Technical Report EL-96-16
September 1996

US Army Corps of Engineers
Waterways Experiment Station

Environmental Impact Research Program

Environmental Value of Riparian Vegetation

by Mary M. Davis, Wilma A. Mitchell, James S. Wakeley, J. Craig Fischenich, Monica M. Craft

Prepared for Headquarters, U.S. Army Corps of Engineers

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Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

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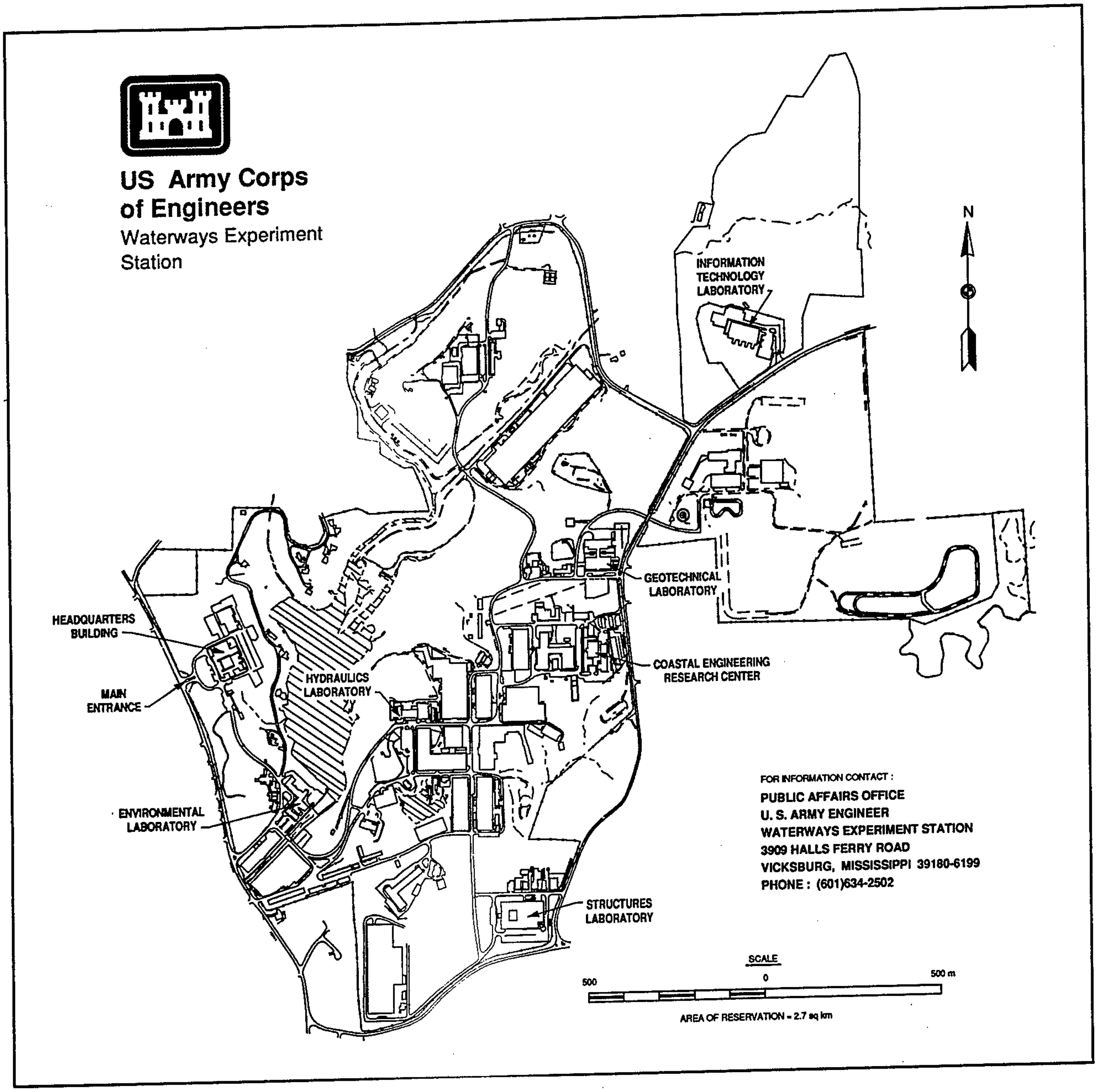

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Environmental Impact Research Program

US Army Corps of Engineers
Waterways Experiment Station

Riparian Vegetation Functions

Environmental Value of Riparian Vegetation (TR EL-96-16)

ISSUE: The U.S. Army Corps of Engineers develops river projects across the country that have potential impacts on the vegetation in areas adjacent to the river, called riparian corridors. As part of the project review process, the impact of the proposed project on the environment must be evaluated. Information about the environmental value of riparian vegetation is difficult to access, because it is diffuse in the literature.

RESEARCH OBJECTIVE: The objective of this research is to review the literature for information pertinent to assessing the environmental value of riparian vegetation.

SUMMARY: Vegetation contributes greatly to the hydraulic, hydrologic, water quality, and life support functions commonly performed in riparian corridors. The resistance to flow by vegetation reduces flow velocity and the energy of flowing water that erodes shorelines and carries suspended sediments. Bank materials are bound and supported by roots. Vegetated watersheds help to stabilize baseflow rates by increasing infiltration and permeability of soils. The result is that vegetation helps to stabilize stream morphology and hydrology and attenuate floods. In addition, suspended solids and dissolved chemicals and nutrients in river water are reduced proportionately with residence time in vegetated floodplains. Riparian vegetation provides food, refuge, and nesting areas for a diverse array of terrestrial and aquatic fauna. Losses of riparian vegetation can lead, therefore, to a destabilization of stream morphology, alteration of hydrology, degraded water quality, and reductions in many types of fish and wildlife.

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About the Authors: Dr. Mary M. Davis is an ecologist; Drs. Wilma A. Mitchell and James S. Wakeley are wildlife biologists; Dr. J. Craig Fischenich is a hydraulic engineer; and Ms. Monica H. Craft is an Oak Ridge National Laboratory post-graduate at WES. Point of contact is Dr. Davis, WES, telephone (601) 634-2853.

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Preface

This study was conducted by the Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES), as part of the Environmental Impact Research Program (EIRP). The EIRP is sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE), and is assigned to WES under the purview of the EL. The HQUSACE technical monitors were Dr. John Bushman and Messrs. David P. Buelow and Dave Mathis. Dr. Russell F. Theriot, WES, was the EIRP Program Manager.

The report was prepared by Drs. Mary M. Davis and James S. Wakeley and Ms. Monica M. Craft, Ecological Research Division (ERD), EL; Dr. Wilma A. Mitchell, Natural Resources Division (NRD), EL; and Dr. J. Craig Fischenich, Environmental Engineering Division (EED), EL.

The study was performed under the direct supervision of Dr. Conrad J. Kirby, Chief, ERD; Dr. Robert M. Engler, Chief, ERD; and Mr. Norman R. Francingues, Chief, EED; and under the general supervision of Dr. John W. Keeley, Director, EL. Technical reviews by Drs. Rebecca Seal, Hydraulics Laboratory, WES, and Mr. Fischenich, EL, are gratefully acknowledged.

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1 The Riparian Environment

Riparian ecosystems occur along streams and rivers (Mitsch and Gosselink 1993). The riparian corridor (Figure 1) encompasses the stream channel and that portion of the terrestrial landscape from the water edge landward where vegetation may be influenced by river-associated water tables or flooding and by the ability of soils to hold water (Naiman, Decamps, and Pollock 1993). Riparian corridors do not include terraces or other elevations in the geomorphic floodplain that are not connected with surface water of the present river during most years (Mitsch and Gosselink 1993). The term "riparian vegetation" refers to the vegetation found growing within the riparian corridor.

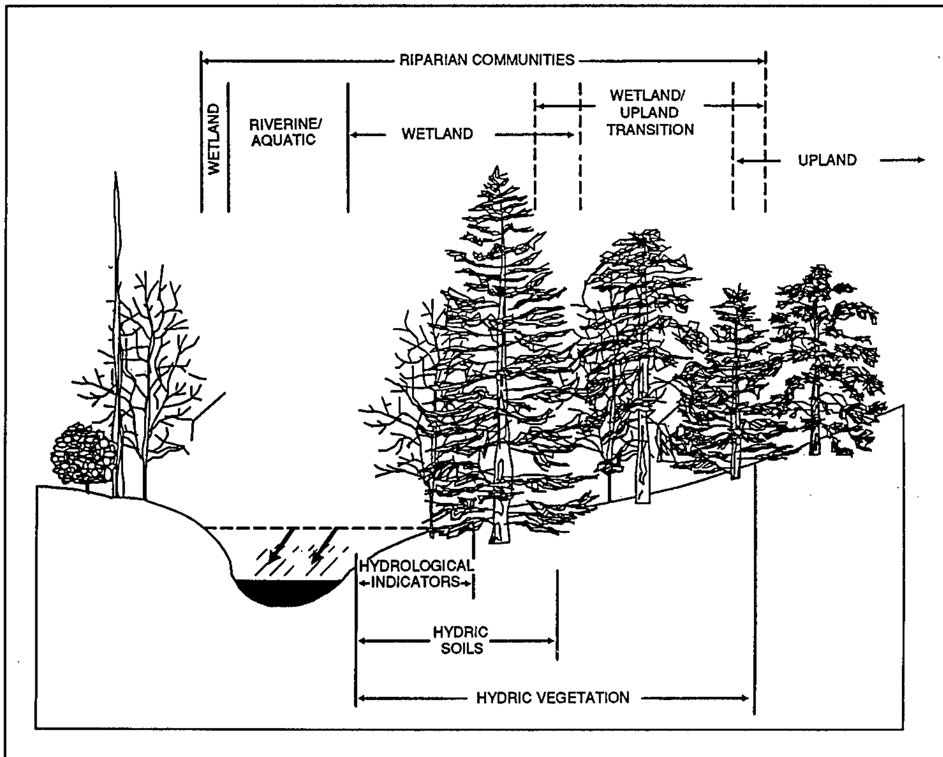

Figure 1. Relationship of aquatic, wetland, and upland areas within riparian corridors

Ecological investigations of riparian corridors have shown them to be key landscape features with unusually high levels of biodiversity (Naiman, Decamps, and Pollock 1993). Riparian habitats form a mosaic of communities differing in species and structure which allows a wide variety of species to coexist (Naiman, Decamps, and Pollock 1993). Furthermore, the mosaic of habitats within many riparian corridors is in constant flux. Newly created habitats shift over time and in space as point bars are created by the river dynamics, mature into different types of communities, and are eventually eroded away as the river continues to change position. Characteristics such as the flood regime and energy of the river system determine how rapidly these processes occur and the degree of maturation reached by the vegetation. This dynamic equilibrium of habitats results in a diversity of vegetation composition, age, density, and structure.

The presence and dynamic nature of riparian vegetation pose problems for hydraulic engineers estimating resistance of the vegetation to flow in flood control channels. Resistance coefficients of vegetation are highly variable depending on plant structure and density and are not well understood. Traditional management approaches for floodways attempt to minimize the amount of riparian vegetation. Whether considering natural or constructed systems, however, the presence of riparian vegetation enhances the environmental value of floodways and is desirable. Furthermore, vegetation management to minimize resistance to floodwater is expensive and is becoming more difficult to justify as the environmental value of riparian vegetation is becoming more clearly understood.

The value of riparian vegetation is derived from the environmental processes to which it contributes that are valued by society. For example, riparian vegetation helps to stabilize banks. This is valued because expensive structures would have to be built to stabilize the bank in place of the vegetation. These environmental processes that take place in riparian ecosystems can be termed the functions of the ecosystem (Brinson 1993). Riparian ecosystem functions include maintenance of fish and wildlife habitat, nutrient retention and removal, sediment trapping, streambank stabilization, and floodflow attenuation (Brinson et al. 1995). These functions can be classified as life support, water quality, and hydrologic functions (Table 1).

Not all functions are performed nor are functions all performed equally in all riparian ecosystems (Brinson 1993). Contributions of vegetation to riparian ecosystem functions depend to a large degree on the physical configuration of the river or stream system. For example, retention of nutrients flowing from surrounding uplands into a low-gradient river with a wide, vegetated floodplain is likely to be greater than nutrient retention in a narrow, sparsely vegetated riparian buffer along a high-gradient river. Both types of riparian systems exist naturally in the landscape, and both levels of nutrient retention are acceptable in their respective systems. There is greater value of the nutrient retention properties of the wide, vegetated floodplain than the narrow, sparsely vegetated riparian buffer to society if river water quality is a problem.

Table 1
Functions of Vegetation in Riparian Ecosystems (based on Brinson et al. 1995)

Hydrologic
Energy dissipation Flood attenuation Stream stabilization
Water Quality
Nutrient retention Particulate retention Carbon production and export
Life Support
Maintain characteristic plant communities Maintain characteristic detrital biomass Maintain characteristic distribution and abundance of invertebrates Maintain characteristic distribution and abundance of vertebrates

The objectives of this chapter are to introduce an ecological concept of the riparian corridor and the environmental factors that influence the composition, distribution, and structure of riparian vegetation. The following chapters present the influences riparian vegetation have on the riparian environment, how riparian ecosystems function, and potential impacts of riparian losses. Chapter 2 discusses effects vegetation have on hydrologic functions. Interactions of vegetation with water quality are presented in Chapter 3. Wildlife habitat value of riparian vegetation is presented in Chapter 4.

Eastern and Western Riparian Ecosystems

One of the first distinctions of riparian ecosystems and the associated vegetation is based on whether the riparian system is situated in relatively humid, semiarid, or arid conditions. Humid regions occur where precipitation exceeds evapotranspiration (i.e., water lost to the atmosphere in evaporation from soil and water surfaces and transpiration from plants). Semiarid and arid regions have greater evapotranspiration than precipitation. Eastern and Pacific Northwest portions of the United States are generally humid, while the majority of the central and southwestern portions of the country are semiarid or arid (Figure 2). As a consequence, eastern riparian ecosystem processes are driven by an excess of surface water. Central and southwestern riparian processes are more dependent on the relative depth to groundwater from the soil surface.

As will be discussed in later sections, the presence of water is the driving force that determines characteristics of riparian areas. Riparian areas with an excess of surface water that remains in the floodplains for a significant period

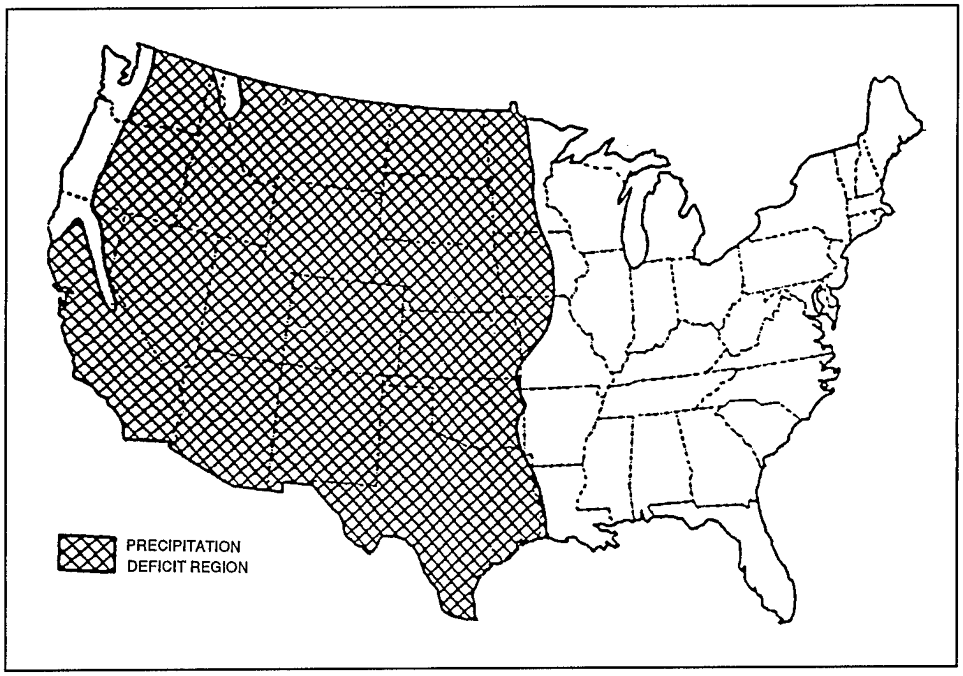

Figure 2. Areas of excess rainfall and rainfall deficit in the United States as determined by the U.S. Geological Service

of the year have much different ecologies than riparian areas that experience surface water primarily as short-term spring floods. Since the presence of saturated soils for at least 2 weeks in most years is a requirement for wetland formation ("wetlands" are ecosystems with anoxic soils due to prolonged saturation; see section below), more wetlands are associated with eastern riparian systems than western systems (Figure 3). In contrast, western riparian systems are areas within otherwise dry landscapes where water is most readily available. Even if streams are ephemeral or intermittent, groundwater is relatively close to the surface in riparian areas. Western riparian systems serve as refuges or oases for plants and animals from the inhospitable conditions of the surrounding arid uplands.

Levels and types of functions in riparian areas differ with the hydraulics and hydrologies found in humid and arid regions. For example, improvement of water quality by riparian areas occurs when surface water flows onto the floodplain surface. As the water slows, sediments are deposited, and the increased contact time with plants and sediments allows nutrients and other substances to be retained. In general, eastern riparian systems have surface water for longer periods of the year than western systems and, therefore, more opportunity to improve water quality. These differences will be discussed further in Chapters 2 through 4.

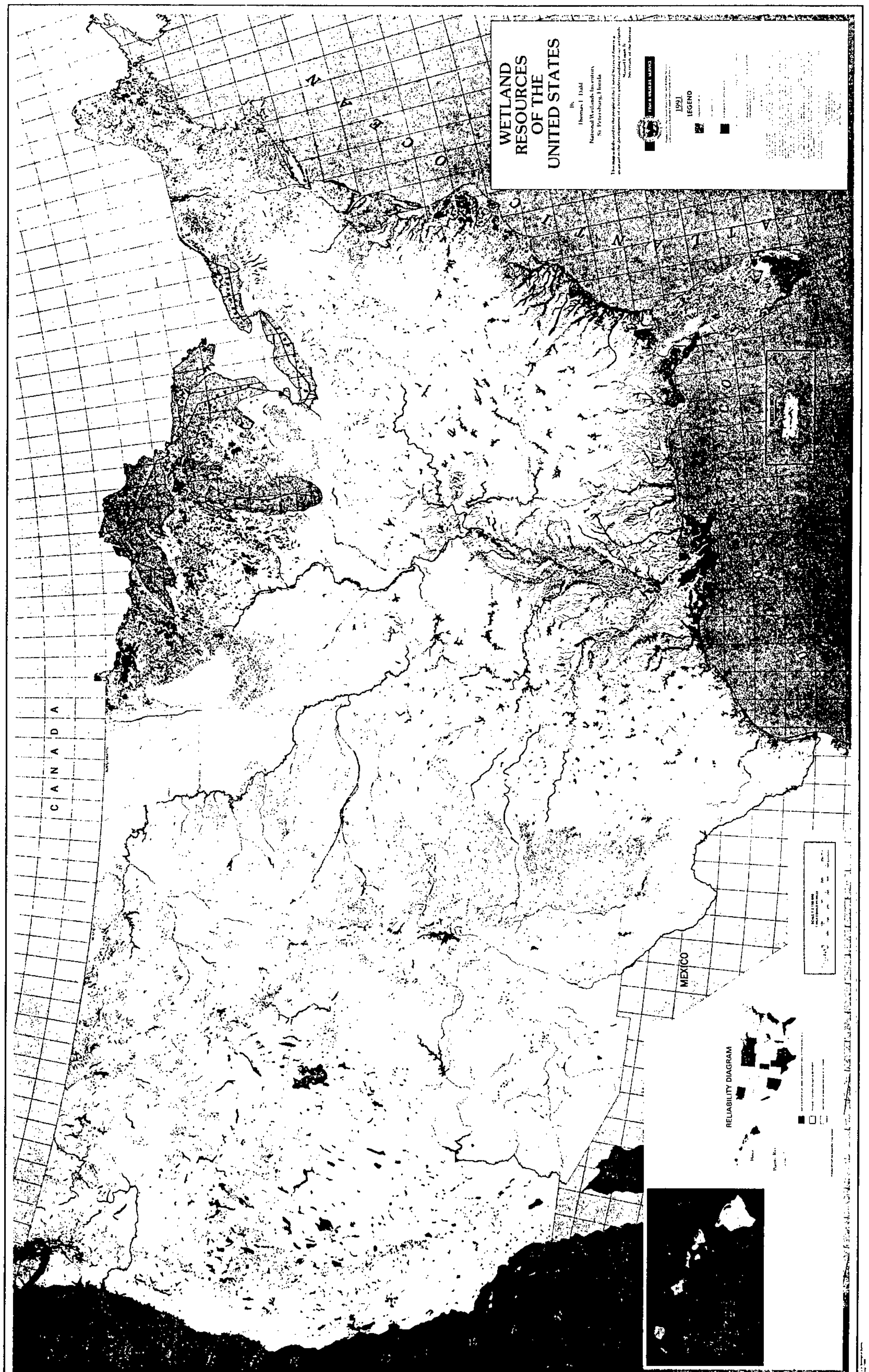

Figure 3. Distribution of wetlands in the United States (by Thomas E. Dahl, U.S. Fish and Wildlife Service 1991)

Types of Riparian Vegetation

Few eastern plant species are found exclusively in riparian areas. Most riparian species will grow well in upland situations; however, they are at a competitive advantage under the conditions found in riparian areas. For example, bald cypress trees usually occur in southeastern swamps that have long periods of annual flooding. These trees will also grow in surrounding upland communities and, in fact, are often used for landscaping. Cypress does not dominate upland plant communities, because it cannot become established in the shade under existing vegetation or it is burned out by the periodic fires that are common in the Southeast. Upland plant species, on the other hand, often are not tolerant of the conditions found in riparian areas. Riparian plant species in the moister eastern portion of the country must be able to tolerate periods of inundation. Eastern riparian species such as bald cypress[1] that do not grow well in the presence of more aggressive upland species are able to flourish along rivers and streams where upland species are excluded.

In contrast, many western riparian plant species are restricted to the relatively moist conditions along streams and rivers or other types of wetlands. Seedling establishment of many riparian species requires a moist ground surface for a sufficient period of time to allow the seed to germinate and establish a root system that can follow the receding groundwater level. For example, Segalquist, Scott, and Auble (1993) showed that cottonwood establishment was restricted if groundwater levels receded faster than seedling roots could grow.

Other limiting conditions exist for plants in riparian areas. Species intolerant of abrasion or sediment deposition may be excluded from high-energy riparian areas. Riparian plant species that occur near active channels, such as willow (*Salix* spp.) and cottonwood (*Populus* spp.), commonly are very flexible and have the capacity to resprout after damage (Rood et al. 1994). Increased flexibility helps minimize damage during high flows. Because establishment by seed in riparian areas is difficult, it is a distinct advantage for a broken plant to be able to resprout and utilize the energy stored in the established root system. If plants are broken or stripped of leaves, they must be able to recover rapidly to survive subsequent high-flow events. Rapid recovery also ensures that the plant will outcompete new colonizing plants.

Excessive deposition of sediments is detrimental to plants primarily because oxygen diffusion to the roots is restricted. Roots require oxygen for respiration and usually cannot live long in the absence of oxygen. The depth of sediment required to block oxygen depends on the texture. Experimental deposits of 8 cm of sediments on a saltmarsh grass (*Spartina alterniflora*) reduced stem densities, with clays having a greater effect than equal depths of

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[1] Scientific names of plants commonly found in freshwater riparian areas are reported in Appendix A.

sand (Reimold, Hardisky, and Adams 1978). In addition, seedbanks are smothered by deposition, restricting the capability of plants to reestablish themselves following a catastrophic depositional event (Jurik, Wang, and van der Valk 1994). Furthermore, siltation on leaves harms plants by blocking light for photosynthesis. Therefore, while a certain amount of deposition in riparian areas is natural and desirable to replenish nutrients, excessive deposition limits plant distributions.

Species that are tolerant of deposition have several survival mechanisms. Some herbaceous species can grow up through the overlying material. Vines, such as blackberries (*Rubus* spp.) and morning glories (*Ipomoea* spp.), and grasses that spread with underground stems, such as reed canary grass and common reed, produce roots along the stem and continue to grow from the tips following deposition. The deeply buried portion of the plant may eventually die. Woody species are usually less adaptable. Some woody species, however, such as willow, are capable of producing adventitious roots on the aerated portion of the stem and surviving deposits up to 1 m depth (U.S. Army Engineer Waterways Experiment Station, unpublished data).

While many plant species occur in riparian areas because they are tolerant of the conditions, the life history characteristics of some riparian species restricts them to areas with flowing water and newly deposited sediments. Examples include several western willows and cottonwoods. Flowing water carries their seeds and deposits them on exposed areas, such as sandbars. The seeds have adequate moisture in these areas to enable them to establish a root system that is capable of following the receding water levels and soil moisture (Fowells 1965). These plants require full sunlight to survive and grow, and so are not capable of growth under existing vegetation. The constant creation of exposed sites by the river is necessary for regeneration of these trees (Everitt 1968; Fonda 1974; Noble 1979). These conditions are only found in or near active channels; hence, regeneration of these species is not found in other areas of riparian corridors.

Species distributions

Riparian corridors form links among many portions of the landscape and, as a consequence, have high levels of biodiversity. Biodiversity is best documented for plants, although nearly 70 percent of vertebrate species in a region will use riparian corridors during their life cycle (Raedeke 1989). Up to 20 percent of local floras have been estimated to occur in riparian corridors in Sweden (Nilsson 1992), the Amazon basin (Junk 1989), and France (Tabacchi, Planty-Tabacchi, and Dechamps 1990). The reasons for the high diversity of riparian vascular plants are thought to be related to (a) the intensity and frequency of floods, (b) small-scale variations in topography and soils as a result of lateral migration of river channels, (c) variations in climate as streams flow from high to low altitudes or across biomes, and (d) disturbance regimes imposed on the riparian corridor by upland environments. The migration capacity of plants along riparian corridors is also an important factor explaining the high biodiversity observed along river courses. Collectively, these forces create a mosaic of riparian habitats which allow a wide variety of species to coexist (Naiman, Decamps, and Pollock 1993).

Plant species vary widely in the range of geographic areas in which they naturally grow (Appendix A). A few species such as green ash and poison ivy have nationwide distributions. Most species are restricted to a region that may consist of one to several States. Many riparian species that are limited to one area, however, have closely related species in the same genus, called congeners, in other riparian areas. For example, eastern cottonwood occurs in eastern riparian zones, while its congener, Fremont cottonwood, is common in arid western riparian zones. Willow, cattail (*Typha* spp.), and sedges (*Carex* spp.) are other examples of widely distributed riparian genera. Although congeners may have some similar habitat requirements, a species usually cannot be planted and successfully grown outside of its normal geographic distribution.

Species planted outside of their normal distribution are considered to be exotic species in the new area. Planting exotic species can be detrimental to native vegetation, because the natural controls on the species from the native range are not transferred as well. With no controls such as insects or fungi to keep plants suppressed, the exotic species can become a nuisance by outcompeting and eliminating the native vegetation.

Riparian zones in different parts of the country have characteristic plant species assemblages. The assemblages result from controls on the vegetation from local climate, watershed physical and chemical characteristics, hydrologic regime, disturbances such as grazers or fire, and other natural and man-induced forces in the environment. The assemblages are typically dominated by few species that determine the characteristic structure and functions of the riparian zone (Figure 4). Controls on riparian species distribution are discussed below.

Aboveground structure

Dynamics of the stream interact closely with the vegetation structure, particularly during early developmental stages of vegetation. Early stages of riparian community development are largely determined by the hydrologic regime and energy in the riparian corridor. As vegetation communities mature, the physical control of the flowing water over species composition and structure is reduced as the plant structure becomes more robust with size (Adams and Viereck 1992). The aboveground structure of vegetation in riparian areas is characterized by the growth form, size, density, and aerial coverage of the plants.

Plants of all growth forms are found in riparian corridors (Table 2), but freshwater riparian areas are often dominated by trees, shrubs, and vines (Figure 5a,b). Both eastern and western early successional riparian forests are

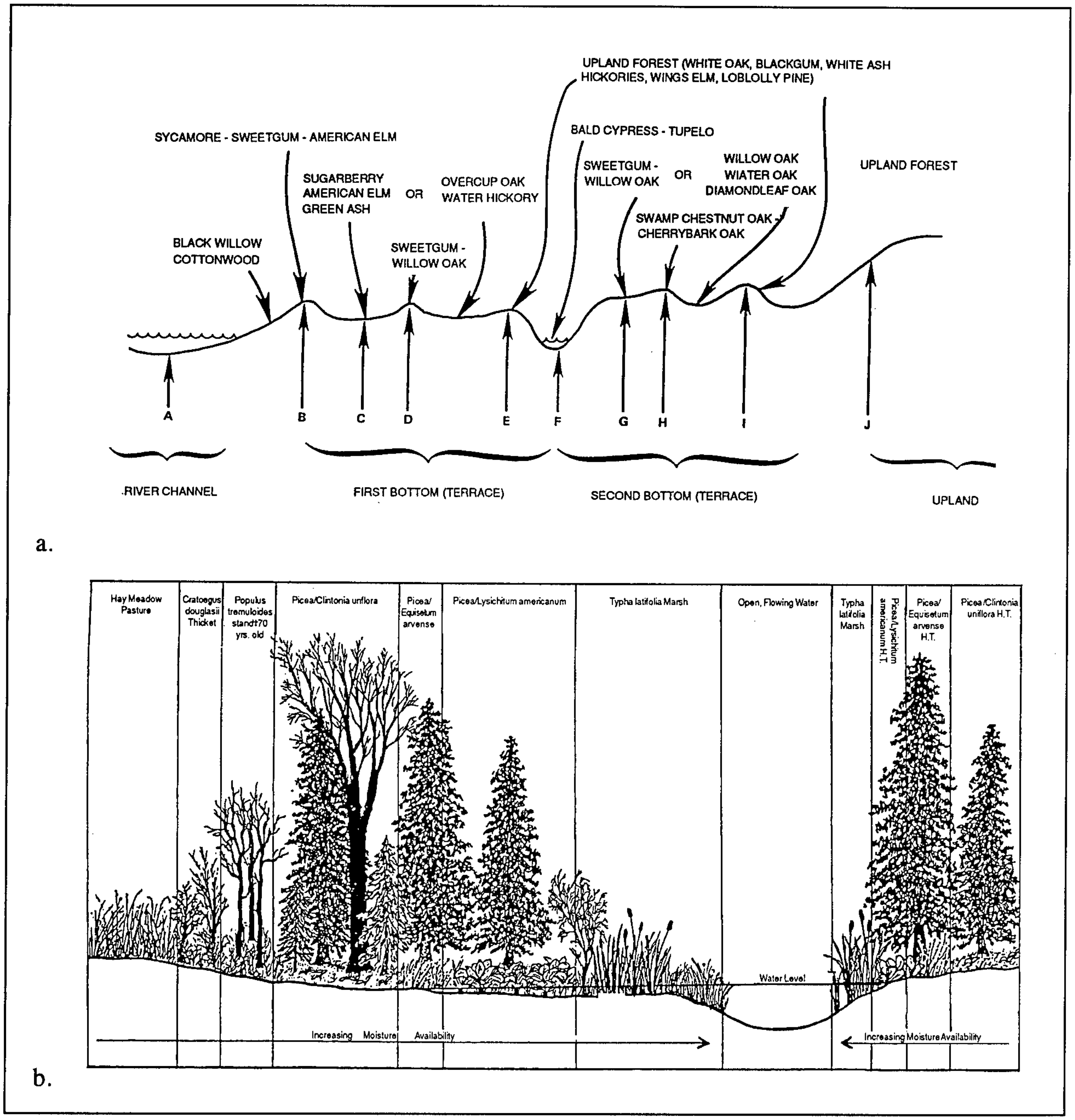

Figure 4. Characteristic riparian vegetation assemblages of the (a) Southeast (Wharton, Kitchens, and Sipe 1982); (b) Pacific Northwest (after Oliver and Honkley 1987); and (c) Southwest (after Bloss and Brotherson 1979) (Continued)

often dominated by willows, cottonwoods, and alders (*Alnus* spp.). Mature riparian forests are often dominated by other species. Bottomland hardwood forests of the Southeast, for example, are one of the most extensive and well studied types of wetlands in the country (Wharton, Kitchens, and Sipe 1982). These riparian forests are dominated by cypress (*Taxodium* spp.), gum (*Nyssa* spp.), oak (*Quercus* spp.), ash (*Fraxinus* spp.), and many other tree species (Appendix A). Red maple is a widely distributed species in eastern riparian

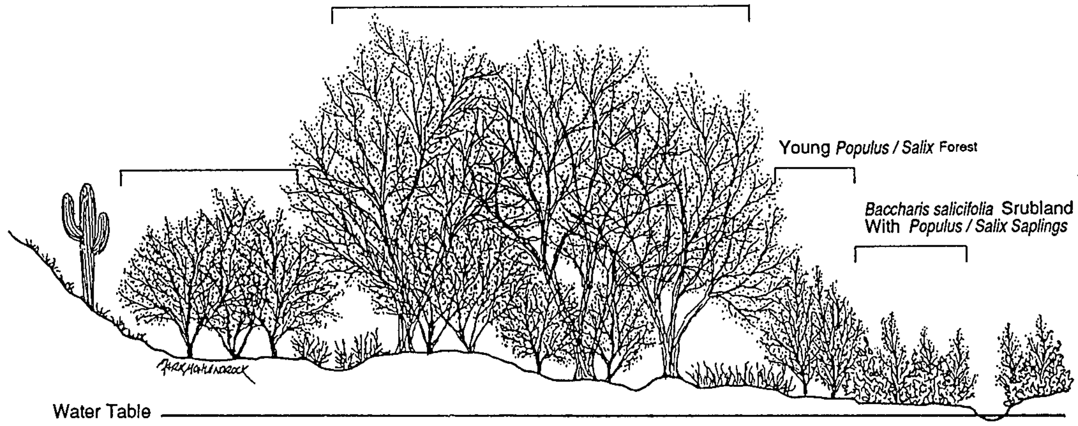

Figure 4. (Concluded)

Table 2
Characteristics of Plant Growth Forms in Riparian Areas

Tree
Tall, woody, long-lived plants that usually have a solitary trunk or main stem. Depending on species and latitude, leaves may be retained throughout the year (i.e., evergreen), have reduced numbers, or be completely lost each year (i.e., deciduous) from soon after first frost to last frost. Tree size is usually characterized as follows:
(a) Canopy - usually refers to the tallest trees in a forest that form the upper layer of vegetation; can be of any height ranging up to 50 m tall. (b) Midstory - trees that form a midlevel layer of leaves under a canopy; may include shade-tolerant or young canopy species; usually range in height from 5 to 15 m tall and have smaller stem diameters than canopy trees. (c) Understory - trees <5 m tall; usually includes seedlings and saplings of midstory and canopy species.
Resistance - well characterized for large trees and depends on stem diameter and density; resistance varies with relative height of water to level of leaves, presence of leaves, leaf stripping, deformation of small-diameter stems and branches, and breakage; fallen trees and exposed root systems increase roughness of ground surfaces and streambeds.
Shrub
A woody, long-lived plant that usually branches from the base with several main stems; usually small-to-medium-sized plants up to 5 m tall; may be the natural growth form of a species or formed by a resprouting tree with broken or fallen stems; may be evergreen or deciduous.
Resistance - not well characterized; resistance varies with similar factors for trees.
Vine
A plant which climbs by tendrils or other means, or which trails or creeps along the ground; may be woody or herbaceous, long-lived or an annual species; may be evergreen or deciduous.
(Continued)

Table 2 (Concluded)
Vine (Continued)
Resistance - not well characterized; resistance varies with similar factors for trees as well as whether live annual species are present.
Herb
A vascular plant (i.e., not a moss or liverwort) that lacks a woody stem. Herbaceous species are characterized as either grasses and grasslike or forbs.
Grasses and grasslike - members of the Poaceae, Cyperaceae, or Juncaceae families; growth forms include sod, bunch, and trailing which differ in density and height of stems; heights usually range from 0.05 to 1 m tall but can be >4 m tall; may be long-lived or annual species.
Resistance - well characterized and varies with depth of water.
Forb
A herbaceous plant that is not a grass or grasslike species; wide range of size characteristics; usually <1 m tall; may be long-lived or annual species.
Resistance - not well characterized.

forests, often codominating northeastern riparian forests with alders (Huffman and Fosythe 1981). Mature semiarid and arid western riparian forests may contain willow, cottonwood, ash, oaks, cedars (e.g., *Juniperus* spp.), mesquite (*Prosopis* spp.), and many others (Appendix A).

The amount of herbaceous vegetation in the groundcover of a riparian forest depends on the amount of flooding and light an area receives. There is generally little herbaceous groundcover in forested areas that are flooded frequently or for long durations. Herbaceous vegetation is also sparse if trees form a closed canopy, and light is limited on the forest floor. Herbaceous vegetation will quickly become established, however, under gaps in the forest canopy (Figure 5d).

Herb-dominated riparian areas usually occur in prairies where woody vegetation is limited (Figure 6a) or where grazers, fire, or other factors prevent woody species from dominating (Figure 6b). Historically, prairie cordgrass (*Spartina pectinata*) covered hundreds of square kilometers of bottomlands along the rivers and their tributaries throughout the tall-grass prairie region (Costello 1981). Sedges (e.g., *Carex* spp.) and grasses (e.g., *Poa* spp., *Deschampsia* spp., and *Festuca* spp.) commonly dominate western riparian areas where woody species are excluded (Youngblood, Padgett, and Winward 1985, Appendix A).

Woody species rarely dominate brackish or saltwater riparian areas because most of these species are intolerant of salinities above 5 ppt. Herbaceous species, therefore, usually dominate riparian areas with significant saltwater influences. *Spartina* spp. and *Juncus* spp. are common in saltwater riparian areas. Plant species tolerant of saline conditions, called halophytes, are also common along saline areas of the prairies and other arid lands. Desert salt

Figure 5. Forested riparian areas: (a) southern bottomland hardwoods, (b) tidal freshwater swamp in Pacific Northwest

6a. 

6b. 

Figure 6. Herb-dominated riparian areas: (a) grass-dominated prairie riparian area near Jamestown, ND, and (b) grazers and fire maintain dominance of herbs in meadows of Yellowstone National Park

grass (*Distichlis stricta*) occurs in saline soils of the Great Plains and is found along stream courses and in the beds of intermittent ponds (Costello 1981). Brackish water areas may have a large variety of plant species present, including rice (*Zizania* spp.), arrowhead (*Sagittaria* spp.), bullrush (*Scirpus* spp.), cattail, burweed (*Sparganium* spp.), cow lily (*Nelumbo* spp.), and many others (Appendix A). Mangroves (e.g., *Avicennia* spp., *Rhizophora* spp.) are the only tree species tolerant of full-strength seawater.

Riparian plant growth form is greatly influenced by browsing and grazing (Figure 7). The natural succession of riparian plant communities includes the colonization and eventual dominance by woody species (see succession discussion below). Areas with heavy pressure on woody vegetation from wildlife species (e.g., beaver, elk[1]) or farm livestock (e.g., cows, horses, sheep) can be stripped of woody vegetation and become dominated by herbaceous vegetation. Browsing limits regeneration of woody species (Kay and Chadde 1992) and stimulates shoot production of herbs (Allen and Marlow 1992). Intense grazing pressure will eventually eliminate herbaceous vegetation due to removal of leaves and stems, as well as soil compaction and reduced root biomass. Season and amount of grazing in riparian areas can be managed to maintain woody vegetation that is critical for stream stability due to deeper

Figure 7. Effects of grazing on vegetation (fence divides grazed and ungrazed areas)

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1 Scientific names of wildlife species found in freshwater riparian areas are in Appendix B through D.

rooting depths than herbaceous vegetation (Kovalchik and Elmore 1992; Rosgen 1995).

The size, density, and aerial coverage of riparian plants in an area are dependent on the vegetation growth forms and physical dynamics of the site over time (Figure 8). Growth forms limit the size and density that vegetation can attain. Mature, woody plants, for example, are generally larger and less dense than herbaceous vegetation. The physical dynamics of a site influence all three parameters. Small, young plants dominate recently disturbed areas. As vegetation matures following disturbance, they get larger, some larger than others. Light becomes limiting to the smaller plants, and they die. Stem densities decrease. If the area becomes dominated by woody species, the height of the canopy will increase with time and maturation of the trees. The depth of the canopy will initially decrease as light becomes limiting at lower levels. The canopy will eventually stratify as understory, midstory, and canopy species reach maturity. Plants may rapidly cover up to 100 percent of an area soon after disturbance. Young, actively growing vegetation can maintain 100-percent canopy cover. The canopy usually begins to decrease coverage as plants mature and die out. Canopies are also opened up when wind or some other force damages plants.

