MANAGEMENT OF NATURAL RESOURCES IN RIPARIAN CORRIDORS

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ABSTRACT

Riparian corridors are important components of the diverse landscape found in the Southwest although they occupy less than 2% of the total land area. Historically these riparian corridors have provided a productive environment for sustaining diverse plant and animals communities, including humans. Riparian plant communities can be found occupying the stream banks of perennial, ephemeral, and intermittent streams. The riparian corridors share numerous complex biological, physical, and chemical linkages with the surrounding watershed. Also these moist streamside environments provide critical habitat for many species of fish, mammals, birds, amphibians, and reptiles, many of which are currently threatened or endangered. Past uses for livestock grazing, wood cutting, recreation, and water withdrawal and transfer have destroyed many of the formerly productive riparian corridors. Management of existing corridors and restoration concerns are therefore high priority concerns to present-day land managers.

INTRODUCTION

Riparian areas provide ecologically important habitats in Arizona, and the Southwest, because they possess a unique combination of hydrologic, biologic, and geomorphologic features (DeBano and Baker 1999; Rinne in press a, b, c, d) (Fig. 1). Compared with other land forms, a combination of high species diversity, species density, and biological productivity characterizes riparian areas (Johnson and Jones 1977, Hoover et al. 1985). These highly sensitive areas support plant communities interrelated with the surrounding watershed. Riparian plant communities are important because they:

- Determine the quality of the associated aquatic habitat;
- Provide a vegetative buffer for bottomland stability during overland water flows;
- Offer seasonal and year-long habitats to diverse wildlife populations;
- Attract and accommodate important recreational activities; and
- Create a pleasing combination of land, water, vegetation, and wildlife, which is aesthetically valuable (Hoover et al. 1985).

Southwestern riparian plant communities provide valuable habitats for many threatened and endangered plant and animal species (Rinne in press a) (Fig. 2). Riparian ecosystems have also played a vital role in the settlement and occupancy of the Southwest, and they continue to be important to regional societies.

This paper presents an overview of the characteristics, ecological relationships, and uses associated with the riparian ecosystems. We also present past and present management practices, and their impacts.

Figure 1. *Riparian vegetation response to livestock removal. Although riparian stream resources, such as shown here in the Verde River, Arizona, occupy <2% of the Southwest desert landscape, they are a vital resource to many animal and plant species. Restoration of these habitats is a prime objective of land managers.*

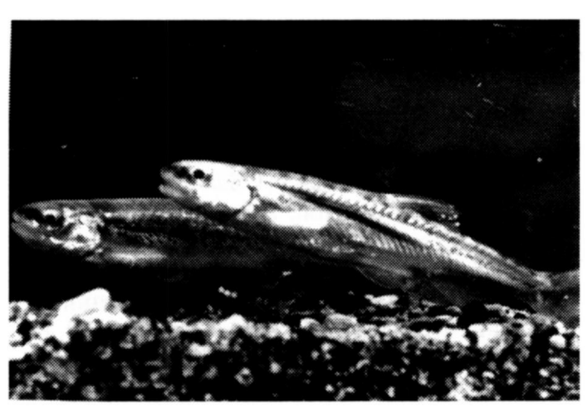

Figure 2. *The threatened spikedace (*Meda fulgida*), once widespread throughout the Gila River basin in Arizona and New Mexico, is now only in the Gila River headwaters of New Mexico and Aravaipa Creek, Arizona.*

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HISTORICAL PERSPECTIVE

Riparian areas supported early human civilizations throughout the southwestern United States for thousands of years by providing drinking water, irrigation water, firewood as fuel for heating and cooking, game, fish (Minckley and Alger 1968), edible plants, and other amenities. The availability of water in these riparian ecosystems allowed dense and highly complex pre-Columbian societies to exist and flourish in the inhospitable climate of the Southwest. The Hohokam irrigated and farmed areas in the Salt River Valley, the Santa Cruz River, the San Pedro River, and other river valleys in Arizona between 900 and 1400 A.D. (Tellman et al. 1997). Their extensive irrigation systems significantly affected Southwestern riparian ecosystems.

During Spanish exploration in the 1600s and later during Anglo settlement in the late 1800s, people depended on riparian ecosystems in the Southwest to satisfy their water needs, and those of their livestock and agricultural crops. Although the Spanish did not establish towns until the second half of the eighteenth century, they founded missions in 1732 at Bac and Guevari (Sheridan 1995, Scurlock 1998). When Anglo explorers arrived in the 1800s, many river bottoms were already heavily impacted (Johnson and Carothers 1982). People settling in the Southwest probably did not recognize the sensitivity of riparian areas to concentrated use. As a result, they quickly stressed the water, grass, and timber resources in these attractive riverside environments (Minckley and Rinne 1985). Exploitation of riparian areas continued after Spanish and Mexican settlement.

