooding; higher baseflows	Reduced downstream flooding
Water Temperature	Unknown; more studies needed	Less variable and lower summer temperatures
Organic Matter and Primary Production	Greater primary production; more algae, macrophytes	Greater organic matter inputs; less less chance of excessive primary production
Macroinvertebrates	Higher per-unit-area abundance and biomass, more herbivores	Greater overall abundance (?), more shredders and detritivores
Fish	Better habitat in some cases, with higher trout abundance; fewer beaver; easier fishing in spring and fall	Better habitat if high summer temperatures or excessive primary production are problems

establishing extensive grassy riparian areas would not offset the economic and ecological costs of removing woody vegetation. However, localized replacement of woody vegetation with grassy vegetation to address a specific management concern might be warranted in some instances. Here the geographic scale of management activities would be particularly important. Benefits that accrued from establishing small areas of grassy riparian vegetation might not persist if grassy vegetation were established over a longer length of stream. For instance, short reaches (30-100 m) of grassy riparian vegetation might improve fish habitat and increase trout abundance in an otherwise forested stream, but longer reaches of grassy stream banks could lead to excessive instream primary productivity and higher water temperatures, resulting in a decline in the stream's trout population. A mix of occasional short grassy zones interspersed among much more extensive woody zones might be the best way to maximize habitat heterogeneity and biodiversity in forested watersheds (Schlosser, 1991; Slawski 1997).

The width of grassy riparian areas is also important, particularly in regard to filtering of terrestrial runoff. Grassy buffer strips as narrow as 4 m have been shown to remove significant amounts of nutrients and sediments from runoff (Parsons *et al.*, 1994), but maximum benefits are normally achieved with widths of 30 m or more (Osborne and Kovacic, 1993; Castelle *et al.*, 1994). Government management agencies in the United States usually recommend a minimum grassy buffer width of 8-10 m to protect water quality (e.g., NRCS, 1997a). For riparian areas with slopes of greater than 6 percent (perpendicular to the stream channel), minimum buffer widths up to 20 m are advised, and for slopes greater than 20 percent, grassy buffers are not recommended.

We believe that establishment and maintenance of extensive grassy riparian areas is most appropriate in agricultural or urban streams of central North America that currently lack adequately vegetated riparian zones. For these streams, either grassy or woody vegetation would be an improvement over current conditions, although grassy vegetation might be more in keeping with the original character of the landscape (see also Schueler, 1995). Establishment of grassy vegetation might be more acceptable to riparian landowners than woody vegetation, especially if the riparian area could continue to be used for certain agricultural activities such as hay production or management-intensive livestock grazing (Undersander *et al.*, 1993; DeVore, 1998). We have encountered many farmers who were reluctant to establish woody riparian buffer zones because of the loss of livestock access to valuable riparian lands and because of concerns about increased flooding and beaver activity. To date, voluntary efforts to install riparian buffer strips in the midwestern United States have generally met with limited success, even when government cost-sharing was available, in large part because of farmer reluctance (e.g., Wolf, 1995). The option of grassy vegetation and continued use of the riparian zone might encourage more farmers to develop well-vegetated riparian zones. However, some government policies discourage this option. For example, the most recent U.S. "Farm Bill" requires landowners to plant trees in riparian buffer areas in order to qualify for a government subsidy (NRCS, 1997b), despite the fact that grassy riparian buffer strips are already a government-sanctioned practice for protecting stream water quality, reducing bank erosion, and improving wildlife habitat (NRCS, 1997a). We believe that all government policies for riparian vegetation management in the central United States should be flexible enough to allow for either grassy or woody vegetation as site conditions and management goals warrant.

Maintaining Grassy Riparian Areas

Once grassy vegetation has been established in the riparian zone, it requires regular management, or it will likely revert to woody vegetation through natural plant succession (White and Brynildson, 1967; Trimble, 1997). The processes that once maintained the vast grasslands and savannahs of central North American, burning from wildfires and grazing by large wild herbivores, no longer operate. Management options to maintain grassy vegetation include mowing, controlled burning, herbicide treatments, or livestock grazing. Mowing, burning, and herbicides can be costly, and are probably impractical on a large scale. Grazing is feasible over large areas of riparian zone in watersheds that already have well-developed livestock agriculture, but must be done very carefully to minimize stream bank damage (Trimble, 1994; Trimble and Mendel, 1995; DeVore, 1998). Practices such as intensive rotational grazing (Undersander *et al.*, 1993) that do not concentrate livestock in the riparian zone for extended periods and that emphasize maintaining a thick, healthy, grassy turf will be the most appropriate.

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