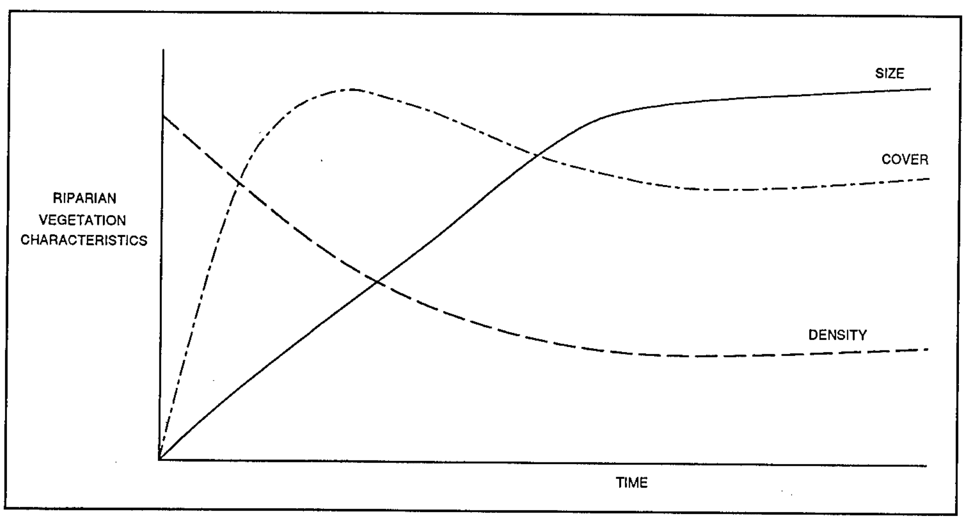


Figure 8. Development of vegetation over time

Figure 9 is an illustration of how the basal area of vegetation varies with precipitation. Progressing from areas with high to low precipitation, a transition zone is crossed between upland forests and grassland/desert ecosystems. For upland ecosystems, the basal area of trees decreases with reductions in rainfall, and trees disappear at approximately 45 to 60 cm per year precipitation. However, abundant examples of robust stands of riparian forests are found in regions with less than 50 cm annual precipitation. This indicates that the aboveground structure of riparian vegetation is less dependent on amounts

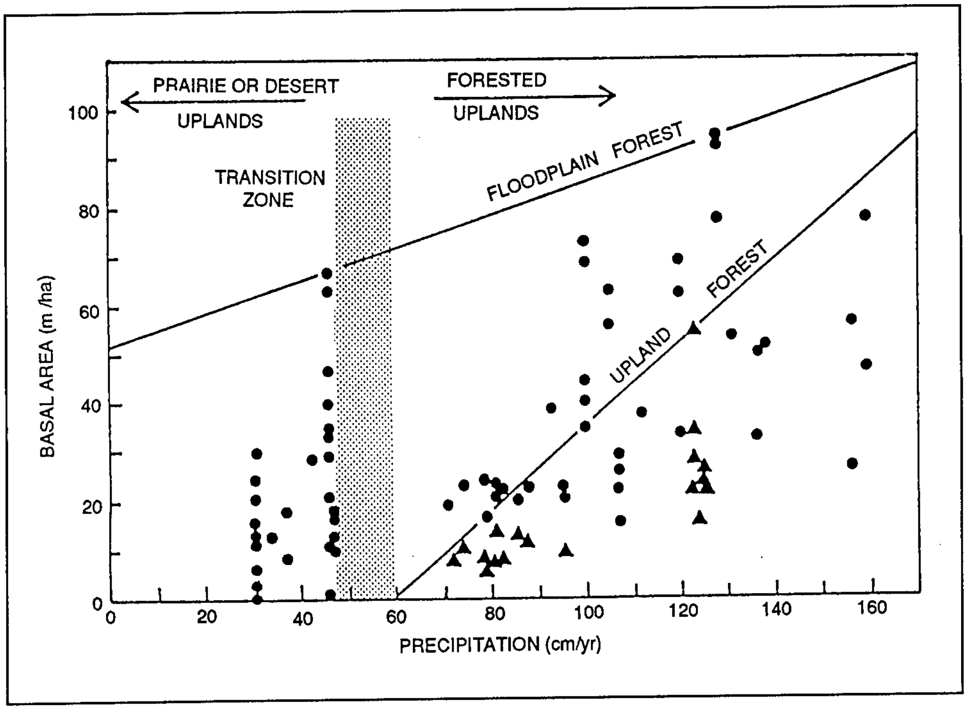


Figure 9. Effects of precipitation amounts on forest basal area (after Brinson 1980)

of precipitation than upland vegetation (Brinson 1980). Large western riparian trees are capable of utilizing groundwater and are not so reliant on precipitation and surface water as are small trees and herbs (Flanagan et al. 1992).

Belowground structure

One of the most critical but least well-studied aspects of riparian vegetation is the root system. Roots contribute to many functions of riparian vegetation. Hydrology of riparian areas is affected by the increased infiltration of water along root channels and the depth to which roots can access water (Dunne and Leopold 1978). Substrate stability is increased by roots binding soil into aggregates, which are in turn broken up by the mechanical effects of the living roots and kept from coalescing into clods (Weaver 1968). Nutrients are transformed with oxygen transported into saturated soils via roots (Mitsch and Gosselink 1993). Roots anchor vegetation in place. Belowground fauna use roots for food. Roots, however, are particularly difficult to access and study; so much of the information regarding roots is indirect or anecdotal. Of importance in riparian areas is an understanding of the depth, density, and strength of roots.

In general, the larger the plant, the larger the root system. Tree root systems extend out roughly 1.5 times the canopy diameter. Flanagan et al. (1992) showed that large western riparian trees can access deep groundwater, whereas small individuals of the same species had relatively shallow root systems that can only access stream water and precipitation.

Depth of the root system is highly dependent on species characteristics and site limitations. Some species, called phreatophytes, have very deep root systems that can reach deep groundwater (see next section). Many species such as pine trees and members of the carrot family (Apiaceae) have taproots that extend straight down into the ground. Tap roots function for increased plant stability and access of deep water and nutrients. It is the nonwoody, fibrous roots, however, that are primarily responsible for uptake of most nutrients and water. All plants have fibrous roots. Most fibrous roots are generally located in the top 30 cm of soil (Weaver 1968). Shallow fibrous roots can become very dense and effectively bind upper soil layers. Trees and shrubs develop networks of woody roots that extend farther into the ground. This network of woody roots includes fibrous roots that in combination strongly bind soils into aggregates and provide sediment stabilization to much greater depths than fibrous roots alone. This is why trees and shrubs provide better shoreline stabilization in most cases than herbaceous species with relatively shallow roots (Figure 10).

Phreatophytes

Rates of evapotranspiration are related to the depth of plant roots relative to the capillary zone above the water table (Figure 11). Evapotranspiration rates become reduced as water tables recede and shallow-rooted plants transpire less. Deeper rooted plants can tap water in the subsoil and continue to transpire at potential rates. Trees usually transpire more than grass because they are more deeply rooted (Dunne and Leopold 1978).

Phreatophytes are defined as plants that obtain water from the zone of saturation, either directly or through the capillary fringe (Meinzer 1927). The term is usually applied to deep-rooted species that occur in arid, riparian areas. Roots of salt cedar, an invasive phreatophyte in the Southwest, for example, have been excavated from as deep as 30 m. Excessive losses of water in water-limited areas have been attributed to high evapotranspiration rates of phreatophytes (Dunne and Leopold 1978). Management of phreatophytes to reduce water loss has included techniques such as plant removal, replacement with more shallow-rooted species, lowering of water tables, and antitranspirants (Ritzi, Bouwer, and Sorooshian 1985; Stabler 1985). Phreatophyte management in different parts of the country has had mixed success, often with undesirable side effects such as loss of wildlife habitat and mass wasting (Dunne and Leopold 1978).

Distribution Patterns of Riparian Vegetation

The term riparian vegetation brings different things to mind for different people, often depending on whether they are from the East or West. The

Figure 10. Shallow rooting depths of grasses are less effective at stabilizing banks than deeper rooted trees and shrubs

eastern portion of the country is generally moister than the western portion where annual rainfall amounts are often much less than the evapotranspiration rates. In addition, riparian vegetation in high-gradient, confined streambeds is much different in form and function from riparian vegetation in low-gradient, alluvial systems. In general, riparian vegetation can be described in terms of type, zone, and landscape position.

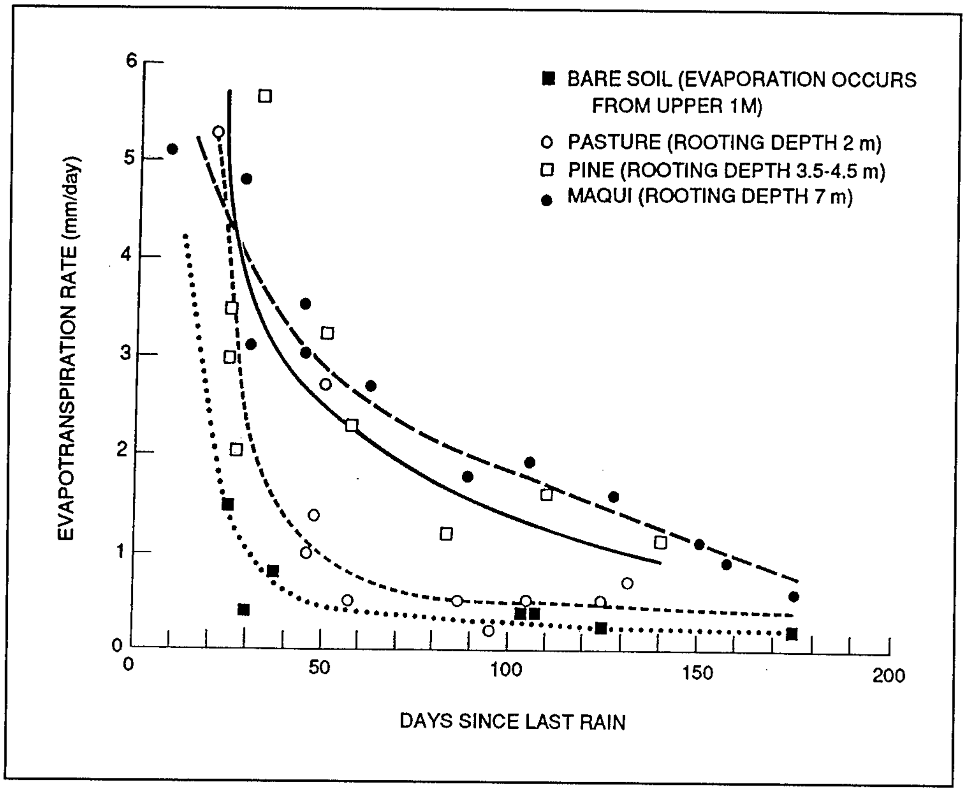


Figure 11. Relationship between rooting depth and rates of transpiration with soil drying time (from Schachori et al. 1967)

Moisture gradients

Johnson and Lowe (1985) describe riparian corridors as having two gradients. The intrariparian continuum extends upstream from the mouth of the stream or river to the headwaters. Hypothetically, one can travel from the estuarine system upstream along perennial riverine systems, past confluences with other streams, proceeding to mesophytic habitats of intermittent reaches, and possibly terminating in dry, desert xerophytic habitats of ephemeral streamcourses. The transriparian continuum extends across the hydrologic gradient from the water in the stream or river to the surrounding upland. In moving along this continuum, one sequentially transverses aquatic, wetland, and upland ecosystems (Figure 12).

There is a sharp contrast in these continuua between different parts of the country (Johnson and Lowe 1985). Intrariparian continua located in the more mesic eastern U.S. and Pacific Northwest often have perennial water from the source to the mouth of the river system. Conversely, some important western drainage systems, especially in the Sonora Desert and Baja California, are entirely or essentially ephemeral from their origin to the Pacific or Gulf of California. As one proceeds from hydric to xeric conditions, the transriparian continuum becomes less distinct, and similarities decrease between the riparian

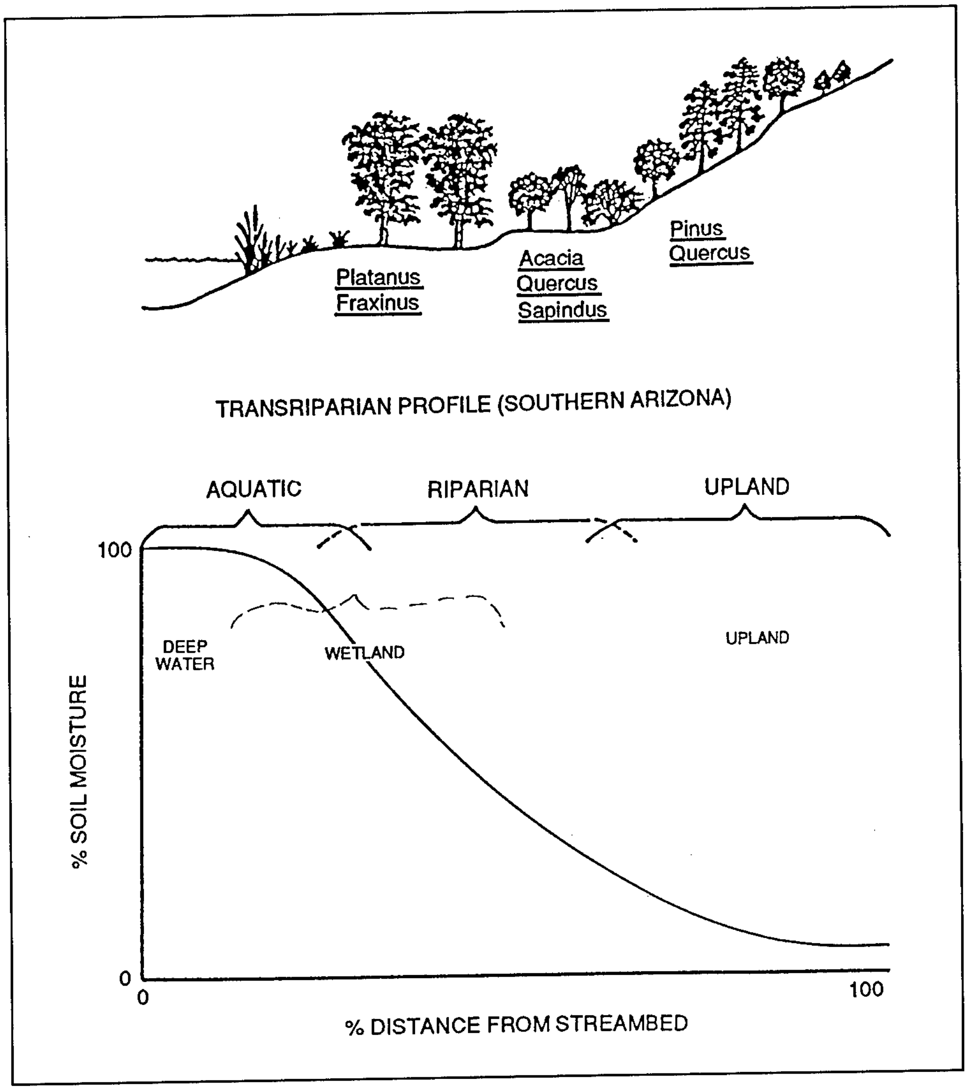


Figure 12. The transriparian gradient from uplands through wetlands and into aquatic habitats of the stream channel (based on Johnson and Lowe 1985)

vegetation and adjacent upland communities. For example, there is a clear distinction between riparian species along perennial eastern rivers and surrounding upland communities. In first order washes or arroyos, however, most species of plants and animals are shared with biotic communities of the surrounding uplands (Johnson et al. 1989).

Riparian corridors can be complexes of aquatic, wetland, and upland habitats. These occur primarily in the eastern U.S. and the Pacific Northwest where floodplains are broad and morphologically complex (Wharton, Kitchens, and Sipe 1982). Aquatic habitats include the floodplain lakes, ponds, and sloughs. Wetlands occur throughout the terrestrial portion of the riparian corridor in areas associated with permanent aquatic habitats (e.g., on and behind river levees, oxbow lake fringes), as well as areas that are only periodically inundated by floodwaters. Wetlands also occur in riparian corridors along intermittent streams, but are usually more limited in distribution to narrow fringes along the stream corridor. Upland habitats in the riparian corridor occur on relatively high ground relative to the river, usually on abandoned floodplain terraces or adjacent to uplands surrounding the geomorphic floodplain. Upland riparian habitats experience infrequent flooding for short durations.

Uplands. Riparian corridors are characterized as areas with greater water availability than in surrounding landscapes. Upland areas within riparian corridors are characterized by increased soil moisture in comparison with adjacent uplands and infrequent flood events (Figure 12). The vegetation may or may not differ in composition from the adjacent uplands, but is usually denser, larger, and more productive.

There has been discussion among eastern and western riparian ecologists about whether all terrestrial areas within riparian corridors should be considered wetlands. Johnson and Lowe (1985) took the western point of view that the definition of wetlands is based on moister eastern conditions, but the term should encompass the relatively wet riparian corridors of the West. Even the xeric riparian habitats of southwestern deserts dominated by sahuaro cactus differ from the surrounding uplands because of the increased relative availability of water. Use of the term "wetland" in this report, however, is restricted to the definition given in the next section. Many riparian corridors do not include wetlands, because they do not have adequate periods or frequencies of inundation to support hydrophytic vegetation or hydric soils.

It should be noted here that even though dredge and fill activities in many riparian areas are not regulated under Section 404 of the Clean Water Act (CWA) as being in wetlands, they may be regulated because they occur in other "Waters of the United States." The CWA specifically regulates activities in certain "Waters of the United States," including the following waters as defined in 33 CFR 328.3; "... 1) all waters that are currently used, or were in the past, for interstate or foreign commerce, including all waters that are subject to the ebb and flow of the tide; 2) all interstate waters including interstate wetlands; 3) all other waters such as intrastate lakes, **rivers, streams (including intermittent streams)**, mud flats, sandbars, wetlands, slough, prairie potholes, wet meadows, playa lakes, or natural ponds; 4) all impoundments of waters otherwise defined as waters of the United States as defined; 5) **tributaries of waters identified in numbers 1-4 above;** 6) the territorial seas; and 7) wetlands adjacent to water listed in 1-6 above." (Bold added by author.) This could be interpreted to mean that Waters of the United States exist where there is evidence of the presence of water at the surface (e.g., scouring, drift lines). Waters of the United States, therefore, can extend upland as well as upstream of wetlands. It is recommended that the local Corps of Engineers office be contacted for a Section 404 determination prior to any dredge and fill operations in riparian corridors.

Wetlands. Wetlands are defined as "those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas" (Environmental Laboratory 1987). Ecological processes in riparian wetlands are dependent upon inundation during annual cycles of river stage fluctuations. Some wetlands, however, are perched in the floodplain and upper elevations of the riparian corridor where their primary water sources are groundwater and precipitation (e.g., abandoned sloughs perched on old terraces). These wetlands are only indirectly influenced by the river through groundwater connections. While these wetlands occur in the riparian corridor, they may not be considered to be riparian wetlands, because their ecological processes are not directly affected by the river.

Riparian wetlands are critical areas for the health of the riparian corridor and downstream ecosystems. Riparian wetlands are often highly productive systems that support diverse and abundant wildlife (Wharton, Kitchens, and Sipe 1982). In addition, riparian wetlands provide valuable functions for society (Taylor, Cardamone, Mitsch 1990; Brinson et al. 1995). Floodwaters are stored and slowly released from riparian wetlands, ameliorating flood intensities in downstream areas. Many nutrients, toxins, and sediments are retained or transformed in wetlands, providing cleaner water. Moreover, the beauty of the flora and fauna of these areas cannot be duplicated elsewhere.

The most well-studied riparian wetlands are the bottomland hardwood forests of the eastern and central United States. In contrast with other types of wetlands, these wetlands are often adjacent to gauged rivers and streams, and relationships between the river-water level fluctuations and ecology of the areas have been described (Clark and Benforado 1981; Wharton, Kitchens, and Sipe 1982). Due to concern about extensive losses of these wetlands to agriculture and river management, much work has been done to understand effects of cumulative impacts on bottomland hardwood forests (Gosselink, Lee, and Muir 1990).

Huffman and Forsythe (1981) described several characteristics of bottomland hardwood forests that distinguish them as wetlands:

a. The habitat is inundated or saturated by surface or groundwater periodically during the growing season.

b. The soils within the root zone become saturated periodically during the growing season.

c. The prevalent woody plant species associated with a given habitat have demonstrated the ability, because of morphological and/or physiological adaptation(s), to survive, achieve maturity, and reproduce in a habitat where the soils within the root zone may become anaerobic for varying periods during the growing season.

Characteristics of these wetlands are closely tied to frequency and duration of flooding (Figure 13). Swamps are inundated nearly 100 percent of the time. They occur at low elevations adjacent to the channel and in perched depressions that retain water after floodwaters recede. These forests are typically dominated by only two tree genuses (*Taxodium* spp. and *Nyssa* spp.).

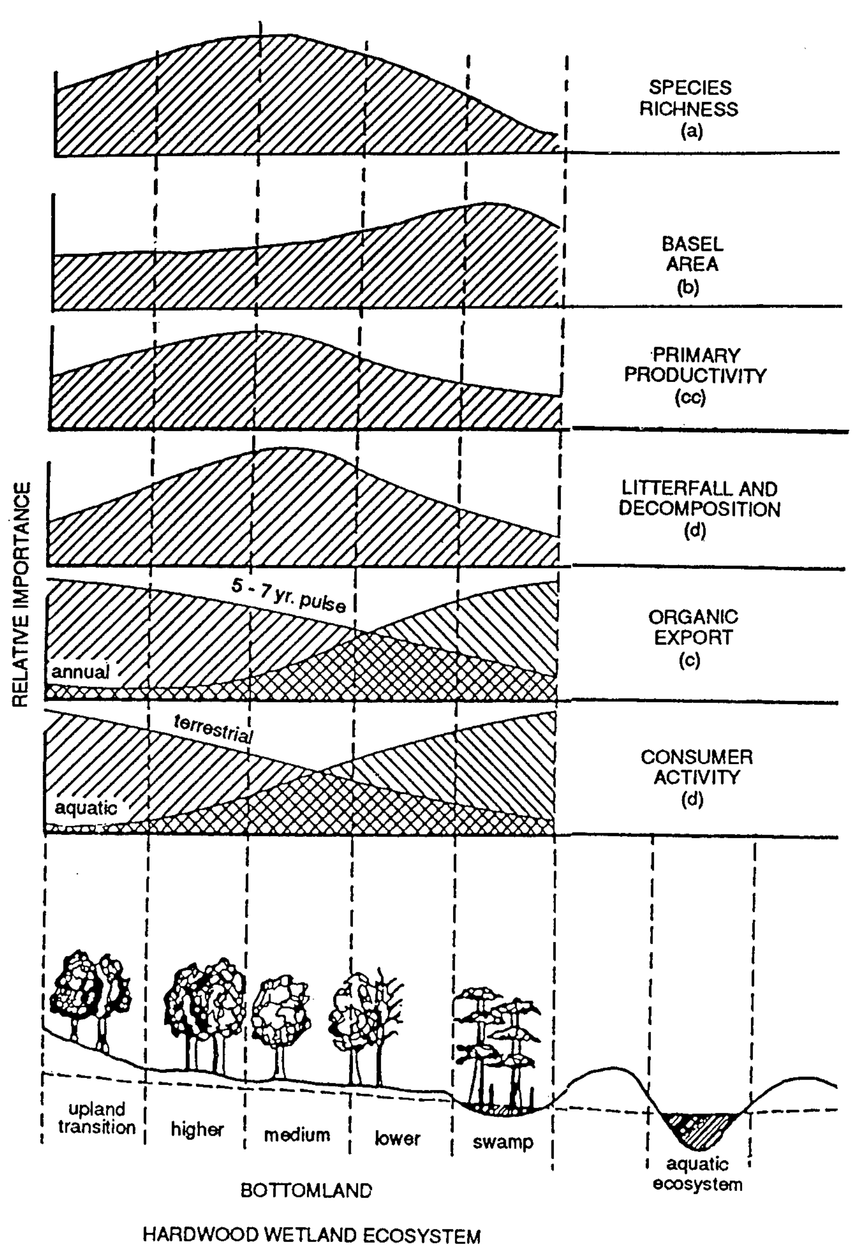


Figure 13. Characteristics of bottomland hardwood forests across a flooding duration and frequency gradient (after Taylor, Cardamone, and Mitsch 1990)

Hardwood wetlands located at slightly higher elevations than swamps are inundated for shorter periods of time and less frequently. These wetlands have higher plant species richness, with water-tolerant oaks, maples, sweet-gum, ash (*Fraxinus* spp.), and many other hardwood trees in the canopy. Hardwood wetlands at high relative elevations are inundated less than half of the years and for only short periods of time. These are marginal wetlands that are transitional with upland areas (Clark and Benforado 1981).

Many of the functions that riparian vegetation contributes to bottomland hardwood forests change with elevation above the river (Figure 13). As will be elaborated in later sections, much of the value of riparian vegetation is for food production, nesting, and refuge areas for wildlife. Medium- and high-zone bottomland hardwood wetlands generally have higher plant species richness and primary productivity relative to other zones, but they do not necessarily support more wildlife. Each zone has value for different species. Swamps and lower bottomland hardwood wetlands, for example, support more aquatic species than terrestrial species. Higher zones support more terrestrial species. Together the different wetland zones form a highly diverse and productive ecosystem (Mitsch and Gosselink 1986).

Physical and chemical functions of bottomland hardwood wetlands are also closely tied with river level fluctuations (Figure 14). Sediment deposition and anaerobic biochemical transformations predominate at lower elevations due to the longer and more frequent periods of inundation. Most biologically mediated chemical transformations occur at lower and medium bottomland hardwood zones, because there is ample moisture and organic matter on the forest floor to serve as a substrate for respiration (Taylor, Cardamone, and Mitsch 1990).

Riverine littoral zone. In addition to the habitats presented above, the riverine littoral zone should be identified as having particular importance. Aquatic river-edge environments are outstanding examples of ecological boundaries, although they have received little attention from lotic and terrestrial ecologists. The riverine littoral zone provides comparatively calm water and stable sediments, with habitat structure provided by rocks, snags, plants, and bank irregularities. The littoral boundary is a key part of the corridor, being a zone of concentrated physical and biological diversity and a resource for both riverine and terrestrial communities. It is particularly vulnerable to patterns of disturbance, particularly changes in water level (Walker, Thomas, and Sheldon 1992).

The riverine littoral zone is characterized in most areas as the river bank, from the edge of the water to the top of the bank. This may include active bars, shelves, and islands within the channel (Hupp and Osterkamp 1985). Upper portions of the bank are usually forested with species common to swamps or lower riparian habitats. Overhanging vegetation, exposed roots, rocks, and debris provide excellent habitat structure along the mid and upper portions of the bank. The lowest portion of the bank and shelves are frequently barren sediments that are exposed at low river stages.

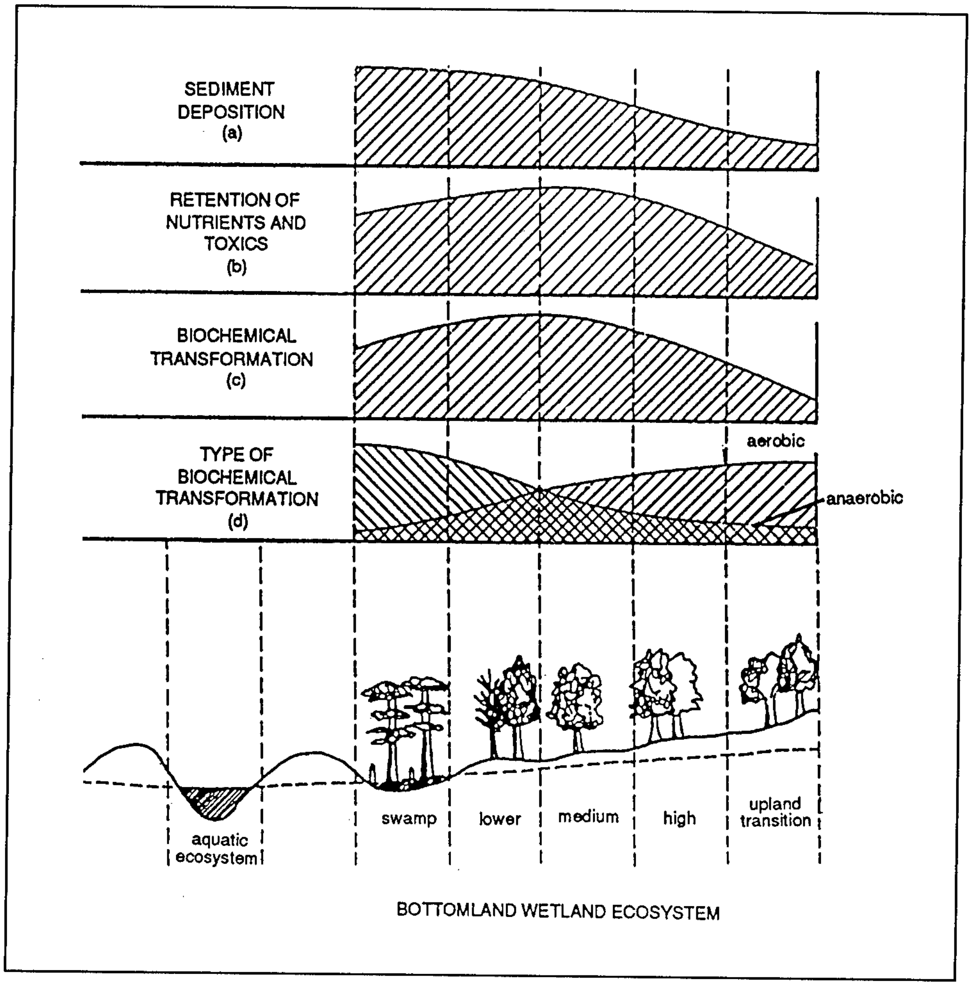


Figure 14. Functions of bottomland hardwood forests in relation to flooding duration and frequency (after Taylor, Cardamone, and Mitsch 1990)

This zone is unique because it provides constant contact between the aquatic and terrestrial portions of the riparian corridor. It is, therefore, directly affected by river level fluctuations and currents. High river stages inundate the entire littoral zone and provide access to the upper littoral zone resources by fish and other aquatic or amphibious species. Low river stages remove access to refuge, food, and spawning areas for aquatic and amphibian animals as the higher elevation areas become exposed. Periods of low water are necessary, however, to allow the terrestrial plants and animals to recover from the inundation as part of the annual cycles that make these areas so valuable.

Habitat value provided in the vegetated portions of the riverine littoral zone is important for several reasons (Sweeney 1993). Overhanging vegetation shades and cools the water and surroundings, helping to provide thermal refuges in an otherwise exposed and stressful environment. Roots and debris are colonization sites for algae and macroinvertebrates. Organic matter is eaten by macroinvertebrates. Many organisms take refuge from predators and currents among the roots, rocks, and other structures. In addition, roots form tight networks over the soil of banks that keep them from sloughing into the river and provide stable habitats, as well as good water quality. Stable banks provide nesting sites for many vertebrate species including kingfishers, swifts, and mink. Habitat value is apparently highest when the river inundates plants, roots, debris, and other structures, linking aquatic with high quality terrestrial resources along these corridors.

Aquatic habitats. Aquatic habitats are differentiated from wetlands as those areas that are permanently inundated to greater than 2-m depths (Cowardin et al. 1979). This is generally the depth beyond which emergent plants can grow. Riparian aquatic areas include oxbow lakes, sloughs, the main channel, and other permanently inundated areas. Although submerged vegetation can grow in these habitats, this vegetation is not riparian vegetation and is beyond the scope of this report.

Fluvial geomorphic landforms

Associated with the transriparian moisture zones described above are the vegetational distribution patterns on fluvial geomorphic landforms common to many rivers. The type of landforms associated with alluvial rivers depends on the constancy of streamflow and position in the floodplain (Figure 15). Alluvial rivers in the East are perennial and have complex mosaics of depositional bars, active-channel shelves, floodplains (including levees, flats, ridges, swales, and oxbow lakes), and terraces (Wharton, Kitchens, and Sipe 1982;

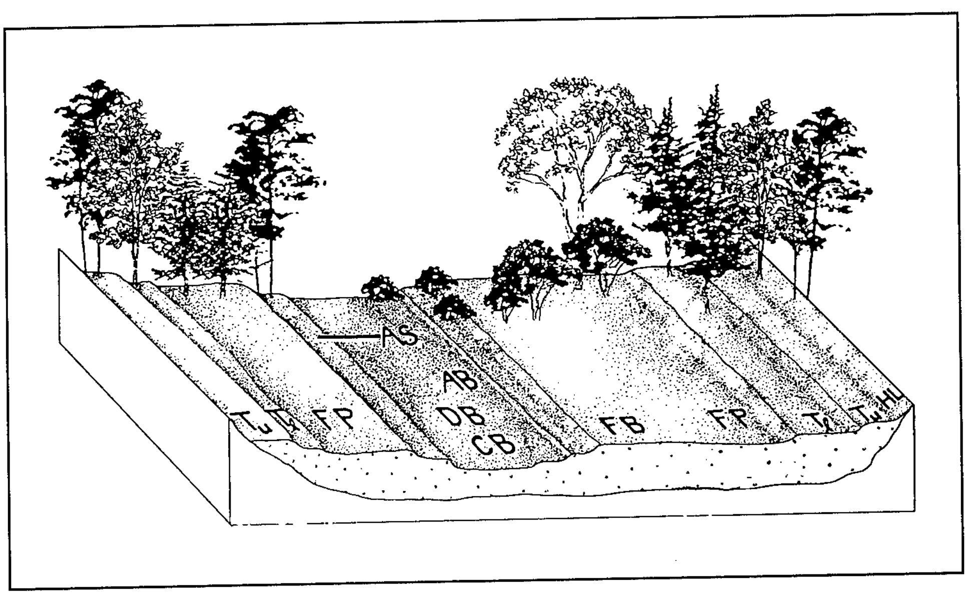


Figure 15. Landforms associated with alluvial rivers (hillslope (HL), upper and lower terraces (T), floodplain and bank (FP and FB), channel shelf and bank (AS and AB), depositional bar (BD), and channel bed (CB) (from Hupp and Osterkamp 1985)(© 1985 ESA))

Hupp and Osterkamp 1985). Lush riparian vegetation in these areas is distributed among these landforms in different species associations, ages, and structures. Western river floodplains can be equally complex; however, the arid climate limits development of extensive floodplain vegetation. The extent and complexity of the fluvial landforms decrease with decreasing basin size and water availability due to lower flows and energy to carry alluvium. Vegetation within the intrariparian gradient, therefore, generally becomes less complex in composition and distribution towards the headwaters. Appendix A lists riparian species and the fluvial geomorphic zones where they are typically found.

Active channel. Active channels include all areas within banks, including point bars and shelves. The plant species in active erosional/depositional channels are often capable of rapid colonization and are relatively short-lived. These species are often widely distributed because their seeds are small and wind dispersed (Hupp and Osterkamp 1985). The life history of these species depends on continual renewal of open, moist areas for regeneration. In the east, sycamore (*Platanus* spp.), cottonwood, willow, and elm (*Ulmus* spp.) are the most common genera in these areas (Hupp and Osterkamp 1985). *Salix lasiandra*, *Populus trichocarpa*, and *Alnus rubra* are common trees along active perennial channels in British Columbia, where there are also marsh species such as *Typha latifolia*, *Glyceria grandis*, and *Puccinella pauciflora* (Teversham and Slaymaker 1976). In the arid West, Fremont cottonwood, willow, sycamore (*Platanus wrightii*), alder (*Alnus oblongifolia*) and ash (*Fraxinus pennsylvanica velutina*) are common trees. Seep willow (*Baccharis glutinosa*) and watercress (*Rorippa nasturtium-aquaticum*) were common along flowing streams in Arizona (Glinski 1977). Mesquite (*Prosopis* spp.), catclaw acacia (*Acacia gregii)*, ironwood (*Olneya tesota*), and blue paloverde (*Cercidium floridum*) are common within xeroriparian corridors of the sub-Mogollon desert region (Johnson and Lowe 1985).

Floodplains. Composition and complexity of floodplain vegetation depend on the size and geomorphic complexity of the riparian corridor. Bottomland hardwoods, for example, can be extensive such as in the Mississippi Delta or more restricted to narrow bands along smaller rivers. Elevation gradients within floodplains associated with ridges and swales, oxbows, and other abandoned riverine features affect the duration and frequency of inundation an area receives. Plant species composition is directly determined by these hydrologic patterns (Bell 1992; Teversham and Slaymaker 1976; Robertson, Weaver, and Cavanaugh 1978; Wharton, Kitchens, and Sipe 1982; Theriot 1993). Similar to the relationship of eastern bottomland hardwood vegetation with hydrology described above, there is a correlation of tree and shrub species in British Columbia with flood frequency. The frequency of five species, *Thuja plicata* (red cedar), the shrubs *Viburnum pauciflorum*, *Cornus stolonifera*, (red-osier dogwood), and *Spirea douglasii* (hardback), were found to be good predictors of flood frequency of the Lillooet River (Teversham and Slaymaker 1976).

Western riparian ecologists do not report similar variations in distributions of floodplain vegetation species with frequency and period of inundation along a transriparian gradient. Composition of western riparian vegetation varies with depth to the water table (Figure 4). Species composition changes with distance from the stream because rooting depths of plant species become limiting with depth to the water table (Segelquist, Scott, and Auble 1993). In these arid areas, the distinctions in vegetation are made between ephemeral, intermittent, and perennial streams along an intrariparian gradient.

Both intermittent and perennial western rivers have floodplains. Intermittent western streams and rivers support a higher proportion of grasses and shrubs than trees. Sacaton grass (*Sporobolus airoides*) and scrub species dominate the upper alluvial valley of Sonoita Creek, Arizona, with scattered individuals of mesquite (*Prosopis juliflora*), walnut (*Juglans major*), Fremont cottonwood, and sycamore (*Plantanus wrightii*). Farther down the Sonoita Creek where flow becomes perennial, there is a near-continuous forested belt of cottonwood, sycamore, willow (*Salix gooddingii*), ash (*Fraxinus velutina*), and walnut trees. This forest is bordered frequently by mesquite and hackberry (*Celtis reticulata*). These forest floors are covered with annual and perennial grasses and forbs (Glinski 1977). Velvet mesquite (*Prosopis velutina*) forms closed-canopy forests together with other riparian trees and shrubs including netleaf hackberry (*Celtis reticulata*), walnut, and lotebush (*Zizphyus obtusifolia*) in perennial river floodplains in the Sonoran Desert (Stromberg 1993). Tree species richness varied in a bell curve fashion with flood size in the Verde River watershed, Arizona, with the greatest richness occurring at streams with intermediate flood magnitudes (Stromberg 1993). Bloss and Brotherson (1979) found an increase in floodplain plant species diversity with increased available moisture near an ephemeral stream in comparison with adjacent slope communities in central Arizona.

Many floodplain species are widespread, with a wide moisture tolerance range. In the east, for example, red maple, sweetgum, and water oak have very broad distributions within floodplains. Velvet mesquite is widely distributed within the Sonoran Desert from xerophytic riparian washes with ephemeral flow to perennial river floodplains (Stromberg et al. 1993). Suhuaro cactus becomes more abundant and larger in xerophytic riparian areas in comparison with individuals in upslope areas (Johnson and Lowe 1985).

Terraces. Terraces are floodplain surfaces that became hydrologically abandoned with downcutting of the river to lower elevations or deposition of sediments usually associated with extreme events. Occurrence of riparian vegetation is not consistently reported in terms of presence on terraces versus simply high elevations within the floodplains. Distributions of vegetation have been reported here in terms of relative elevation above the present river level. The distinction becomes important, however, when presenting distributions of vegetation along rapidly eroding rivers and streams. Existing riparian vegetation becomes isolated from surface and groundwater in these areas and frequently dies from dehydration (Bryan 1928). New riparian vegetation becomes established at lower elevations near the river level as the channel broadens and relatively stable shelves develop. This process occurs naturally over long time periods. Fonda (1974) described different tree communities among river terraces of the Hoh River of the Olympic Peninsula, Washington, that differed in age from active to over 750 years old.

Stream gradients

The influence of stream gradients on the riparian vegetation composition and structure depends primarily on the watershed configuration. For example, high-gradient streams (>3-percent slope) are often constricted within steep valley walls and dominated by tree species. The streambed is composed of bedrock, boulders, cobble, or gravel that form falls and cascades interspersed with small pools. Flood events are intense and short in duration. Debris carried downstream during floods is a major type of disturbance for riparian vegetation. Trush et al. (1989) found lower densities of trees in active channels of steep entrenched streams than in lower gradient streams within floodplains in coastal California. They suggest that the increased energy in the entrenched streams during floods was detrimental to tree establishment and survival. Baker (1989) suggests that trees dominate riparian areas along high-gradient streams rather than the shrub-like willows found in low-gradient systems of western Colorado, because trees are simply more resistant to the destructive action of large gravel and boulders carried in floods.

Trees carried into streams can become lodged across and within the channel. The resulting accumulations of woody debris provide valuable in-stream functions such as dissipation of energy, storage of sediment, and provision of habitat. Forest management affects channel morphology in several ways. Removal of large woody debris from channels reduces sediment storage and eliminates the local hydraulic variability associated with the obstruction. Excessive input of coarse sediments from the surrounding watershed can smooth the channel gradient by filling pools. Land uses that change the natural amounts of sediment or water contributed to the streams disrupt the balance of sediment input and removal. Loss of in-stream habitat diversity by any of these practices may reduce or change the fish species found in a stream reach (Gregory et al. 1987).