Late in the 1950s and early 1960s, people viewed riparian ecosystems mainly as a water source. As populations grew, demands for more water-dominated riparian area management. This focus resulted in riparian area destruction in an attempt to salvage water (Horton and Campbell 1974). However, by the 1970s, people were beginning to understand that riparian areas were a critical part of the landscape (Johnson and Jones 1977). Wildlife biologists understood that riparian areas provided essential habitats for many animals including fish, birds, mammals, and amphibians. Also, by the mid to late 1980s, managers began to apply the concept of ecosystem management which integrates the physical, chemical, and biological processes, along with socioeconomic concerns, into riparian management strategies.

RIPARIAN SETTING

Although riparian ecosystems occupy <2% of the total land area of Arizona, they are the most productive and unique of all the state's ecosystems. Southwestern riparian ecosystems are saturated in diverse ecological and climatic environments that range from high-elevation montane forests to low-elevation desert shrub and grasslands (Szaro 1989). Some major river drainages, and their tributaries, in Arizona that support riparian ecosystems include the:

- Lower Colorado River (from Lee's Ferry in northern Arizona to the Gulf of Mexico);
- Gila, Salt, and Verde Rivers in central Arizona; and
- Santa Cruz and San Pedro Rivers in southern Arizona (Brown and Davis 1977, Rinne in press b).

Riparian communities in these river environments exist mainly along stream channels where surface or near surface water is present regularly throughout the year. The streams are either perennial, intermittent, or ephemeral. Headwaters for these major rivers support narrow strips of riparian vegetation (called stringers) along perennial streams at high elevations. Other riparian and wetland ecosystems are wet meadows called ciénegas at elevations 1,000 m and higher (Hendrickson and Minckley 1985), and mesic areas found around water storage structures at all elevations (DeBano and Schmidt 1989).

Physiography, Geology, and Soils

A wide range of geologic events and processes has shaped Arizona's geology for at least 1.8 billion years (Nations and Stump 1981, Chronic 1983, Hendricks 1985). Arizona is composed of three physiographic provinces—the Basin and Range province in the south and west, the Colorado Plateau in the north and east, and the Transition Zone. The Basin and Range province is intensively deformed and occurs as numerous elevated and depressed blocks. Both deserts and mountainous areas make up the major subdivision of the Basin and Range. In contrast, the Colorado Plateau has only undergone moderate deformation processes. Between these two contrasting physiographic provinces is the Transition Zone, which consists of many canyons and large structural troughs.

The rock in the Basin and Range province ranges from Precambrian to Quaternary. Igneous, metamorphic, and sedimentary rock are well represented throughout the province. Igneous rocks include granites and volcanic rocks (Hendricks 1985). The sedimentary rocks are in the intermontane basins where gravels, sands, silts, clays, marl, gypsum, and salt represent a combination of fluvial, lacustrine, colluvial, and alluvial fan deposits that support a wide range of riparian communities. In

contrast, the Colorado Plateau is composed of thick layers of gently dipping sedimentary rocks that eroded to form prominent plateaus dissected by deep canyons. Volcanoes occurring during the late Cenozoic Period added to the geologic diversity by forming prominent mountains such as the San Francisco Peaks near Flagstaff.

Soils in high elevations are consolidated or unconsolidated alluvial sediments from a wide range of granitic, metamorphic, and sedimentary bedrock materials, which form the surrounding high-elevation uplands (Hendricks 1985). Soil depths vary in riparian ecosystems, depending largely on the topographic setting and parent materials. Soils in mountainous areas are usually shallow, rocky, and gravelly. This contrasts with soils on low-elevation floodplains that, although they exhibit little profile development, were recently deposited and are uniform within horizontal strata. Alluvial soils in all ecosystems are subject to frequent flooding and contain a range of textures. Riparian ecosystems are in widely different geomorphologic environments, which vary from narrow, deep, steep-walled canyon bottoms to intermediately exposed sites with at least one terrace or bench to exposed, wide valleys with meandering streams.