Plant communities generally undergo little change along stable streams such as riffle-pool or entrenched meadow streams. These streambeds change little over time, because the water and sediments are effectively conveyed through the reach with little erosion or deposition (Rosgen 1995). There is little disturbance to the vegetation and no creation of new habitats for colonization. These plant communities are mature and resilient to flood events. In contrast, plant communities along low-gradient, unconfined alluvial streams vary in maturity depending on the time since establishment following deposition on point bars (Wharton, Kitchens, and Sipe 1982; Hupp and Osterkamp 1985). Erosion and deposition are natural in these streams, as the streambed constantly changes position within the floodplain. Mature vegetation is lost with erosion of the outside bends of meanders as areas for colonization are formed on the inside bends. Floodplain vegetation in this type of system occurs in a continuum of successional stages, from newly colonized point bars to mature forests.

Riparian Ecological Processes

As interfaces between terrestrial and aquatic systems, ecological processes in riparian settings are dependent on the dynamics of the associated uplands and streams. Ecological processes such as plant succession and response to natural disturbances occur in most types of ecosystems. Natural rates and direction of these processes in riparian habitats, however, are overridden by flooding, erosion, and deposition events associated with streams. In addition, disturbances from uplands such as debris slides, fire, and grazing affect riparian habitats.

Succession

The maturation process of natural plant communities is termed "succession" (Drury and Nesbet 1973) or community development (Niering 1987). Plant communities develop from two starting conditions. The first type of development, often called primary succession, takes place on newly formed areas where no plant community has ever occurred before, such as on volcanic flows, that eventually support diverse, mature plant communities. In this situation, community development can be extremely slow. Soils must form. Colonization by microbes, plants, and animals is slow at first due to the extremely harsh and stressful conditions. Establishment of riparian plant communities on newly formed point bars can be considered to be primary succession.

Plant communities, however, more commonly develop following a disturbance that is severe enough that community development is set back to earlier developmental stages or the system must develop anew (Drury and Nisbet 1973). This second type of development is called secondary succession. An example of secondary succession is the development of a forest over many years after an agricultural field is left fallow. In this situation, plant community development is more rapid. Soils capable of supporting plants are already formed. Site conditions are not as harsh, and colonization is rapid; annual plant species are present in the first year. The types of plants and animals present will change over time. For example, in classical old field succession, annual and grass species are often the first dominant plant species as a site develops. As colonizing plants become established, conditions for plant growth are improved, and different species become dominant that are not tolerant of the harsher site conditions. Shrubs may dominate early and mid developmental stages. Trees begin to colonize a site during early succession, but do not dominate the site structurally until mid to late successional phases. Eventually, the rate of new species introductions decreases, the plants onsite regenerate themselves, and the species composition stabilizes. At this point, the community is considered to be a in a "climax" or steady state (Odum 1978; Neiring 1987). Many cases of riparian community succession can be considered secondary succession because site conditions retain some of the components of the degraded system after the disturbance.

Succession of riparian plant communities is integrally related with the associated stream dynamics. It is the sequence of floods and shifting sediments that create new surfaces and deliver seeds of colonizing species. Seeds of many riparian species such as maples and willow are carried by water and deposited on newly exposed areas. Animals deposit seeds from fruit they have eaten such as mulberry and elderberry (*Sambucus* spp.). Colonizing plants may also result from clumps of plants that have broken off eroding areas and subsequently stranded on bars downstream (Bliss and Cantlon 1957).

There are relatively few plant species that are capable of becoming established on newly developed bars because the environmental conditions are often very harsh. With little organic matter or soil development, the exposed bars dry rapidly following falling river levels. Seeds and new seedlings are often desiccated and die before root systems that can reach the groundwater are developed (McBride and Strahan 1984). Ware and Penfound (1949) describe bars of the South Canadian River in central Oklahoma as being very unstable habitats for plant growth. Annual floods inundate and destroy much of the existing vegetation. In addition, as the bars dry out, winds blow sands that may completely cover seedlings, uncover roots, or undermine plants and blow them away. The point bar colonizing species share several adaptations that ensure the establishment of floodplain forests despite the vagaries of the river. These include an extended period of seed dispersal, large numbers of seeds, and plumes that carry the seed on the water and become entrapped in sands (Noble 1979).

In spite of the harsh conditions, there is often a fairly dense cover of plants on newly deposited bars. Willow, cottonwood, and alders are the most common tree species that colonize newly developed bars in many kinds of streams. Cottonwood (*Populus deltoides*), sandbar willow (*Salix interior*), and salt cedar (*Tamarix gallica*) are common colonizers on bars of the South Canadian River in central Oklahoma (Ware and Penfound 1949). Various willow, balsam poplar, and mountain alder (*Alnus incana*) are the primary tree colonizers on newly formed areas of the Beatton River in northeast British Colombia (Nanson and Beach 1977). Black willow is a primary colonizer of depositional bars of eastern rivers (Wharton, Kitchens, and Sipe 1982; Hupp and Osterkamp 1985). In riparian communities of the arid Southwest, the same species that colonize depositional bars ultimately constitute the mature community (Lowe 1964). Cottonwood (*Populus fremontii*), willow (*Salix bonplandiana, S. gooddingii*, and others), sycamore (*Platanus racemosa wrightii*), ash (*Fraxinus velutina*), and walnut (*Juglans microcarpa major*) are termed the "big five" in reference to widespread riparian trees in the Arizona lowlands (Johnson et al. 1989). However, mesquite, catclaw acacia (*Acacia greggii*), ironwood (*Olneya tesota*), blue paloverde (*Cercidium floridum*), and desert willow (*Chilopsis linearis*) dominate xerophytic riparian communities along desert washes (Johnson et al. 1989). See Appendix A for additional woody species that colonize in river and stream channels.

Grasses and herbs are often among the colonizing plants on depositional bars (see Appendix A), but they tend to comprise a minor component of the total biomass that is dominated by woody species. Because they are not structurally resistant to the stress of flood flows, seedling herbs are often uprooted and washed away if flooded too soon after germination. Herbaceous species tend to become established, therefore, on higher or protected portions of depositional bars or following the establishment of shrubs (Bliss and Cantlon 1957). Alternatively, if depositional bars are adjacent to established herbaceous communities, existing plants may be able to spread vegetatively onto the new bars and rapidly establish robust vegetation. There are many desirable species capable of vegetative spread. However, common reed and cattails are examples of nuisance species with horizontal underground stems that readily spread vegetatively. These are very aggressive species that can become nuisances along many waterways due to their dense growth and minimal wildlife habitat value.

Once established, the vegetation on depositional bars provides resistance to floodwaters, slowing the velocity and increasing further deposition. Elevation of the bar surface increases as sediments accumulate around stems. All plants contribute to the resistance, but woody perennials are most important (Ware and Penfound 1949). Deposition amounts eventually decrease as the bar becomes inundated less frequently. Decreased periods of inundation and reduced current velocities over the bar result in improved conditions for establishment of additional species. For example, balsam poplar initially becomes established on young ridges of bars in river channels of the Beatton River in British Columbia. Following an abrupt decline in sedimentation on surfaces approximately 50 years old, white spruce rapidly colonize the bare mineral soil beneath the poplar canopy (Nanson and Beach 1977). Further increases in elevation with sedimentation and organic matter accumulation allow continued decreases in period and frequency of inundation and additional species to survive. Surviving willow trees in interior portions of the diverse bottomland hardwood forests of the Southeast are evidence of historic river movements.

The degree to which a plant community will develop and change over time since establishment on a river bar depends on the area and behavior of the river. The lack of succession from colonizing species in the arid Southwest forms one end of a continuum. Floods recur on roughly 100-year cycles in the Southwest that destroy riparian forests; this may be adequate to retard succession (Johnson et al. 1989). Fonda (1974) described a succession of forests on terraces of the Hoh River, Washington. Each successional stage is dominated by one or two tree species. The very diverse mature Southeastern bottomland hardwood forests do not resemble the colonizing plant community at all and define the opposite end of the continuum. These forests occur in river systems that are constantly changing shape (Wharton, Kitchens, and Sipe

1982). While some newly colonized areas are destroyed by floods, many are eventually abandoned by the river as it changes course. Although floods still occur in the abandoned areas, succession can proceed under less stressful conditions.

Just as stable river channels have areas of erosion and deposition, stable riparian plant communities have areas of regeneration and loss. Ideally, as point bars are creating areas for colonization, eroding banks are removing equal areas of mature communities in a dynamic equilibrium.

Responses to disturbances

Disturbances are common forces on ecosystem dynamics. As systems develop towards a steady state, disturbances of various types and levels of intensity occur that can alter the vegetation developmental process. Disturbances can affect the types and structures of plant populations in a community by the following:

- Changing species mixtures by eliminating propagules (i.e., seeds and vegetative propagules) of some species.

- Creating harsh conditions for seed germination or vegetative growth for some species or enhanced conditions for others.

- Reducing competition for available resources by removing dominant vegetation.

- Altering growing conditions that change species survival, growth, and reproduction rates, hence shifting species dominance and structure.

Ecosystems that are regularly subjected to low-intensity disturbances (e.g., fire in southeastern forests and inundation in wetlands) have characteristic species associations that are adapted to these conditions. If the communities are mature, there is little species turn over after a low-intensity disturbance event, and the species complement remains relatively steady. The occurrence of the disturbance acts to reduce competition from species that would invade in the absence of the disturbance (such as a pine forest developing into a mixed hardwood forest in the absence of fire or a wetland forest developing a more mesic mixture of species when drained). It can be argued that "disturbance" is a misleading term used in this manner, that fire and water, for example, are natural forces in the landscape that are necessary to maintain certain types of communities. Disturbance is often taken to mean a discrete event in time that disrupts ecosystem resources, availability of substratum, or the physical environment. Regardless of the term used, the absence of frequent, low-intensity periodic events such as fire and flooding from areas where they naturally occur results in shifts in ecosystem characteristics.

High-intensity natural disturbances usually occur with less frequency and are more catastrophic to ecosystems than low-intensity disturbances. Intense disturbances can remove all vegetation and set back succession to the initial developmental stages. For example, prolonged flooding creates conditions beyond the tolerance threshold of many wetland species, and they eventually succumb. As described above, fallow agricultural fields have been subjected to intense land use practices that remove all natural vegetation. The resulting successional plant communities develop and change with time.

Disturbances help maintain a dynamic mosaic of plant communities in different developmental stages within a landscape. Riparian systems of the arid Southwest, for example, are renewed by intense episodic floods that remove portions of established forests and create new areas for regeneration. In addition, disruption caused by fires, pulses of sediment, or drought is extensive but not complete. Communities are often adapted to regenerate from undisturbed areas in the riparian corridor (Hecht 1993). Rather than being detrimental, the increased diversity within landscapes is often beneficial. Wildlife value, for example, is often increased as different habitats are created and edges between habitats are increased that support different species (see Chapter 4). Dynamic mosaics of these landscapes is the natural and desirable state of the riparian system.

Hydrologic regime. Hydrologic conditions are primary factors in determining the distribution and functions of riparian vegetation (Brinson et al. 1981; Mitsch and Gosselink 1993). By definition, surface hydrology of riparian areas is driven by flows in streams and rivers (Brinson 1993). Establishment and growth of vegetation in most riparian areas is limited by inundation or flow energy of surface water. Vegetation in riparian areas that receive only short periods of overland flow, however, may be further limited by availability of groundwater. In arid areas in particular, rooting depths of riparian vegetation must be adequate to reach groundwater a sufficient period of the year to sustain the plants. In contrast to riparian vegetation in humid regions, riparian vegetation in arid regions is limited to areas where groundwater is available rather than being limited by too much water. It is, therefore, important to understand groundwater hydrology of riparian areas as well as surface water hydrology.

Hydrologic regimes in wetlands are usually characterized by the depth, duration, frequency, and season of inundation by surface water or saturation by groundwater. Depth and duration of flooding determine the availability of oxygen to plant roots by creating a barrier to oxygen diffusion into saturated soils. The longer an area is inundated, the lower the oxygen content of the soil becomes because plants and soil microbes utilize it in respiration. When the oxygen concentration is low, respiration pathways switch from aerobic to anaerobic (i.e., fermentation), and energy becomes very limited. Toxic by-products of anaerobic respiration accumulate in the soil, and conditions become stressful for most plant life (Mitsch and Gosselink 1993). Many plants are not tolerant of low-oxygen conditions and consequently are not capable of surviving in flood-prone wetlands (Whitlow and Harris 1979).

Wetland plants have adaptations that allow them to either tolerate short periods of low oxygen or oxygenate their roots (Kozlowski 1984). Floodplain areas that experience long periods of inundation have a suite of species that are more flood tolerant than areas that experience short periods of inundation (Wharton, Kitchens, and Sipe 1982).

Vegetation is more tolerant of flooding if at least part of the plant remains above the water. The emergent portion of the plant is capable of accessing oxygen and continuing photosynthesis to provide energy for respiration. Plants that are completely submerged do not have much energy available for growth or maintenance. In addition to limiting oxygen, depth of water, therefore, has a direct influence on the survival of flooded vegetation. This is illustrated, for example, in floodplain forest vegetation that is typically comprised largely of trees with little groundcover in areas that experience long periods of deep inundation (Figure 5c). Shrubs and vines become more common as flooding depth decreases. And finally, grasses and herbs become abundant in the groundcover of floodplain forests that experience relatively short periods of shallow inundation (Figure 5a).

Frequency of inundation influences plant distributions because the plants must have a period of recovery between flooding events to tolerate conditions at a site. In addition to reduced growth rates while flooded (Young et al. 1995), plants can be damaged or silt can be deposited on the leaves, providing further stress. Frequent inundation stresses most plants beyond their capability to repeatedly recover.

In riparian areas that are not bordered by wetlands, the depth and duration of surface inundation or soil saturation is not necessarily adequate to produce significantly low-oxygen levels that plant growth is limited. In these areas, groundwater hydrology primarily determines the distribution and functions of riparian vegetation. The rate and depth of groundwater decline affect plant establishment and survival. As seeds are deposited on newly exposed, moist surfaces, they absorb water, germinate, and produce the first root. If groundwater declines too rapidly for the root growth to maintain contact, the seedling cannot survive. Segelquist, Scott, and Auble (1993) showed that plains cottonwood seedling survival was highest under slow groundwater drawdown rates and declined significantly with faster drawdown rates. The groundwater usually is sufficiently close to the surface to support different vegetation in riparian zones from the adjacent uplands. Even in dry arroyos of the arid Southwest, more moisture is available in the riparian area than in adjacent uplands, and there is a clear distinction between riparian and upland vegetation (Anderson and Ohmart 1985).

Vegetation in individual riparian systems reflects in part the characteristic groundwater and surface water hydrologic regimes of the site. The vegetation that has been able to become established and survive the preceding hydrologic events is likely to be able to tolerate future events in the system, because there is a certain amount of predictability of water behavior based on basin characteristics. With all else being equal, patterns of water delivery are not likely to change radically over time.

The variability of hydrologic regimes, however, must be recognized and plans made for them. "Normal conditions" are difficult to define. Hydrographs vary widely on daily, monthly, and annual bases. Determination of hydrologic conditions based on average flows and season of duration is helpful to understand the general conditions to which plants will be subjected; however, extreme events more commonly determine the vegetation distribution and function. For example, a 10-year return flood (368 m^3s^{-1}) occurred in the Hassayampa River, a perennial stream (0.1 m^3s^{-1}) within the Sonoran Desert. An average of 8 cm of sediment was deposited on the floodplain, with maximum deposition (to 0.5 m) on densely vegetated surfaces. Native riparian vegetation showed resistance and resilience to the flood disturbance. Survivorship corresponded to floodplain elevation. Cottonwood and willow plants on high floodplains (e.g., *Prosopis velutina* trees and saplings and *Populus fremontii* and *Salix gooddingii* trees) had low mortality; but 40 percent of *Populus* pole trees died on low floodplains where water was >2 m deep. Although some adults died, the same plant species maintained populations in the area. Seedlings of cottonwood and willow established abundantly after the flood along overflow channels and main channel sediment bars, contributing to age-class diversity for these episodically recruiting species. The exotic species salt cedar (*Tamarix pentandra*) had greater mortality and lower postflood recruitment compared with the native species. Shrub and herbaceous species largely recovered via vegetative regrowth and spread (Stromberg, Wilkins, and Tress 1993).

Changes in hydrologic regime result in changes in the associated riparian plant communities. Bryan (1928) described hydrologic changes in the arid Southwest through the 19th century, some of which were natural and some man induced. There was a general decline in groundwater level and loss of the vegetation associated with moist conditions. For example, entrenchment of the Arivaca Creek, a tributary of the Santa Cruz River in Arizona, destroyed the springs among the bulrushes, the swamps, and ponds that once existed. Groundwater pumping in the karst topography of the Florida peninsula has led to a shift of plant species in nearby wetlands to those more characteristic of upland conditions (Rochow 1985).

Loss of groundwater is relatively slow, and the vegetational response may not be obvious in the short term. Impoundments, however, create abrupt and radical changes in hydrology that have dramatic effects on riparian vegetation. Harms et al. (1980) found increasing rates of mortality of floodplain trees with depth of inundation within 2 years of impounding the Oklawaha River in Florida. Species richness was reduced even where effects of flooding were minimal in the upper reaches of the reservoir. Plant communities downstream of impoundments are also affected by altered hydrology. Reduced flooding in dam-controlled streams permits plant life to colonize streambanks and shift to more mesic species associations. Flood-induced mortality of perennial riparian plants was high with regulated releases, with significant differences in mortality rates among plant species of the Colorado River corridor downstream of the Glen Canyon Dam (Stevens and Waring 1985).

Hydraulics and sedimentation. Stream current energy experienced by riparian plant communities in terms of velocity, depth of flow, local shear, and turbulence intensity can be a strong organizing force due to the potential destruction of existing plants, erosion of substrates, and deposition of sediments. As discussed above in relation to adaptations of riparian plants, plants adjacent to streams can be subjected to high rates of flow during floods that can break or remove plants altogether. Plants such as willow that minimize breakage by deforming with flows and are capable of rapid vegetative recovery are at an advantage for survival in riparian corridors.

Types and amounts of particles transported by streamflow affect the relative energy the riparian vegetation will experience as well as the availability of regeneration sites. It is surmised that trees dominate riparian vegetation along high-gradient streams, because they can tolerate the force of being hit with large rocks. There is relatively little erosion of substrates along constricted, high-gradient streams with rock beds, however, and loss of riparian vegetation is largely due directly to stream energy or erosive forces initiated in adjacent uplands (e.g., debris slides). Erosion and deposition of sediments resulting from stream currents become more important for the distribution of riparian vegetation in lower gradient streams with erodible bed material.

Local scour around plants is a natural phenomenon in riparian systems. Erosion destablilizes plants by removing the structure in which the plant is rooted. If too much sediment is eroded from around plant roots, the plant can no longer support itself upright. A certain amount of erosion is tolerable; however, the plant dies if enough of the root system is exposed so that there is not adequate water and nutrient uptake.

Historical riparian plant communities along the Platte River in Nebraska were maintained as herbaceous communities by the dynamics of alluvium with annual floods and the lack of woody species to colonize streambanks (U.S. Fish and Wildlife Service 1981). Tree species were made available for colonization by pioneers planting tree claims under the Timber Culture Act of 1873. Trees did not become established in riparian zones of the Platte River, however, until dams were constructed that reduced river discharges and sediment loads. The reductions in discharge decreased scouring and shifting of the alluvium on the streambed and have allowed extensive forest development on the floodplain since 1930. The development of woody vegetation, and subsequently a channelized river, where there was once only an open, wide, sandy, intermittent braided river has contributed to drastic reductions in use of the area by sandhill and whooping cranes, seriously endangering these species populations (U.S. Fish and Wildlife Service 1981). In addition, the development of wooded corridors facilitated movement of eastern forest birds into the Rocky Mountains.

Sedimentation can be beneficial. As in the well-known stories of agricultural areas of the Nile River Valley relying on the annual deposition of sediments to replenish soil nutrients, all alluvial rivers transport sediment that can nourish riparian systems. As will be discussed in more detail in Chapter 3, overbank flooding allows current velocities to be reduced and particulates with associated nutrients to settle out onto the floodplain floor.

Sedimentation rates vary with many factors such as the characteristics of the watershed and position within the riparian corridor. Sedimentation rates on point bars are the most rapid in comparison with other areas in stable streams. Within floodplains of southeastern rivers, sedimentation rates are generally much lower and average <2-3 mm/year.[1] Greatest sedimentation rates are reached within the floodplain, however, in depressions such as oxbows or pits from tipped-up tree roots.

Excessive sedimentation blocks oxygen transport to roots that is required for normal plant functions. The combination of stress from sedimentation and flooding can be detrimental to tree regeneration. Kennedy (1970) demonstrated that survival of 40-cm-tall water tupelo (*Nyssa aquatica*) seedlings was decreased 12 percent with only 7.5 cm of sand in shallow flooding, but survival was decreased 32 percent with deep flooding. Seedling survival was further reduced with deeper sand deposits and longer flooding periods.

Sediment accumulation rates in an area change with time, ground-surface elevation relative to bank full levels, and vegetation density. Sedimentation rates averaged 6.1 cm/year in 50-year-old areas up to 2.5 m above the lowest elevations where vegetation was established on point bars of the Beatton River in British Columbia. Sedimentation rates decreased to 0.8 cm/year in 200-year-old areas 4 m above the point bars and becoming negligible in older, higher areas where vegetation density was relatively low (Nanson and Beach 1977). See Chapter 2 for further discussion of sedimentation in riparian areas.

Grazing. In addition to the physical environment determined by the hydrologic, hydraulic, and sediment characteristics of the associated streams, riparian vegetation is subjected to myriad disturbances that affect plant structure and composition. Grazing by natural and stocked animals is of primary importance because of the extensive damage of riparian systems caused by overgrazing. Before the extensive herds of bison were hunted to near extinction, the intense grazing pressure on prairie riparian systems was very destructive. These areas were allowed to recover, however, as the herds moved off to better forage (Costello 1980). Cattle and sheep grazing in the West brought a rapid decline of riparian vegetation in the 19th century (Bryan 1928). Extensive riparian areas throughout the country have been degraded by grazing, converting them to lower value habitats and making them the most

[1] Personal Communication, 1995, C. Hupp, U.S. Geological Survey.

endangered habitat type in the West (Brinson et al. 1981; Chaney, Elmore, and Platts 1990).

Riparian zones provide preferred habitat for both domestic and wild ungulates because they contain the following:

- Easily accessible water.
- More favorable terrain.
- Hiding cover.
- Soft soil.
- More favorable microclimate.
- Abundant supply of lush palatable forage (from Kovalchik and Elmore 1992).

Damage to riparian areas by grazing is initiated by consumption of and damage to the vegetation. Kovalchik and Elmore (1992) report several studies showing that although the riparian habitat covered less than 2 percent of the area and produced 20 percent of the available summer forage, cattle used 75 percent of the current year's herb growth and 30 to 50 percent of the current year's willow growth in the riparian zone. Grazing can have a stimulatory effect on plants, causing them to sprout and branch more abundantly. For example, beaked sedge (*Carex rostrata*) produced more shoots per plot in grazed versus ungrazed plots in southwestern Montana (Allen and Marlow 1992). Too much grazing, however, taxes plant energy reserves, and the plant eventually reaches a point where it cannot continue to sprout and recover. At this point, the overgrazed plant begins to loose vigor (Figure 16). Continued grazing together with additional stresses to the plant lead to loss of the vegetation.

Regeneration of riparian vegetation is limited by grazing. Recruitment and growth of willow seedlings were reduced when subjected to continued season-long, heavy to very heavy grazing in comparison with other areas that received no grazing to moderate grazing in the spring or fall (Shaw 1992). Native ungulates (elk, moose, mule deer, pronghorn, bighorn sheep, and bison) of Yellowstone National Park reduce willow seed production and establishment because they consume the flowers (Kay and Chadde 1992). In addition, grazers limit plant regeneration because they trample and pull out small seedlings as they feed (Kovalchik and Elmore 1992).

The bank destabilization that results from the loss of riparian vegetation leads to a predictable sequence of events that creates stressful conditions for reestablishment of the vegetation (see Chapter 2). Vegetation responds to the increased erosion, lowered water tables, and increased flow rates of the degraded stream. Species that are unable to tolerate grazing or to access the

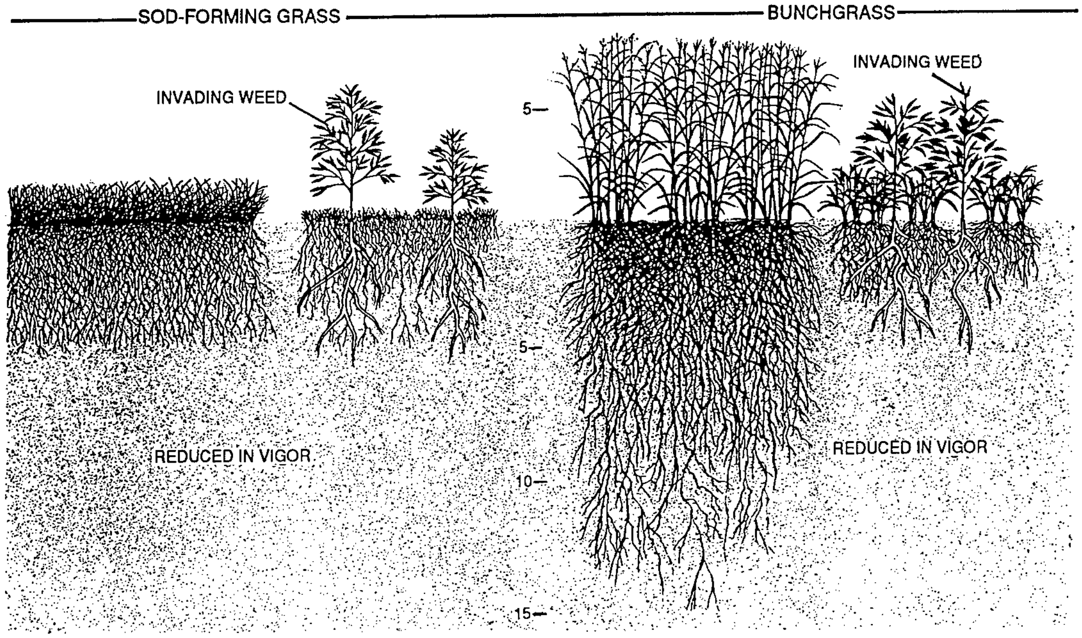


Figure 16. Overgrazing reduces root production and plant vigor of sod-forming grass and bunchgrasses and allows invading weedy species to become established (from Chaney, Elmore, and Platts 1990)

lowered water tables are replaced by species that can. Continued grazing and flooding stress the vegetation beyond its capacity to stabilize the streambanks. Downcutting of the stream further lowers the water table and can lead to a complete turnover from riparian to lower value upland species (Figure 17).

Other disturbances. Riparian vegetation is subjected to a wide variety of disturbances from the adjacent stream and upland environments. In addition to those discussed above, fire, debris slides, introduction of exotic species, and adjacent land uses often influence the structure and composition of riparian vegetation. Fire and debris slides are natural forces in many landscapes. Natural riparian vegetation subjected to these forces is adapted to the characteristic frequency and intensity of events in much the same manner as vegetation can be adapted to a hydrologic regime; regeneration, survival, and growth of the vegetation depend on and is timed to coincide with the predictable occurrence of the disturbance. A stable native riparian plant community is able to dominate under the series of disturbances that are characteristic of the site.

Introduction of aggressive exotic species and changes in surrounding land uses, however, are the types of disturbances to which riparian vegetation cannot readily adapt. Exotic species are those brought to an area from elsewhere. Aggressive exotic species are often able to invade and exclude existing native vegetation because there are no natural population controls on the exotic species. Reed canary grass, for example, has spread throughout the

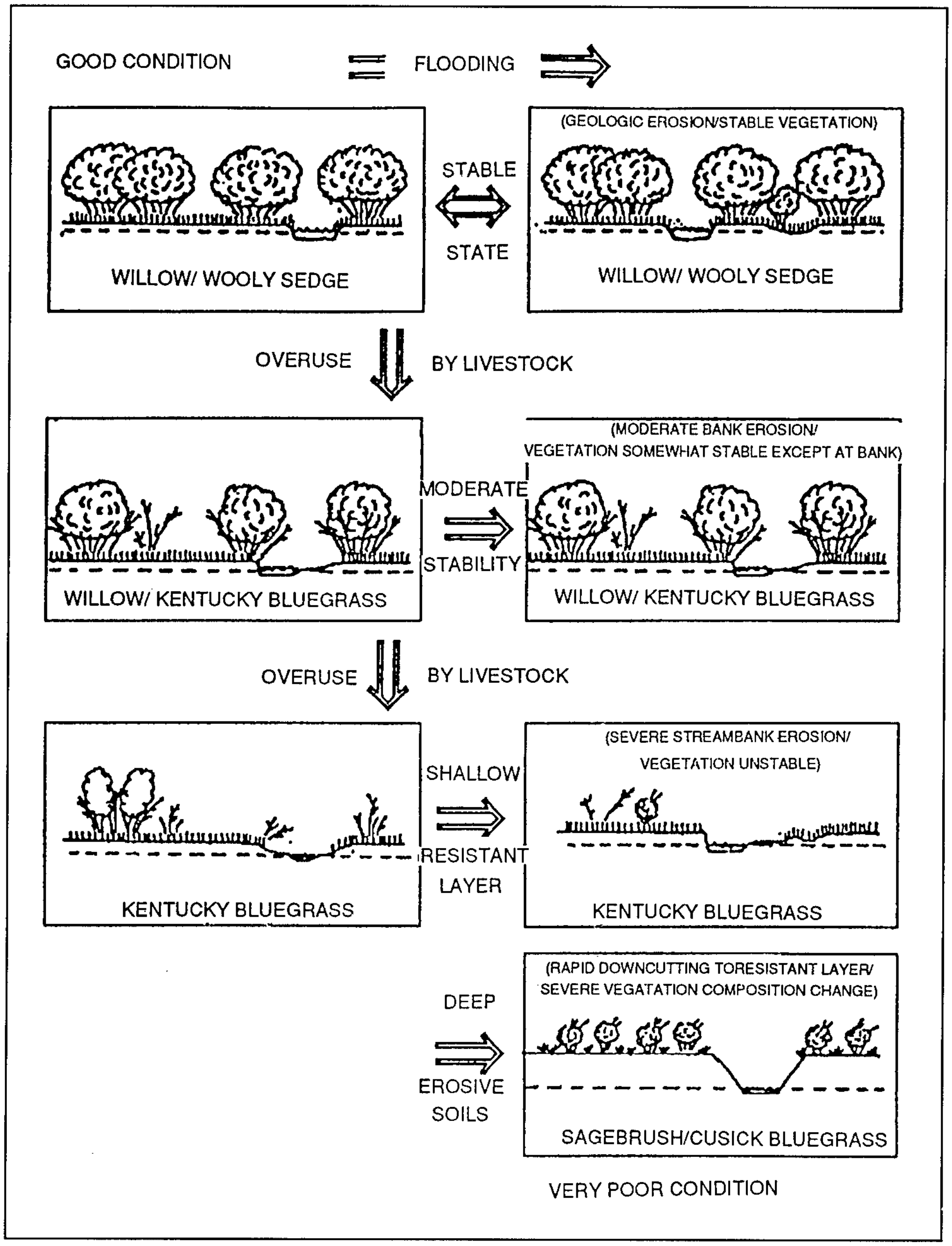


Figure 17. Deterioration of sites supporting the willow/wooly sedge (*Carex languinosa*) plant association with flooding and improper use by livestock in central Oregon (from Kovalchik and Elmore 1992)

riparian zone of the northern tier of the country, because of the lack of insects, fungi, or other organism to slow its growth. The native vegetation and associated value is usually reduced if not lost as it loses dominance. Many types of land uses encroach on riparian areas and destroy the riparian vegetation. Grazing is a primary cause of these losses, but many others exist. Forestry, agriculture, and urbanization can also be devastating to natural vegetation and its associated functions if best management practices and sound development plans are not followed.

Functions of Riparian Ecosystems

The importance of riparian zones far exceeds their minor proportion of the landscape because of their prominent location within the landscape and the intricate linkages between terrestrial and aquatic ecosystems (Gregory et al. 1991). In addition, riparian corridors form linear connections that facilitate movement of water, sediment, nutrients, plants, and animals between upstream and downstream portions of the watershed (Harris 1986). Landscape position, width, and continuity of the vegetated portions of these areas are critical to the hydrologic, water quality, and life support functions of riparian corridors (Table 1). In addition, it is important to recognize that riparian ecosystems have general functions that can be performed based on the hydrological, geological, and morphological conditions of the basin (Brinson et al. 1995). It should be emphasized that not all riparian ecosystems perform all functions nor are all functions performed to the same level in all riparian ecosystems (Brinson 1993).

Riparian ecosystems and the associated functions change as streams progress and enlarge from headwaters to rivers at the base of the watershed. For example, in watersheds of the Southeast, riparian corridors are narrow in the upper reaches that originate in the Piedmont region. Here the rivers are relatively steep and small; the riparian corridors are confined in the hilly terrain. Riparian vegetation is limited to narrow streamside fringes that are similar in composition to the bordering upland vegetation. Riparian corridors broaden in the rivers flowing through the relatively flat portions of the Coastal Plain. River discharge and range of stage fluctuations become larger in downstream portions of the drainage basin. Alluvial floodplains of these basins increase in extent and complexity as the rivers approach the Gulf of Mexico or Atlantic Ocean. Riparian vegetation in these areas is classified principally as bottomland hardwood swamps, which is different in species composition from the surrounding uplands. The diversity and complexity of these highly productive riparian wetlands reflect the geomorphic complexity of the alluvial floodplains.

Functions of riparian vegetation change with stream-reach characteristics. For example, broad areas of dense vegetation of the bottomland hardwoods in the low-gradient reach of the example cited above provide more resistance to flood flow than the narrow fringe of vegetation adjacent to the higher gradient headwaters. Wildlife value changes as well. For example, fish are able to move from the river into the bottomland hardwoods during floods to forage prior to breeding, whereas there is less opportunity to forage out of the channel in upper reaches. Similar changes in function occur among different reaches in other types of riparian systems.

2 Hydrologic and Hydraulic Functions of Riparian Vegetation

Riparian ecosystems characteristically transfer water and other materials from upstream to downstream areas. Surface and groundwater flows from upstream and adjacent uplands are the primary sources of water (Brinson 1993) since direct precipitation on the riparian zone contributes little to the hydrologic budget of the riparian systems. As conveyors of water, riparian systems perform a number of hydrologic functions including surface and subsurface water storage, energy dissipation, and moderation of groundwater flow or discharge (Brinson et al. 1995). The specific hydrologic functions and the levels at which a particular riparian area performs those functions depend upon characteristics of the watershed including the land use, geomorphology, hydrologic condition, sediment availability, and vegetation. Riparian vegetation affects channel morphology and riparian hydraulic and hydrologic functions through interactions with the system water budget, by providing resistance to surface water flow, and by decreasing soil erodibility.

Maintenance of Stream Morphology

Many recent studies of the hydraulic geometry of natural channels have discussed the importance of bank vegetation in affecting bank processes and channel geometry (Thorne 1990). The soil and slope stabilizing benefits of riparian vegetation contribute to the prevention of lateral migration of banklines due to erosion. Dense vegetation stands in the floodplain affect the floodplain morphology by influencing the location of natural bendway cutoffs. Logs and woody debris can also reduce a channel's gradient, induce localized erosion, and cause changes in local width, depth, velocity, stage, and bed composition. There are natural limits to the benefits of vegetation in resisting bank erosion, however, as evidenced by streams that, despite the presence of vegetation, meander across their floodplain. Nevertheless, as will be discussed below, vegetation plays a significant role in influencing bankline morphology.

The Platte River in Nebraska is an example of how live vegetation within the channel can significantly influence channel morphology as described by Fischenich (1989). The Platte River is a wide, shallow braided river characterized by large, periodic, and geometrically distinct bedforms called macroforms. These macroforms are emergent during all but the highest flows. Since the development of irrigation, channel patterns on the Platte River have been changed by the establishment of vegetation on the macroforms and their subsequent conversion to islands as vegetation-induced sediment deposition builds the macroform elevation and the stabilizing influence of the vegetation prohibits erosion of the islands. In the reach form North Platte to Kearney, NE, the formerly broad open channel has been transformed at many locations into a series of small, incised channels intertwining among islands of various sizes. In 1860, the width of the Platte River ranged from 1,150 m at Cozad, NE, to 1,480 m at Kearney, NE. In 1979, the width of the Platte River between Cozad and Kearney ranged from 101 to 250 m.

Stream morphology is complex and characterized by channel planform, width, depth, discharge, slope, velocity, roughness of channel materials, sediment size, and sediment load (Leopold, Wolman, and Miller 1964; Rosgen 1994). Riparian vegetation influences most of these factors. As stream morphology parameters change along the headwater to outlet channel continuum, the relative importance of vegetation in determining stream morphology changes as well. This will be elaborated in the following sections.

Bank stabilization

Channel width, depth, and slope are determined to a large degree by bank stability. Erodible banks allow adjustment of the channel width, depth, and sinuosity. As the channel moves within the floodplain to optimize gradients, for example, erosion allows a change in channel course into the bank and a widening of the channel. The cross-sectional area of the channel is maintained, and the width-to-depth ratio is increased. The channel slope is decreased when eroded material is deposited either on bars that increase channel sinuosity or in downstream reaches. Stabilization of banks helps to constrain movements of the channel and stabilizes the channel morphology.

Vegetation stabilizes banks by reducing erosive forces on the bank, decreasing erodibility of bank materials, and adding structural support to the bank (Table 3). Effects of vegetation on soil stability are the protection of soil surfaces from erosive forces, root reinforcement, soil moisture modification, and buttressing benefits counteracted by root wedging and plant-overturning drawbacks. The net effect of these contributing forces is generally positive. Comparison of streambanks or slopes that have good vegetative cover with those that do not shows the stabilizing benefits of vegetation to the soil. The stabilizing benefits of vegetation can be a strong inducement for their incorporation into flood control projects.

Table 3
Vegetation Factors Influencing Shoreline Stability (based on Thorne 1990)

Flow Erosion
Retardance of near bank flow - The effective roughness height of the boundary is increased, increasing flow resistance and displacing the zero plane of velocity upwards away from the bank.
Reduction of soil erodibility - Soil surfaces are directly protected, but the roots and rhizomes of plants also bind the soil and introduce extra cohesion over and above any intrinsic cohesion that the bank material may have.
Bank Stability
Bank drainage reduces mass failure - Vegetated banks are drier because (a) the canopy prevents 15 to 30 percent of the precipitation from reaching the soil surface; (b) water is drawn from the soil and transpired into the atmosphere; and (c) suction pressures in the soil are increased by water abstraction at the roots, so that the height of the capillary fringe is increased and water is drawn from greater depths than unvegetated banks.
Soil reinforcement - Roots add tensile strength to the soil and through their elasticity, distribute stresses through the soil, so avoiding local stress buildups and progressive failures.
Slope buttressing and soil arching - Well rooted and closely spaced trees along a bank toe can act as gravity buttresses and/or cantilever piles with soil arches between them.
Surcharging - On gently sloped banks, the contribution of surcharge weight of the vegetation to the downslope component of weight increases bank stability by increasing frictional resistance to shearing. On steep banks, the converse is true, and surcharging decreases stability.
Bank Accretion
Increase local flow resistance
Trapping fine material carried as wash load

Resistance to flow. Vegetation presents an obstruction to water flow that tends to decrease flow velocities. This "resistance" to flow is due to a combination of shear and form drag that are highly variable and a function of many vegetation and flow variables to be discussed below. The consequences of this increased resistance of vegetation relate to impacts on (a) soil stability and particle transport for both lateral and longitudinal flows and (b) hydraulic parameters including depth and velocity that are applicable only to longitudinal flows.

Vegetation generally reduces soil erosion on streambanks and in floodplains by decreasing the velocity gradient and thus the shear at the soil-water interface, as well as by damping turbulence. The magnitude of this benefit depends upon the density and type of vegetation cover and rooting characteristics. Rahmeyer, Werth, and Cleere (1994) demonstrated, however, that local erosion can actually increase with the presence of vegetation cover under some conditions (Figure 18).

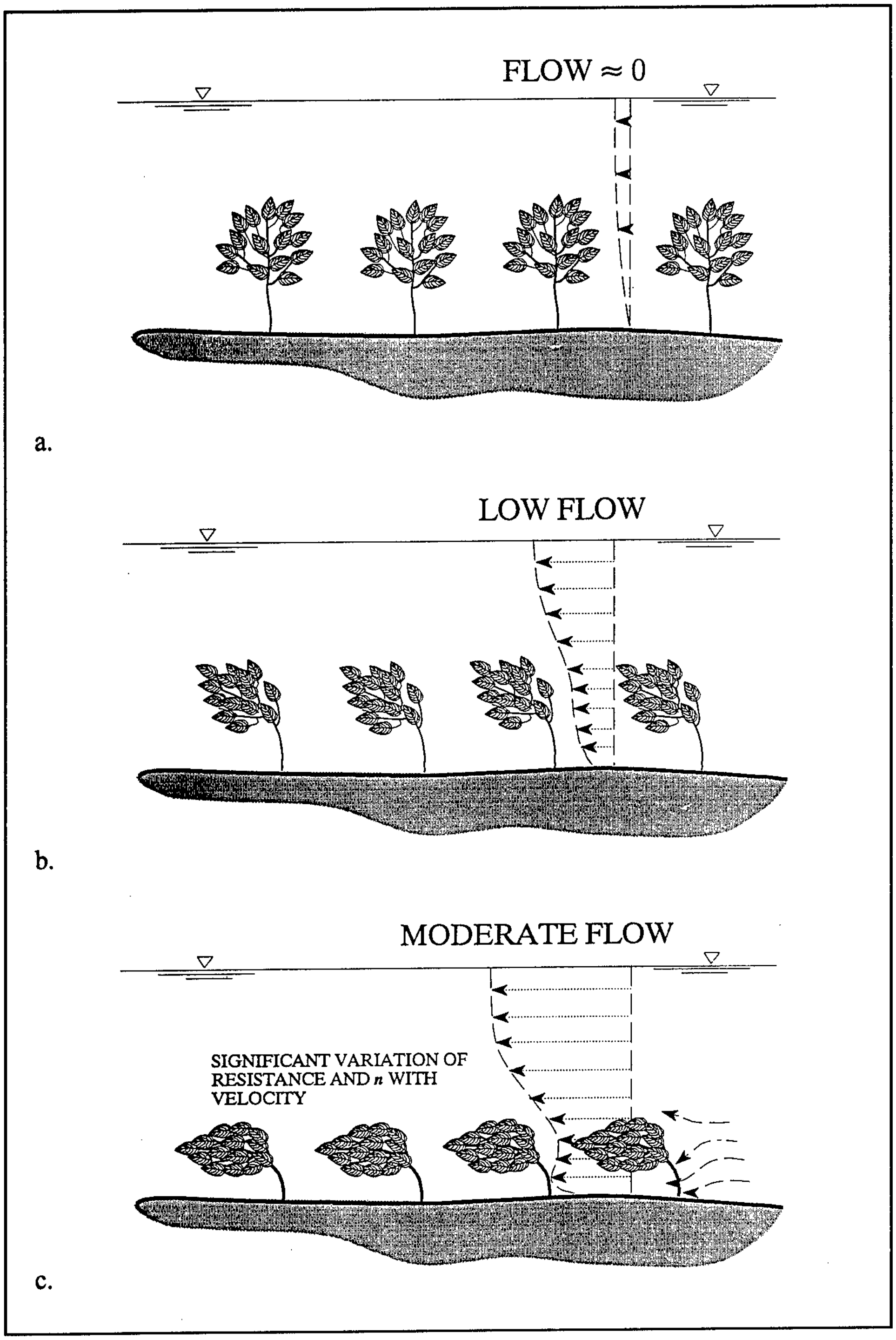


Figure 18. Effects of vegetation deformation on flow and erosion patterns: (a) plants to zero flow are erect; (b) plants at low flow are slightly deformed. Velocities at and below the height of the plant crown are decreased; (c) plant crowns at moderate flows are deformed in a tear-drop shape. Velocities are reduced greatest within the crown, but increase along the ground surface as flow is diverted below the plant (Continued)

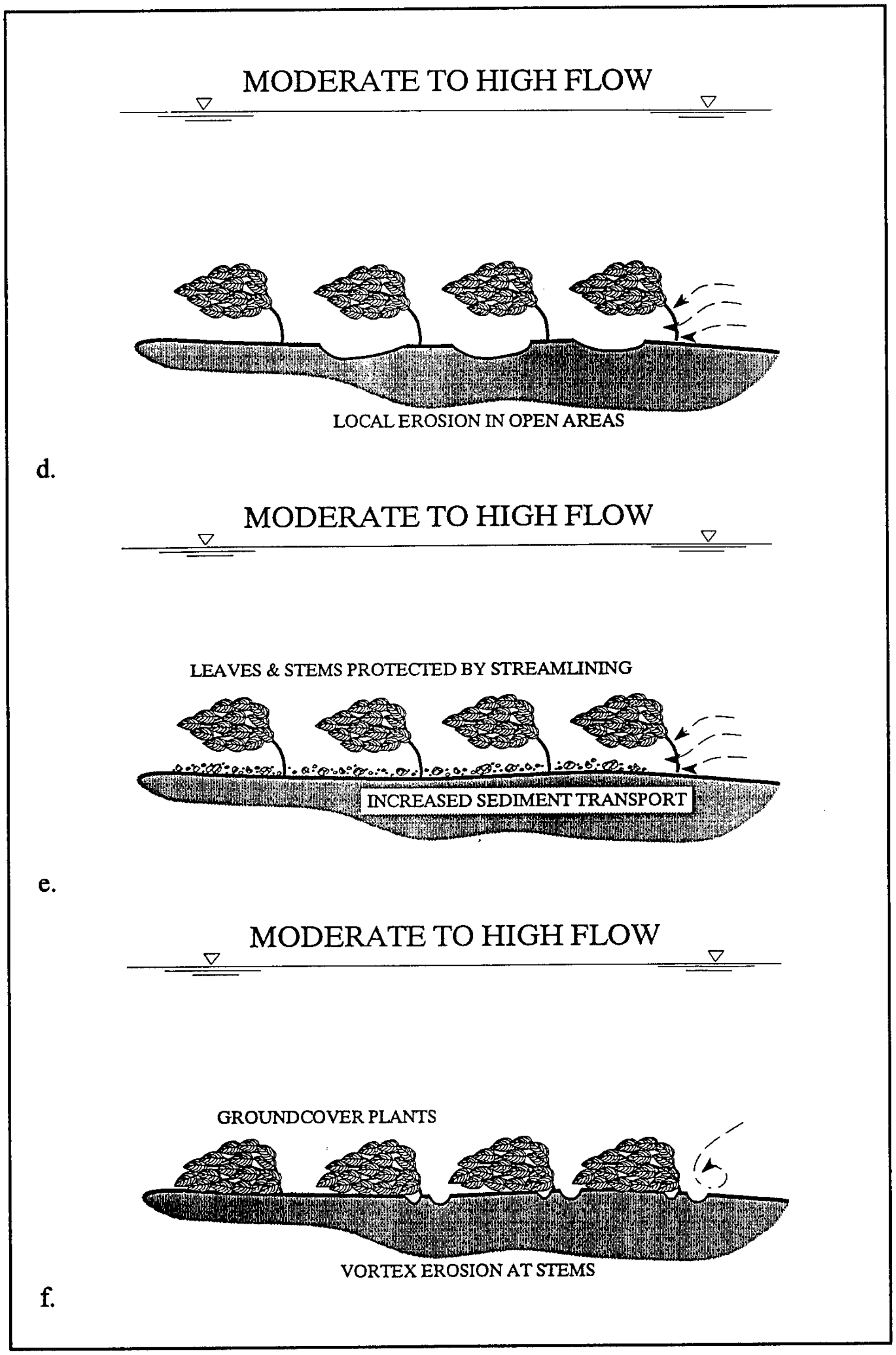


Figure 18. (Concluded) (d) Local erosion occurs in open areas under deformed plant crowns with moderate to high flows; (e) sediment transport is increased under deformed plant crowns at moderate to high flows; (f) moderate to high flow rates sufficient to flatten plant crowns to the ground surface result in vortex erosion at stems and limited sediment transport (after Rahnmeyer, Werth, and Cleere 1994)

The critical condition for soil erosion of a densely vegetated bank or floodplain is the failure threshold of the plant stems by snapping, stem scour, or uprooting that protect soils from detachment and entrainment. Vegetation failure is usually associated with much higher levels of flow intensity than soil erosion (Thorne 1990).

Calculations of resistance to flow over a vegetated surface are complicated, because natural vegetation tends to bend when subjected to streamwise drag force. The amount of bending depends on the interaction between the flexural stiffness of the plant stem and the magnitude of the drag (Thorne 1990). Thus, several thresholds exist at which the resistance components change because of the response of the plant(s) to flow rates. At low flows, resistance is primarily the result of form losses from drag induced by the trunks/stems of the vegetation. As flow increases and reaches the height of the canopy, the resistance increases because of increased drag generated by the plant's stems and leaves. Resistance begins to decrease only when the plant yields by deforming to present a smaller area to the flow. If the force of the flow continues to increase, additional decreases in resistance may result from failures of the plant's leaves and stems and, at some point, the entire plant may be uprooted. When fully submerged, resistance consists not only of the form loss due to drag, but also of the viscous shear stress on the boundary of the vegetation field.

The flexural stiffness and drag presented to flow by riparian vegetation depend on the type, size, density, and aerial extent of the plants (Vogel 1981; Rahmeyer, Werth, and Cleere 1994), as well as the Reynolds number of the flow. The type of plant affects the cross-sectional area, flexibility, and strength characteristics (Figure 19, Table 2). Plants with the greatest resistance to flow, typically mature trees, have large cross-sectional areas that do not deform under stress and are strong enough to withstand the stress of flow without stripping or breaking (Vogel 1984).

Many of the factors affecting plant resistance to flow change in time and space depending on the maturity and horizontal distribution of the plants. Mature vegetation tends to have higher resistance factors than young plants because of increased height and stiffness. Deciduous plants have different resistance factors through the year depending on their foliage condition. Complete ground coverage by low-growing plants reduces effects of deformed plants to concentrate flows on the soil surface and create areas of local erosion (Figure 18).

The diameter, density, and crown height of trees determine the degree of resistance to flow. At low flow, resistance to flow by trees depends on the area presented by stems, a function of diameter and density. Resistance increases as the crowns of young trees become submerged with increasing water depth; however, there may be some deformation depending on the species. Sparse trees or isolated logs can generate serious bank scour by acceleration of flow around their trunks. For trees to be effective in reducing flow rates and bank erosion, they must be spaced sufficiently close enough

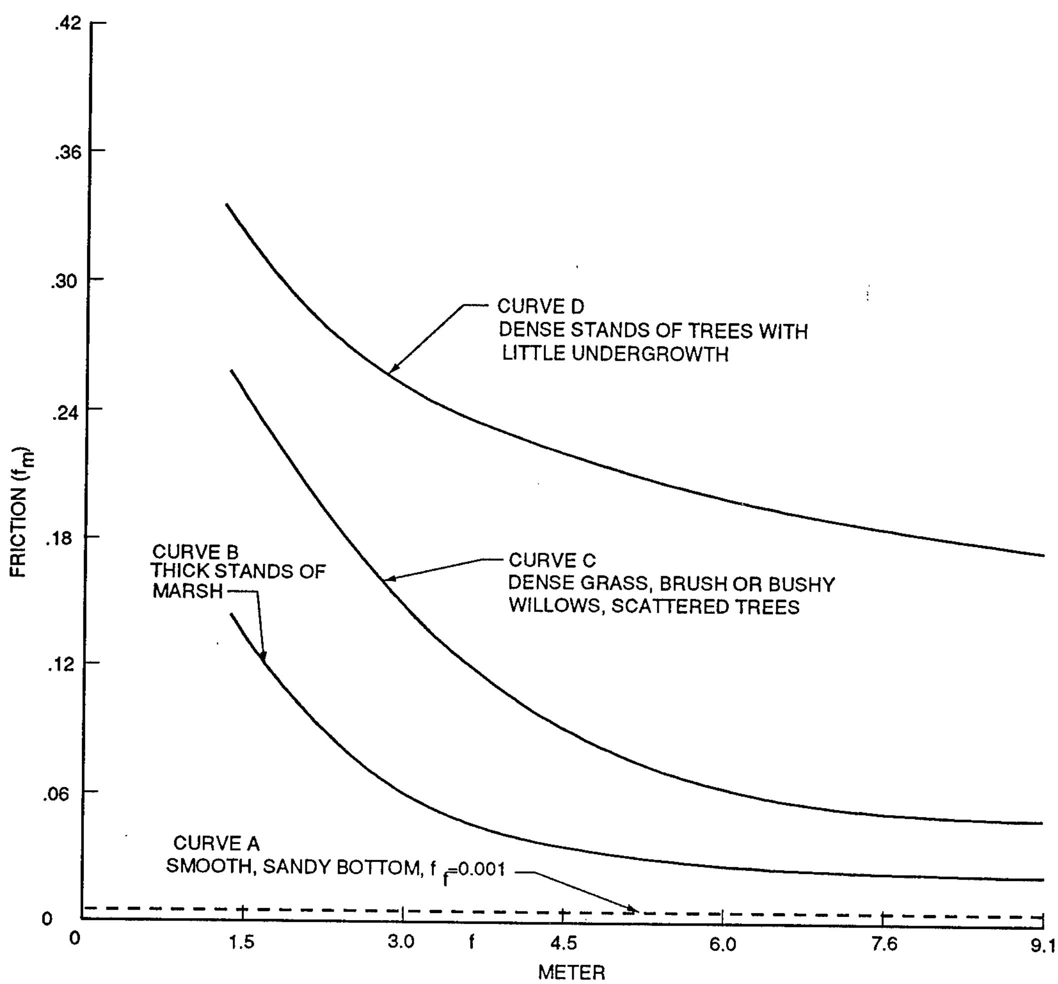


Figure 19. Effects of different types of vegetation on resistance to flow with increasing depth of water (from Camfield 1977)

that the wake zone for one tree extends to the next tree downstream, preventing reattachment of the flow boundary to the bank in between (Thorne 1990).

Shrubs provide higher resistance to flow than herbaceous plants, because many shrubs are stiff and likely to break with increasing stress after only moderate deformation. In addition, shrub leaves and small branches extend farther into the water column affecting flows to greater water depths. Plant species that can bend with the flow and lose their leaves and branches, however, present less resistance to flow. Willows are good examples of plant species that are well adapted to riparian hydraulic conditions. Flexible stems and easily stripped leaves minimize resistance to flow and stress to the plant. Grasses and low herbaceous groundcover are flattened against the ground surface by flows and present relatively little resistance to flow. While grasses and shrubs provide resistance at low velocities, their impacts decrease as velocities increase and are all but eliminated once the stems are prone (Ree and Palmer 1949).

Highly nonuniform velocity distribution and low Reynolds numbers are common in densely vegetated channels and floodplains. Manning's n values in the range of 0.10 to 0.30 are common, and values exceeding 1.0 are possible. The spatial and temporal variation of Manning's n can be significant in vegetated floodways and canals. Watts and Watts (1990) describe the seasonal variation of velocity and resistance as a consequence of changes in aquatic plant growth stage. Even daily fluctuations of an order of magnitude have been shown (Powell 1978; Watson 1987). As a consequence, there is little confidence in using Manning's Equation in these situations without good estimates of n.

Procedures for the computation or estimation of flow resistance can be grouped into five categories. They include those based upon direct measurement, those based upon analytical solution (Cowan 1956; Ree and Palmer 1949; Petryk and Bosmajain 1975), those following handbook methods (Chow 1959; Barnes 1967; Hicks and Mason 1991), effective area techniques, and atmospheric sciences approaches. Direct measurement may be the most accurate means of obtaining the estimate. In practice, however, measurement of the hydraulic parameters of a channel for the full range of flows for which resistance values are sought is seldom possible. Furthermore, the considerable variability of resistance for even a single location and discharge value make predictions of resistance based upon direct measurement somewhat suspect.

Fischenich and Abt (1995) evaluated 19 channel reaches using measured n values to assess the prediction methods described above. Four of the reaches were excavated canals, one was a laboratory flume, and the remainder were natural channels. Eight of the natural channels were evaluated for a discharge contained within the banks and seven for overbank flows. Three general cases of vegetal retardance were represented: (a) dense vegetation on the streambanks; (b) submerged or partially submerged aquatic vegetation; and (c) dense vegetation on the floodplains. The effective area techniques and atmospheric sciences techniques were not evaluated because they have not been fully developed for riverine application. Results of their investigation are summarized in Table 4.

The investigators found that none of the six methods tested proved satisfactory for measured n values in excess of 0.10. The benefits of using physically based approaches such as the n-VR/MEI and Petryk and Bosmajian methods are largely offset by the additional data requirements and uncertainties in coefficient or curve selection. The handbook methods, while offering simplicity, tend to discourage the selection of n values in excess of 0.10, and the pictorial handbooks can be quite misleading. In general, it can be concluded that each of the methods offer insight into a probable range of n values for

Table 4
Measured and Computed Manning's n Values and Statistical Summary (from Fischenich and Abt 1995)

Stream/Location	Chow	H&M	Barnes	Cowan	P&B	Measured n-Value		Predicted Mean
						n-Value	n-VR	n-Value
Tug Fork River, WV (Bankfull)	0.050	0.040	0.046	0.046	0.054			0.047
Tug Fork River, WV (Overbank)	0.074	0.080		0.080	0.111	0.200		0.109
Pearl River, LA (Marshy Reach)	0.065	0.035			0.074		0.065	0.060
Pearl River, LA (Wooded Reach)	0.095	0.100			0.109	0.190		0.124
Chisolm Creek, near Park City, KS	0.056	0.035	0.032	0.026	0.043			0.038
Hanging Moss Crk., near Jackson, MS	0.074	0.100	0.066	0.070	0.077	0.130		0.086
Gila River, near Yuma, AZ	0.082	0.078	0.046	0.049	0.069	0.097		0.070
Cypress Creek, near Downsville, LA	0.100	0.100			0.105	0.085		0.098
Fall River, near Estes Park, CO	0.110	0.050	0.088	0.065	0.093	0.275		0.114
River Yare, near Norwich, Norfolk	0.150	0.100	0.140		0.117		0.080	0.117
Thompson Creek, near Clara, MS	0.200	0.120			0.155	0.151		0.157
River Bain, U.K.	0.214	0.035			0.095			0.115
Don River, near Toronto, Canada	0.225	0.150			0.150			0.175
River Ebble, U.K.	0.326	0.100	0.120		0.138			0.171
Naanai Canal, Egypt	0.040	0.050	0.060		0.057			0.052
Port-Said Canal, Egypt	0.074	0.080	0.060		0.057			0.068
Kaskaskia Chn., near Bondville, IL	0.080	0.070	0.041	0.045	0.089	0.057		0.064
Two-Mile Sl., near Sadorus, IL	0.120	0.070	0.066	0.070	0.093	0.065		0.081
Flume w/Bulrush	0.329	0.150			0.112	0.398	0.350	0.268
Number of Points	19	19	11	8	19	10	3	19
Correlation Coefficient	0.614	0.733	0.536	0.718	0.705	0.963	0.897	
Standard Error	0.072	0.057	0.022	0.063	0.060	0.052	0.040	
Mean Percent Error	32.3	32.6	30.2	26.7	64.9	17.7	22.5	

cases where the resistance due to vegetation is not extreme, but will grossly underpredict resistance in cases where the vegetation resistance is great.

Binding and reinforcement of bank material. Roots and rhizomes contribute tensile strength to soil structure. A root-reinforced soil behaves as a composite material in which elastic fibers of relatively high tensile strength (roots) are embedded in a matrix of relatively plastic soil. Tractive forces between the roots and the soil add shear strength to the composite. Increased tensile strength helps vegetated banks resist the development of tension cracks due to desiccation and to tensile stresses behind steep banks that often trigger both slab-type and cantilever failure of unvegetated banks (Thorne 1990).

Plant roots and rhizomes also bind bank materials together, increasing their cohesiveness and reducing the effectiveness of weakening and loosening processes which are often the precursors to flow entrainment (Thorne 1990). A fine network of roots is more effective at binding soils than a network of woody roots. Woody roots are too large to bind most erodible bank materials, and in the absence of fine roots, may act to destabilize banks by wedging. A combination of root types is optimal, however, particularly in areas subjected to high flows. Herbaceous species with fine roots lack the strength to withstand high shear stress. The sedges typically found along meadow streams, for example, can be washed out by excessively high flows. Plants with thick rhizomes (i.e., underground stems) or woody roots have the strength to withstand high shear stress but also have the fine roots that bind soils.

Most plants have fine roots concentrated within 30 cm of the soil surface that are capable of binding soil, but the age and health of the plants will affect the fine root distribution (see Chapter 1). Plants growing on eroding banks may continue to live when the root system is exposed; however, the ability of the plant to bind bank material on the eroding edge is decreased. Fine roots die rapidly when desiccated, leaving only larger diameter roots that are less capable of binding soils.

Roots also modify the soil moisture content of the soil, thus increasing slope stability and can eliminate geotechnical failures related to high pore water pressure. Compared with unvegetated streambanks, soils in vegetated banks are much drier and better drained. Like the root systems, anchored and embedded stems can act as buttress piles or arch abutments in a slope, counteracting shear stresses and preventing soil sliding around and between vegetation components.

Bank reinforcement by vegetation extends only as deep as the roots. Vertical root systems penetrate through the soil mantle into firmer strata below, thus anchoring the soil to the slope and increasing resistance to sliding. Trees and shrubs generally have deeper root systems than grasses and provide better bank protection on taller banks or when exposed to higher flows. To be effective, vegetation must extend down the bank at least to the average low water plane, otherwise the flow will undercut the root zone during significant flow events. In this respect, plants that are tolerant of inundation or soil saturation are more effective than upland species (Thorne 1990).

The downslope component of stress imparted from surcharge or weight of the plants can have a destabilizing influence on steep slopes, however, and this must be weighed against the benefits described above. There are other destabilizing influences of vegetation as well. Of generally minor concern is the alleged tendency of roots to invade cracks, fissures, and channels in a soil or rock mass and thereby cause local instability by wedging or prying action. Of greater concern is the destabilizing influence from turning moments exerted on the soil mass as a result of strong winds or flowing water moving across the vegetation. This can become particularly troublesome when the turning forces are sufficient to uproot the vegetation and expose the underlying soil to further erosion.

In addition to vegetation type and rooting depth, the degree of bank stabilization provided by vegetation over time depends on the width of the vegetated riparian zone. A wide strip of vegetation along channels is more likely to support the basic conditions necessary to maintain the vegetation. This is because plants modify the conditions in which they are growing in such a manner that benefits the plants around them. For example, evaporation from the ground surface is reduced by the shade and slower wind velocities beneath the vegetation. Reduced water loss with reduced evaporation creates a more favorable root environment. Isolated plants or narrow strips of plants are often stressed, because they experience hotter and drier conditions than when surrounded by plants. In addition, trees lend structural support to each other. Broken and fallen trees occur along edges of cleared forests where individual trees are exposed to wind and are no longer protected and supported by neighboring trees. Furthermore, continued replacement of aging and dying riparian vegetation depends on the presence of adequate area to support continual regeneration. Wide riparian corridors can support the many individuals of multiple ages that are required to maintain a healthy and viable stand of riparian vegetation.

Width of riparian areas between slopes and channels is important for protection at the toe of slopes. Dwyer, Wallace, and Larsen (1995) surveyed effects of riparian corridors on levee stability along a 24-km segment of the Missouri River after the 1993 Great Midwest Flood. A systematic sample of the river, as well as a total inventory of levee failures within the study area, revealed some interesting relationships. Primary levees that did not fail had a significantly wider woody corridor along the river channel than levees that did fail. Analysis of the total inventory of failed levees revealed that as the width of woody corridor decreased, the size of the levee failure increased. Based on the results of this study, the number of levee failures and their severity of damage could be substantially reduced if the woody corridors between slopes and channels were at least 100 m in width.

Discharge

In small headwater streams, discharge is a direct function of the amount and type of vegetation in the watershed. Vegetation reduces the amount of surface water reaching the stream by intercepting direct rainfall (Thorud 1967; Leyton, Reynolds, and Thompson 1967; Rutter 1967) and increasing permeability rates into soils (Smith and Leopold 1942). Stream discharge rates are more stable in vegetated watersheds because increased permeability increases base flows and decreases peak runoff events (Leopold 1968; Seaburn 1969; Anderson 1970). The effects of vegetation on discharge decrease with increase in stream order, because cumulative effects of streamflow, runoff, and direct precipitation on stream discharge eventually outweigh vegetation effects. In high-order streams, the influence of vegetation on discharge is greatest during low periods, with peak discharges generally being unaffected.

Vegetation determines how much rainfall reaches the ground surface. A complete canopy of vegetation intercepts roughly the first 2.5 mm (0.1 in.) of a rainfall event and holds the water on the wetted leaf and branch surfaces. Excess water runs off the plants as throughfall. An estimated 15 to 30 percent of precipitation reaches the ground surface through a well-developed plant canopy for average rainfall events (Thorne 1990).

Plants increase the relative amount of water entering the soil by two processes: maintaining soil structure for good infiltration and increasing soil noncapillary porosity for permeability (Lassen, Lull, and Frank 1951). When soil aggregates are not protected by vegetation from the energy of raindrops, the aggregate disintegrates. Fine-soil particles are washed into pores, creating blocks to water infiltration. Rainfall runs off the unprotected, nonporous soil surface into stream channels.

After water has infiltrated into the soil, the rate of its continued downward movement depends on the noncapillary porosity of the various soil layers through which it passes. Vegetation increases noncapillary porosity of the top 30 to 45 cm by contributing organic matter that separates soil particles and creates larger pores, moving soil with root growth and leaving channels as roots die that are filled with porous organic material (Lassen, Lull, and Frank 1951). Roots increase noncapillary porosity to even greater depths, but affect a smaller soil volume due to limited root distributions at depth.

The best documented and greatest effect of riparian vegetation on discharge is through evapotranspiration (Lassen, Lull, and Frank 1951). Evapotranspiration is actually two processes: evaporation from the soil surface and transpirational loss of water from plants. The loss of water through vegetation can be a significant influence on hydrology depending on the relative amounts of water loss from the system from surface flows, groundwater recharge, or evaporation. This is particularly important in the arid Southwest. The depression of groundwater can lead to reduced base flow in streams. Bowie and Kam (1968) computed the average water loss from the vegetated lower reach of the Cottonwood Wash in Arizona to be 10 ha-m (80 acre-ft) per growing season, a quantity which represented about 18 percent of the average flow entering the reach in the same period. The average loss after defoliation and eradication of the riparian vegetation was 5 ha-m (42 acre-ft) per growing season, a quantity which represented about 12 percent of the average flow entering the reach in the same period.

Effects of riparian vegetation on base flow in streams depend on the efficiency of the plant in removing water, which is a function of root depth

(Schachori, Rosenzweig, and Poljakoff-Mayber 1967). Studies in the arid Southwest have shown that the exotic species salt cedar removes much more water from stream systems than native species such as quail bush (*Atriplex lentiformis*) and honey mesquite (*Prosopis qlandulosa*) (Anderson and Ohmart 1975).

The amount of surface runoff is indirectly proportional to the amount of vegetation in a watershed (Lassen, Lull, and Frank 1951). Narrow, sparse bands of vegetation, therefore, will have less effect on discharge than wide areas of well-established vegetation. Reduced coverage of vegetation will intercept less precipitation and have less ground surface area with increased permeability.

Slope and velocity

Vegetation can directly influence stream slope and flow velocity by providing grade control, particularly along high-gradient streams (>4-percent slope). High-gradient streams are typically small and confined in narrow valleys in the upper portions of watersheds. Trees and large branches falling across the channel can become incorporated into the stream hydraulic geometry by forming log steps or small dams. As the water falls over the steps, flow energies are dissipated. Upstream from the steps, flow velocities are reduced due to backwater. Once sediment accumulates above the log steps, the deposit gradients will be lower than those of the original bed, also reducing velocities (Heede 1985). As the tree height to channel width ratio decreases, the importance of direct grade control and reduced flow velocities by trees in streams decreases.

Riparian vegetation along low-gradient streams has indirect effects on channel slope and flow velocities. As discussed above, intact riparian vegetation stabilizes streambanks and stream hydraulics. Alternatively, in streams with erodible bank material, fallen trees and branches can create local scour and destabilize banks. Eroded bank material is a major source of sediment loads to streams. If excessive amounts of sediment are deposited downstream, the channel geometry can be altered.

Sediment load

Riparian vegetation affects stream morphology by regulating sediment supply and points of deposition. Stream reaches are considered dynamically stable if the transport rate out of the reach equals the rate transported in or if deposition equals erosion within the reach. Vegetation influences sediment availability by stabilizing the banks and bars and influences transport by reducing velocities and causing deposition. In addition, in agricultural watersheds with significant sediment laden runoff, riparian vegetation traps sediments before they reach the stream (Lowrance et al. 1984). Since the primary source of sediment in many streams is bank erosion (Dunne and Leopold

1978), sediment load can be significantly limited in areas where vegetation protects the banks.

In addition to limiting sediment load, resistance of vegetation contributes to reduced velocities and settling of sediment load. Point bars are points of deposition. Vegetation stabilizes the sediments on point bars and increases resistance to water flowing over the bars. Deposition rates are accelerated; elevation and extent of the vegetated bars are increased. Logs and other riparian debris that fall into high-gradient streams are very effective in slowing velocities. The result in small streams is the formation of pools as sediment drops out of suspension above the log jams (Figure 20).

Figure 20. A fallen log traps sediment, changing the stream morphology to a lower gradient pool

Vegetation plays a central role in the deposition of sediments on streambanks and floodplains. The capacity of flowing water to transport bed material load increases approximately with the sixth power of the velocity. Vegetation dramatically retards near bed and bank velocities by increasing the local flow resistance. This promotes deposition of the bed material load, particularly on streambanks.

Because of its ability to reduce velocities and to act as a filter, vegetation is also effective in trapping sediments carried as wash load. Forested floodplains frequently contain berms of material deposited within and behind particularly dense stands of vegetation. These berms were formed when flood-borne wash load was deposited as the vegetation reduced local turbulence and filtered sediment. They are critical to the evolution of floodplain ecosystems as the successional development of vegetation is often influenced by minor variations in topography (Wharton et al. 1981).

Flood Attenuation

Detention of floodwaters is an important riparian function. As overbank flow or upslope surface inputs are detained in riparian wetlands, the flood height is reduced, and duration of the flood wave is increased (Figure 21). This alteration of the flood wave and detention of water may result in reduced extent of downstream flooding.

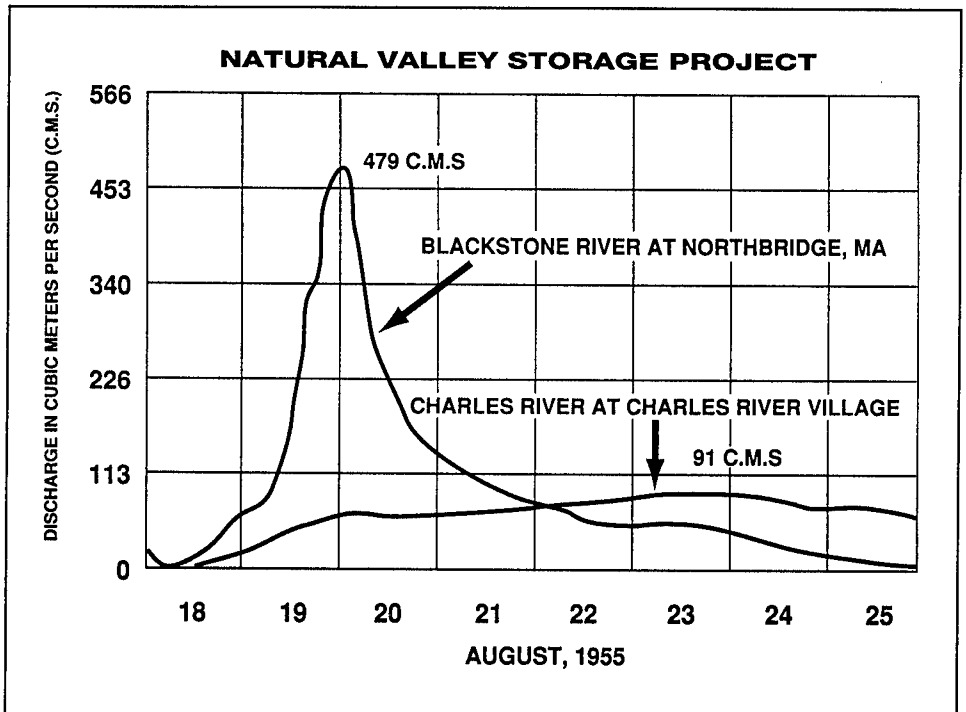


Figure 21. Peak flow for the Charles River watershed in Massachusetts is much lower than peak flow for the Blackstone River, a similar watershed with fewer remaining wetlands (from Welsh et al. 1995)

The movement of surface water through the riparian corridor is controlled by its physical conditions such as width, slope, and roughness. Burkham (1976) described "changes in bottomland vegetation between December 1965 and October 1972 that apparently caused significant differences in stage, mean cross-sectional velocity, mean cross-sectional depth, and boundary roughness at peak discharges of three major floods in an 18.5 km study reach of the Gila River in Arizona. The first flood, which had a peak flow of 1,100 m^3/s, occurred in December 1965 when the dense bottomland vegetation was dormant. The second flood, which had a peak discharge of 1,130 m^3/s, occurred in August 1967 when the vegetation had large amounts of foliage; however, the vegetation had been eradicated in the upstream half of the study reach prior to this flood. The third flood, which had a peak discharge of 2,270 m^3/s, occurred in October 1972; the vegetation had been eradicated in the whole study reach prior to this flood. Compared to the 1965 flood, the large amounts of foliage in the uncleared half of the reach during the 1967 flood apparently caused a 7% decrease in mean velocity, a 6% increase in mean depth, and an 11% increase in the Manning roughness coefficient at peak stage. Compared to the 1965 flood the clearing of the riparian vegetation in the study reach apparently caused a 25% increase in mean velocity, a 15% decrease in mean depth, and a 30% decrease in the Manning roughness coefficient at peak stage in the 1972 flood."

Riparian vegetation modifies the roughness of channel banks, and the smaller the stream, the greater the influence (Maddock 1976). Velocity of water in headwater streams is slowed more by a given amount of vegetation than in stream reaches with higher flows, because a proportionately greater amount of water contacts the plants. Velocity is slowed in flooded forested bottomlands in lower alluvial reaches, but the effects on velocity are from the increased area of flow as well as the resistance of the vegetation.

The seasonality of vegetation processes interact with flow dynamics. Seasonal variation in amounts of riparian vegetation affect the dynamics of flood flow and is an important link between channel form and process (Watts and Watts 1990). In addition, evapotranspiration by actively growing vegetation within a watershed reduces flood flow and frequency by increasing soil storage capacity, particularly where there are deep, porous soils (Lassen, Lull, and Frank 1951).

The longer water is detained as it moves through the riparian corridor, the greater the potential for other water quality and wildlife habitat functions to be supported (Brinson et al. 1995). For example, flood attenuation allows water to be detained long enough and velocities to be reduced sufficiently for particulate organic matter and sediments to settle out of the water column (see Chapter 3). The slower moving surface water in riparian zones, in comparison with higher velocity water in the stream channel, provides a refuge to aquatic organisms as well as a conduit for organisms to access areas for feeding and recruitment (see Chapter 4).

Vegetation Stability

The use of vegetation, primarily grasses and forbs, for the prevention of surficial erosion on slopes is fairly common and well understood. Biostabilization techniques to reinforce slopes and streambanks, popular in the 1930s in the U.S., have seen a resurgence in recent years here and in southeast Asia and have been used for centuries in Europe. The role that vegetation plays in this application is fairly well understood, although there are many aspects left to learn. Considerably less understood and quantified are the impacts of vegetation on hydraulics, sedimentation, and channel morphology. Vegetation undoubtedly plays a major role in the morphological processes occurring within a channel and floodplain, and its influence on channel stability should be considered during the project formulation and design.

When vegetation is used within a flood control channel, both resistance to flow and the stability of the vegetation need to be determined to evaluate the capacity of the channel. The stability criteria for vegetated channels can be stated in a number of ways, but each relates to the point at which the vegetation completely fails leading to possible failure of the underlying material.

To date, five methods to evaluate the stability of a grass-lined channel have been proposed: Maximum Permissible Velocity, Maximum Permissible Depth, Equivalent Stone Size, Permissible Tractive Force, and Maximum Permissible Deflection. Only the method based on maximum permissible velocities is based on direct observations. Each of these methods is discussed briefly below (Kouwen, Li, and Simons 1980).

Maximum permissible velocity (V_{max}). Fortier and Scobey (1926) provide values for maximum permissible velocities in bare earth channels that have been widely applied. Velocities near the bed are greatly reduced in vegetated channels, however, due to the drag on the vegetation stems. Thus, for an equal velocity of flow near the soil-water interface, it is possible to have a much higher mean velocity of flow for a vegetated channel. Work by Ree and Palmer (1949) summarized in Table 5 indicates allowable velocities for channels lined with grass. Unfortunately, this information provides little insight into the allowable velocities for channels and floodplains vegetated with plant species other than grass. Recent laboratory studies at Utah State University suggest that for many species of shrubs, velocities in excess of 1 mps may cause excessive erosion of underlying soils (Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, unpublished data).

Maximum permissible depth. Normann (1975) describes the design concept of Maximum Permissible Depth (d_{max}), which ensures the stability of any channel, whether unlined or lined with a nonrigid material such as vegetation, riprap, or artificial fibrous material. Design charts of d_{max} versus channel slope S_o are given for particular linings and soil erodability. To provide a method to determine the stability of grass linings which is compatible with the d_{max} approach, Normann converted the Maximum Permissible Velocities listed in Table 5 to values for Maximum Permissible Depth. For a series of slopes, he found the permissible velocity, then using published n - vR curves, found n and R to match n versus VR. Next, he set $d_{max} = R$ and plotted d_{max} versus slope for various types of vegetation.

Equivalent stone size. Parsons (1963) introduced the notion of an equivalent stone size to describe the resistance of vegetation to destruction by

Table 5
Permissible Velocities for Channels Lined With Vegetation[1] (values apply to average, uniform stands of each type of cover (from Palmer 1945))

Cover	Slope Range, Percent	Permissible Velocity	
		Erosion Resistant Soils, mps	Easily Eroded Soils, mps
Bermuda Grass	0-5	2.4	1.8
	5-10	2.1	1.5
	Over 10	1.8	1.2
Buffalo Grass	0-5	2.1	1.5
Kentucky Bluegrass	5-10	1.8	1.2
Smooth Brome	Over 10	1.5	1.0
Blue Grama	0-5[2]	1.5	1.2
Grass Mixture	5-10	1.2	1.0
Lespedeze Sericea	0-5[3]	1.1	0.8
Weeping Lovegrass			
Yellow Bluestem			
Kudzu	0-5[4]	1.1	0.8
Alfalfa			
Crabgrass			
Common Lespedeza[5]			
Sudangrass[5]			

[1] Use velocities exceeding 1.5 ft per second only where good covers and proper maintenance can be obtained.
[2] Do not use on slopes steeper than 10 percent except for side slopes in a combination channel.
[3] Do not use on slopes steeper than 5 percent except for side slopes in a combination channel.
[4] Use on slopes steeper than 5 percent is not recommended.
[5] Annuals—used on mild slopes or as temporary protection until permanent covers are established.

flowing water. Using Ree and Palmer's (1949) tabulation of allowable velocities, slopes and hydraulic radii, Parsons computed the stone sizes required to give the same bank protection. The equivalent sizes are reproduced in Table 6. This approach can give the designer familiar with the capability of stone protection an appreciation of the protective capabilities of a vegetative liner. It also permits a ready comparison of costs.

Table 6
Equivalent Stone Size for Bermuda Grass Linings (from Parsons 1963)

Condition of Bermuda Grass	Allowable Shear Stress N/sq m	Equivalent Stone Diameter cm
Fair stand, short, dormant[1]	43	5.1
Good stand, kept short, dormant	53	5.1
Good stand, long, dormant[2]	134	14.0
Excellent stand, kept short, green	129	14.0
Good stand, long, green	153	16.5

[1] Less than 12.7 cm high.
[2] Greater than 20 cm high.

Permissible tractive force: Because the actual removal of soil particles occurs when the force exerted on the particle exceeds the force resisting movement, basing the stability criteria on local boundary conditions is appropriate. Using a tractive force approach for this makes more sense than the permissible velocity approach because relating local velocity to average velocity is difficult. However, for a vegetative-lined channel, the application of the tractive force approach becomes difficult.

Because the drag exerted on the vegetation by the flowing water is proportional to the square of the shear velocity for turbulent flow, much of the fluid shear is transferred to the vegetation at the tips where the velocity is greatest. As the velocity is greatly reduced at lower levels in the vegetation, the amount of shear transferred by the fluid towards the bed is greatly reduced; if the vegetation is tall and stiff, a layer of virtually zero-velocity gradient will exist.

As a result, the only shear acting on the soil is that required to reduce the residual velocity to zero. Temple (1980) defines the effective shear stress at the soil-water interface τ_e as:

$$\tau_e = \rho g y_n S[(1 - C_F)(\frac{n_s}{n})^2]$$

where

y_n = depth of flow

C_F = an empirical parameter describing potential of vegetative cover to dissipate turbulent eddies near the bed

n_s = Manning's n associated with bare soil

n = reach-wise Manning's n

The other parameters are as previously defined.

Thus, for a design problem, this equation can be used to determine the effective shear on the soil, and a check can be made as to whether the allowable tractive force for the soil is exceeded. Temple (1980) has provided a table indicating values of C_F for various grasses.