Climate and Hydrologic Features

Climatic characteristics of riparian ecosystems exhibit a wide range of conditions due to extreme elevation differences and the distribution of associated mountain ranges and deserts. Although the climate of Arizona is generally arid, variations in moisture and temperature exist between the high mountain and the low desert environments (Green and Sellers 1964, DeBano and Baker 1999). Annual precipitation ranges from <5 cm in the low-lying deserts to >76 cm in high-elevation mixed-conifer forests (Rinne 1995). In low-elevation environments, annual precipitation is limited to only a few months in the summer (July-September) and the winter (November-March), which causes frequent and long drought periods during the remainder of the year. In Arizona, about 50% of the precipitation at high elevations falls as rain or snow between November and April. Although intensity is low, these winter storms release large amounts of water that sustain perennial streamflow. Another 35% of the high-elevation precipitation falls from July to September as localized, intense storms, which significantly affect erosion and sedimentation processes. The remaining annual precipitation has little hydrologic importance because it is so small and infrequent. From the northern regions of Arizona heading south, summer rain amounts increase because most summer storms originate in the Gulf of Mexico and move north (Green and Sellers 1964). A key characteristic of Arizona's riparian systems is the general availability of water throughout the year or at least during the growing season.

The hydrologic processes important in riparian stream dynamics reflect the climatic regime described. Runoff magnitude and timing are influenced by whether the precipitation falls as rain or snow. Sediment movement and channel configurations depend on the size and intensity of the rain storms.

Streamflow

Streamflow generated by the climatic regime described is important to maintain riparian areas throughout Arizona. Most streams in low-elevation desert environments are intermittent. Generally, water flows in these streams during the winter months or infrequently during the summer in response to convection storms (Hibbert et al. 1977). Although streamflow in the low-elevation environments is usually ephemeral or intermittent, riparian vegetation often occupies the adjacent flood plains because the water table is near the surface for most of the year. Potential evapotranspiration exceeds precipitation in the desert environments. At high elevations, precipitation is generally sufficient to sustain longer streamflow periods. Perennial streamflow is common in many high-elevation streams, where it provides a reliable source of water to sustain riparian plant communities.

Riparian vegetation occupies the banks of perennial, ephemeral, and intermittent streams. However, water that flows into streamside riparian zones differs significantly between perennial streams and intermittent or ephemeral streams. In perennial streams that flow in more mesic environments, such as the eastern United States, precipitation infiltrates into the soil and is delivered downslope as groundwater into the riparian zone and associated streams. During this type of water flow, the riparian vegetation acts as a buffer by removing source and nonpoint source pollutants released from the watershed during precipitation events.

In contrast, in arid environments, such as the southwestern United States, surface runoff is important process because the sparse vegetation cover on a watershed does not protect the soil surface from high-intensity convection rainstorms. Therefore, surface runoff quickly reaches dry ephemeral and intermittent streams, where it becomes channel flow without filtering into the groundwater to perennial streams (Martí et al. 2000). When this occurs, water in streamside riparian zones, which border intermittent and ephemeral streams, is replenished by stream bank recharge. This type of stream bank recharge eliminates the buffering capacity of the on-site

riparian vegetation, thus, upstream contaminants might travel considerable distances downstream before riparian vegetation successfully immobilizes them.

Sediment Movement and Channel Dynamics

The storage and movement of sediment through the channel system affects how riparian ecosystems in Arizona function (DeBano et al. 1996, DeBano and Baker 1999). Generally, the transport of sediment into and through riparian ecosystems throughout the Southwest is episodic because only infrequent, large storms provide sufficient streamflow to move the sediment that has been deposited in the stream systems earlier during smaller storms. The intermittent storage and subsequent movement of sediment through channel systems in response to disturbances are complex processes (Heede et al. 1988). The loss of plant cover associated with either management practices or wildland fire, which produces sufficient surface runoff and streamflow to move sediment that was previously stored in the channel system (DeBano et al. 1998), is an important disturbance factor.

Channel dynamics in areas supporting riparian ecosystems depend on the movement of sediment from hillslopes into the channel systems. Disturbances, such as road construction, timber harvesting, grazing, and fire, can cause excessive sediment movement. In intermittent systems, sediment is deposited in the channel until a sufficiently large streamflow event moves the sediment farther downstream. Sediment can be stored in a channel for many years, making it difficult to interpret the sediment-generating processes (Heede et al. 1988). Although suspended sediment is usually the largest portion of the total sediment moved in a channel, the bedload component is important to determine the channel structure, and its dynamics (Heede 1980). The episodic movement of sediment, involving both aggradation and degradation, also affects the stability of downstream riparian ecosystems.

RIPARIAN FLORA

Riparian vegetation in Arizona is extremely diverse and reflects a wide range of site-specific differences in climate, water availability, and soil, geomorphologic, and geologic conditions (Brown 1982, Szaro 1989). Although studies have described Arizona's different riparian ecosystems according to several classification systems (Johnson and Lowe 1985, Szaro 1989), in this chapter, a generalized system using three types of ecosystems is presented. The classification system used here categorizes vegetation into the following three classes, which are delineated by elevation.