Hydrologic Consequences of Riparian Vegetation Losses

Loss of riparian vegetation is a primary cause of altered stream morphology (Rosgen 1995) and reduces the capacity of riparian areas to attenuate floods. Once the riparian vegetation is lost, a predictable sequence of events occurs that degrades the stream structure and quality. The sequence of vegetation and hydrologic changes in response to grazing include the following (from Kovalchik and Elmore 1992):

a. Soil compaction, lower soil infiltration rates, and increased surface erosion.

b. Accelerated loss of streamside and in-stream cover with increasing bank streambed erosion.

c. Increased stream capacity with less dissipation of flood energy over the floodplain.

d. Straightening of the stream channel resulting in higher water velocity, especially at headcuts and cut meanders.

e. Increased peak flow and lower summer flow.

f. Increased flood energy causing either downcutting or (if bedrock is near the surface) braiding.

g. Lowered floodplain water tables and reduced availability of soil moisture.

h. Increased silt deposition on spawning gravels and invertebrate food production areas.

i. Increased water temperatures with loss of overhanging vegetation.

Vegetation is removed from riparian areas for many reasons. Intensive grazing of riparian areas can lead to total removal of riparian vegetation and is the primary reason for the extensive damage of western riparian systems (Chaney, Elmore, and Platts 1990). Plowing for crops to the edge of streambanks removes permanent vegetation and the associated root systems that bind bank materials. Many miles of western riparian vegetation have been destroyed to eliminate the transpirational water losses in this arid region. Riparian vegetation is often removed along streams and rivers managed for flood flow conveyance with the objective of reducing resistance to flow and increasing flow capacity (U.S. Department of Agriculture Soil Conservation Service 1994). Channelization reduces the length of riparian systems and increases the slope of the stream (Brooker 1985). This reduces the capacity of the remaining riparian vegetation to stabilize banks by increasing the stress to which the vegetation is subjected with increased flow velocities.

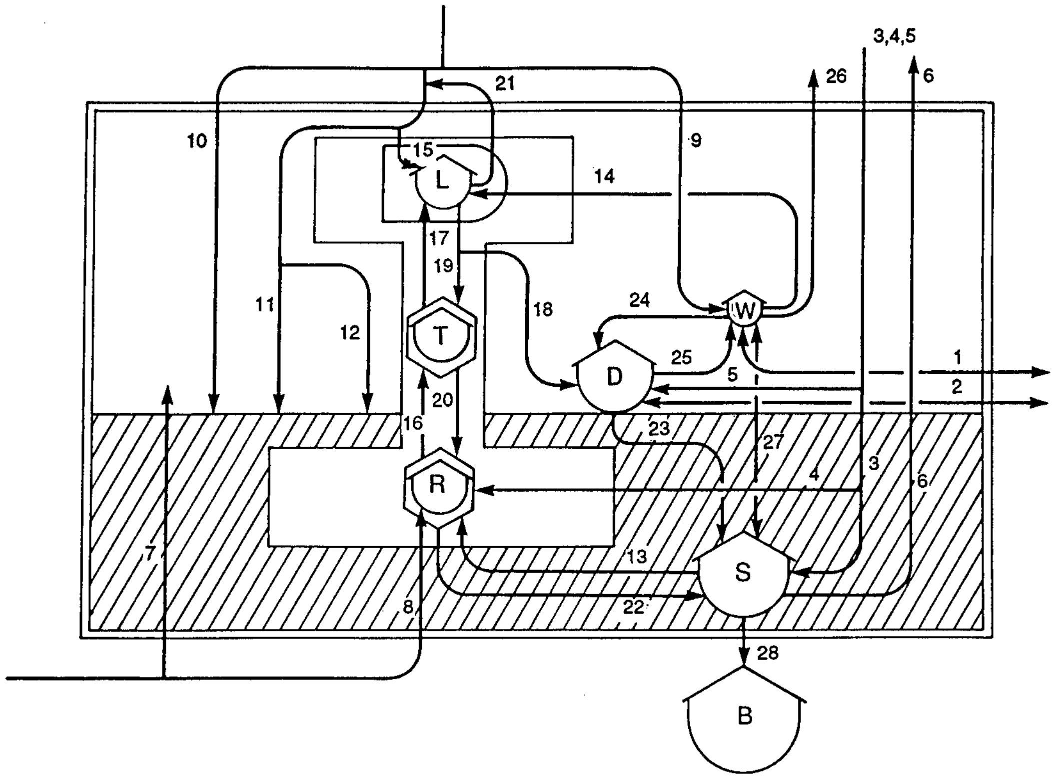
Streambank stability can be reduced indirectly through lowered groundwater tables and the consequent loss of riparian vegetation. Changes in riparian vegetation with lowered water tables due to climatic changes, changes in stream morphology, and agricultural uses of water have been noted in the west since the early 1800s (Bryan 1928). Groeneveld and Griepentrog (1985) cite studies of riparian vegetation losses along areas of the Carmel River in California where groundwater levels were lowered 2 m near wells. Regardless of the cause of groundwater level reductions, riparian vegetation is lost and cannot be replaced by vegetation effective at stabilizing banks.

3 Water Quality Functions of Riparian Vegetation

Riparian vegetation plays a vital role in the water quality functions of riverine systems. Due to their landscape position, riparian areas intercept overland and groundwater flow from adjacent uplands as well as overbank flow from rivers. They are buffers where materials and energy from broad areas and diffuse sources converge. Floodplains control large exchanges of sediments, organic matter, and nutrients among these ecosystems and regulate their dynamics. In addition, riparian vegetation influences other biologically important water quality parameters such as dissolved oxygen and temperature. The type and amount of vegetation within riparian areas have a profound influence on the processes that affect water quality.

The quality of water flowing through riparian areas is changed by the reduced velocity and increased contact with soils and vegetation relative to in-channel flows. There is a flux of material that often results in improved water quality (Johnston 1991). The pathways along which materials move in riparian ecosystems are complex and highly interrelated (Figure 22). Water clarity is generally increased as suspended sediments settle out and become incorporated into sediments. Dissolved materials such as nutrients or toxins can adsorb to soil particles or be taken up by vegetation.

Hammer (1992) described the importance of these processes for the Paraguay River in South America. A broad, heavily vegetated floodplain known as the Pantanal buffers the Paraguay River from many of its tributaries. In addition to untreated sewage and extremely high sediment loads from timber clearing and agricultural practices, these tributaries have high loads of industrial and mining pollution. For example, one iron ore mill discharges 4.8 kg of detergent per day used to wash ore stacks into the Rio Correntes; gold miners discharge 36,000 ℓ/day of organic waste into rivers draining the northern plateau of Brazil. The combined impacts of these pollutants on the receiving rivers have been devastating. Amazingly, however, the concentrations of these pollutants are reduced to innocuous levels by the Pantanal before they drain into the Paraguay River. The role that riparian vegetation plays in improving the water quality of this system is but one example of its importance as a component to minimize effects of flood control projects.



Storages: L = above-ground shoots or leaves

T = trunks and branches, perennial above-ground storage

R = roots and rhizomes

W = dissolved and suspended particulates in surface water

D = litter or detritus

S = near-surface sediments

B = deep sediments essentially removed from internal cycling

Flows: 1 and 2 are exchanges of dissolved and particulate materials with adjacent waters; 3-5 are nitrogen fixation by sediments, rhizosphere microflora, and litter; 6 is denitrification by sediments (N_2 and N_2O); 7 and 8 are ground-water inputs to surface water and roots; 9 is atmospheric deposition on water; 10 is on land; 11 and 12 are aqueous deposition from the canopy and in stemflow; 13 is uptake by roots; 14 is foliar uptake from surface water; 15 is uptake from rainfall; 16 and 17 are translocations from roots through trunks and stems to leaves; 18 is the production of litter; 19 and 20 are the readsorption of materials from leaves through trunks and stems to roots and rhizomes; 21 is leaching from leaves; 22 is death or sloughing of root material; 23 is incorporation of litter into sediments or peat; 24 is uptake by decomposing litter; 25 is release from decomposing litter; 26 is volitization of ammonia; 27 is sediment-water exchange; 28 is long-term burial in sediments.

Figure 22. Simplified general model of major flows and storages of materials through ecosystems that influence the quality of adjacent waters (after Nixon and Lee 1986)

The removal of suspended and dissolved material can be offset, however, by the natural influx of materials from the riparian ecosystem into the water (Figure 22). Plants contribute particulate and dissolved organic matter that is important for downstream aquatic ecosystems, but color and turbidity are increased. Degradation of litter releases minerals into the water and sediments that were bound in the organic matter resulting in a net increase in dissolved matter export. The effectiveness of riparian areas in removal of particulate and dissolved material from water depends on many factors including residence duration, season, and depth of inundation.

Water carries materials through ecosystems in dissolved and particulate form. Dissolved materials occur in both surface and subsurface water, while particulate matter is primarily restricted to surface drainage. Bormann, Likens, and Eaton (1969) demonstrated that concentrations of dissolved materials are relatively constant over a range of flow rates, while particulate matter increases with flow rates (Figure 23). Annual losses of dissolved substances, therefore, are dependent upon the total volume of liquid water passing through the ecosystem. Annual losses of particulate matter from an ecosystem, however, are primarily a function of discharge rate and erodibility rather than total volume. Consequently, changes within an ecosystem in the relative amounts of surface and subsurface water shift the relative importance of particulate and solution removal.

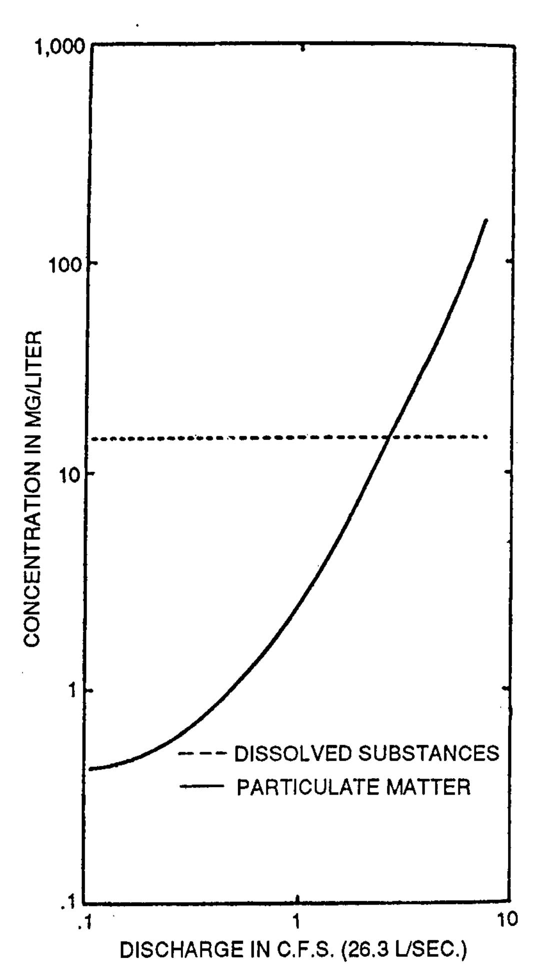


Figure 23. Curves showing the relationship of the concentration of dissolved substances and particulate matter to flow rate in a mature northern hardwood forest ecosystem (after Bormann, Likens, and Eaton 1969) (© 1969 AIBS.)

Water quality functions performed in riparian ecosystems are dominated by particulate removal, because the hydrology is dominated by surface flow and erosion is a natural source of particulates. Riparian corridors differ in their particle retention effectiveness, depending largely on roughness and the capability to trap materials. Plant stems, woody debris, root mounds from fallen trees, and leaf litter are the primary features that contribute to ground surface roughness in riparian areas. Vegetative cover in riparian areas reduces sediment inputs into streams by reducing potential soil erosion. As organic and mineral sediments are trapped, a great deal of dissolved materials in surface water can also be removed from the water column by adsorption to the particles. In addition to trapping sediments, plants also reduce concentrations of dissolved materials in surface and subsurface water by taking up nutrients and incorporating them into plant matter.

Sediment Trapping

Sediment deposition in riparian corridors occurs when flow velocity and energy of sediment-laden water is reduced and sediments drop out of suspension. Surface water can carry sediments to riparian areas from upstream sources during overbank events as well as runoff from adjacent uplands (Hupp, Woodside, and Yanosky 1993). The linear nature of riparian vegetation acts as a buffer strip between upland sediment sources and aquatic systems to trap sediments. This is a particularly important function in agricultural watersheds (Lowrance et al. 1984). Both upland and wetland portions of riparian corridors are capable of filtering surface water runoff from adjacent uplands. As a consequence of the direct relationship between residence time and sedimentation rates (Hupp and Bazemore 1993), however, riparian wetlands are more effective than uplands in reducing suspended sediments in floodwater. The primary points of sedimentation from floodwater within riparian corridors are point bars within the channel, natural levees, and depressions within the floodplain where flood waters are trapped.

Rates of deposition in riparian areas are related to stream gradient, stream power, percent wetland, hydroperiod, and land use (Hupp, Woodside, and Yanosky 1993). Mean rates of deposition in floodplains range from 0.07 to 2.62 cm/year (Johnston 1991; Hupp and Bazemore 1993; Hupp, Woodside, and Yanosky 1993). Highest rates of deposition were noted on levees (2.62 cm/year) and in swamps and sloughs (0.2 to 0.34 cm/year). Significant portions of sediment inputs into streams are stored in riparian wetlands. In watersheds ranging from 300 to 2,000 km^2, riparian wetlands stored from 33 to 91 percent of sediment inputs (Johnston 1991).

Amount of deposition is also related to the river stage. Kleiss et al. (1989) compared daily water quality measurements at gauges upstream and downstream of a large and intact bottomland hardwood swamp along the Cache River, Arkansas, for 1 year (Figure 24). They found that suspended sediment concentrations increased during in-bank flow periods; suspended sediment concentrations decreased during all overbank flow events. Greatest decreases

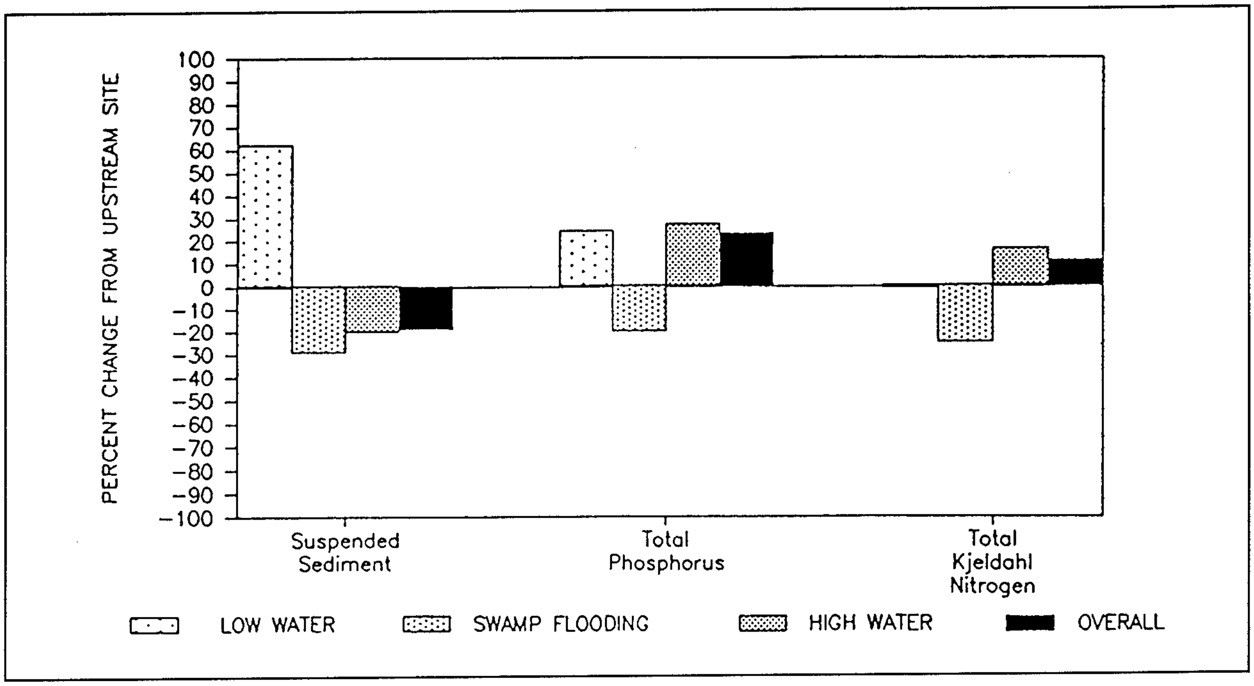


Figure 24. Percent difference in chemical loadings between the upstream and downstream sites on the Cache River (Negative values indicate wetland retention, while positive values indicate wetland export (after Kleiss et al. 1989))

were found during periods when only low swamps were flooded. High-water events that flooded the entire floodplain also resulted in decreased suspended solid concentrations; however, the reductions were less on a per hectare basis than for the swamps during lower flows.

The primary effect of vegetation on sediment trapping is to increase resistance to flow (see Chapter 1). Vegetation is most effective at increasing sedimentation of large silt and sands in floodwater, since fine silt and clays have long settling times and are readily resuspended by water movement. Silt and clays settle out of still water in depressions where vegetation has little effect other than to minimize wind movement of the water surface. Sediments in surface runoff from adjacent uplands are filtered out through stems, coarse woody debris, and leaf litter as it passes through the riparian vegetation buffer.

Plant stems present resistance to flow that is proportional to the stem cross-sectional area. In general, the greater the stem size and density, the greater the resistance to flow (Li and Shen 1975; Petryk and Bosmajian 1975). Too sparse stems have little effect on flow velocity. Too dense vegetation, however, does not necessarily proportionately or uniformly reduce flows. Very dense stems usually result from multistemmed woody individuals such as shrubs or tussuck-forming grasses or other herbaceous species (e.g., cattail, cordgrass). These clumped stems often collect organic and mineral matter around their bases, forming dense, raised mounds. Water does not easily flow through these mounds and thus tends to flow around the mounds (Kadlec

1990). The water is channelized; the cross-sectional area of the flooded area is less than predicted for shallow floods based on the stem cross-sectional area alone. Sedimentation does not occur uniformly throughout the flooded area. Total sedimentation in areas with mounded vegetation actually may be reduced relative to areas with uniform spacing of equal stem density due to flow velocity maintained in the channels.

Flow patterns around riparian vegetation are also affected by the structural rigidity of the plants (Rahmeyer, Werth, and Cleere 1994). If stems are uniformly distributed and rigid, flow velocity is uniformly reduced and sedimentation is evenly distributed. If, however, stems are deformed by flow, erosion, and sediment, transport may be increased under the bent crowns of the vegetation (Figure 19).

Dissolved Material Retention and Removal

Dissolved materials such as nutrients and metals are removed from surface and subsurface water by several mechanisms (Figure 21). The most effective removal mechanism, particularly for phosphorus (P), is adsorption to mineral and organic particulates. The particles fall out of suspension and become buried, removing the materials from further cycling. Some nutrients such as nitrogen are lost to the atmosphere as gases released from anaerobic microbial processes in wetlands. Plants contribute to these mechanisms and also take up nutrients that become incorporated into leaves, stems, and roots. These mechanisms have been thoroughly reviewed by Nixon and Lee (1986) and Johnston (1991).

Peterjohn and Correll (1984) demonstrated the effectiveness of riparian forests in Maryland in reducing carbon, nitrogen (N), and P concentrations in surface and subsurface water. From the surface runoff that had transited about 50 m of riparian forest, an estimated 4.1 mg of particulates, 11 kg of particulate organic-N, 0.83 kg of ammonium-N, 2.7 kg of nitrate-N, and 3.0 kg of total particulate-P per hectare of riparian forest were removed in 1 year. In addition, an estimated removal of 45 $kg \cdot ha^{-1} \cdot year^{-1}$ occurred in subsurface flow as it moved through the riparian zone. Riparian vegetation contributed to deposition primarily by creating roughness on the ground surface, thereby slowing flows and trapping the materials. In addition, although most of the N and P deposition was probably associated with mineral sediments (Johnston 1991), a portion of the deposited nutrients were components of or adsorbed to plant organic matter.

Atmospheric losses of N can be a significant removal mechanism in riparian areas, particularly in wetlands (Mitsch and Gosselink 1993; Johnston 1991). Nitrogen is an important component of water quality, because it is one of the major nutrients required by plants and animals and is often in short supply. High N concentrations in aquatic systems result in rapid growth of algae and other organisms that use up the dissolved oxygen. Without oxygen, fish and most other organisms die. This condition is called eutrophication.

Riparian wetlands remove N from water by several microbial processes called denitrification that take place in the absence of oxygen. These processes require organic matter. Riparian vegetation is very productive and produces large amounts of organic matter that serves as a substrate for microbial processing of N. Soils of wetland riparian ecosystems have ideal conditions for denitrification: high organic matter from forest litter, seasonal waterlogging, and large inputs of N. Denitrification outputs alone were enough to remove all the N inputs from upland agricultural fields to the riparian zones in a Georgia watershed (Lowrance et al. 1984).

The flux of nutrients into, within, and out of plants is very complex, involving a number of pathways (Figure 21). Plant uptake is the net annual flux of nutrients into plant roots (fluxes 8 and 13). Once taken up, nutrients may remain in the roots or be translocated upward into aboveground woody tissues (flux 16) and/or herbaceous tissues (flux 17). Leaching, the removal of soluble nutrients from living and standing dead plants by precipitation, can return substantial amounts of nutrients to wetland surface waters (flux 21). As tissues senesce, nutrients may be translocated downward (fluxes 19 and 20), or leave the plant as litter fall (flux 18) or root sloughing (flux 22) (Johnston 1991).

Net uptake of dissolved nutrients by mature vegetation comprises a relatively small portion of nutrient removal in riparian areas. In herbaceous wetland plants, net annual retention of nutrients is equal to annual uptake minus losses from leaching and litter fall. While it is often assumed that the nutrient standing stocks represent annual uptake in herbaceous wetland vegetation, a large proportion of nutrients in aboveground biomass of many wetland perennials is translocated upward from belowground storage structures in the spring and downward from the shoots in the fall. This internal recycling of nutrients helps plants conserve nutrients, but reduces their net uptake of nutrients. Cumulative standing stocks of nutrients stored in wood can be high due to their slow turnover rate, but annual additions of nutrients to woody tissues are small, averaging only 0.05 g $P \cdot m^{-2} \cdot year^{-1}$. This is comparable with the amount lost annually from leaching (Johnston 1991). Net uptake of dissolved nutrients is only significant in riparian areas, therefore, where plant biomass is increasing (e.g., following colonization of a newly created site) or where harvesting removes significant amounts of stored nutrients.

Carbon Production and Export

One of the most widely recognized functions of riparian vegetation is the contribution of carbon to downstream aquatic habitats (Vannote et al. 1980; Brinson et al. 1981). Carbon is a basic component of the sugars produced by plants during photosynthesis. Carbon is assimilated from the atmosphere by plants and made available as food to other organisms in the basic form of sugars. Animals eat the plants or microbes decompose the litter, transferring the energy contained in the sugars up the food chain. Litter and leachates from riparian vegetation is flushed into downstream aquatic ecosystems by floodwater and groundwater, thereby supplying energy and supporting the organisms in those areas. Measured litter fall rates for riparian forests range from 386-977 $g \cdot m^{-2} \cdot year^{-1}$ (Elder and Cairns 1982). Although a large portion of this material is consumed in the floodplain, a large amount is available as a vital source of energy for downstream systems.

Transfer of particulate and most dissolved carbon from the floodplain to the river system is seasonal depending on timing and energy of flowing water. Kleiss et al. (1989) measured the percent difference of total and dissolved organic carbon in river water between sites upstream and downstream of a large riparian forest on the Cache River, Arkansas (Figure 25). Organic carbon was exported from the riparian forest under most conditions. During low-water conditions, overhanging vegetation constantly contributed small amounts of leachates and leaf and stem matter, increasing the organic carbon concentration of river water that drained from agricultural fields. At flow levels adequate to enter the floodplain, suspended materials settle out on the forest floor, decreasing organic carbon content of the water. High flows resuspend the material, exporting significantly more organic carbon than entered the forest from upstream.

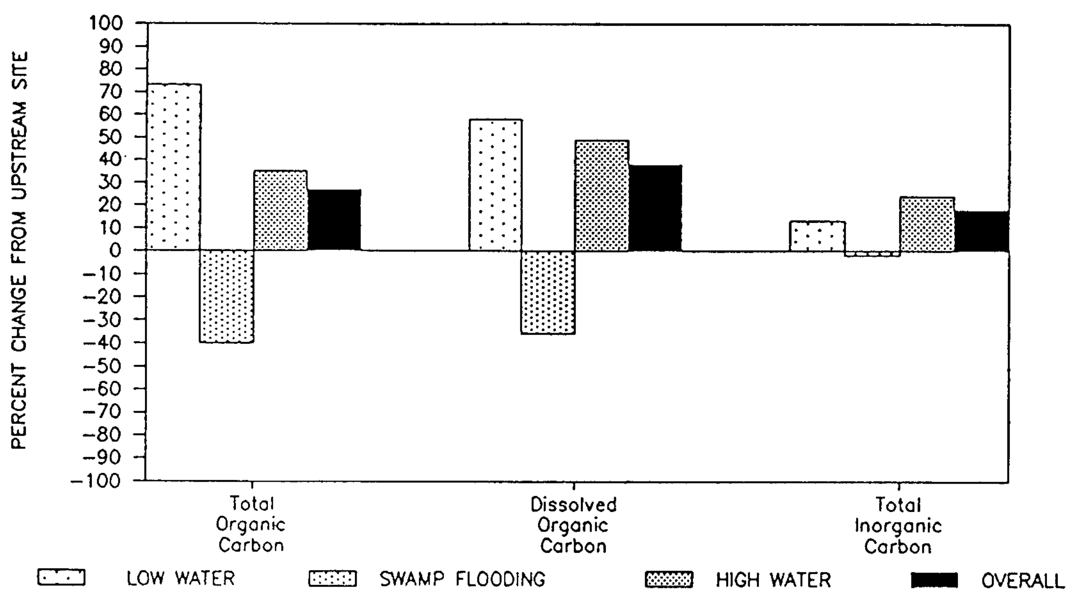


Figure 25. Percent difference of carbon constituents between upstream and downstream sites on the Cache River, Arkansas

Alteration of Other Water Quality Characteristics

In addition to flux of material, riparian vegetation also affects water temperature that determines dissolved oxygen concentrations and freezing.

Dissolved oxygen is critical for aquatic life. High water temperatures are stressful for fish and aquatic invertebrates because oxygen is forced out of solution. Low dissolved oxygen also affects the oxidation state and solubility of many nutrients and metals which alters the bioavailability of these materials. In addition, aquatic areas adjacent to vegetated shorelines often remain ice free longer than along unvegetated shorelines. The presence of the vegetation apparently increases the humidity and heat-holding capacity of the air. The increased duration of the ice-free condition allows longer access to water and increased winter dissolved-oxygen concentrations in the water. Effects of riparian vegetation on water temperature and dissolved oxygen are discussed more fully in Chapter 4.

Impacts of Riparian Vegetation Losses on Water Quality

Riparian vegetation is a primary factor for the protection of water quality from nonpoint sources of pollution. By virtue of its position along riverine aquatic systems, riparian vegetation has the potential to modify the water quality of all surface flows into streams and rivers (National Research Council 1992).

Loss or degradation of riparian areas has an incalculable impact on the nation's water quality. The environmental stress and altered characteristics and functions of aquatic ecosystems are reflected in the status of fisheries, as reported by the U.S. Fish and Wildlife Service (Judy et al. 1984). Of the 666,000 miles[1] of perennial U.S. streams surveyed, more than 40 percent of the stream miles were adversely affected by turbidity, 32 percent by elevated temperature, 21 percent by excess nutrients, and 11 percent by low dissolved oxygen. The nonpoint sources of pollution and their percentage contribution to total impacted river miles included agriculture (64 percent), mining (9 percent), silviculture (6 percent), urban runoff (5 percent), hydromodification (4 percent), construction (2 percent), and land disposal (1 percent) (Association of State and Interstate Water Pollution Control Administrators 1984).

Improvement of water quality undoubtedly depends on land-use practices that minimize pollution runoff. Maintenance of riparian areas is particularly critical, however, in areas of significant nonpoint pollution sources. The Clean Water Act of 1977 recognized the need to consider instream flows, nonpoint source pollution, riparian habitat, and wetlands as part of a watershed-scale program for improvement of the nation's waters (National Research Council 1992).

[1] To convert miles (U.S. statute) to kilometers, multiply by 1.609347.

4 Life Support Functions of Riparian Vegetation

Riparian areas in the United States provide wildlife benefits far out of proportion to their extent on the landscape. This is particularly true in the arid West where riparian corridors occupy <1 percent of the land surface (Brinson et al. 1981) and yet play a critical role in maintaining regional biological diversity (Hubbard 1977; Johnson, Haight, and Simpson 1977). For a given number of acres of habitat, riparian systems in the Southwest support higher population densities of breeding birds than any other forest habitat type (Carothers, Johnson, and Aitchison 1974). Bottomland forests of the Southeast also support a wide variety of wildlife species and population densities not found in other habitats (Dickson 1978). Many aquatic species use riparian areas during flooding (Mitsch and Gosselink 1986), and some species move into riparian habitats from uplands during dry periods. In landscapes extensively altered by man, such as by agriculture and urbanization, riparian zones are critical refuges and movement corridors for wildlife.

Wildlife Use of Vegetation

Food, cover, water, and space are the critical environmental resources necessary for the survival and maintenance of healthy wildlife populations in any type of habitat. The presence of appropriate vegetation and its spatial arrangement are the primary elements responsible for meeting the food, cover, and space requirements of a wildlife species.

Vegetation supplies the energy source for the operation and maintenance of food chains. Terrestrial herbivores depend directly upon plant foliage, stems, and fruit for food. Omnivorous animals, such as the red fox, utilize plant parts as major dietary items during spring and summer and as supplementary items during seasons of decreased prey availability. Insectivores (e.g., bats and many birds) feed upon the insects associated with plant communities; and carnivores at the top of food chains, such as the cats (*Felis* spp.), are indirectly dependent upon the presence of appropriate vegetation for their prey species.

All structural levels of vegetation are food sources for terrestrial wildlife. Smaller trees, shrubs, and woody vines provide browse in the form of leaves, twigs, and young stems; mature trees, shrubs, and vines produce many kinds of fruit, such as acorns and berries, eaten by wildlife. Herbaceous plants include the grasses, grasslike plants (rushes and sedges), and forbs (broad-leaved flowering plants) that are important food sources for a wide range of herbivores from small mammals such as mice to large mammals such as elk. Mushrooms and lichens are also utilized by herbivores. It is essential that the vegetation used as wildlife food sources not only be available but also be of sufficient palatability, digestibility, and nutritive quality to provide energy levels necessary to sustain a given wildlife population.

Cover is the physical habitat or landscape feature that provides an animal protection from hazards and predators (Patton 1992). Cover is generally defined by the function it serves, i.e., protective, escape, feeding, breeding/nesting, resting, and roosting cover. Vegetation is the primary component of cover in most wildlife habitats and usually serves more than one function. For example, woody vegetation provides nesting, denning, resting, and roosting cover for a wide variety of birds and mammals, as well as breeding and protective cover for amphibians and reptiles; herbaceous vegetation may be used for nesting and protective cover by terrestrial ground and marsh dwellers. An animal frequently uses a particular type or structural level of vegetation for more than one life activity; e.g., white-tailed deer may forage, hide their fawns, and rest in the dense cover of a bottomland hardwood forest.

Vegetation offers protection in some form to virtually all wildlife species. Protective cover may be used for hiding, escape through vegetative corridors in open or semiopen habitats, or insulation against the weather (thermal cover). Herbaceous vegetation in edges around fields or along ditch banks in agricultural lands serves as escape cover for amphibians, reptiles, ground-dwelling birds, and small mammals. Forests provide not only escape cover but also thermal cover for large ungulates. As defined by Thomas, Maser, and Rodiek (1980), thermal cover for elk in Oregon and Washington is any stand of coniferous trees 12 m (40 ft) or more in height with an average canopy closure exceeding 70 percent; and for deer, coniferous trees either pole or sapling size, at least 1.5 m (5 ft) tall with 75-percent canopy closure.

The spatial arrangement of food and cover is a critical determinant of habitat suitability for wildlife. A species seeking food and cover in different vegetation types is benefitted if those types are in juxtaposition, i.e., close enough together to reduce the energy requirements and natural hazards associated with the search for food away from cover. For example, wild turkeys or white-tailed deer grazing in an open meadow need forest cover or tall brush nearby to escape from potential predators.

Riparian Vegetation as Wildlife Habitat

Riparian vegetation provides year-round habitat for many wildlife species, as well as breeding sites, wintering areas, and stop-over habitats for a wide variety of migratory birds. Riparian vegetation and wildlife communities have been most intensively studied in western arid regions and the southeastern floodplain forests. Therefore, the greater portion of this section will emphasize work done in these regions.

Species richness and diversity

Riparian ecosystems are valuable habitats for breeding birds. Brinson et al. (1981) tabulated breeding bird census data from various studies and showed that individual stands of riparian woodland usually have 10 to 50 breeding bird species, with most having between 20 and 34. Population densities of birds breeding in riparian areas generally fall between 40 and 900 pairs per 40 ha, but most often are between 150 and 550 pairs per 40 ha. The species richness of bird communities in riparian ecosystems during winter is comparable with that in summer, and the abundance of winter residents is generally equal to or greater than that of summer birds (Ryder and Ryder 1978, 1979). The number of species found in a riparian ecosystem during spring and fall is increased, because it includes departing and incoming seasonal residents as well as year-round residents and transient species (Parnell 1969).

Studies compiled by Brinson et al. (1981) showed that mammal species in riparian woodlands usually range from 5 to 30. A typical riparian community may include several furbearers, a few small and medium-sized mammals, and one or more large mammals. Although some of these species also inhabit nonriparian areas, many depend on or prefer riparian ecosystems.

The diversity of amphibians and reptiles in riparian ecosystems is probably comparable with that of mammals, except in the southeastern floodplain forests, which contain a large number of herpetofaunal species (Brinson et al. 1981). Many species of amphibians are specifically adapted and restricted to riparian environments (Hairston 1949; Organ 1961; Tilley 1973; Fredrickson 1979; Wharton 1978; Krzysik 1979). Reptiles are less dependent on water, but the alligator and some turtles and snakes prefer riparian and wetland habitats.

Because riparian ecosystems are suitable for many upland as well as riparian species, a majority of the species in any given region may be found there. For example, riparian systems have been found to harbor 59 percent of the bird species in Louisiana and 82 percent of the mammals in Mississippi (Glasgow and Noble 1971), 97 percent of the vertebrates in the South Platte Valley in Colorado (Fitzgerald 1978), 82 percent of the mammals and 49 percent of the herpetofauna in south-central Oklahoma (Barclay 1980), and 75 percent of the breeding birds in the San Juan Valley of New Mexico (Schmitt 1976).

Dependence on riparian ecosystems is based on requirements for open water and/or riparian vegetation. Although certain groups of wildlife tend to predominate in undisturbed riparian ecosystems across the United States, the presence or absence of particular species is often determined by specific habitat variables, geographic location, or site specific alterations from human disturbance (Brinson et al. 1981).

Riparian vegetation characteristics

Various authors have suggested ecological attributes that contribute to the attractiveness of riparian systems as fish and wildlife habitat (Wauer 1977; Odum 1978; Thomas, Maser, and Rodiek 1980; Brinson et al. 1981; Wilkinson et al. 1987). These include the following:

a. Juxtaposition of the three critical resources: food, cover, and water.

b. Increased availability of water, in combination with deep soils, that promotes a rich and structurally diverse plant community, which in turn provides habitat for a diversity of animals.

c. Predominance of woody plant communities, which are critical to wildlife populations where extensive forests are lacking.

d. Unique riparian plant communities, such as wet meadows and moist deciduous woodlands, that increase the diversity and interspersion of habitats.

e. Elongated "edges" formed by riparian corridors that attract edge specialists as well as users of surrounding habitats.

f. Migration routes for birds and many large mammals that use different summer and winter ranges.

g. Corridors for movement and dispersal through landscapes altered by man.

h. Shady and moist microclimates that are critical to many species and may be lacking in the surrounding communities.

i. Surface water that provides essential breeding habitat for amphibians and foraging areas for many other wildlife species.

j. Input of nutrients and organic matter from the river that promotes highly productive food chains and diverse communities of consumers.

Vegetation at its various structural levels is the common element of these ecological attributes. Vegetation is the basis of food chains in riparian communities, and it provides the cover necessary for breeding and wintering habitats, edge interfaces, and corridors for movement and migration. Riparian areas are able to support dense growths of herbaceous shrub and forest vegetation, which is often interspersed with natural drainages, marshes, ponds, and brushland to provide suitable habitats for many species. Vegetation associated with streams and rivers has been referred to as the "aorta of an ecosystem" (Wilson 1979) because of its importance in perpetuating aquatic, fish, wildlife, forest, and rangeland resources. The major characteristics of riparian vegetation that contribute to the abundance and diversity of faunal communities are discussed below.

Spatial features. Numerous studies have demonstrated that complex habitats support more species than structurally simple habitats because more resource dimensions are available, and these can be exploited in more ways (MacArthur and MacArthur 1961; Pianka 1967; Recher 1969; Karr and Roth 1971; Rosenzweig 1973; Cody 1974; Cody 1981). The unique arrangement of riparian vegetation and other habitat features allows a greater complexity of habitat development.

Plant associations have diffuse edges. Riparian systems, at the interface between aquatic and terrestrial habitats, demonstrate the ecological principle of edge effect; i.e., the diversity and abundance of species tend to be greatest at the ecotone, or "edge" between two distinct ecotypes (Odum 1978). The close proximity of diverse structural features in a riparian ecosystem results in extensive edge and structurally heterogeneous wildlife habitats (Brinson et al. 1981). Both species density and diversity tend to be higher at the land-water ecotone than in adjacent uplands, especially in arid climates. Edges and their ecotones are usually richer in wildlife than adjoining areas because they harbor species from multiple ecotypes (Hardin 1975; Thomas, Maser, and Rodiek 1980). The interface between stream and woody plant communities contains many species (e.g., river otter, alligator, yellow-crowned night heron) that occur almost entirely in this zone (Brinson et al. 1981), and riparian-upland ecotones contain many upland and edge species (e.g., cottontail rabbit, canebrake rattlesnake, summer tanager) where woody riparian communities adjoin relatively open ecotypes such as rangeland, grassland, or farmland (Thomas, Maser, and Rodiek 1980).

The linear nature of riparian ecosystems along rivers creates distinct corridors, or pathways, for birds and mammals to use as migration and dispersal routes and as protective forested connectors between habitats (Brinson et al. 1981). Birds, bats, deer, elk, and small mammals are known to use these corridors, which provide the woody vegetation needed for food and cover by migrating and terrestrial species (Blair 1939; Rappole and Warner 1976; Stevens et al. 1977; Wauer 1977; Willson and Carothers 1979). The value of riparian corridors for animal movement is accentuated in arid regions (Wauer 1977) and in landscapes where upland habitats have been converted to other uses such as agriculture.

Woody vegetation. Woody plant communities are the predominant vegetation in riparian ecosystems and are particularly important in regions where the riparian zone is the only wooded habitat present, as in desert or heavily farmed regions (Brinson et al. 1981). Besides protective cover for wildlife species, woody plants contribute many structural components to wildlife habitat. Large living trees are used for nesting and roosting by birds such as the bald eagle and great blue heron, foraging by woodpeckers and smaller birds, perching by hawks and eagles, and denning by mammals such as squirrels and raccoons. Standing dead trees (snags) provide nest sites for cavity-nesting birds, dens for small and medium-sized mammals, and feeding and perch sites for many species, especially smaller birds. Fallen logs function as cover for snakes and many small invertebrates (e.g., snails and insects) and the amphibians and small reptiles (e.g., skinks and lizards) that feed upon them (Figure 26). Dead woody material partially submerged in water provides excellent habitat for aquatic species and amphibians (Maser et al. 1980).

Figure 26. Woody debris provides valuable wildlife habitat for reptiles and amphibians

Woody plants provide abundant and diverse food resources for wildlife species. A wide variety of both hard (e.g., acorns and nuts) and soft (e.g., berries) mast is produced by bottomland trees and shrubs to be readily consumed by birds and mammals. Browse is a major product of woody plant communities in the earlier stages of vegetational succession. Abundant insect populations associated with woody plants in wet environments are also sources of food for insectivorous fauna (Lochmiller 1979).

Detritus in riparian ecosystems is primarily the product of woody plant communities. Detritus is leaves and twigs in the form of coarse, fine, and dissolved particulate organic matter that has been enriched by bacterial and fungal activity (Wharton, Kitchens, and Sipe 1982). The food webs that originate in riparian ecosystems begin with the production of detritus, and the resulting altered organic matter not only supports a great diversity of fauna but is also exported by flowing water to downstream systems (Brinson et al. 1981; Wilkinson et al. 1987). A unique feature of riparian wetlands is that the detrital production supports both aquatic and terrestrial communities (Vannote et al. 1980; Brinson et al. 1981; Gregory et al. 1991). Riparian ecosystems provide a large organic export partly because of the large surface area of detritus that is exposed to river water during flooding (Brinson et al. 1981). Large woody material contributes energy to the adjacent stream and serves as an important source of structure for aquatic habitats (Sedell and Froggatt 1984; Sweeney 1993).