- Riparian ecosystems below 1,000 m are associated with perennial, intermittent, and ephemeral rivers, with broad alluvial floodplains and terraced bottoms. These sites currently support high densities of deep-rooted trees including saltcedar (*Tamarix pentandra*), sycamore (*Platanus wrightii*), cottonwood (*Populus fremontii*), palo verde (*Parkinsonia* spp.), and a wide range of herbaceous plants (e.g., *Carex* spp., *Juncus* spp., *Eleocharis* spp., *Scirpus* spp.). Before intensive settlement in New Mexico, Arizona, and southern California, many of these rivers were perennial, and were lined with riparian communities dominated by willow (*Salix* spp.), cottonwood, and mesquite (*Prosopis* spp.) (Minckley and Rinne 1985). Today, only a few of the large rivers that traverse the low-elevation deserts maintain a perennial flow (e.g., the lower Colorado River). Past timber harvesting and regulating the flow of large rivers has destroyed many original riparian areas. As a result, only a few of the formerly widespread mesquite bosques remain, and saltcedar and Russian olive (*Elaeagnus angustifolia*) have replaced most of the large cottonwood and willow galleries.
- Riparian ecosystems between 1,000 and 2,000 m contain the greatest number of plant species and the most canopy cover. Cottonwood, willow, sycamore, ash (*Fraxinus velutina*), and walnut (*Juglans major*) are typically found here, with three or four species often growing together, along with several species of herbaceous plants. These species usually grow as narrow strips along mainly intermittent and ephemeral streams, although some perennial streams exist at intermediate elevations. Chaparral, pinyon-juniper (*Pinus-Juniperus*) woodlands, and encinal (oak [*Quercus*]) woodlands often occupy the watersheds surrounding the mid-elevation riparian ecosystems.
- Above 2,000 m, willow, chokecherry (*Prunus virens*), boxelder (*Acer negundo*), Rocky Mountain maple (*Acer glabrum*), and various coniferous trees and herbaceous plants dominate stream channels. In some locations, cienegas and other wetland communities occupy areas that have excessive perennial soil moisture. Ponderosa pine (*Pinus ponderosa*) and mixed conifer forests occupy the surrounding watersheds, some aspen (*Populus tremuloides*) stands, and well-defined mountain meadows and grasslands.

Both vegetation and topography affect sediment movement and storage. Vegetation dissipates streamflow energy and stabilizes stream banks (Medina 1995, Brooks et al. 1997). Decreasing flow

velocity allows more water to infiltrate into the stream bank, which recharges groundwater. The dissipation of energy and increase in infiltration prevents excessive erosion, maintains the physical stability of the riparian ecosystem, and encourages riparian vegetation establishment.

RIPARIAN FAUNA

Riparian ecosystems provide food, water, and cover for many different kinds of wildlife. Species of fish, mammals, birds, amphibians, and reptiles thrive in the water and lush vegetation provided by cool, shaded streamside environments. In Arizona and New Mexico, 80% of all vertebrates depend on riparian ecosystems during at least half of their life cycle, and more than half are totally dependent on riparian areas (Chaney et al. 1990). Additionally, many of these wildlife species are either threatened or endangered.

Fish

Native fish species are in high mountain streams (elevations >1,800 m), streams at intermediate elevations (1,800 to 3,600 m) and streams in the low desert (elevations <1,800 m) (Rinne and Minckley 1991, Rinne in press a). Riparian ecosystems provide critical habitats for about 40 native fish species in the Southwest (Rinne 1994, 1996). In Arizona alone, 21 of the 27 native fish species are threatened, endangered, or are being considered for listing. Native trout species, including the Apache (*Oncorhynchus apache*), the Gila trout (*O. gilae*), and the Rio Grande cutthroat (*O. clarki virginalis*), are found in high-elevation mountain streams (Rinne 1982, 1985, 1988; Calamusso and Rinne 1998, in press) (Fig. 3). The high-elevation riparian habitats also provide stable channels; a sustained supply of clean, cool water; shelter for insects under overhanging vegetation, which produces vegetative matter for fish and other aquatic life; and a diverse mixture of grasses, forbs, shrubs, and trees.