Vegetation type and structure. Preference for certain kinds of riparian vegetation is most prevalent among passerine birds. Hardwoods have been found to support a greater diversity of birds and higher breeding bird densities than coniferous forests (Thomas et al. 1975). In Louisiana and eastern Texas, species such as the yellow-billed cuckoo, tufted titmouse, Carolina wren, and northern cardinal were found to be prevalent in oak-gum swamps but not in tupelo swamps (Dickson 1978). Cottonwood and willow communities are preferred riparian bird habitats in the western states (Anderson, Higgins, and Ohmart 1977), whereas salt cedar appears to be used by only a few species (Anderson, Higgins, and Ohmart 1977; Cohan, Anderson, and Ohmart 1978).

Species composition of plant communities is important where there are clear differences in the food values of the various vegetation types (Brinson et al. 1981). For example, the presence of mast-producing trees in a bottomland hardwood forest is especially favorable for use by waterfowl, wild turkey, and mammals such as deer and squirrels, and various plant species may host different invertebrate populations that directly affect their value to many songbird species. However, riparian wildlife communities are generally influenced more by the structural form of vegetation than by species composition or riparian community type (Brinson et al. 1981). The type, size, and arrangement of canopy, shrub, and herbaceous vegetation basically determine the suitability of a site for wildlife. For example, most songbird species have specific requirements such as dense understory or closed canopy, deer require twigs within browsing height, and bald eagles need trees that can support large nests. The variety of wildlife habitats, especially for birds, is greatest in structurally diverse woodlands where all three vegetation layers (tree, shrub, and herbaceous) are present and distributed in patches throughout an area (Beidleman 1954; MacArthur and MacArthur 1961; Austin 1970; Glasgow and Noble 1971; Carothers, Johnson, and Aitchison 1974; Carothers and Johnson 1975; Whitmore 1975; Anderson and Ohmart 1977; Gaines 1977; Stevens et al. 1977; Dickson 1978).

Gill, DeGraaf, and Thomas (1974) found that vegetation structure was the primary habitat characteristic controlling bird density and diversity. A strong correlation was found to exist between breeding bird species diversity and foliage height diversity (variation in the height of foliage layers) (MacArthur and MacArthur 1961; Willson 1974), both of which increase through vegetational seral stages (Karr 1968; Shugart and James 1973). There is also a positive nonlinear correlation with percent vegetative cover, and the greatest increase in bird species diversity occurs where both shrubs and trees are present (Willson 1974). In forested wetlands, an increase in the number of small shrubs (1-4 m in height) was associated with an increase in both breeding bird density and species richness (Swift, Larson, and DeGraaf 1984), indicating that an increase in the structural heterogeneity of a forest probably increases the avian niches available (Roth 1976).

Riparian stand size and shape. The size (width and/or area) of a plant community has a direct relation to its ecological values, but standard dimensions have not been determined for the size of riparian stands needed to support maximum wildlife populations (Brinson et al. 1981). Even very narrow strips of riparian vegetation are important to instream communities and wildlife that inhabit shorelines; species such as the belted kingfisher and mink often establish territories in narrow riparian woodlands (Curtis and Ripley 1975). However, narrow woodland strips are unsuitable for animals requiring large tracts of forest, such as the black bear (Landers et al. 1979), osprey (Swenson 1979), and great blue heron (Scott 1980).

The area of riparian vegetation most heavily used by terrestrial wildlife is that within 200 m of a stream (Brinson et al. 1981). Many mammals, reptiles, and amphibians concentrate their activities within 60 m of water (Hairston 1949; Organ 1961; Tilley 1973; Krzysik 1979). Dickson and Huntley (1985) found that uncut hardwood stringers through young pine stands in east Texas contained resident populations of gray squirrels only if they were more than 50 m wide. Terrestrial small mammals (Dickson and Williamson 1988) and herpetofauna (Rudolph and Dickson 1990) are more abundant in narrow streamside (0 to 25 m) zones characterized by intact overstory and midstory, sparse shrub and herbaceous vegetation, and abundant leaf litter than in wider zones without this vegetation structure.

Although some avian species will move as much as 4 km from nesting to foraging areas (from sources compiled by Brinson et al. 1981), a 200-m-wide strip of riparian vegetation will accommodate the breeding territories of most songbirds (Stauffer and Best 1980). Minimum corridor widths for 20 species of birds in Iowa ranged from 10 to 200 m, with scarlet tanagers, American redstarts, and rufous-sided towhees requiring the widest corridors. Although Stauffer and Best (1980) found yellow-billed cuckoos in fairly narrow corridors, Gaines (1974) reported that cuckoos in California required riparian strips at least 100 m wide and 300 m long. Uncut hardwood strips within pine plantations in Virginia had to be at least 80 m wide to support the maximum number of bird species (Tassone 1981).

Keller, Robbins, and Hatfield (1993) counted birds in 117 wooded riparian corridors in the largely agricultural landscape of the Delmarva Peninsula in Maryland and Delaware. They found that the number of year-round resident bird species did not vary with riparian zone width, but that the number of neotropical migrant species increased with corridor width. Short-distance migrants declined slightly with increasing width. Corridors < 100 m wide were dominated by short-distance migrants, whereas those > 100 m wide supported more neotropical migrants, including several area-sensitive species such as Acadian flycatchers, wood thrushes, and Kentucky warblers.

Although they did not report corridor widths, Gutzwiller and Anderson (1987) determined critical sizes of riparian woodland fragments in Wyoming for various species. These included about 2 ha for red-headed woodpeckers, 6.8 ha for black-capped chickadees, and 15 ha for tree swallows. In desert areas of California, even fairly small (0.2 to 9.8 ha) riparian oases attracted large numbers (41 to 82 species) of breeding and migrating birds; however, only sites larger than 10 ha supported more than 100 species of birds (England, Foreman, and Laudenslayer 1984).

Habitat Values of Riparian Ecosystems

Southeastern floodplain forests

Lowland hardwood wetlands are distributed in the eastern United States on floodplains of the lower Mississippi River alluvial valley as far north as southern Illinois and western Kentucky, and along streams that drain into the Atlantic Ocean on the south Atlantic Coastal Plain and on the Atlantic Coastal Plain from Maryland to Florida (Taylor, Cardamone, and Mitsch 1990). These wetlands also radiate from the Mississippi Delta along rivers into Texas and Oklahoma (Fredrickson 1978). It has been estimated that approximately 13.2 million hectares (32.6 million acres) of lowland hardwood wetlands existed in the southeastern and south-central United States in 1980 (Abernethy and Turner 1987).

Plant and animal communities have characteristic distributions within the lowland hardwood wetland (bottomland hardwood forest) that is related to flooding duration, frequency, and depth (Fredrickson 1978). The entire bottomland, forested or not, over which flooding occurs is a functional part of this wetland system. There is a gradual change in topography and moisture gradient from a water body to an upland (Wharton, Kitchens, and Sipe 1982), and plant composition changes in a definite pattern along a continuum from the lowest to the highest sites (Fredrickson 1978). These changing levels have been described as Zones (I-V) with characteristic moisture regimes and typical plant (Table 7) species.

Table 7
Dominant Bottomland Hardwood Wetland Tree Species Associated With Different Hydrologic Regimes (Wharton, Kitchens, and Sipe 1982)

Zone	Moisture Regime	Typical Species
I	Permanently inundated	
II	Intermittently exposed—soil is saturated nearly permanently, except during extreme drought periods	Baldcypress Water tupelo
III	Semipermanently inundated or saturated—saturation typically exceeds 25 percent of the growing season	Overcup oak Water hickory Virginia sweetspire Black willow Buttonbush
IV	Seasonally inundated or saturated—typically saturated from 12.5 to 25 percent of the growing season.	Green ash Sweetgum Laurel oak American elm Stiff dogwood Possum haw Poison ivy
V	Temporarily inundated or saturated—typically saturated from 2 to 12.5 percent of the growing seasons	Loblolly pine Cherrybark oak River cane Swamp chesnut oak Paw paw

Floodplain forest zones have different values for the various faunal species in bottomland wildlife communities. Zone II harbors aquatic and semiaquatic species, whereas Zones IV and V have the greatest diversity and density of terrestrial fauna (Wharton et al. 1981). Semiaquatic species may follow the water's edge as it rises and falls. The distribution of some species extends through several zones (Figure 27), reflecting the abundance of food and the interspersion of habitats found in floodplain forests.

Species richness and diversity. Floodplain forests support an abundance and diversity of wildlife. Reviews on the fauna of bottomland hardwood forests are given by Fredrickson (1979); Brinson et al. (1981); Wharton et al. (1981); and Wharton, Kitchens, and Sipe (1982). The fauna of bottomland hardwood forests of Texas and Oklahoma is typical of those in southeastern floodplain forests.[1] Total numbers of vertebrate species that have been found in the bottomland hardwood forests of Texas and Oklahoma (Wilkinson et al. 1987) are 187 species of fish, 49 species of amphibians, 76 species of reptiles, 282 species of birds, and 61 species of mammals.

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1 Unpublished Presentation, 1986, J. Neal, Bottomland Hardwoods Workshop, Savannah, GA, January 13-17.

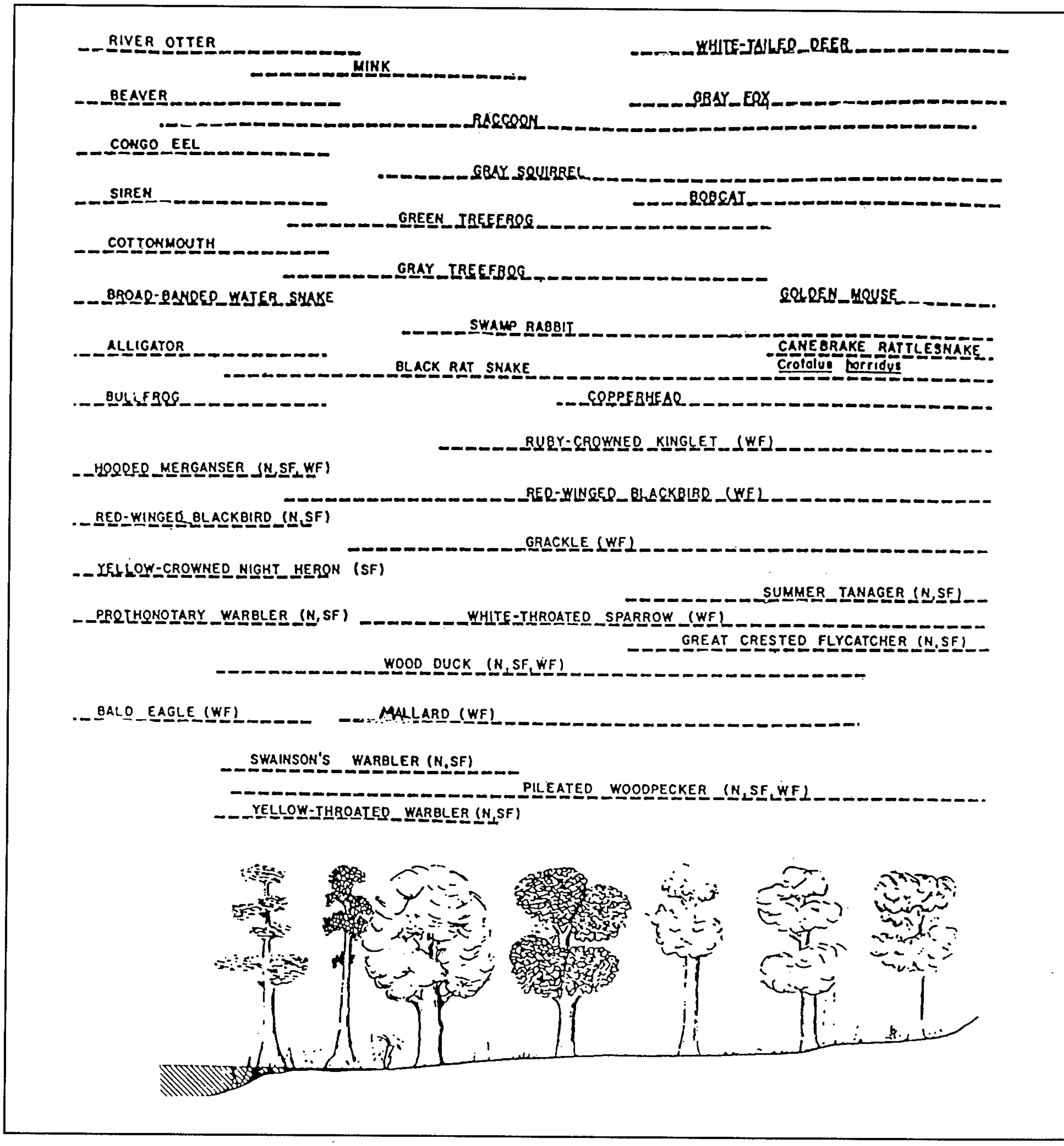

Figure 27. Distribution of common bird species along hydrologic gradients in bottomland hardwood forests (Fredrickson 1978)

A comprehensive discussion of the species that inhabit southeastern floodplain wetlands is not intended here because of the great numbers that use this environment, but abundance and dominant species will be pointed out for the major vertebrate groups.

Floodplain forests provide important habitat for colonial wading birds, raptors, woodpeckers, shorebirds, and passerine species (Wilkinson et al.

1987). These forests support higher densities of breeding birds than upland woodlands or herbaceous habitats in Iowa (Stauffer and Best 1980). In eastern Texas, studies during the breeding season showed that bottomland hardwood stands had higher bird density (1,050 individuals/km^2) than did pine stands (835/km^2) or pine-hardwood stands (422/km^2) (Anderson 1975). The density of breeding birds in mature bottomland hardwoods of Louisiana and eastern Texas was 2 to 4 times than that found in upland pine or pine/hardwood forests (Dickson 1978). Some species tend to be restricted to bottomland hardwood stands during the breeding season in the South; these include the red-shouldered hawk, yellow-billed cuckoo, Acadian flycatcher, prothonotary warbler, northern parula, American redstart, and Swainson's warbler (Curtis and Ripley 1975; Dickson 1978). Various species occupy different zones of the floodplain forest. The prothonotary warbler and Louisiana waterthrush seem to prefer Zone II. Along the Cache River in Arkansas, distributions of chimney swifts, prothonotary warblers, and great crested flycatchers were skewed toward the wetter zones, whereas summer tanagers, red-eyed vireos, and Swainson's thrushes were more abundant in the higher floodplain zones (Wakeley and Roberts 1996).

High bird densities also occur in mature bottomland hardwoods during the winter. Many songbirds that nest in widely dispersed populations on their northern breeding grounds concentrate in winter into the less extensive tracts of southern floodplain forests. An oak-gum-cypress bottomland in Mississippi supported 1,188 birds/km^2 (Ryder and Ryder 1978, 1979), and a bottomland area in Louisiana had winter populations that varied between 1,400 and 2,000 birds/km^2, approximately twice the breeding bird density in that area (Dickson 1978). The estimated winter bird population in eastern Texas was 1,168 birds/km^2 in bottomland hardwoods compared with 845/km^2 for pine and 672/km^2 for pine-hardwood stands (Anderson 1975).

Floodplain forests provide habitat for overwintering waterfowl; for example, the Cache River Basin in the lower Mississippi flyway harbors 250,000 overwintering mallards in addition to other waterfowl species (Hancock and Barkley 1980). Bottomland hardwoods along the Mississippi River drainage, as well as eastern Texas and Oklahoma, are part of a major migration corridor for ducks, geese, and other waterbirds (Bellrose 1968). The principal dabbling ducks migrating or wintering in the area are mallard, wood duck, green-winged teal, blue-winged teal, northern pintail, northern shoveler, gadwall, and American wigeon (U.S. Fish and Wildlife Service 1984). Diving ducks that commonly use these bottomland hardwoods include the lesser scaup, canvasback, redhead, ring-necked duck, and hooded merganser. The Canada goose, snow goose, and greater white-fronted goose also overwinter in bottomland hardwood forests.

Temporarily flooded bottomland forests provide habitat that supports a diversity of mammals. Mammals closely tied to streams and riparian habitats in southeastern floodplain forests include the raccoon, nutria, muskrat, mink, beaver, river otter (Wilkinson et al. 1987) and swamp rabbit (Schmidly 1983). Some mammals, though not dependent on them, use bottomlands heavily;

these include predators such as the gray fox, bobcat, and Virginia opossum (Schmidly 1984). Small mammals characteristic of bottomlands are the marsh rice rat, eastern woodrat, least shrew, southern short-tailed shrew, and eastern mole (Wilkinson et al. 1987).

Even mammals that use a variety of habitat types often attain greater densities in bottomland forests. For example, eastern cottontail rabbits occur in open or cutover bottomland forest (Schmidly 1983), and gray squirrels in Mississippi are more abundant in hardwood riparian corridors than in young pine stands (Warren and Hurst 1980). Floodplain forests support some of the highest populations of white-tailed deer in the United States. Hall (1979) estimated carrying capacities as high as one deer per 2 to 6 ha (5 to 15 acres) in floodplain forests, compared with one deer per 8 to 14 ha (20 to 35 acres) in upland habitats.

The diversity of amphibians and reptiles in southern hardwood wetlands has been well documented by Conant (1975). As indicated above, the floodplain forests of east Texas and Oklahoma have high numbers of herpetofaunal species, as many as 36 and 37 species of amphibians and 59 and 57 species of reptiles in Texas and Oklahoma, respectively (Wilkinson et al. 1987). The highest species density of amphibians and reptiles in North America north of Mexico occurs in the upper Apalachicola River basin; salamanders are unexpectedly diverse, probably because of the numerous species associated with floodplain lowland forests (Means 1977).

Dominant amphibians in floodplain forests are the lesser siren; two-toed amphiuma; southern dusky, dwarf, two-lined, three-lined, many-lined, mud, red, four-toed, spotted, mole, and marbled salamanders; and southern cricket, bird-voiced tree, gray tree, upland chorus, river, and southern leopard frogs (Means 1977; Fredrickson 1978; Wharton, Kitchens, and Sipe 1982). Dominant reptiles include the eastern mud, yellow-bellied, and box turtles; green anole; and cottonmouth, mud snake, redbelly and brown water snakes, glossy crayfish snake, and rat snake. The American alligator is also an inhabitant of wetter sites in southern floodplain forests (Figure 28) (Means 1977; Fredrickson 1978).

The higher sites contain amphibians and reptiles that may be found in adjacent uplands (Wharton, Kitchens, and Sipe 1982). Amphibians include the slimy and redback salamanders, eastern spadefoot, and eastern narrowmouth toad. Reptiles include snakes such as the copperhead, canebrake rattler, and ribbon, garter, northern brown, and rough green snakes; and upland skinks, namely, the ground, 5-lined, and southeastern 5-lined skinks (Means 1977; Wharton, Kitchens, and Sipe 1982).

Floodplain forests are also used by riverine fishes as a source of food and cover and as spawning and nursery grounds (Larson et al. 1981; Wharton, Kitchens, and Sipe 1982; Lambou 1990). Seasonal inundation of vegetated floodplains provides sites for egg deposition, shelter for nests, protective cover for juvenile fishes, and food in the form of abundant macroinvertebrate

Figure 28. Alligators sunning on a channel shelf

prey (Wharton et al. 1981). Floodplain ponds and backwater lakes often serve as reservoirs for fishes during periods of low water (Lambou 1990; Mitsch and Gosselink 1986).

A total of 42 species are known to inhabit the main channel of the upper Ochlockonee River in Florida, and 75 percent of those species were collected in the floodplain during flood conditions (Leitman, Darst, and Nordhaus 1991). During the drought, 13 species were observed or collected in small floodplain ponds which had been isolated from the river continuously for 8 to 13 months. Fishes commonly collected in the floodplain use vegetative structures as shelter for nests, sites for deposition of adhesive eggs, and protective cover for young fishes. Decomposing leaf litter and plant debris serve as food for fishes and macroinvertebrates.

Vegetation contributions. Riparian vegetation of floodplain forests provides a wide variety of wildlife habitats, ranging from permanently flooded swamps and bogs to infrequently flooded forests, beaver ponds, and brushland. Both the vertical structure and distribution of riparian vegetation contribute to the multiplicity of ecological niches available to wildlife species.

The diverse forest strata offer numerous niches that birds exploit throughout the year (Fredrickson 1978). Vertical strata are highly utilized during summer breeding. For example, barred owls and red-shouldered hawks nest high in large trees with broad forks or broken tops; summer tanagers and great crested flycatchers nest near the canopy, and blue-gray gnatcatchers nest in the understory. Carolina chickadees and Carolina wrens use cavities in the understory, whereas woodpeckers usually nest in higher cavities in larger trees. Red-winged blackbirds frequently nest in shrubs such as buttonbush.

The horizontal distribution of birds in a bottomland hardwood forest is affected by changes in land elevation and plant species composition across the floodplain. For example, some birds nest in cavities over water and forage nearby, such as wood ducks (Drobney and Fredrickson 1979) and hooded mergansers (Morse, Jakabosky, and McCrow 1969), whereas bald eagles nest or roost in the tops of large trees near the water that supplies their foraging needs. Brushy sites provide winter habitat for many small birds such as the white-crowned and white-throated sparrows (Figure 29), American goldfinch, golden-crowned and ruby-crowned kinglets, pine siskin, and purple finch. Ground-nesting birds (e.g., American woodcock and wild turkey) are found on higher sites in floodplain forests. Bottomlands with the most small bird guilds (species that exploit the same class of resources in a similar way) are those with advanced succession, more vertical layering, a more xeric moisture-nutrient-soil gradient, and trees having high shade tolerance (Samson 1979).

Figure 29. A white-crowned sparrow perched on a branch

Mammals and herpetofauna exploit a diversity of niches in floodplain forests. Some wildlife species can use multiple habitat types because of their mobility and adaptability (Fredrickson 1978). Mammals such as raccoons, bobcats, gray foxes, and white-tailed deer range over a large area from swamps to uplands, and move into floodplain zones when these sites are not inundated. Arboreal mammals (e.g., gray squirrels) can use the entire floodplain forest whether it is flooded or not.

The woody vegetation of southeastern floodplain forests provides an extensive supply of both hard and soft mast. Oaks produce acorns that become available to wild turkey (Campo 1983), waterfowl (especially dabbling ducks), and mammalian herbivores such as the white-tailed deer and gray squirrel (Wharton et al. 1981). With a mixture of white oaks, which bear every year, and red oaks, which bear in alternate years, acorn production is sustained over time and constitutes reliable fall and winter food sources. The presence of other nutbearing trees, such as beech, pecan, and hickories, adds additional hard mast for fall and winter diets. Soft mast in the high canopy is produced by numerous trees such as sugarberry, tupelo gum, black gum, and persimmon. Soft mast is available in the subcanopy and shrub zone from trees such as American and deciduous holly, dogwoods, hawthorns, mulberry, pawpaw, blueberries, swamp palm, and large gallberry, and by vines such as grapes, poison ivy, greenbriers, Alabama supplejack, and Virginia creeper. These and associated herbaceous plants (e.g., cane and sedges) also provide browse. Shrub zone species are particularly important for wildlife communities that inhabit the higher sites of floodplain forests (Wharton et al. 1981).

In addition to hardwood mast production, bottomland plant communities offer other food resources for wildlife. Beavers feed on the bark of hardwood trees. Woodpeckers and other bark gleaners benefit from the high concentrations of insects in the dead and dying trees on sites flooded by beaver ponds (Lochmiller 1979). The fallen logs and extensive litter produced by woody plant communities harbor an abundance of insects and other small invertebrates that are food sources for insectivorous mammals and herpetofauna such as toads and skinks. In small openings caused by lightning strikes, windfalls, and other stresses, herbaceous plants provide forage for swamp rabbits (Korte 1975) and seeds for waterfowl or ground-feeding birds in fall and winter (Fredrickson 1979). On large open sites that stay dry during the summer, dense stands of vegetation may develop and produce abundant seeds for seed-eating birds when conditions are dry and for waterfowl and rails when sites are flooded (Arner, Norwood, and Teels 1974).

Desert and arid lands

Riparian ecosystems of the western United States most often occur as narrow belts of vegetation along ephemeral, intermittent, and perennial streams and rivers (Figure 30) (Knopf et al. 1988). Riparian areas are most obvious in steppe, shrubsteppe, and desert regions, particularly in the Southwest. The majority of arid land riparian systems are associated with ephemeral streams that run for only a few months, weeks, or days each year (Johnson 1989), and riparian communities often occur only in patches and isolated pockets along these stream corridors (Szaro and King 1990). Even the Sacramento River system of California, which at one time supported a riparian forest of 313,000 ha (773,110 acres) (McGowan 1961; Thompson 1961), has a belt of riparian vegetation <91 m (100 yards) wide (Thompson 1977). However, the width of western riparian areas may be highly variable. For example, riparian vegetation exists wherever periodic flooding occurs

Figure 30. Riparian strip in a semiarid landscape

along the Rio Grande in Texas and varies from strips a few meters wide to areas that extend inland a distance of 1 km (0.6 mile) to form broad flat floodplains (Boeer and Schmidly 1977). The South Platte River in eastern Colorado also consists partially of floodplain systems in contrast to the North Platte River with its narrower and more variable riparian widths in western Colorado (Knopf 1986).

Many mammals and reptiles and most amphibians in the western United States depend upon riparian habitats, especially in desert regions. In the Southwest, where 99 percent of the land surface is hot and dry for most of the year, streams are linear oases of plant and animal life (Johnson 1989). About 80 percent of all vertebrates in Arizona and New Mexico are dependent upon riparian habitats for at least a portion of their life cycles, and more than half are restricted to riparian systems. At least 30 percent would experience population declines without suitable riparian environments as part of their total habitat (Hubbard 1971; New Mexico Department of Game and Fish 1985; Arizona Game and Fish Department 1988).

Species richness and diversity. Although <1 percent of the West contains riparian vegetation, it is used by more species of breeding birds than any other vegetation type in North America (Knopf and Samson 1988) and supports higher population densities of breeding birds than any other forest habitat type (Carothers, Johnson, and Aitchison 1974). Numerous studies have shown the importance of riparian habitat to birds. At least 67 avian species have been found to nest in the limited riparian forests of the Sacramento Valley (Gaines 1977); this is about 24 percent of the 277 regular nesters in California (Small 1974). In northern Colorado, 82 percent of breeding bird species nest annually in riparian vegetation (Knopf 1985), and wild turkeys nest almost exclusively in riparian habitats along the South Platte River (Schmutz, Braun, and Andelt 1989).

The highest population densities of noncolonial nesting birds in North America are recorded for the xeroriparian ecosystems of the desert Southwest (Johnson 1970; Carothers, Johnson, and Aitchison 1974); 51 percent of the 166 species that breed in this region are completely dependent upon riparian vegetation (Johnson, Haight, and Simpson 1977). Studies on southwestern rivers show that the associated riparian systems are extremely rich in breeding birds; these rivers include the Verde (Carothers and Johnson 1973) and Colorado in Arizona and the San Juan (White and Behle 1961; Schmitt 1976) and Gila (Hubbard 1971) in New Mexico. The two New Mexico river valleys alone support 16 to 17 percent of the entire breeding avifauna of temperate North America. In the Gila Valley, at least 49 percent of the 112 species of breeding birds depend upon riparian habitats (Hubbard 1971), and 45 percent of the breeding species in the San Juan Valley show riparian dependence (Schmit 1976).

During the critical winter period, western birds tend to congregate in riparian habitats (Gaines 1977; Johnson and Haight 1985). Birds specialize in fewer habitat types and attain higher population densities in winter than in other seasons (Anderson and Ohmart 1977). Wintering populations consist mainly of migratory species derived from distant breeding areas. Although discussed as a special topic, the importance of riparian areas to stop-over migrant passerines in the Southwest is noted here (Stevens et al. 1977). Stop-over by migrants occurs commonly in the Southwest, and riparian habitats support significantly higher migrant passerine densities and diversity than do adjacent, nonriparian habitats.

Riparian-dependent mammals in Arizona and New Mexico include the water shrew, Arizona gray squirrel, meadow vole, mink, muskrat, beaver, raccoon, and river otter (Hubbard 1977). Williams and Kilburn (1984) identified 21 taxa of mammals that require riparian areas in California, including the riparian brush rabbit, Colorado River cotton rat, Yuma mountain lion, 6 shrews (*Sorex* spp.), and 2 bats (*Myotis* spp.). Although 30 species of terrestrial mammals have been recorded from riparian habitats along the Rio Grande in Texas, the beaver is the only species restricted to riparian systems (Boeer and Schmidly 1977). Common mammals in this riparian corridor are the desert cottontail, yellow-faced pocket gopher, desert pocket mouse, Merriam's kangaroo rat, white-footed mouse, hispid cotton rat, southern plains woodrat, coyote, and raccoon. The ringtail is more abundant in riparian than in other desert habitats (Belluomini and Trapp 1984).

In California, Brode and Bury (1984) identified 16 amphibian and 5 reptile species that are restricted to riparian habitats throughout their lives and 11 species of amphibians that must return to aquatic habitats to breed. In the Mojave, Sonoran, and Chihuahuan desert subdivisions of the Great North American Desert, 58.8 percent of the 143 species of amphibians and reptiles are riparian and/or wetland species; more than half (37.1 percent) of these are restricted to the obligate riparian and/or obligate wetland ecological position (Lowe 1989).

Riparian-dependent reptiles in the desert Southwest include mud (*Kinosternon* spp.) and softshell (*Trionyx* spp.) turtles, green snakes (*Opheodrys* spp.), blotched water snake, garter snakes (*Thamnophis* spp.) (Hubbard 1977), Arizona skink, greater earless lizard (Jones and Glinski 1985), Arizona alligator lizard, and Gilbert's skink (Stebbins 1966). Other species concentrate in riparian habitats due to favorable microclimates or food availability. For example, lizard densities in riparian areas of the Grand Canyon were found to be up to 10 times greater than those in nearby desert scrub, apparently due to the greater availability of insects on streamside plants and debris (Warren and Schwalbe 1985).

Vegetation contributions. A great variety of plants compose the riparian vegetation of the Southwest, including both obligate and facultative species (Hubbard 1977). Typical obligates are cottonwoods, willows, alders, and other broadleaf trees. Facultative species are invaders from other habitats that can survive outside riparian systems. Over 100 kinds of woody plants occur regularly in the floodplains of New Mexico, of which about 40 percent are obligates. The "wet riparian big five" trees as described by Lowe (1961, 1964) are (a) ash species (*Fraxinus velutina* in Arizona and New Mexico and *F. latifolia* in California); (b) cottonwood (*Populus fremontii*); (c) sycamore (*Platanus racemosa*); (d) walnut (*Juglans microcarpa* in Arizona and New Mexico and *J. hindsii* in California); and (e) willow (*Salix goodingii*).

Just the presence of riparian vegetation in desert and arid lands greatly affects the diversity and density of wildlife, especially the avifauna. For example, 65 avian species depend upon discrete riparian habitats in the Toiyabe Range of central Nevada (Dobkin and Wilcox 1986), and the presence of riparian habitats almost doubles avian diversity in the Gila and San Juan valleys of New Mexico (Schmitt 1976). Even the driest of riparian habitats in the Southwest supports significantly more birds than do nearby areas of desert upland. Johnson and Haight (1985) found that dry desert washes had 5 to 10 times the diversity and/or density of birds compared with uplands throughout the year, and Stevens et al. (1977) found that riparian plots contained up to 10.6 times the number of migrants per hectare found on adjacent, nonriparian plots. The presence of riparian vegetation is also important in environments disturbed or created by man. A study in Carmel Valley, California, indicated that a narrow strip of riparian trees tripled the number of bird species observed at a golf course (Williams and Williams 1989), and another study showed that avian diversity was 32 percent and density was

95 percent less on agricultural lands associated with riprapped streambanks than on those associated with riparian vegetation (Hehnke and Stone 1978).

A wooded riparian corridor affects bird populations in a zone several hundred meters beyond the limits of the riparian vegetation (Stevens et al. 1977). Szaro and Jakle (1985) studied breeding bird communities in central Arizona and found that riparian woodland contributed up to 33 percent of the birds using the desert wash and up to 15 percent of those in the adjacent desert upland. Bird density in the adjacent desert decreased gradually with distance from the riparian edge reaching a low point 600 to 1,000 m (1,969 to 3,281 ft) away.

As in the East, structural characteristics of vegetation influence wildlife species abundance and diversity in western riparian systems. The following vegetation parameters are particularly important for breeding bird communities: (a) foliage volume (Anderson and Ohmart 1975; Finch 1989a; Atkinson 1993); (b) foliage height (Anderson and Ohmart 1975; Atkinson 1993); (c) total vegetation volume (Mills, Dunning, and Bates 1991); (d) width of riparian vegetation (Manuwal 1986); (e) structural complexity (Manuwal 1986; Finch 1989b; Schmutz, Braun, and Andelt 1989); and (f) plant species composition (Strong and Bock 1990). Correlations between bird population parameters and vegetation structural characteristics vary seasonally (Anderson and Ohmart 1977). The mean habitat breadth of all species is narrowest with respect to vegetative structure in winter and broadest in summer. Permanent residents occupy the structural types more evenly than do visitors; i.e., permanent residents tend to be less specialized with respect to structure than are visitors.

Total vegetation volume is highly correlated with breeding bird densities in southwestern lowlands regardless of plant species composition (Mills, Dunning, and Bates 1991). If plants provide resources in proportion to their volume (e.g., more insect prey, more nest sites, or more favorable roost sites), then bird density should be proportional to vegetation volume. The extensive studies by Mills, Dunning, and Bates (1991) indicated that breeding birds responded strongly to resources associated with vegetation and that such a resource-based response may explain such well-known patterns as the edge effect and high avian breeding densities in southwestern riparian habitats.

The structural complexity of vegetation varies with the elevational location of riparian systems. Finch (1989b) found that vegetation of lowland riparian habitats along the North Platte River in southeastern Wyoming was structurally more complex than that of riparian habitats at higher elevations and bird species richness and abundance were greatest in riparian lowlands. Most lowland species were generalized in habitat use and occupied habitats that were similar among species; therefore, the conclusion was that diversity was greater in lowlands because woodlands were more heterogeneous. However, riparian woodlands at higher elevations in the Southwest have a greater variety of trees and shrubs than the river valleys (Pase and Layser 1977). It was found that the type of dominant riparian tree species in the Huachuca

Mountains of southeastern Arizona influenced bird species richness and total density during the breeding season (Strong and Bock 1990). Cottonwood habitats had the greatest species richness, and both cottonwood and sycamore habitats had high bird densities.

Prairie and grasslands

Less information is available on riparian systems in the Midwest than in other regions of the United States. However, several studies have shown the importance of riparian habitat to wildlife in the Great Plains, with the focus on breeding bird communities.

Avifauna. More than 190 species of birds are known to breed in Iowa (Kent and Bendorf 1991). Data derived from 60 sources for 144 avian species in 20 habitats showed that breeding bird diversity in the agricultural landscapes of Iowa was highest in floodplain forests (107 species) (Best et al. 1995). Diversity was lowest in agricultural habitats with 31 species in small grain fields and 27 species along herbaceous fence rows; it was intermediate (85 spp.) in upland forest. Changes in the South Platte River drainage basin in eastern Colorado during the 20th century have allowed riparian communities to develop in the floodplain (Nadler 1978) accompanied by a diverse avifauna (Knopf 1986). Of the 83 avian species that have been recorded in the riparian zone, most were species that occurred primarily in the eastern or western United States with the site being peripheral to each broad range (Knopf 1986).

The variety of vegetation in riparian areas of the Great Plains includes tree, shrub, and herbaceous layers and, therefore, provides nest sites for diverse assemblages of breeding birds. An Iowa study showed the importance of vegetation structure for breeding birds in riparian communities (Stauffer and Best 1986). Major structural parameters for nest site selection related to (a) support-structure height for open-nesting birds, (b) tree selection for cavity-nester sites, and (c) cover above and below the nest. Width of riparian vegetation also influences species richness (Stauffer and Best 1980). Floodplain woodlands in Iowa riparian systems supported greater densities of breeding birds than did upland woodlands or herbaceous sites, and bird-species richness increased with the width of wooded riparian habitats. Thirteen of thirty-two species nesting in floodplain woodlands bred only in relatively wide patches of riparian habitat.

Mammals. A number of studies have shown the importance of riparian habitats to white-tailed deer in eastern Montana (Allen 1968; Swenson, Knapp, and Wentland 1983; Herriges 1986) and other areas of the Great Plains (Cook 1945; Zwank et al. 1979; Smith and Flake 1983). The amount of riparian cover may determine the potential number of white-tailed deer that bottomland habitats can support. A seasonal study along the lower Yellowstone River in eastern Montana showed that the amount of riparian forest and shrubland cover was the most important factor influencing deer distribution and accounted for 70 percent of the variation observed in relative deer density among sections of river bottom (Compton, Mackie, and Dusek 1988). The close linear relationship between deer density and amount of riparian cover may provide an important criterion for determining relative deer abundance between portions of river bottom.

Coniferous forests of Pacific Northwest

Avifauna. Research by McGarigal and McComb (1992) in the central Oregon Coast Range did not bear out the striking avian use of riparian habitats that occurs in other regions. Upslope areas had greater bird species diversity, richness, and total bird abundance than streamside habitats. They attributed this lack of avifaunal diversity along forest streams to the structural character of the vegetation. Streamsides had more herbaceous, tall shrub, and midstory cover and less low shrub and overstory cover than upslope areas. The scarcity of large conifers along mountain streams reduces the availability of snags and large trees for breeding bird nests. The surrounding uplands are moist and forested, and the transriparian gradients in vegetation structure are relatively subtle compared with arid land riparian systems (Salt 1957). Therefore, the streamside vegetation does not contain the abundance and diversity of birds that it does in floodplain forests and desert and arid land riparian systems.

Mammals. Riparian ecosystems are important for mammals in the northwestern United States. A study in the Cascade Range of Oregon showed that small mammal species abundance and diversity were greater in riparian than in upland habitat (Doyle 1985), and research in the Pacific Northwest has shown that the larger streams and rivers at middle and low elevations support a variety of large mammals (Raedeke, Taber, and Paige 1988). Riparian-dependent species or those that find optimum habitat in riparian areas are nutria, beaver, muskrat, raccoon, mink, river otter, Virginia opossum, elk, and mule deer. Species that are more abundant in riparian areas than in adjacent uplands are snowshoe hare, grizzly bear, western spotted skunk, white-tailed deer, and moose. Mammals that use riparian systems but are as abundant in other habitats include the eastern cottontail, Nuttall's cottontail, red fox, gray fox, fisher, striped skunk, black bear, and bobcat. Lower order streams, generally found at higher elevations, are insufficient to meet the needs of most large mammals.

The vegetation along higher order streams is the most important feature of riparian habitat for large mammals (Raedeke, Taber, and Paige 1988). Productivity of the shrub/herbaceous layer, especially in early spring, provides abundant and diverse food sources, and hence enhanced forage choice, for omnivorous animals. Predators feed on the abundant prey species and carrion of deer, elk, and moose that use riparian areas heavily in spring (Figure 31). Because they are cooler in summer and warmer in winter than the surrounding habitat, riparian areas also provide thermal cover for large mammals (Oakley

Figure 31. A moose in a shrub-dominated riparian area

et al. 1985). Seasonal movement of deer and elk into these areas reflects this phenomenon.

Special Wildlife Concerns in Riparian Corridors

Two groups of vertebrates that especially benefit from the presence of riparian corridors are neotropical migrant birds and vertebrate species that are threatened, endangered, or approaching either status.

Neotropical migrants

Most migratory birds in the United States are neotropical migrants that breed in North America and winter in tropical Central and South America and the Caribbean Basin; a large percentage of these migrants are songbirds. At least 75 percent of avian species that breed in North American deciduous forests migrate south for the winter (Welty 1964). Rappole et al. (1979) documented movements of more than 150 species of neotropical migrants through Texas and Mexico; Partners in Flight, a cooperative program dedicated to the conservation of neotropical migrants, estimates that more than 250 species of birds migrate to the neotropics each year (Partners in Flight, undated).

Biologists have become increasingly concerned with neotropical migratory birds as a group because of declining populations since the 1940s (Droege and

Sauer 1989; Morton and Greenberg 1989; Terborgh 1989; Robbins et al. 1989; Askins, Lynch, and Greenberg 1990; Finch 1991). Population declines have been reported for nearly one-third of all neotropical migrant birds (Rappole and McDonald 1994). Therefore, the main thrust of migratory bird research in the 1990s is toward identifying declining populations, determining the causes of decline, and developing management techniques and policies to reverse these declines.

One of the main causes of the decline of neotropical migratory birds is thought to be fragmentation of habitats, particularly forested ones, on the breeding grounds in North America (Whitcomb et al. 1981; Terborgh 1989). A forested habitat becomes fragmented when large continuous tracts are subdivided into smaller and smaller units by highway corridors, urban expansion, logging, and agricultural conversion. Bird species that nest primarily in the interiors of large tracts and away from forest edges, such as many warblers, vireos, and tanagers that are neotropical migrants, are replaced by ubiquitous edge species that tend to be year-round residents or short-distance migrants (Temple 1986; Blake and Karr 1987). Fragmentation also increases nest parasitism by brown-headed cowbirds and predation by jays and crows, which are more abundant in edge habitats (Temple and Cary 1988).

Riparian forests in the United States are important both as breeding habitats and migration routes for neotropical migratory birds. In the East, bottomland hardwood forests tend to be less developed and less fragmented than upland areas; therefore, riparian forests constitute some of the largest remaining contiguous habitats for neotropical migrant species. Wooded riparian zones also serve as connecting corridors between blocks of upland forest, increasing habitat value and regional biodiversity.

Riparian systems are essential movement corridors and stopover habitats for migrating birds (Gaines 1977; Wauer 1977; Barclay 1980). In the arid Southwest, riparian areas provide the only acceptable habitat for many long-distance migrants. Riparian habitats in Arizona may contain 10 times greater densities of spring migrants than nearby upland sites and generally support a greater number of species (Stevens et al. 1977). Hehnke and Stone (1978) found that riparian systems in the Sacramento Valley supported 14 times the number of species found on surrounding lands during fall migration. Wauer (1977) reported that the Rio Grande corridor is an important migration route for many birds because it provides food, water, and cover that are unavailable elsewhere in the region and is oriented in an appropriate direction.

Threatened and endangered species

Riparian areas are often critical corridors for endangered and threatened species because they allow wildlife movement from one segment of riparian habitat to another and between separated upland tracts. This is especially true in the arid Southwest where travelways are needed to connect isolated "island habitats" too small to support viable populations of some species. Riparian areas in Arizona and New Mexico harbor a large number of vertebrate species that are threatened or endangered in those States, while some are also listed as Federally endangered or threatened. Of the 149 species listed for these States, only 17 are found in both Arizona and New Mexico (Johnson 1989), and approximately 70 percent occur in and near riparian zones (Arizona Game and Fish Department 1988; New Mexico Department of Game and Fish 1985). Since there is little contiguity of riparian systems between Arizona and New Mexico, the presence of riparian vegetation in each system becomes even more critical to maintaining viable populations of species approaching low levels in those States.

Even though floodplain forests of the eastern United States are much broader and provide wider zones of vegetation than southwestern riparian systems, fragmentation and contiguity of the vegetation are equally important. For example, studies in the Tensas watershed of Louisiana indicate that the densities of some forest-dependent bird species have decreased with decreases in forest area, and the data suggest that local extinctions of forest-dependent species will probably occur if these trends continue (Burdick et al. 1989). The authors estimated that of the 151 forest and swamp bird species in the 50,000-ha study area, at least one species will become locally extinct every 44 years, even if no further forest destruction occurs. In the past, this riparian ecosystem was inhabited by the endangered red wolf, Florida panther, and ivory-billed woodpecker (considered extinct), and present populations of the Louisiana black bear are now threatened. These species are all wide-ranging predators that require large territories to support stable breeding populations, but the Tensas riparian system can no longer provide the amount of contiguous habitat needed for population survival.

The continuity of riparian corridors helps to counteract fragmentation of forests and the resulting faunal collapse (Wilcox 1980). As islands of forest decrease in area and become more distant from one another, the number of forest species inhabiting those islands decreases. This is because smaller islands have higher extinction rates and cannot sustain as many species, while smaller and more distant islands are less likely to be colonized by new species. Thus, newly formed fragments that once composed larger islands tend to be supersaturated with species, and even without further reduction in island area, the number of species is expected to decline dramatically (Wilcox 1980).

Riparian vegetation can, however, provide significant amounts of habitat for threatened and endangered species that are small enough to survive and reproduce in fragmented habitats. This is especially true for species potential to a site, but absent, or for those that are in low abundance because they exist at the margins of their natural ranges. For example, a male Indiana myotis was netted on lands surrounding the Paducah Gaseous Diffusion Plant in Kentucky, and a study later revealed that a riparian forest on the Ohio River floodplain contained 231 ha (571 acres) of good potential summer habitat for this Federally endangered species (U.S. Army Engineer Waterways Experiment Station 1994). Aerial photos showed the Paducah site as an "island of habitat" with much larger areas of potential habitat in surrounding counties.

As the Indiana bat appears to be expanding its summer range in western Kentucky, this relatively small area of riparian vegetation on the Paducah site is significant because of its potential for attracting and nurturing roosting colonies.

Although abundant elsewhere, a species may appear on a State list as threatened or endangered because it is at the margin of its natural range in that particular locale. However, a marginal population is significant because of its contribution to the maintenance of heterogeneity in the gene pool of the larger population and should be protected in low-abundance areas. This ensures the perpetuation of healthy populations and helps to maintain the biodiversity of an area.

Small areas of riparian vegetation can be reestablished to provide habitat for the recovery of some endangered species. A good example is the restoration of riparian habitat for the endangered least Bell's vireo in southern California (Klimas and Evans 1993). During the 1940s this vireo was common within its breeding range from interior northern California to northwestern Baja California, Mexico, but had become restricted to coastal river valleys in southern California by the 1980s (Franzreb 1989). Surveys during the 1989 breeding season indicated that approximately a third of the 400 pairs of least Bell's vireos nesting in the United States were within the Santa Margarita River valley (Klimas and Evans 1993). Camp Pendleton Marine Corps Base became the site of a restoration project that utilized 91 ha (37 acres) along the Santa Margarita River to reestablish riparian vegetation and create additional nesting habitat for the vireo. Typical vireo habitat was created by providing a mosaic of willow-dominated woodland interspersed with shrubfields and/or dense willow reproduction of shrub height in such a pattern to ensure that appropriate combinations of closed-canopy woodland and adjacent shrub-stature habitat would exist at various locations within the site at all times over a period of several decades.

Importance of Riparian Vegetation to Aquatic Fauna

Riparian vegetation is an important component of aquatic faunal habitat. Platts (1983) and Moring, Garman, and Mullen (1985) reviewed the role of streamside vegetation from the perspective of fisheries habitat and described five important riparian functions: (a) provision of fish cover; (b) provision of streambank stability; (c) regulation of stream temperatures; (d) input of nutrients to the system by allochthonous material; and (e) direct input of invertebrates as fish food.

Cover

Cover for fishes refers to instream areas that provide quiet resting places and protection from predation (Wesche, Goertler, and Frye 1987). It may be the most fragile and important element affecting a fishery (Platts 1983). The importance of cover to fish is well documented by the many studies that have found salmonid abundance declining as stream cover was reduced (Boussu 1954) and increasing as cover was added (Hunt 1976; Hanson 1977; Binns 1979).

Streamside vegetation provides cover by creating quiet, shaded resting areas where it overhangs the water surface (Figure 32) and by contributing material for the formation of debris and log dams (Platts 1983). Wood boles (>10-cm diam) from the riparian forest enter streams of all sizes (Naiman et al. 1990). Large pieces of debris and log jams create pools and protective cover for fishes, especially salmonids in small mountain streams (Meehan, Swanson, and Sedell 1977).

Figure 32. Overhanging riparian vegetation cools aquatic habitats

Results of a study to evaluate the relative importance of cover parameters to brown trout populations in small streams indicated that overhead bank cover, provided primarily by riparian vegetation, is the parameter that explains the greatest amount of variation in trout population size (Wesche, Goertler, and Frye 1987). The amount of overhead bank cover available in small streams predominated by brown trout (*Salmo trutta*) exerts the strongest influence on trout carrying capacity, and the riparian system is the dominant factor controlling this cover type. The findings of Wesche, Goertler, and Frye (1987) quantitatively verify the conclusion of Platts (1983) that banks bordering small streams (order <6) provide the habitat edges or niches needed to maintain high fish populations.

Streambank and channel stability

Riparian vegetation plays an important role in building and maintaining productive streams (Platts 1983). Stems and low-hanging canopy retard movement of sediment, water, and floated organic debris during floods (Swanson, Fredrickson, and McCorison 1982). Riparian trees provide streambank stability because of their large size and massive root systems, and brush builds stability through its root systems and litter fall (Platts 1983). Grasses form the vegetative mats and sod banks that reduce surface erosion and mass wasting of streambanks.

Trees are especially important in maintaining channel stability (Platts 1983). As they mature and fall into or across streams, trees not only cause high-quality pools and riffles to form but their large mass helps to control the grade and stability of the channel. If it were not for the constant entry of large trees falling into the stream, the channel in many reaches would degrade and soon flow on bedrock. This would result in insufficient spawning gravel and few high-quality rearing pools for salmonid fishes.

Fish are often adapted to the habitat interface between the streambank and water because stable, well-vegetated streambanks provide cover, control water velocities and temperatures, and supply terrestrial foods (Platts 1983). The condition of the streambank often governs the water depths and velocities in which the fish must live. Therefore, streamside vegetation needs high vigor, density, and species diversity because each of the vegetative types plays an important role in forming and protecting the aquatic habitat.

Stream temperature control

Riparian vegetation, chiefly tree canopy and stems, above the stream channel provides shade that controls temperature and instream primary production (Swanson, Fredrickson, and McCorison 1982). Temperature changes can affect the metabolic rates of fishes, change the dissolved oxygen content in the water, and influence hatching success (Platts 1983).

Shade reduces water temperatures in summer and protects against heat loss in winter (Platts 1983). Unusually high stream temperatures can lead to disease outbreaks, cessation of feeding, stopping of migrations, and inhibition of fish growth. Temperatures above 68 °F (20 °C) have been known to completely stop fish migration while temps above 77 °F (25 °C) are often lethal to salmon and trout (Reiser and Bjornn 1979). Riparian vegetation not only intercepts and reduces the intensity of solar radiation but also provides shade for cover, especially along stream margins (Platts 1983). This type of cover can be critical to good fish survival because shaded streamside areas are a preferred habitat of juvenile salmonids.

Streamside vegetation also protects against extremely cold temperatures. Streams with little or no vegetative canopy are susceptible to the formation of anchor ice, which can form on cold clear nights when the channel radiates heat directly into the atmosphere (Platts 1983). Heavy formations of anchor ice can produce a complete fish kill or restrict the oxygen supplied to fish eggs in the gravel.

Certain types of vegetation are needed to control stream temperatures (Platts 1983). Grasses can provide overhanging cover, but their shortness makes them ineffective in intercepting the sun's rays, except in very small streams (orders 1 and 2). The height of the vegetation is proportional to the width of the stream. In large streams (order 6 or larger), trees must border the stream to provide effective shading. In small to medium streams (orders 3 to 5), brush is sufficient, but grasses and forbs have little effect.

Nutrient input

Riparian forests add large amounts of leaves, cones, wood, and dissolved nutrients to low- and mid-order streams (Gregory et al. 1991). These organic inputs originate as particles that fall directly from the forest into the stream channel or move downslope along the forest floor by erosion and as dissolved materials in subsurface water.

The riparian forest helps regulate stream productivity through the amounts and qualities of material directly contributed to the stream. Small streams annually receive 300 to 600 g of carbon per square meter, with the rate per unit area decreasing as channel width increases (Conners and Naiman 1984). In deciduous riparian forests, >80 percent of these organic inputs may be leaves that enter the stream over a 6- to 8-week period in autumn, whereas in coniferous riparian forests, 40 to 50 percent of the material may be cones or wood.

Subsurface water moving from the uplands to the stream carries large quantities of dissolved organic matter and nutrients essential for stream function (Naiman et al. 1990). Riparian forests chemically alter these materials as the subsurface water flows past their root systems. Riparian forests take up nutrients for growth, promote denitrification, and modify the chemical composition of carbon and phosphorus (Pinay et al. 1990). The presence of riparian forests significantly regulates the amount of nitrogen and phosphorus reaching streams from upland areas (Karr and Schlosser 1978; Schlosser and Karr 1981a,b).

Macroinvertebrates

Riparian vegetation provides substrate for the production of macroinvertebrates, a major source of food for fishes. Macroinvertebrates are those invertebrates that are large enough to be seen without magnification; the main taxonomic groups occurring in freshwater environments are annelids, crustaceans, flatworms, mollusks, and insects (usually predominant) (Platts, Megahan, and Minshall 1983).

Macroinvertebrates are important intermediaries in the utilization of plant material (e.g., algae, vascular hydrophytes, leaves, and wood) and the recycling of nutrients in aquatic environments (Platts, Megahan, and Minshall 1983). Riparian forests affect food quality and quantity for macroinvertebrates both directly and indirectly. The input of particulate matter (detritus) can be used directly for food by macroinvertebrates, while the structure and productivity of the microbial food web is influenced indirectly through stream shading and modification of levels of dissolved organic carbon and other nutrients.

Leaves and other coarse particulate detritus from streamside forests are readily used as food by macroinvertebrates (Cummins et al. 1989). Tributaries flowing through forested areas or having well-developed riparian canopies, continuously receive organic detritus throughout the year. Vannote and Sweeney (1980) found that the standing crop of detritus in small forested streams averaged 248 g of organic matter per square meter for the year with leaf litter detritus rarely falling below 40 g per square meter.

Most of the biological activity in stream ecosystems takes place on inorganic and organic substrates on the surface of or within the benthic (bottom) area of the channel (Sweeney 1993). Existing data strongly suggest that streamside forests greatly increase the amount and complexity of benthic habitat available for colonization by macroinvertebrates. Surface area for macroinvertebrates is continuously added to streams in the form of woody debris shed from the streamside forest (tree twigs, branches, whole trunks). This debris provides surface area of a different texture from that of roots or rocks and has an additional dimension (interior) for benthic organisms to use for various stages of their life histories. At periodic intervals the accumulating woody debris forms small dams that add local habitat variety, such as depth and flow (Triska and Cromack 1981).

White Clay Creek, Pennsylvania, provides an example of the importance of riparian vegetation to macroinvertebrate populations. The presence or absence of a forest along sections of its channel affected the amount of exposed surface available for colonization by benthic organisms (Sweeney 1993). A forested second order channel contained substantially more woody debris, in terms of both number and volume of woody pieces, than a contiguous meadow reach. Although the amount of additional surface area varied according to the nature and extent of the riparian forest, this section of White Clay Creek had an average of 4.73 m^2 of surface area (in the form of woody debris) added per

25 m of channel length. For a coastal plain stream in Virginia, Smock, Metzler, and Gladden (1989) found that benthic areas covered with woody debris dams contained an annual average of about 22,302 macroinvertebrates per square meter.

Numerous studies have shown that streams with woody debris are generally more retentive of particulate organic matter than streams without wood (Bilby and Likens 1980; Bilby 1981; Speaker, Moore, and Gregory 1984; Golladay, Webster, and Benfield 1987; Bilby and Ward 1989; Webster et al. 1988; Bilby and Ward 1991). Thus, macroinvertebrates specializing in either eating woody debris or using it as substrate for attaching larval retreats or nets, building larval cases, or laying eggs will be severely limited in meadow reaches of streams because of the lack of direct particulate woody input, the limited amount of input from upstream forested reaches, and the possibility that narrow meadow channels have less retention capacity for particulate organic material if or when it might enter the channel (Sweeney 1993).

The woody roots of trees growing close to the stream provide additional surface for macroinvertebrate colonization (Figure 33) (Rhodes and Hubert 1991). Tree roots have an extremely high surface area to volume ratio, can persist for a long time, and provide habitat for a variety of macroinvertebrate species, whereas roots of herbaceous plants, such as grasses along meadow streams, are very fine and provide poor habitat because they quickly collect silt particles to form sod or break off readily in strong current (Sweeney 1993).

Tree roots in streams on the coastal plain of eastern North America show significant macroinvertebrate colonization (Sweeney 1993). In the Upper Three Runs of Aiken County, South Carolina, tree roots along the streambank contained 2,000 or more macroinvertebrates per 0.06 m^2 of root mat throughout most of the year, whereas densities of macroinvertebrates on mud flats of bare streambanks were always less than 1,000 per 0.06 m^2. The large difference between macroinvertebrate densities in these two benthic habitats means that streamside trees can substantially increase the standing stock of macroinvertebrates per unit length of stream channel.

Tree roots are prime substrata for collecting a diversity of aquatic insects in large numbers (Sweeney 1993). Rhodes and Hubert (1991) described streams in Wyoming where exposed root filaments of banks represented only 8.5 percent of total habitat but contained an estimated 44 percent of the total aquatic insect fauna in July and 30 percent in August. In some small coastal plain streams of the eastern United States, the roots from streamside trees have been shown to create the majority of debris dam sites for organic matter accumulation, and these debris dams support 10 to 15 times the density and biomass, respectively, of macroinvertebrates relative to sites without debris (Smock, Metzler, and Gladden 1989).

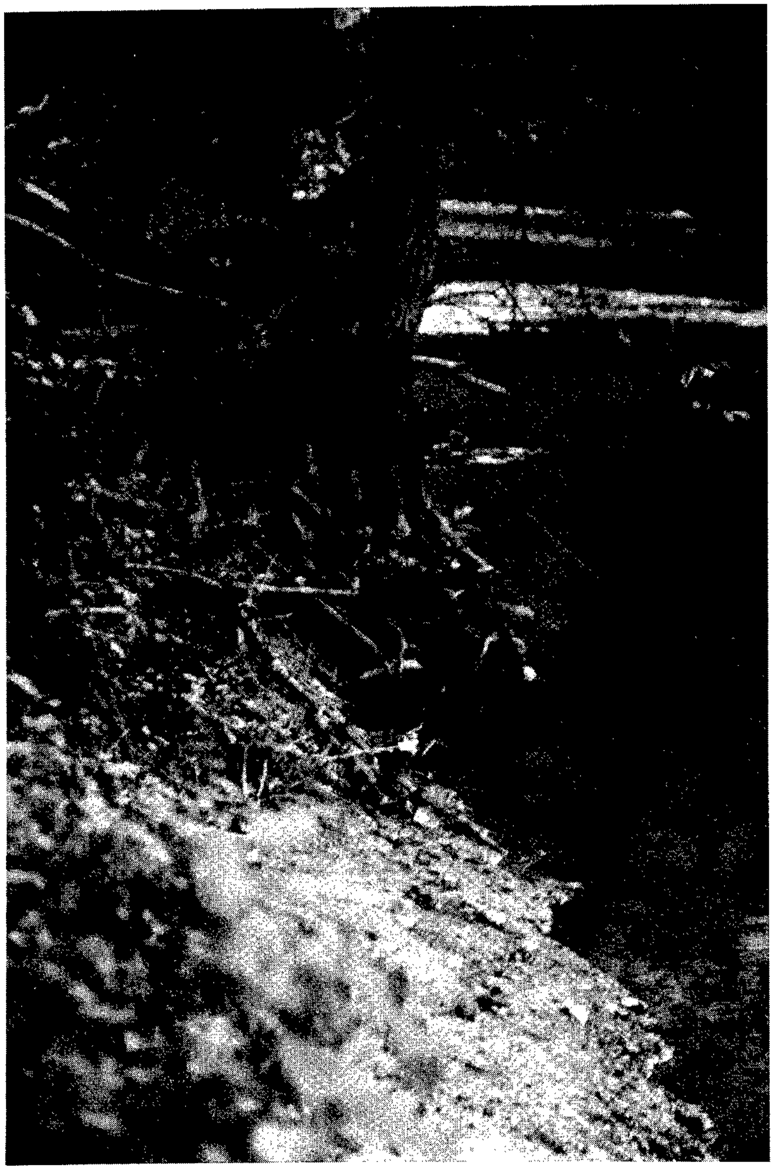

Figure 33. Exposed woody roots of riparian vegetation provide important refuge and colonization areas for macroinvertebrates

Although streamside vegetation is considered necessary to control water temperature and provide optimal fish habitat (Swanson, Fredrickson, and McCorison 1982; Platts 1983), at least two studies have indicated that macroinvertebrate populations are less abundant in shaded streams of the northwestern United States (Hawkins, Murphy, and Anderson 1982; Carlson, Andrus, and Froehlich 1990). Studies by Carlson, Andrus, and Froehlich (1990) indicated that macroinvertebrate communities were most abundant in streams that were shaded less by surrounding vegetation, and Hawkins, Murphy, and Anderson (1982) found that canopy type was more important than substrate character in influencing total abundance and guild structure of macroinvertebrates in Oregon streams. However, existing data from the northeastern United States strongly suggest that streamside forests greatly increase the amount and complexity of benthic habitat available to macroinvertebrates (Sweeney 1993). The canopy of trees growing on opposite banks of a small stream will form a complete vegetative bridge that provides shade during appropriate seasons, while the streamside trees provide woody debris and roots that are readily colonized by macroinvertebrates. Sweeney (1993) estimated that deforested reaches along White Clay Creek in Pennsylvania had 50-percent less potential benthic habitat than those with riparian vegetation.

Impacts of Habitat Alteration on Riparian Wildlife Communities

For many of the same reasons that streamside habitats attract abundant wildlife, human activities also tend to be concentrated in riparian zones. The availability of water, fertile soils, productive plant communities, and pleasant microclimates in riparian areas attract recreationists, residential developers, farmers, loggers, and domestic livestock. Streams are channelized to prevent flooding and facilitate agricultural or urban development of floodplains, and water is impounded or diverted for irrigation or municipal use. The resulting changes in natural plant communities have had profound impacts on native riparian wildlife. The following section examines the effects of three important causes of riparian habitat alteration—channelization, streamflow modification, and grazing. These topics were chosen because of their relevance to the U.S. Army Corps of Engineers and because the results can be extended to other activities that have comparable effects on riparian systems.

Channelization and streambank stabilization

Channelization, with its attendant destruction of streamside vegetation, is almost invariably detrimental to riparian wildlife communities. Channelization affects streamside habitats in at least three ways: (a) it affects habitat quality by altering the structure or composition of the vegetation (Hehnke and Stone 1978; Barclay 1980); (b) it reduces the acreage or linear extent of riparian habitat when meandering streamcourses are straightened (Barclay 1980); and (c) it alters the flooding regime, initiating long-term changes in floodplain plant communities (Fredrickson 1980; Klimas, Martin, and Teaford 1981). Furthermore, by reducing flooding of surrounding lands, channelization promotes the encroachment of agriculture and urbanization into the riparian zone (Barclay 1980; Fredrickson 1980).

Channelization of several Vermont streams resulted in the loss of about one-third of the bird species found on unchannelized reaches of the same streams (Possardt and Dodge 1978). Impacts on birds were due primarily to destruction of the vegetation along channelized reaches. With the loss of foraging areas in the canopy and understory, warblers, thrushes, and vireos declined precipitously after channelization. However, sparrows, flycatchers, and hummingbirds were unaffected. Spotted sandpipers and swallows were actually more abundant in channelized areas. Similarly, shrews and jumping mice declined along channelized reaches, whereas white-footed mice and meadow voles did not.

In northern California, Hehnke and Stone (1978) sampled birds in unaltered riparian habitat, riprapped areas, and adjacent agricultural fields along the Sacramento River. On the average, riprapped reaches supported only 28 percent of the species and 7 percent of the densities found in unaltered riparian areas. Riparian species that were missing from riprapped areas included woodpeckers, flycatchers, wrens, thrushes, vireos, warblers, and grosbeaks. The greatest disparity in avian densities between riparian and riprapped reaches occurred in September, when riparian habitats contained 56 times the number of birds counted in riprapped areas. Furthermore, agricultural fields adjacent to natural riparian areas supported 50 percent more bird species than those adjacent to riprapped reaches, indicating that streambank clearing affects bird populations beyond the limits of the riparian vegetation (Hehnke and Stone 1978).

Channel straightening in Missouri resulted in drier conditions in the floodplain, stimulating the growth of ground-layer vegetation and an increase in small-mammal populations (Fredrickson 1980). However, riparian-dependent furbearers (mink, beaver, and muskrat) disappeared after channelization. Where forests remained intact, bird abundance and diversity was similar between channelized and unchannelized reaches. Where trees were removed, however, fewer bird species and individuals were encountered. Similarly, straightening and riprapping of southwestern streams significantly reduced their use by birds (Ohmart and Anderson 1978).

Flood-control projects in the Southeast often involve channel clean-out and enlargement and/or streambank clearing and snag removal done by floating dredge from within the stream, without the need to clear vegetation beyond the top of the bank. This approach helps preserve some of the values of the riparian corridor while focusing impacts on the aquatic community and users of the streambanks. Besides the obvious impacts to fish, macroinvertebrates, and stream-dwelling reptiles and amphibians, streambank clearing can result in the decline of other aquatic and semiaquatic species such as wood ducks, wading birds, raccoons, and muskrats due to the removal of protective cover (both live vegetation and woody debris) used by the animals during foraging and the destruction of den sites and food resources. For example, the loss of streambank cover reduces overall habitat suitability for mink to zero even though riparian forests beyond top bank are preserved (Allen 1986).

Amphibians and reptiles along Oklahoma streams declined when channelization destroyed important habitat features such as meanders, pools, and overhangs, and reduced the frequency and duration of flooding (Barclay 1980). Channelized sites also supported consistently fewer bird and mammal species and smaller numbers of individuals. Impacts on birds in particular were intensified by streamside clearing and development of riparian areas following channelization. Forested riparian strips are extremely valuable stopovers for birds that migrate through grassland regions. Their destruction through channelization could have widespread impacts on distant breeding and wintering populations (Barclay 1980).

Streamflow alteration

Natural flow regimes are altered when streams are impounded for flood storage, water supply, or hydropower generation, or when water is diverted for irrigation or small hydro development. Changes in water regimes in turn may have indirect effects on wildlife by altering the distribution of plant species and substrate materials downstream of the project (Franz and Bazzaz 1977; Klimas, Martin, and Teaford 1981; Harris 1986; Johnson and Carothers 1987). Occasionally, ill-timed releases of water from reservoirs cause direct mortality of riparian wildlife (Brown and Johnson 1985).

Diversion of Sierra Nevada headwater streams for hydropower projects resulted in changes in the density, species composition, and structure of riparian plant communities, but the changes along individual streams also depended upon channel width and depth, floodplain gradient, and floodplain width (Harris, Fox, and Risser 1987). Kondolf et al. (1987) reported that the effects of streamflow diversion in the eastern Sierra Nevada depend on local hydrology and geomorphology. Stream reaches in which flow is augmented by groundwater are much less sensitive to upstream diversions than are reaches that lose water to the porous alluvial deposits over which they flow. Almost the entire flow of many creeks along the eastern Sierras has been diverted into the Los Angeles aqueduct. Stine, Gaines, and Vorster (1984) documented the resulting loss of riparian vegetation along streams that once flowed into Mono Lake. Rood and Mahoney (1990) concluded that streamflow alteration by dams on rivers in the western prairies was responsible for the decline of riparian cottonwood forests due to reduced summer flows, producing drought stress in seedlings and mature trees, and reduction of spring flooding, which inhibits development of seedbeds.

Filling of the reservoir at Lake Powell on the Colorado River in 1980 necessitated increased discharges of water through Glen Canyon Dam. During a particularly large release of water in June 1983, Brown and Johnson (1985) reported that 60 percent of Bell's vireo nests in the Grand Canyon were inundated, resulting in a population decline that was felt for at least 2 years. However, a greater long-term threat to riparian-dependent wildlife in the Grand Canyon, according to Brown and Johnson (1985), is the scouring of sediment by floodwaters and the eventual loss of riparian vegetation through erosion.

Among the intended human benefits of flood-control projects is reduced frequency or duration of flood events to protect transportation corridors, residences and other structures, and agricultural crops. Similar benefits occur below dams that regulate flow and reduce flood peaks from historical levels. An often unintended consequence of reduced flooding risk is the subsequent clearing of any remaining woody riparian vegetation and the conversion of the land to other uses. Thus, broad riparian corridors may be narrowed as woodlands are converted to crops or suburban development, with resulting loss of riparian wildlife diversity. (See the section on Riparian Stand Size and Shape.)

Grazing

Grazing by livestock affects riparian zones, particularly on western rangelands, through compaction of the soil, removal of forage, and physical damage to the vegetation due to trampling and browsing (Kauffman and Krueger 1984). These direct impacts may result in increased erosion, increased stream sediment loads, increased water temperatures, elimination of overhanging banks, changes in channel width, reductions in trout and salmon populations, and changes in the vigor, growth form, and species composition of riparian vegetation (Kauffman, Krueger, and Vavra 1983a,b; Kauffman and Krueger 1984; Bohn and Buckhouse 1986).

Grazing may have positive, negative, or neutral effects on riparian wildlife depending upon its timing and intensity, and the wildlife species concerned (Kauffman and Krueger 1984). For example, increased grazing activity in southeastern Oregon was correlated with decreased shrub volumes and heights, and decreased abundance and diversity of breeding birds in streamside habitats (Taylor 1986). One area that had been ungrazed since 1940 supported 50 percent more species and 5 to 7 times the density of songbirds found in areas that had been grazed extensively through 1980. Reduction in grazing pressure and cessation of willow cutting in the same area produced dramatic increases in populations of willow flycatchers and yellow warblers, two riparian-dependent species that are declining throughout the West (Taylor and Littlefield 1986).

In Wyoming, Krueger and Anderson (1985) reported that moderate grazing actually improved high-altitude shrub-willow habitats for birds by producing tunnels through the willow stands, promoting expansion of grasses and sedges and increasing habitat diversity. On the other hand, grazing of high-altitude riparian areas in New Mexico reduced garter snake populations by eliminating escape cover and reducing the availability of invertebrate foods (Szaro et al. 1985).

Impacts of grazing in riparian areas are much less severe when grazing is limited to fall and winter. In Colorado, shrub-willow pastures subjected historically to spring and summer grazing pressure contained fewer breeding bird species than traditionally winter-grazed pastures (Knopf, Sedgwick, and Cannon 1988). Knopf, Sedgwick, and Cannon (1988) identified bird species that were particularly sensitive to changes in shrub density or distribution resulting from summer grazing; these were the willow flycatcher, Lincoln's sparrow, and white-crowned sparrow.

Sedgwick and Knopf (1987) introduced cattle into pastures in cottonwood bottomlands in Colorado that had been ungrazed since 1951. During the first 3 years of moderate fall (October-November) grazing, they could detect no differences in abundance of six bird species that depended upon shrubs and herbaceous vegetation for nesting or foraging. Although prolonged grazing pressure may prevent regeneration of the forest by eliminating seedlings (Kauffman and Krueger 1984; Sedgwick and Knopf 1987), moderate fall and winter grazing apparently has little short-term impact on riparian bird communities.

5 Summary and Conclusions

Riparian vegetation occurs along streams and rivers and contributes greatly to many riparian ecosystem functions that are highly valued by society. Riparian ecosystems occur at the interface between upland and riverine systems where much of the water, nutrients, and animals from a wateshed converge. Riparian vegetation is influenced by these factors from both the upland and riverine ecosystems. An understanding of the ecology of the vegetation in these systems is helpful to understanding the role riparian vegetation plays in stabilizing stream morphology and hydrology, attenuating floods, improving water quality, and supporting wildlife.

Riparian Vegetation Ecology

The structure and function of vegetation of the humid riparian areas of the East differ from riparian vegetation in the arid West. Riparian systems in the East are often dominated by overland flow. Large, complex floodplains develop along eastern rivers and include a large percentage of wetlands by area. Plants in these areas must be adapted to periods and depth of inundation of sufficient duration that soils become anaerobic. Western riparian ecosystems, in contrast, have less surface water through the year. Plants in these areas must be adapted to accessing groundwater that can be very deep relative to rooting depths.

Riparian vegetation varies widely in type, size, and distribution. Grasses, shrubs, vines, and trees are all found in riparian areas, although an area is often dominated by one type of vegetation. Many plant species can occur in both riparian and adjacent uplands, but some species such as western willows have life history characteristics that depend on an association with a river to reproduce and grow. The age and distribution of vegetation often reflects the dynamics of the associated river. Rivers that meander through a floodplain over time, for example, often have vegetation in many phases of succession.

Distribution patterns of riparian vegetation also depend on the moisture gradients, fluvial geomorphic landforms, and stream gradients. Moisture gradients are determined by surface flooding as well as depth to the groundwater. As described above, these differences often relate to eastern and western riparian systems. Plants differ in their ability to withstand inundation, and as a consequence, become distributed within the riparian corridor along an elevation-hydrologic gradient. Similarly for depth to groundwater in more arid systems, plants differ in their ability to access groundwater with varying root depths. Many western plant species are restricted to riparian areas where groundwater is closest to the surface and can be accessed. Distributions of plants on fluvial geomorphic landforms such as bars and terraces are often associated with a moisture gradient. However, the energy of the river also affects the ability of plants to survive close to the river where current energies are greatest. Trees typically dominate vegetation along streams with greater than 4 percent slopes, because they can tolerate the high forces from currents and debris during floods.

Natural ecological processes occur in riparian areas that alter vegetation in space and with time. Vegetation is often tolerant of disturbances such as floods, fire, and landslides that occur on fairly predictable cycles in a given area. The plants often persist following disturbances of low intensity. The species associations change through time as site conditions change in a process called succession. For example, willow that colonizes a newly created sandbar is eventually replaced by other species that are in turn replaced by other species over time. Catastrophic disturbances can remove existing vegetation, and the process of primary succession is set in motion. Disturbances and succession are desirable processes in natural systems because they aid in the maintenance of the system's characteristics. If the disturbance regime or succession of plant communities is changed, the ecosystem changes and may not be capable of sustaining itself into the future.

Hydraulic and Hydrologic Functions

Riparian vegetation affects hydraulic and hydrologic functions of streams and rivers in several ways. Maintenance of stream morphology is improved by the bank stabilization afforded by riparian vegetation. The vegetation minimizes erosion by resisting flow and binding and structurally supporting bank materials. In addition, stream morphology is stabilized by vegetation that stabilizes stream baseflow through interactions with the surface and groundwater inputs from the watershed. Water losses by evapotranspiration help dewater bank materials, minimizing bank failure. Stream morphology is affected by patterns of erosion and deposition. Rates of erosion and deposition generally are minimized in vegetated riparian systems because minimized bank erosion contributes less to the sediment load. Deposition often occurs in vegetated areas such as on newly colonized bars and within floodplains.

Flood attenuation is increased in vegetated riparian systems. As is the case for maintenance of stream morphology, the resistance of vegetation to flow is an important attribute for flood attenuation. The area vegetation presents to flow is proportional to resistance, measured as Manning's n, and effectiveness at reducing flow velocity. Area of vegetation presented to flow can be increased by the size and density of stems. Trees are most effective at resisting flow. Resistance of riparian vegetation is difficult to estimate because it is rarely evenly distributed throughout the area of interest. In addition, resistance of vegetation can change seasonally and degree of maturation.

The use of vegetation, primarily grasses and forbs, for the prevention of surficial erosion on slopes is fairly common. Resistance to flow and stability of vegetation are important considerations in the design of flood control projects. Plant species differ in their tolerance thresholds to flow above which they completely fail and are torn out of the ground. As with resistance, plant failure thresholds to flow are highly variable depending on the age and size of the plant. These thresholds can be measured directly and indirectly in a variety of ways.

Water Quality Functions

Due to their landscape position between upland and riverine ecosystems, riparian corridors are capable of intercepting the majority of surface water entering riverine systems and thereby affecting water quality in the majority of surface waters of the nation. The primary effects of vegetation on water quality are due to increased resistance and nutrient uptake.

Most chemicals and nutrients in river water are associated with suspended solids, both mineral and organic. The increased resistance to flow by riparian vegetation allows suspended solids to settle out of the water column. The associated chemicals and nutrients are also removed from the water column and can become incorporated into the soils. Improvements in water clarity are directly related to the residence time of the overbank river water in the riparian corridor.

Riparian vegetation is intricately involved with the natural cycles of nutrients. Vegetation takes up nutrients that become incorporated into plant materials. Leaves and fruits are consumed by animals. As the plants become dormant in the fall or die, plant material is returned to the soils. Decay processes that are mediated by microorganisms release the minerals back into forms once again available for plant uptake. Nitrogen and phosphorus are taken up by plants in the largest amounts relative to other nutrients. Plants, however, are only temporary reservoirs for nutrients. Only developing plant communities that are increasing in biomass are effective in removing significant amounts of nutrients from the environment.

Riparian vegetation can offset reductions in suspended solids in the water column by adding dissolved and particulate organic carbon. The detrial export from riparian ecosystems, however, is critical to support of ecosystems downstream.

Life Support Functions

Riparian corridors provide critical wildlife habitat in many landscape settings. There is access to water, refuge from predators in the plants, and a variety of food sources. A wide diversity of animal species utilize riparian corridors because of the interface between upland and riverine habitats and linear linkage between upstream and downstream parts of watersheds. On an area basis, far more animals utilize riparian areas than any other landscape feature.

Riparian vegetation provides support for many wildlife requirements. If food is not directly provided to an animal by plants in the form of leaves, fruit, or stems, the insects and other primary consumers of plant materials are a source of food. The plant structure provides areas for rest, nesting, breeding, and escape. Although these characteristics are not unique to riparian vegetation, the proximity of riparian vegetation to other habitats and availability of moisture increases their value for both aquatic and terrestrial animal species.

The value of riparian areas is related to their size and contiguity with other riparian areas. Small or narrow riparian zones do not have adequate structure to support many desirable animal species, particularly neotropical migratory birds. A minimum of a 100-m buffer around streams is often cited as adequate to support most riparian-dependent wildlife species. Riparian areas are most valuable that remain intact and form a continuous corridor for migration.

Riparian vegetation effects on water quality are often beneficial to aquatic fauna. Dissolved and particulate organic matter contributed to streams by riparian vegetation provides critical food sources for downstream ecosystems. Water is cooled in the summer as it passes through vegetated floodplains or under overhanging vegetation. Riparian vegetation helps maintain critical dissolved-oxygen concentrations for aquatic fauna by modifying water temperatures and aiding mixing of oxygenated water from the surface into the water column.

Conclusions

As a corollary to the contributions of vegetation to the many valuable functions provided by riparian ecosystems, those functions are impacted or lost when the vegetation is altered. When rivers and streams are impounded, channelized, or receive increase inputs from developed watersheds, the natural structure of the riparian vegetation is lost. Even if the plants are not directly impacted, the natural hydrologic regime and hydraulics under which the system developed are disrupted, and the system cannot maintain itself. If upland activities such as grazing or crops encroach into the riparian zone, the natural structure of the riparian vegetation is lost. Benefits of the vegetation from resistance to flow, erosion reduction, nutrient cycling, and wildlife support are diminished. The vegetation will recover and stabilize to the new environmental conditions if given ecologically reasonable conditions and the opportunity. Costly engineering solutions, however, are often necessary to replace the functions naturally performed by riparian ecosystems at no cost to society.

Development of rivers must be undertaken with a holist view. The river and riparian corridor form an intricately related complex. If the river is altered, the riparian corridor will be altered and vice versa. The functions performed by riparian corridors cannot be overlooked when evaluating flood control or other river development projects. The costs to society to replace the hydraulic controls, water quality improvement, and wildlife support provided by intact riparian corridors may ultimately be greater than can be justified.

Further study is required to more fully understand how the functions performed by riparian corridors can be integrated with river management requirements. For example, how can the benefits of riparian ecosystems be estimated in dollars? How can natural processes be reestablished in degraded reaches? The benefit for all is a minimization of costs for stream maintenance and water quality improvement.

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Appendix A
A Compilation of Woody and Herbaceous Species Commonly Found in Riparian Systems

Scientific Name	Common Name	Riparian Zone[1]	Value	Reference[2]	Local
		Woody Species			
Abies amabilis	Pacific silver fir	MMF	Aesthetics	Brinson et al. 1981	NW
Abies balsamea	Balsam fir	MLF	Timber, wildlife, aesthetics	Sykes et al. 1993	N, NW
Acacia greggii	Catclaw	AET		Johnson et al. 1989	SW
Acer macrophylum	Big-leaf maple	MMF	Aesthetics	Trush et al. 1989	W, NW
Acer negundo	Box elder	MMF	Wildlife	Sands and Howe 1977; Sykes et al. 1993	N, C, NW
Acer saccharinum	Silver maple	MHF	Timber, wildlife, aesthetics	Sykes et al. 1993	S, NE, C
Acer saccharum	Sugar maple	MHF	Timber, wildlife, aesthetics	"	N, NE, C
Acer rubrum	Red maple	MHF	Timber, wildlife, aesthetics, water quality	"	SE, NE
Aesculus glabra	Buckeye	MMF	Timber	Brinson et al. 1981	NW, N
Aesculus octandra	Yellow buckeye	MHF	Timber	Sands and Howe 1977	E, N

(Sheet 1 of 14)

[1] Riparian zone modifers for vegetation: (East and Pacific Northwest): MLF = Mesic low floodplain; MMF = Mesic medium floodplain; MHF = Mesic high floodplain; MTF = Mesic transitional floodplain; (West): AEC = Arid ephemeral channel; AET = Arid ephemeral transition; AIC = Arid intermittent channel; AIF = Arid intermittent floodplain; AIT = Arid intermittent transition; APC = Arid perrennial channel; APF = Arid perrennial floodplain; APT = Arid perennial transition.

[2] References cited in this appendix are located at the end of the main text.