Streams at intermediate elevations support several species of short-lived minnows (e.g., spikedace [*Meda fulgida*]) and longer-lived suckers and minnows (e. g., Sonoran sucker, [*Catostomus insignis*]) (Rinne in press a). The physical conditions of streams at intermediate elevations are highly variable, and water temperature ranges from 2°C to 30°C in the summer and from 12°C to 25°C in the winter. Streamflow at these intermediate elevations is also highly variable during the year, varying from intermittent flows in the fall months, to sustained perennial flow during the winter, and flash floods during the summer monsoon season. Fish communities in the low-desert rivers (riverine environments) contain species such as roundtail chub (*Gila robusta*), speckled dace (*Rhinichthys osculus*), bluehead mountain-sucker (*Pantosteus discobolus*), and the flannelmouth sucker (*C. latipinnis*) (Rinne in press a). Low-desert river environments are usually remnants of regional rivers such as the Salt, Gila, Verde, San Pedro, and Santa Cruz Rivers in Arizona. The streamflow in many low desert streams is intermittent because the water is often diverted for irrigation, industrial, and domestic use (Rinne in press b). Also, native Southwestern fish are subjected to additional threats including aquifers pumping (Neary and Rinne 2001, Wirth and Hjalmarson 2000), water diversions, and competition from introduced fish species (Rinne 1995, in press a, b).

Mammals

A wide range of large and small mammals partially or wholly depend on healthy riparian ecosystems. Important species of large mammals include mule deer (*Odocoileus hemionus*), white-tailed deer (*O. virginianus*), elk (*Cervus elaphus*), coyote (*Canis latrans*), raccoon (*Procyon lotor*), and the river otter (*Lutra longicaudis*), which was once extinct in Arizona but was successfully reintroduced in the Verde River. These mammals use riparian habitat for food and water, cover from heat and cold, cover from predators, and breeding and rearing areas. Beavers (*Castor canadensis*) were once widespread—they occupied most Southwestern streams and rivers. Beginning in the early in the 1800s, trapping and extensive habitat modification dramatically reduced beaver numbers (Sheridan 1995). Small rodents, such as the desert pocket mouse (*Perognathus penicillatus*), Merriam's kangaroo rat (*Dipodomys merriami*), and cactus mouse (*Peromyscus eremicus*), also depend on Arizona's riparian ecosystems (Anderson et al. 1977).

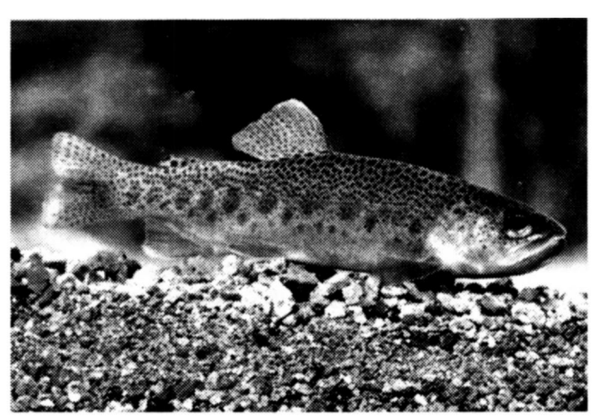

Figure 3. *The endangered Gila trout, once widespread in the Gila River headwaters in Arizona and New Mexico, now lives in <5 streams naturally and 12 streams due to restoration efforts.*

Birds

Riparian ecosystems provide food, cover, and nesting sites for birds ranging in size from hummingbirds to eagles and are either resident or migratory populations. Rapidly growing riparian vegetation provides a multistoried habitat, and old trees with holes or cavities provide homes for many bird species. Examples of birds found in Southwest riparian ecosystems include vermilion flycatchers (*Pyrocephalus rubinus*), yellow warblers (*Dendroica petechia*), orioles (*Icterus* spp.), ladder-backed woodpeckers (*Dendrocopis scalaris*), mourning doves (*Zenaida macroura*), violet-crowned hummingbirds (*Amazilia violiceps*), elegant trogons (*Trogon elegans*), and tropical kingbirds (*Tyrannus melancholicus*) (Wauer 1977, Brown and Davis 1998). Large predatory birds, such as the black hawk (*Buteogallus anthracinus*) and the great horned owl (*Bubo virginianus*), depend on riparian ecosystems for survival. Bald eagles (*Haliaeetus leucocephalus*) in areas with permanent water to support fish, which are a food source. Riparian areas, marshes, and other wetlands in the Southwest provide an important source of food and cover for birds that migrate south in the winter and north in the summer (Stevens et al. 1977). Species of neotropical migrants are abundant in many Southwestern riparian ecosystems and include the black-chinned hummingbird (*Archilochus alexandri*), the black-headed grosbeak (*Pheucticus melanocephalus*), and the blue grosbeak (*Guiraca caerulea*) (Yong and Finch 1996).

Amphibians and Reptiles

Amphibian and reptile species in the Southwest depend on water provided by riparian habitats. Amphibians include toads (*Bufo* spp.), spadefoot (*Scaphiopus* spp.), frogs (*Rana* spp.), and salamanders (*Ambystoma* spp.) (Rosen et al. 1998). The Chiricahua leopard frog (*R. onca*) is an endangered amphibian that is declining precipitously in population and was thought extinct in the 1950s (Sredl and Howland 1995).

Several species of reptiles that require the moist environment to complete their life cycle are the yellow mud turtle (*Kinosternon flavescens*), Sonoran mud turtle (*K. sonoriense*), Mexican garter snake (*Thamnophis eques*), checkered garter snake (*T. marcianus*), and the black-necked garter snake (*T. crytopsis*) (Lowe 1985). The Arizona skink (*Eumeces gilberti arizonensis*), the Sonoran whipsnake (*Masticophis hobartsmithii*), and the ring-necked snake (*Diadophis bilineatus*) are confined to riparian areas (Jones and Glinski 1985).

WATERSHED-RIPARIAN-AQUATIC LINKS

Many physical, biological, and chemical links exist among and within the streams, riparian vegetation, and the surrounding watershed (Baker et al. 1998). Processes that are responsible for the continual flux of water, air mass, dissolved particulate matter, organisms and energy occur within and among the stream, riparian vegetation, and surrounding watershed. Specific processes involved include runoff, erosion, sedimentation, groundwater recharge and movement, nutrient cycling, food webs, streamflow, water nutrient enrichment, and water and nutrient exchanges in the hyporehic zone. This zone lies below the stream bed and extends laterally beneath the stream bank to form an area of saturated sediments (Boulton 2000), and is a biologically active area that traps, transforms, and mineralizes organic carbon and contained energy, which otherwise are transported downstream (Kaplan and Newbold 2000).

Water and sediment transport that occurs during surface runoff and erosion have the most obvious links with the watershed, streamside riparian vegetation, and streamflow (DeBano and Baker 1999). Runoff and erosion processes are key factors that affect the stability of land within the stream-channel network, the riparian area, and on the surrounding watershed. As discussed, water falling on the soil surface of a watershed may reach the stream channel via different routing paths depending on whether the stream is perennial, intermittent, or ephemeral.

Groundwater is less obviously linked with the watershed and the riparian and aquatic zones. Contributing water to streams, groundwater contains many dissolved materials that affect the riparian area and water quality. The primary nutrients delivered to riparian areas via groundwater flow are nitrogen and phosphorus, which are important to stream ecology because they limit the primary productivity of aquatic ecosystems.

Food webs also provide links within and between the terrestrial and aquatic components of riparian ecosystems. These pathways represent a flow of energy through the ecosystems, or through parts of them. Members of the food web vary from unicellular protozoa and large insects that live in the streams to birds and mammals residing in the streamside and watershed environments.

An especially important link between the stream and the adjacent riparian area is the hyporheic zone. A dynamic exchange of water and materials between the groundwater below, lateral alluvial aquifers, and the river flowing above occurs in the hyporheic zone. The flow of water through the hyporheic zone

promotes biochemical processes that are important for water quality and to aquatic habitats. Water in perennial streams enters the hyporheic zone at the head of the riffle (i.e., down welling) and returns to the stream at the tail of the riffle (i.e., up welling). As water flows through the hyporheic zone, microbial and chemical processes, which include transforming nutrients, consuming oxygen, decomposing organic matter, and other activities, alter its chemistry (Boulton 2000). The hyporheic zone also exists in intermittent and ephemeral streams (Martí et al. 2000).

Many links involve nutrient cycling. The regular and consistent cycling of nutrients is essential for plant growth, and the sustained productivity of natural ecosystems. Nutrients cycle continually within and among terrestrial, riparian, and aquatic systems. The most important nutrients in natural ecosystems are carbon, nitrogen, and phosphorus. Carbon is important as a source of energy for biological processes (e.g., decomposition, respiration) and as a reservoir for all the other plant nutrients. Organic matter is created when gaseous carbon from the atmosphere is converted to living plant biomass during photosynthesis. Other nutrients enter the system via the soil by natural processes such as precipitation, dry fall (e.g., particulates contained in dust and smoke), nitrogen fixation, and geochemical weathering. The main source of nitrogen in the ecosystem is through nitrogen fixation—precipitation and dry fall are other sources of ecosystem nitrogen.

USE AND MANAGEMENT OF RIPARIAN AREAS

People use riparian ecosystems in Arizona for timber production, livestock grazing, floodplain farming, groundwater pumping, and water-control projects (Johnson and Carothers 1982). In response, managers implement special management practices to try to mediate the increasing competition for a finite water supply among many different users (DeBano and Baker 1999).