Scientific Name	Common Name	Riparian Zone[1]	Value	Reference[2]	Local
Woody Species (Continued)					
Allanrolfea occidentalis	Iodine bush		Wildlife	Dick-Peddie and Hubbard 1977	C, W
Alnus oblongifolia	Alder	MMF	Timber (West) wildlife (East)	Sykes et al. 1993	NW
Alnus rhombifolia	White alder	MMF		Lisle 1989; Trush et al. 1989	NW
Alnus rugosa	Speckled alder	MMF		Brinson et al. 1981	NW
Alnus tenuiflolia	Thin-leafed alder	AIF	Wildlife, aesthetics	Dick-Peddie and Hubbard 1977	SW
Aloysia grattisima	White brush	AIT		Bush and Auken 1984	S
Amorpha fructicosa	False indigo-bush	MFS		Monda, Wedel, and Schenck 1993	C
Ampelopsis arborea	Peppervine	AIT		"	C
Artemisia californica	Coastal sagebrush	AIT		Hanes, Friesen, and Keane 1989	SW
Artemisia douglasiana		AIT		Conard et al. 1977	W
Asimina triloba	Pawpaw	MHF		Hanes, Friesen, and Keane 1989	SW
Atriplex sp.	Shadescale	AET		Pinkney 1992	W
Baccharis emoryi	Baccharis	AET		"	W
Baccharis glutinosa	Seep willow	AET		Hanes, Friesen, and Keane 1989	SW
Baccharius salicina	Great Plains false willow	MMF		Monda, Wedel, and Schenck 1993	C
Baccharis sarothroides	Desert broom	AET		Sands and Howe 1977	W
Baccharius viminea	Mulefat	AIT		"	W
Betula alleghaniensis	Yellow birch	MMF	Timber	Sykes et al. 1993	N, NE
Betula fontinalis	Birch	MHF		"	SW
Betula nigra	River birch	MMF	Timber, aesthetics	"	NE
Betula papyrifera	Paper birch	MHF	Timber, aesthetics	"	NE
Betula populifolia	Grey birch	MHF	Wildlife	"	NE
Brickella laciniata	Brickel brush	AET		Dick-Peddie and Hubbard 1977	W
Bumelia lanuginosa	Gum bumelia	MHF	Aesthetics	Bush and Auken 1984	SW
					(Sheet 2 of 14)

Scientific Name	Common Name	Riparian Zone[1]	Value	Reference[2]	Local
Woody Species (Continued)					
Campsis radicans	Trumpet creeper	AIT		Sykes et al. 1993	SW
Carpinus caroliniana	American hornbeam	MHF	Aesthetics	"	C, NE
Carya aquatica	Water hickory	MLF	Timber, wildlife	"	SE
Carya cordiformis	Bitternut hickory	MMF	Timber, wildlife	Sykes et al. 1993; Monda, Wedel, and Schenck 1993	C, NE, S
Carya glabra	Pignut hickory	MHF	Timber, wildlife	"	SE
Carya illinoensis	Sweet pecan	MHF	Timber, wildlife, aesthetics	Monda, Wedel, and Schenck 1993	S
Carya laciniosa	Shellbark hickory	MHF	Timber, wildlife	"	N, E
Carya lieodermis	Swamp hickory	MIF	Timber, wildlife	"	SE
Carya ovata	Shagbark hickory	MHF	Timber, wildlife	"	E, S, N
Carya pallida	Sand hickory	MHF	Timber, wildlife	"	S, NE
Carya tomentosa	Mockernut hickory	MHF	Timber, wildlife	"	SE
Catalpa bignonioides	Catalpa	MMF	Timber, aesthetics	"	E
Celtis laevigata	Sugarberry	MMF	Timber, wildlife, aesthetics	"	SE, NE, C
Celtis occidentalis	Common hackberry	MMF	Timber, aesthetics, wildlife	Monda, Wedel, and Schenck 1993	NE, SE, C
Celtis pallida	Hackberry	AIF	Wildlife	Bush and Auken 1984	SE, SW, C
Celtis reticulata	Desert hackberry	AIF	Wildlife	"	SW
Cephalanthis occidentalis	Buttonbush	APC/MFS	Wildlife	Sykes et al. 1993; Sands and Howe 1977	Nationwide
Cercis canadensis	Redbud	MHF	Aesthetics	Monda, Wedel, and Schenck 1993	C, N
Cercidium floridum	Palo verde	AET		Pinkney 1992	W
Cercocarpus betuloides	Mountain mahoghany	AET		Hanes, Friesen, and Keane 1989	SW
Chamaecyparis thyoides	Atlantic white cedar	MMF	Timber	Sykes et al. 1993	E, NE
Chilopsis linearis	Desert willow	AET		Pinkney 1992	W
Chrysothamnus nauseosus var. graveolons	Rabbit brush	AET		Dick-Peddie and Hubbard 1977	W, SW
Clematis pitcheri	Pitcher's virgin's bower	AET		Monda, Wedel, and Schenck 1993	C

(Sheet 3 of 14)

Scientific Name	Common Name	Riparian Zone[1]	Value	Reference[2]	Local
Woody Species (Continued)					
Conium maculatum	Poison hemlock	AIT		Conard et al. 1977	W
Condalia hookeri	Brasil	AET		Bush and Auken 1984	S
Cornus amomum	Silky dogwood	MHF	Wildlife, water quality	Monda, Wedel, and Schenck 1993; Sykes et al. 1993	C, SE
Cornus drummondii	Rough-leaf dogwood	MTF	Aesthetics	Great Plains Flora Assoc. 1986; Monda, Wedel, and Schenck 1993	C, N, W
Cornus florida	Flowering dogwood	MTF	Timber, widlife, aesthetics	Sykes et al. 1993	E, NE, S, C
Cornus stolonifera	Red-osier dogwood	MLF	Wildlife, aesthetics	"	E, SE
Corylus americana	Hazlenut	MHF	Timber	"	E, SE
Crataegus sp.	Hawthorn	MMF	Timber	Boldt, Uresk, and Severson 1978; Sykes et al. 1993	E, C
Diospyros virginiana	Persimmon	MLF	Timber, wildlife	Sykes et al. 1993	SE
Elaegnus angustifolia	Russian olive	MMF		Monda, Wedel, and Schenck 1993	C
Eriastrumdensifolium ssp. *sanctorum*	Santa Ana River wolly-star	AIC		Hanes, Friesen, and Keane 1989	W
Ericameria pinifolia	Pine goldenbrush	AIT		"	SW
Eriodictyon trichocalyx	Hairy yerba santa	AIT		"	SW
Euonymus atropurpureus	Wahoo	MHF		Monda, Wedel, and Schenck 1993	S, SW, C
Fagus grandifolia	American beech	MTF	Timber, wildlife, water quality	Sykes et al. 1993	NE, SE, C
Fallugia paradoxa	Apache-plume	AET		Dick-Peddie and Hubard 1977	W, SW
Forestiera acuminata	Swamp privet	MLF	Aesthetics	Sykes et al. 1993	SE, SW
Forestiera neomexicana	New Mexican olive	AET	Aesthetics	Monda, Wedel, and Schenck 1993	W, SW
Forquieria splendens	Ocotillo	AET		Pinkney 1992	W
Franseria dumosa	White bursage	AET		"	W
Fraxinus velutina	Velvet ash	MLF	Timber, water quality	"	W
Fraxinus americana	White ash	MLF	Water quality, aesthetics	Sykes et al. 1993	C, S, NE
					(Sheet 4 of 14)

Scientific Name	Common Name	Riparian Zone[1]	Value	Reference[2]	Local
Woody Species (Continued)					
Fraxinus caroliniana	Swamp ash	MFS	Aesthetics	Sykes et al. 1993	E, SE
Fraxinus latifolia	Oregon ash	MMF	Aesthetics	Sands and Howe 1977; Trush et. al 1989	NW
Fraxinus nigra	Black ash	MFS		Brinson et al. 1981	NE
Fraxinus pennsylvanica	Green ash	MLF	Aesthetics	Sykes et al. 1993	Nationwide
Fraxinus profunda	Pumpkin ash	MMF	Timber	"	NE, SE, C
Gleditsia aquatica	Water locust	MLF	Aesthetics	"	SE, C
Gleditsia triacanthos	Honey locust	MHF	Timber, wildlife, aesthetics	Monda, Wedel, and Schenck 1993	SE, C
Gordonia lasianthus	Loblolly bay	MMF	Aesthetics	Sykes et al. 1993	SE, C, NE
Gymnocladus dioicus	Kentucky coffeetree	MHF	Timber, aesthetics, wildlife	Monda, Wedel, and Schenck 1993	NE, SE, C
Hymenoclea monogyra	Burrow weed	AET		Sykes et al. 1993	SW
Ilex decidua	Deciduous holly	MMF/AIF	Aesthetics, wildlife	Dick-Peddie and Hubbard 1977; Sykes et al. 1993	Nationwide
Ilex opaca	American holly	MMF	Aesthetics	Dick-Peddie and Hubbard 1977	Nationwide
Itea virginicia	Virginia willow	AIF	aesthethics		W, NW
Juglans cinera	Butternut	MHF	Timber, wildlife, aesthetics	Sykes et al. 1993	N, NE
Juglans nigra	Black walnut	MHF	Timber, wildlife	Monda, Wedel, and Schenck 1993; Sykes et al. 1993	C, E, NW
Juglans major	Nogal walnut	AET	Wildlife	Dick-Peddie and Hubbard 1977	W
Juglans microcarpa	Little walnut	AET	Wildlife	"	W
Juniperus californica	Californa juniper	AET		Hanes, Friesen, and Keane 1989	SW
Juniperus virginiana	Eastern redcedar	MTF	Timber, wildlife, aesthetics, water quality	Monda, Wedel, and Schenck 1993; Sykes et al. 1993	SE, E
Larix laricina	Larch	MFS		Brinson et al. 1981	NE
Larrea tridentata	Creosote bush	AET		Pinkney 1992	W
Lepidospartum quamatum	Scalebroom	AET/APT		Hanes, Friesen, and Keane 1989	W
Lindera benzoin	Spice bush	AET		"	NE, E

(Sheet 5 of 14)

Scientific Name	Common Name	Riparian Zone[1]	Value	Reference[2]	Local
Woody Species (Continued)					
Liquidambar styraciflua	Sweetgum	MMF	Timber, wildlife	Sykes et al. 1993	SE
Liriodendron tulipifera	Yellow-poplar	MTF	Timber, wildlife, aesthetics, water quality	"	SE, NE
Lonicera involucrata	Ink berry	AIT		Brinson et al. 1981	W
Lycium sp.	Boxthorn	AET		Pinkney 1992	W
Lycium torreyi	Wolfberry	AIT		Brinson et al. 1981	W
Maclura pomifera	Osage orange	MMF	Timber, wildlife	Monda, Wedel, and Schenck 1993; Sykes et al. 1993	S, C
Magnolia grandiflora	Southern magnolia	MHF	Aesthetics	Sykes et al. 1993	SE
Magnolia virginiana	Sweetbay	MMF	Aesthetics	"	NE, SE
Malosma laurina	Laurel sumac	AIT		Hanes, Friesen, and Keane 1989	SW
Menispermum canadense	Canada moonseed	AIT		Monda, Wedel, and Schenck 1993	C
Morus microphylla	Mulberry	AIF	Aesthetics	Dick-Peddie and Hubbard 1977	SW
Morus alba	White mulberry	MMF	Aesthetics, wildlife	Monda, Wedel, and Schenck 1993	NE, C, S
Morus rubra	Red mulberry	MHF	Timber, wildlife	"	NE, SE, C
Nyssa aquatica	Water tupelo	MFS	Timber, wildlife, aesthetics	Sharitz and Lee 1985; Sykes et al. 1993	SE
Nyssa sylvatica v. biflora	Tupelo swamp	MFS	Timber, wildlife, aesthetics	"	SE
Nyssa sylvatica	Black gum	MFS	Timber, wildlife, aesthetics	"	NE, SE
Olneya tesota	Ironwood	AET		Johnson et al. 1989	W
Opuntia littoralis	Coastal prickly pear	AET		Hanes, Friesen, and Keane 1989	SW
Opuntia parryi	Valley eliotis	AIT		"	SW
Orontium aquaticum	Golden club	AIT			S, E, C
Ostrya rubra	Hophorn beam	MHF		Dick-Peddie and Hubbard 1977	SW
Oxydendrum arboreum	Sour wood	MHF	Wildlife	Sykes et al. 1993	SE, NE
Parthenocissus inserta	Thicket creeper	MMF		Monda, Wedel, and Schenck 1993	C
					(Sheet 6 of 14)

Scientific Name	Common Name	Riparian Zone[1]	Value	Reference[2]	Local
Woody Species (Continued)					
Parthenocissus quinquefolia	Virginia Creeper	MMF		Monda, Wedel, and Schenck 1993	C
Persea borbonia	Red bay	MLF	Timber, aesthetics	Sykes et al. 1993	SE
Philadelphus microphyllus	Mock orange			Dick-Peddie and Hubbard 1977	W
Picea glauca	White spruce	MMF	Timber, wildlife, water quality	Sykes et al. 1993	E, NE
Picea mariana	Black spruce	MMF	Timber, wildlife, aesthetics	"	NW, NE
Picea pungens	Red spruce	MMF	Timber, wildlife, aesthetics	"	NE
Pinus echinata	Shortleaf pine	MMF	Timber	"	SE
Pinus elliotti	Slash pine	MMF	Timber	"	SE
Pinus glabra	Spruce pine	MHF	Timber	"	SE
Pinus rubens	Red pine	MHF	Timber	Sykes et al. 1993	NE
Pinus serotina	Pond pine	MMF	Timber	"	SE
Pinus strobus	White pine	MMF	Timber, wildlife, aesthetics	"	NE
Pinus taede	Loblolly pine	MMF	Timber, water quality	Sharitz and Lee 1985; Sykes et al. 1993	SE
Pinus virginiana	Virginia pine	MHF	Timber	Sykes et al. 1993	E
Planera aquatica	Water elm	MFS	Aesthetics	"	E
Platanus occidentalis	American sycamore	MMF	Timber, aesthetics	Monda, Wedel, and Schenck 1993	N, SE, C
Platanus racemosa	California sycamore	AET	Aesthetics	Hanes, Friesen, and Keane 1989	W
Plantanus wrightii	Sycamore	AET		Conard et al. 1977	SW, NW
Pluchea sericia	Arrow weed	MHF		Dick-Peddie and Hubbard 1977	SW
Populus acuminata	Narrow leaf cottonwood	APC	Aesthetics	"	SW
Populus angustifolia	Cottonwood	APC		Brinson et al. 1981	Nationwide
Populus balsamifera	Balsam poplar	APC		"	NW
Populus deltoides	Eastern cottonwood	MMF/AIC	Timber, wildlife, aesthetics	Ware and Penfound 1949; Sykes et al. 1993	N, SE

(Sheet 7 of 14)

Scientific Name	Common Name	Riparian Zone[1]	Value	Reference[2]	Local
Woody Species (Continued)					
Populus fremontii	Fremont cottonwood	AIF	Aesthetics	Sands and Howe 1977	SW, NW
Populus grandidentata	Bigtooth aspen	MFS	Timber, wildlife	Sykes et al. 1993	N, NE
Populus sargentii	Plains cottonwood		Aesthetics	"	SW
Populus tremuloides	Quaking aspen	MMF	Timber, wildlife, water quality	"	NE, NW
Prosopis juliflora	Mesquite	AET/MHF		Pinkney 1992	C, E
Prosopis pubescens	Screwbean	AET/MHF		"	C, W
Prunus americana	Wild plum	AET/MHF	Wildlife	Boldt, Uresk, and Severson 1978	C, W
Prunus ilicifolia	Holly-leaved cherry	AET		Hanes, Friesen, and Keane 1989	SW
Prunus serotina	Black cherry	MHF	Timber, wildlife	Monda, Wedel, and Schenck 1993	C, NE, SE
Prunus virginiana	Common choke cherry	MTF	Wildlife	Boldt, Uresk, and Severson 1993	C, SW
Quercus alba	White oak	MTF	Timber, wildlife, water quality	Sykes et al. 1993	NE, C
Quercus bicolor	Swamp white oak	MLF	Timber, wildlife, water quality	"	SE
Quercus falcata var. falcata	Southern red oak	MMF	Timber, wildlife, aesthetics, water quality	Sykes et al. 1993	SE
Quercus falcata var. pagdaefolia	Cherrybark oak	MHF	Timber, wildlife, water quality	"	SE
Quercus imbricaria	Shingle oak	MHF	Timber, wildlife, water quality	"	SE
Quercus laurifolia	Laurel oak	MHF	Timber, wildlife, aesthetics	"	SE
Qurecus lobata	Valley oak	MHF		Conard et al. 1977	E
Quercus lyrata	Overcup oak	MLF	Timber, wildlife, water quality	"	C, N
Quercus macrocarpa	Bur oak	MLF	Wildlife, aesthetics, water quality	Monda, Wedel, and Schenck 1993	C, SE
Quercus marilandica	Blackjack oak	MHF	Timber, wildlife, water quality	Sykes et al. 1993	E
Quercus michanxii	Swamp chestnut oak	MHF	Timber, wildlife, aesthetics	"	S

(Sheet 8 of 14)

Scientific Name	Common Name	Riparian Zone[1]	Value	Reference[2]	Local
Woody Species (Continued)					
Quercus muehlenbergii	Chinkapin oak	MHF	Timber, wildlife, water quality	Sykes et al. 1993	S, E
Quercus nigra	Water oak	MLF	Timber, wildlife, water quality	"	SE
Quercus nuttallii	Nuttall oak	MMF/MLF	Timber, water quality	"	S
Quercus palustris	Pin oak	MMF	Timber, wildlife, aesthetics	Monda, Wedel, and Schenck 1993	C, NE
Quercus phellos	Willow oak	MMF/MLF	Timber, wildlife, water quality	Sykes et al. 1993	SE
Quercus prinus	Chestnut oak	MHF	Timber, wildlife, water quality	"	C, NE
Quercus rubra	Northern red oak	MHF	Timber, wildlife, water quality	"	S, NE
Quercus shumardii	Shumard oak	MHF	Timber, wildlife, water quality, aesthetics	"	C, SE
Quercus stellata	Post oak	MHF	Timber, wildlife, aesthetics	"	S, SE
Quercus velutina	Black oak	MHF	Timber, wildlife, water quality	"	S, N, SE
Quercus virginiana	Live oak	MHF	Timber, wildlife, aesthetics	"	S, SE
Rhamnus betulaefolia	Birchleaf buckthorn	AET		Dick-Peddie and Hubbard 1977	W
Rhamnus crocea	Californica redberry	AET		Hanes, Friesen, and Keane 1989	SW
Rhus diversiloba		AIF		Conard et al. 1977	W
Rhus integrifolia	Lemonadeberry	AET		Hanes, Friesen, and Keane 1989	SW
Rhus microphylla	Little-leaf sumac	AET		Conard et al. 1977	W
Rhus ovata	Sugarbush	AET		Hanes, Friesen, and Keane 1989	SW
Rhus radicans	Poison ivy	MMF/AIF		Brinson et al. 1981	Nationwide
Ribes aureum	Golden currant	AET		Hanes, Friesen, and Keane 1989	SW
Ribes missouriense	Missouri gooseberry	MHF		Monda, Wedel, and Schenck 1993	C
Robinia pseudoacacia	Black locust	MHF	Timber, wildlife	Sykes et al. 1993	E
Salix amydaloides	Peach-leaf willow	MLF	Aesthetics	Monda, Wedel, and Schenck 1993	SE, C

(Sheet 9 of 14)

Scientific Name	Common Name	Riparian Zone[1]	Value	Reference[2]	Local
Woody Species (Continued)					
Salix caroliniana	Carolina willow	MFS	Aesthetics	Sykes et al. 1993	SE
Salix cottettii	Bankers willow	MLF/MFS	Aesthetics	"	SE
Salix exigua	Coyote willow	AET		Pinkney 1992	W
Salix gooddingii	Southwestern cottonwood	AIF/MLF	Aesthetics	Sands and Howe 1977	SW
Salix hindsiana	Sandbar willow	AIF	Aesthetics	Ware and Penfound 1949	C, N
Salix nigra	Black willow	MLF	Aesthetics	Monda, Wedel, and Schenck 1993	SE, C
Salix purpurea	Purple osier willow	MFS	Aesthetics	Sykes et al. 1993	C
Salix scouleriana	Scouler willow	AET	Aesthetics	Brinson et al. 1981	NW
Salvia mellifera	Black sage	AET		Hanes, Friesen, and Keane 1989	SW
Sambucus canadensis	American elderberry	MHF		Monda, Wedel, and Schenck 1993	C
Sapindus saponaria	Soapberry	MMF		Bush and Auken 1984	SW
Sarcobatus vermiculatus	Grease wood	AET		Dick-Peddie and Hubbard 1977	W, SW
Sassafras albidum	Sassafras	MTF	Timber, wildlife, aesthetics		NE, SE
Sherpherdia argentea	Buffalo-berry	AIT		Dick-Peddie and Hubbard 1977	W, SW
Smilax bona-nox	Bull briar	MMF		Bush and Auken 1984	C
Smilax hispida	Bristly/greenbriar	MMF		Monda, Wedel, and Schenck 1993	SW
Symphoricarpus occidentalis	Western snowberry	MMF		Boldt, Uresk, and Severson 1978	C, NW
Symphoricarpos orbiculatus	Buckbrush	MMF		Monda, Wedel, and Schenck 1993	C
Tamarix chinensis	Exotic salt cedar	APC	Wildlife	Anderson, Higgins, and Ohmart 1977	SW
Tamarix pentandra	Tamarisk	APC		Pinkney 1992	W
Taxodium ascendens	Baldcypress	MFS	Timber, aesthetics, water quality	Sykes et al. 1993	SE
Taxodium distichum	Pondcypress	MFS	Timber, aesthetics, water quality	"	SE

(Sheet 10 of 14)

Scientific Name	Common Name	Riparian Zone[1]	Value	Reference[2]	Local
Woody Species (Concluded)					
Taxus brevifolia	Pacific yew	MMF	Timber, aesthetics	Trush et al. 1989	NW, N
Thuja occidentalis	Northern white cedar	MFS		Brinson et al. 1981	NE
Thuja plicata	Western red cedar	MHF		"	NW
Tsuga heterophylla	Western hemlock	MHF		"	NW
Tilia americana	American basswood	MLF	Timber	Sykes et al. 1993	NE
Toxicodendron radicans	Kuntze poison ivy	MHF		Monda, Wedel, and Schenck 1993	C
Toxicondendron rydbergii	Redberg poison ivy	MMF		"	C
Ulmus alata	Winged elm	MHF	Timber, aesthetics	"	S, SE
Ulmus americana	American elm	MMF	Timber, wildlife, aesthetics	"	C, NE, SE
Ulmus crassifolia	American cedar	MMF	Wildlife	Sykes et al. 1993	C, NE
Ulmus pumila	Siberian elm	MMF	Timber	"	C
Ulmus rubra	Slippery elm	MMF	Timber	"	C
Vitis cinera	Graybark grape	MMF		Monda, Wedel, and Schenck 1993	C
Vitis girdiana	Wild grape			Monda, Wedel, and Schenck 1993	S, W, C
Vitis mustangensis	Mustang grape	AET		Bush and Auken 1984	SW
Vitis riparia	River-bank grape	AIT		Great Plains Flora Assoc. 1986	W
Vitis vulupina	Winter grape	AET		Monda, Wedel, and Schenck 1993	C
Yucca whipplei	Yucca	AET		Hanes, Friesen, and Keane 1989	SW
Herbaceous					
Agrostis	Bentgrass	MTF		Monda, Wedel, and Schenck 1993	C
Alopercurus sp.	Fox-tail	MHE/AET	Wildlife	Dick-Peddie and Hubbard 1977	Nationwide
Arundo donax	Giant reed	AIT	Aesthetics	"	SE, SW
Bidens sp.	Beggars-ticks	MLF		Monda, Wedel, and Schenck 1993	C
Bromus diandrus	Ripgut brome	AET	Wildlife	"	SW, S

(Sheet 11 of 14)

Scientific Name	Common Name	Riparian Zone[1]	Value	Reference[2]	Local
Herbaceous (Continued)					
Bouteloua sp.	Grama	MMF/AIF	Wildlife	Monda, Wedel, and Schenck 1993	Nationwide
Carex sp.	Sedge	MHF/AET	Wildlife, aesthetics	Dick-Peddie and Hubbard 1977	Nationwide
Carex languinosa	Wolly sedge	MHF/AET	Wildlife, aesthetics	Kovalchik and Elmore 1992	
Catabrosa aquatica	Brook grass	MTF	Wildlife	"	NW, C
Centrostegia lepioceras	Slender-horned spine flower	AET		Hanes, Friesen, and Keane 1989	SW
Chlorogalum pomeridianum	Soap plant	AET		Sands and Howe 1977	W
Commelina sp.	Dayflower	MMF		Monda, Wedel, and Schenck 1993	C
Cyperus sp.	Flat-sedge	MLF/AIF		Dick-Peddie and Hubbard 1977; Monda, Wedel, and Schenck 1993	Nationwide
Cypres esculentus	Chufa	AIC		Ware and Penfound 1989	W
Desmodium sp.	Tickclover	AIT		Monda, Wedel, and Schenck 1993	C
Distichilis stricta	Salt grass	AIF		Dick-Peddie and Hubbard 1977	Nationwide
Echinoochloa sp.	Barnyard grass	MLF		Monda, Wedel, and Schenck 1993	C
Eleocharis sp.	Spikerush	AIF		"	Nationwide
Elymus sp.	Wild rye	MTF	Wildlife	Great Plains Flora Assoc. 1986; Monda, Wedel, and Schenck 1993	N, C, W
Eragrostis pectinacea	Lovegrass	MIT		Great Plains Flora Assoc. 1986	N, C, W
Erigeron sp.		AET		Sands and Howe 1977	Nationwide
Eriogonum fasciculatum	California buckwheat	AET		Hanes, Friesen, and Keane 1989	SW
Equisetum sp.	Horsetail	MMF/AIF		Dick-Peddie and Hubbard 1977; Monda, Wedel, and Schenck 1993	Nationwide
Euphorbia maculata	Spotted spurge	AET		Great Plains Flora Assoc. 1986	N, C, W

(Sheet 12 of 14)

Scientific Name	Common Name	Riparian Zone[1]	Value	Reference[2]	Local
Herbaceous (Continued)					
Euphorbia marginata	Snow-on-the-Mountain	AET		Great Plains Flora Assoc. 1986	N, C, W
Festuca pratensis	Meadow fescue	MMF		Monda, Wedel, and Schenck 1993	C
Festuca octoflora	Six-week-fescue	AET		Great Plains Flora Assoc. 1986	N, C, W
Fimbristylis sp.		AET		"	Nationwide
Galium sp.	Bedstraw	MHF	Wildlife	Monda, Wedel, and Schenck 1993	Nationwide
Gaura coccinea	Scarlet guara	AIT		Great Plains Flora Assoc. 1986	N, C, W
Glyceria striata	Fowl manna grass	MHF	Wildlife	Monda, Wedel, and Schenck 1993	C
Helianthus grosseserratus	Sawtooth sunflower	MMF		"	C
Helianthus petiolarus	Plains sunflower	AIT		Great Plains Flora Assoc. 1986	N, C, W
Helianthus tuberosus	Jerusalem artichoke	MMF		Monda, Wedel, and Schenck 1993	C
Hordeum sp.	Barley	AIT		Dick-Peddie and Hubbard 1977	Nationwide
Juncus sp.	Rush	AIT		"	Nationwide
Koeleria cristata	Junegrass	AET		Great Plains Flora Assoc. 1986	N, C, W
Leersia oryzoides	Cut grass	AET		Dick-Peddie and Hubbard 1977	W
Leptocholoa sp.	Sprangle top	MFS		Monda, Wedel, and Schenck 1993	C
Liatris punctata	Blazing star	AET		Great Plains Flora Assoc. 1986	N, C, W
Luzula sp.	Wood-rush	AET		Dick-Peddie and Hubbard 1977	C, W
Lycopus americanus	American bugleweed	AET		Great Plains Flora Asso. 1986	N, C, W
Lysimachia ciliata	Skeleton weed	AET		Great Plains Flora Assoc. 1986	N, C, W
Lythrum dacotanum	Fringed loosestrife	AIT		"	N, C, W
Medicago sativa	Alfalfa	AET		"	N, C, W
Melilotus albus	White sweet clover	AET		"	N, C, W

(Sheet 13 of 14)

Scientific Name	Common Name	Riparian Zone[1]	Value	Reference[2]	Local
Herbaceous (Concluded)					
Muhlenbergia cuspidata	Plains muhly	AET		Great Plains Flora Assoc. 1986	C
Muhlenbergia sylvatica	Forest muhly	MLF		Monda, Wedel, and Schenck 1993	C
Panicum sp.	Panic grass	AET		Great Plains Flora Assoc. 1986	N, C, W
Phragmites communis	Reed	AIT		"	Nationwide
Phalaris arundinacea	Reed canary grass	MLF		Monda, Wedel, and Schenck 1993	Nationwide
Phyla cuneifolia	Wedge leaf frog fruit	MMF		Monda, Wedel, and Schenck 1993	C
Phyla lanceolata	Lance leaf frog fruit	MFS		"	C
Polygonum sp.	Smartweed	AIT		"	Nationwide
Polypogon sp.	Rabbitfoot	AET		Dick-Peddie and Hubbard 1977	Nationwide
Potentilla sp.	Cinquefoil	MMF		Monda, Wedel, and Schenck 1993	C
Ranunculus sp.	Buttercup	MLF		"	C
Rubus allegheniensis	Common blackberry	MHF/AIF	Wildlife	Monda, Wedel, and Schenck 1993	C, S
Rubus hispidus	Swamp dewberry	MMF	Wildlife	"	C
Rubus occidentalis	Black raspberry	AET	Wildlife	Boldt, Uresk, and Severson 1993; Monda, Wedel, and Schenck 1993	C
Rumex crispex	Curly dock	MLF		"	C
Sanicula canadensis	Canada Sanicle	MHF			NE
Scirpus spp.	Bulrush	MHF		"	Nationwide
Typha latifolia	Cattail	MMF		"	W, S, SW
Viola sp.	Violet	MMF	Aesthetics	Monda, Wedel, and Schenck 1993	C,
Xanthium gallica	Cocklebur	AIC		Sands and Howe 1977; Ware and Penfound 1989	SE, NE
					(Sheet 14 of 14)

Appendix B Nomenclature of Birds Mentioned by Common Name in Text[1]

Common Name	Scientific Name
Bald Eagle	*Haliaeetus leucocephalus*
Osprey	*Pandion haliaetus*
Red-shouldered Hawk	*Buteo lineatus*
Common Black Hawk	*Buteogallus anthracinus*
Zone-tailed Hawk	*Buteo albonotatus*
Prairie Falcon	*Falcon mexicanus*
Barred Owl	*Strix varia*
Spotted owl	*Strix occidentalis*
Chimney Swift	*Chaetura pelagica*
Belted Kingfisher	*Ceryle alcyon*
Red-headed Woodpecker	*Melanerpes erythrocephalus*
Pileated Woodpecker	*Dryocopus pileatus*
Ivory-billed Woodpecker	*Campephilus principalis*
Masked Bobwhite	*Colinus virgianus ridgwayi*
Ring-necked Pheasant	*Phasianus colchicus*
Wild Turkey	*Meleagris gallopavo*
American Woodcock	*Scolopax minor*
Acadian Flycatcher	*Empidonax virescens*
Willow Flycatcher	*Empidonax traillii*
Great Crested Flycatcher	*Myiarchus crinitus*
	(Sheet 1 of 3)

[1] Major species lists for birds in these areas can be found in Stevens et al. 1977; Wauer 1977; Brinson et al. 1981; Wharton et al. 1981; Wharton, Kitchens, and Sipes 1982; Wilkinson et al. 1987; and Finch 1991. (References cited in this appendix are located at the end of the main text.)

Common Name	Scientific Name
Tree Swallow	*Tachycineta bicolor*
Golden-crowned Kinglet	*Regulus satrapa*
Ruby-crowned Kinglet	*Regulus Calendula*
Blue-gray Gnatcatcher	*Polioptila caerulea*
Yellow-billed Cuckoo	*Coccyzus americanus*
Wood Duck	*Aix sponsa*
Mallard	*Anas platyrhynchos*
Green-winged Teal	*Anas crecca*
Blue-winged Teal	*Anas discors*
Northern Pintail	*Anas acuta*
Northern Shoveler	*Anas clypeata*
Gadwall	*Anas strepera*
American Wigeon	*Anas americana*
Lesser Scaup	*Aythya affinis*
Canvasback	*Aythya valisineria*
Redhead	*Aythya americana*
Ring-necked Duck	*Aythya collaris*
Hooded Merganser	*Lophodytes cucullatus*
Canada Goose	*Branta canadensis*
Snow Goose	*Chen caerulescens*
Greater White-fronted Goose	*Anser albifrons*
Great Blue Heron	*Ardea herodias*
Yellow-crowned Night Heron	*Nycticorax violaceus*
Yuma Clapper Rail	*Rallus longirostris yumanensis*
Spotted Sandpiper	*Actitis macularia*
Least Tern	*Sterna antillarum*
Whooping Crane	*Grus americana*
Summer Tanager	*Piranga rubra*
Scarlet Tanager	*Pirangra olivacea*
Yellow-throated Warbler	*Dendroica dominica*
White-crowned Sparrow	*Zonotrichia leucophrys*
White-throated Sparrow	*Zonotrichia albicollis*
Lincoln's Sparrow	*Melospiza lincolnii*
American Goldfinch	*Cardeulis tristis*
Purple Finch	*Carpodacus purpureus*
Pine Siskin	*Carduelis pinus*
Rufous-sided Towhee	*Pipilo erythropthalmus*
Carolina Wren	*Thryothorus ludovicianus*
	(Sheet 2 of 3)

Common Name	Scientific Name
Carolina Chickadee	*Parus carolinensis*
Black-capped Chickadee	*Parus atricapillus*
Tufted Titmouse	*Parus bicolor*
Swainson's Thrush	*Catharus ustulatus*
Northern Cardinal	*Cardinalis cardinalis*
Red-winged Blackbird	*Agelaius phoeniceus*
Common Grackle	*Quiscalus quiscula*
Bell's Vireo	*Vireo bellii*
Red-eyed Vireo	*Vireo olivaceous*
Louisiana Waterthrush	*Seiurus motacilla*
Protonontary Warbler	*Protonotaria citrea*
Northern Parula	*Parula americana*
American Redstart	*Setophaga ruticilla*
Swainson's Warbler	*Limnothlypis swainsonii*
Yellow Warbler	*Dendroica petechia*
	(Sheet 3 of 3)

Appendix C Nomenclature of Mammals Mentioned by Common Name in Text[1]

Common Name	Scientific Name
Virginia Opposum	*Didelphis virginiana*
Indiana Myotis	*Myotis sodalis*
Raccoon	*Procyon lotor*
Ringtail	*Bassariscus astutus*
Nutria	*Myocastor coypus*
Muskrat	*Ondatra zibethicus*
Mink	*Mustela vison*
Fisher	*Martes pennanti*
Striped Skunk	*Mephitis mephitis*
Western Spotted Skunk	*Spilogale gracilis*
Beaver	*Castor canadensis*
River Otter	*Lutra canadensis*
Eastern Cottontail	*Sylvilagus floridanus*
Desert Cottontail	*Sylvilagus audubonii*
Nuttall's Cottontail	*Sylvilagus nuttallii*
Swamp Rabbit	*Sylvilagus aquaticus*
Riparian Brush Rabbit	*Sylvilagus bushmani riparius*
Snowshoe Hare	*Lepus americanus*
Yellow-faced Pocket Gopher	*Pappogeomys castanops*

(Continued)

[1] Major species lists for mammals in these areas can be found in Brinson et al. 1981; Wharton et al. 1981; Wharton, Kitchens, and Sipe 1982; and Wilkinson et al. 1987. (References cited in this appendix can be found at the end of the main text.)

(Concluded)	
Common Name	**Scientific Name**
Desert Pocket Mouse	*Perognathus pencillatus*
Merriam's Kangaroo Rat	*Dipodomys merriami*
White-footed Mouse	*Peromyscus leucopus*
Deer Mouse	*Peromyscus maniculatus*
Golden Mouse	*Ochrotomys nuttalli*
Hispid Cotton Rat	*Sigmodon hispidus*
Southern Plains Woodrat	*Neotoma micropus*
Coyote	*Canis latrans*
Gray Fox	*Urocyon cinereoargenteus*
Red Fox	*Vulpes vulpes*
Red Wolf	*Canis rufus*
Bobcat	*Felis rufus*
Florida Panther	*Felis concolor coryi*
Yuma Mountain Lion	*Felis concolor browni*
Ocelot	*Felis pardalis*
Marsh Rice Rat	*Oryzomys palustris*
Colorado River Cotton Rat	*Sigmodon arizonae plenus*
Eastern Woodrat	*Neotoma floridana*
Least Shrew	*Cryptotis parva*
Water Shrew	*Sorex palustris*
Southern Short-tailed Shrew	*Blarina carolinensis*
Desert Shrew	*Notiosorex crawfordi*
Meadow Vole	*Microtus pennsylvanicus*
Hualapai Mexican Vole	*Microtus mexicanus hualpaiensis*
Eastern Mole	*Scalopus aquaticus*
Gray Squirrel	*Sciurus carolinensis*
Arizona Gray Squirrel	*Sciurus arizonensis*
White-tailed Deer	*Odocoileus virginianus*
Mule Deer	*Odocoileus hemionus*
Elk	*Cervus elaphus*
Moose	*Alces alces*
Black Bear	*Ursus americanus*
Louisiana Black Bear	*Ursus americanus luteolus*
Grizzly Bear	*Ursus arctos*

Appendix D
Nomenclature of Herpetofauna Mentioned by Common Name in Text[1]

Common Name	Scientific Name
Amphibians	
Lesser Siren	*Siren intermedia*
Two-toed Amphiuma (Congo Eel)	*Amphiuma means*
Southern Dusky Salamander	*Desmognathus auriculatus*
Dwarf Salamander	*Eurycea quadridigitata*
Two-lined Salamander	*Eurycea bislineata*
Three-lined Salamander	*Eurycea longicauda guttolineata*
Many-lined Salamander	*Sterochilus marginatus*
Mud Salamander	*Pseudotriton montanus*
Red Salamander	*Pseudotriton ruber*
Four-toed Salamander	*Hemidactylium scutatum*
Spotted Salamander	*Ambystoma maculatum*
Mole Salamander	*Ambystoma talpoideum*
Marbled Salamander	*Ambystoma opacum*
Slimy Salamander	*Plethodon glutinosus*
Redback Salamander	*Plethodon cinereus*
Eastern Spadefoot	*Scaphiopus holbrookii*
Eastern Narrowmouth Toad	*Gastrophryne carolinensis*
	(Sheet 1 of 3)

[1] Major species lists may be found in Brinson et al. 1981; Wharton et al. 1981; Wharton, Kitchens, and Sipe 1982; and Wilkinson et al. 1987. (References cited in this appendix are located at the end of the main text.)

Common Name	Scientific Name
Amphibians (Concluded)	
Bird-voiced Treefrog	*Hyla avivoca*
Green Treefrog	*Hyla cinerea*
Gray Treefrog	*Hyla versicolor*
Upland Chorus Frog	*Pseudacris triseriata feriarum*
Southern Cricket Frog	*Acris gryllus*
Bullfrog	*Rana catesbeiana*
River Frog	*Rana heckscheri*
Southern Leopard Frog	*Rana sphenocephala*
Reptiles	
American Alligator	*Alligator mississippiensis*
Eastern Mud Turtle	*Kinosternon subrubrum*
Yellowbelly Slider	*Pseudemys s. scripta*
Eastern Box Turtle	*Terrapene carolina*
Green Anole	*Anolis carolinensis*
Ground Skink	*Scincella lateralis*
Five-lined Skink	*Eumeces fasciatus*
Southeastern Five-lined Skink	*Eumeces inexpectatus*
Gilbert's Skink	*Eumeces gilbertii*
Arizona Skink	*Eumeces gilbertii arizonensis*
Desert Spiny Lizard	*Sceloporus magister*
Greater Earless Lizard	*Cophosaurus texanus*
Tree Lizard	*Urosaurus ornatus*
Arizona Alligator Lizard	*Elgaria kingii*
Copperhead	*Agkistrodon contortrix*
Cottonmouth	*Agkistrodon piscivorus*
Timber (Canebrake) Rattlesnake	*Crotalus horridus*
Mud Snake	*Farancia abacura*
Redbelly Water Snake	*Nerodia e. erythrogaster*
Blotched Water Snake	*Nerodia erythrogaster transversa*
Brown Water Snake	*Nerodia taxispilota*
Broad-banded Water Snake	*Nerodia fasciata confluens*
Glossy Crayfish Snake	*Regina rigida*
	(Sheet 2 of 3)

Common Name	Scientific Name
Reptiles (Concluded)	
Rat Snake	*Elaphe obsoleta*
Eastern Ribbon Snake	*Thamnophis sauritus*
Eastern Garter Snake	*Thamnophis s. sirtalis*
Wandering Garter Snake	*Thamnophis elegans vagrans*
Brown Snake	*Storeria dekayi*
Rough Green Snake	*Opheodrys aestivus*
	(Sheet 3 of 3)

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The riparian vegetation that occurs along rivers and streams throughout the country performs many functions that have considerable value for society. There is an interaction between the hydrology and hydraulics of streams and vegetation. Riparian ecosystems in eastern and western parts of the country differ considerably due to differences in surface water dynamics. The depth, duration, and frequency of inundation determine in large part the type and distribution of riparian vegetation in areas with more precipitation than evaporation; depth to groundwater is the primary factor influencing distribution of riparian vegetation in arid areas. In turn, riparian vegetation affects hydrologic and hydraulic functions of rivers and streams, such as maintenance of stream morphology and flood attenuation, by providing resistance to flow and stabilizing bank materials. Stream water quality is modified by riparian vegetation as sediment is trapped and dissolved materials are retained or removed by the plants. Riparian vegetation supports a wide diversity of wildlife species that depend on the protected access to water, food, refuge, and breeding area provided in riparian areas. Removal of riparian vegetation often has adverse ecological and hydraulic consequences that need to be weighed against the benefits.

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