Grazing and Livestock Production

In Arizona, livestock grazing by Spanish explorers occurred along permanent streams that provided the animals with shade, water, and forage (Scurlock 1998). Ranchers are beginning to understand the negative impacts of domestic livestock grazing in riparian areas, and they often remove their stock (Medina and Rinne 1999) (Fig. 4). However, land managers remain concerned about the grazing that continues to occur in Arizona's riparian areas. Additionally, balancing grazing with other uses in riparian ecosystems is a critical management concern. Animal use in riparian ecosystems:

- Removes the protective herbaceous cover;
- Compacts the soil through hoof action;
- Interferes with the reproduction of native cottonwood trees;
- Degrades water quality with fecal material and erosion; and
- Creates unstable streambanks and erosion by trailing and concentrated trampling.

Overgrazing, which often severely deteriorates riparian habitats, adversely affects many wildlife species. Protecting critical riparian habitats for threatened and endangered animal (Rinne 1999) and plant species is a focus of many grazing management plans for many riparian ecosystems.

To protect riparian ecosystems, managers are evaluating the following grazing strategies.

- Constructing riparian fences to exclude, either completely or during critical seasons, certain areas from grazing (Platts 1991);
- Developing plant-use standards to help critical plant species; and
- Implementing different pasture rotation plans to ensure healthy riparian ecosystems.

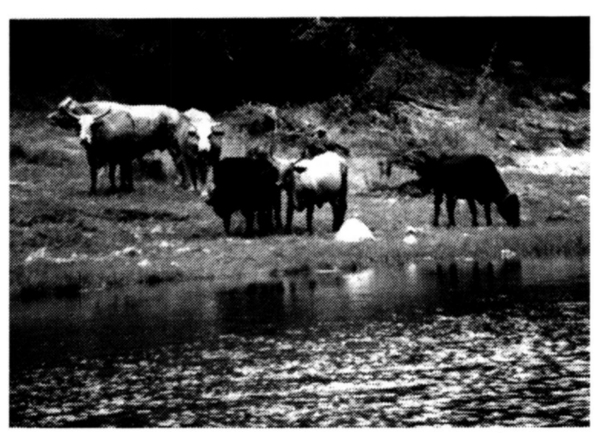

Figure 4. *Livestock grazing in a riparian corridor, Verde River, Arizona. Most domestic livestock have been removed from riparian corridors to restore valuable habitat resources.*

Timber Production

Riparian ecosystems in the Southwest have never been a large-scale source of timber because they cover only <2% of the land area and do not support commercial timber species (e.g., ponderosa pine). However, the Anglo explorers who arrived in the 1800s exploited trees for fuel, poles, and building materials (Johnson and Carothers 1982). Current uses for timber harvested from riparian ecosystems are limited—recreationists, likely the pri-

mary user, occasionally gather dead wood for camp fires.

Recreation and Tourism

Southwestern riparian ecosystems provide opportunities for both consumptive and nonconsumptive recreation uses. Consumptive uses include fishing, hunting, and other activities that remove part of the resource. Although nonconsumptive uses, such as birdwatching, camping, hiking, boating, and rafting, do not remove a resource, intensive nonconsumptive use can affect the recreational quality of riparian areas (Johnson and Carothers 1982). The recreational potential of riparian ecosystems is generally associated with three types of water resource:

- Rivers and streams (running water);
- Lakes and reservoirs (standing fresh water); and
- Beaches adjacent to the Pacific Ocean or around large lakes or other large impoundments (Hoover et al. 1985).

Common activities that affect the riparian plant communities along rivers and streams include fishing, camping, tubing, off-road vehicular use, rafting, swimming, and summer homes. Stream environments provide a shady place to walk, birdwatch, or enjoy a quiet moment. Lakes and reservoirs provide opportunities for a variety of activities including swimming, fishing, waterskiing, power boating, sailing, and canoeing. Riparian vegetation is concentrated mainly where streams and rivers enter lakes and reservoirs. Beaches and associated lagoons are restricted to the Pacific Coast, where they host many activities including surfing, sail boating, swimming, sun bathing, kite flying, and beach combing.

Wildlife Management

Protecting and enhancing the habitat for threatened and endangered species and balancing acceptable grazing activities between native ungulates and domestic livestock are the two objectives of wildlife management in Arizona. Bird management activities include identifying threatened or endangered species, determining their critical habitat, and developing and implementing management plans to ensure current and future species survival. Management of endangered fish species includes providing adequate streamflow and managing introduced fish species. The judicious implementation of instream flow rights (a legal entitlement to the nonconsumptive use of surface water within a specified area of a stream channel for fish, wildlife, recreational use, and maintenance of streamside vegetation [Kulakowski and Tellman, 1990]) is important to provide adequate streamflow for native fish populations.

Water Use

Water provided by streamflow through riparian areas has been in high demand since Arizona's settlement. Some competing uses include floodplain farming, groundwater pumping, and transbasin water transfers. Dams and reservoirs constructed for flood protection and water development have also altered streamflow (Johnson and Carothers 1982; Rinne 1994, in press b).

Floodplain farming and the development of large agrarian societies have occurred in the southwestern United States for thousands of years. Many agricultural operations continue to farm floodplain environments using efficient irrigation technology. Increased floodplain farming and rapid urban sprawl significantly affects the sustainability and health of many riparian habitats, particularly those at low elevations.

Groundwater has been an important source of water in the Southwest for decades. Initially, settlers extracted water from shallow depths using windmills. As pumping and irrigation technology improved, extracting water from greater depths was possible. However, people now understand that surface water is also important to support growing agricultural and urban needs. Water imported from the Owens Valley, the Colorado River, and, most recently, from northern California allows southern California to sustain a high level of development. Most of Arizona, however, relies heavily on groundwater. The Salt River Valley obtains about half its water from groundwater, with the remaining coming from local water storage and the Colorado River. Many Arizona communities depend almost entirely on groundwater. As a result, intense competition has developed between those who need groundwater to support urban development, and those who understand that groundwater as vital to sustain perennial streamflow in riparian ecosystems (Wirth and Hjalmarson 2000, Neary and Rinne 2001).

On the lower Colorado River, engineering structures built for power and water production have resulted in the following changes.

- Increased evapotranspiration;
- Increased soil salinity;
- Physiochemical changes;
- A drastic reduction in many of the native plant and animal populations;
- An increase in populations of introduced species; and
- Changes in the natural erosional and sedimentation processes, particularly in Grand Canyon National Park (Johnson 1979).

The above alterations illustrate the dramatic effect of streamflow modification due to dam construction on large, low-elevation Western river systems (Johnson 1979).

Notable engineering projects affecting water flow and riparian communities include Roosevelt Dam, which was the first Bureau of Reclamation dam, completed in 1911 (Fig. 5); Hoover Dam, completed in 1935; and Glen Canyon Dam, completed in 1962. Engineering structures and water withdrawal have also affected other low-elevation rivers including the Gila, Salt, and Verde Rivers in Arizona (Rinne 1994, in press b).

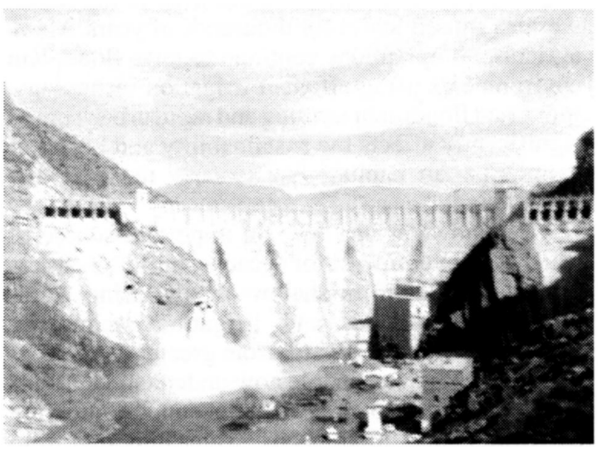

Figure 5. *Completed in 1911, Roosevelt Dam on the Salt River, Arizona, was the first Bureau of Reclamation dam. The dam and many other mainstream dams on the Salt Verde, Gila and Colorado Rivers, have either completely dried mainstream rivers or altered the quantity and quality of the waters. These structures negative impact native fish populations.*

The competitive use of groundwater for agricultural irrigation, urban development, and to sustain healthy riparian ecosystems has intensified rapidly during the past two decades. Sometimes, groundwater management basins have been designated and groundwater laws have been developed to ensure long-term urban and agricultural uses. However, it is becoming increasingly apparent to many riparian managers that increased groundwater withdrawals are beginning to seriously jeopardize perennial streamflow in low elevation streams that support riparian ecosystems. A balance between instream needs and water for agricultural and domestic purposes is currently the focus of active debate.

RIPARIAN RESTORATION

The past loss of riparian and wetland ecosystems in Arizona is significant. Although the estimated loss of riparian ecosystems varies widely, the greatest losses have occurred along banks of large river systems (i.e., the Salt and Gila Rivers) that flow through the lower-elevation deserts (Carothers 1977, Rea 1983). Rinne (1994) suggests that 70% of the streamside habitat has been altered or lost along these low-elevation rivers in Arizona. High-elevation wetland communities in Arizona have fared better, and researchers estimate that 35% of the original area has been lost (Dahl 1990).

The rehabilitation of depleted riparian areas has prompted land managers to implement activities that encourage riparian ecosystem health and to develop management plans that address the condition of the surrounding watershed (DeBano and Schmidt 1989). Also, attention is now focused on ways to improve the condition of degraded ecosystems by evaluating site conditions and identifying the causes of past degradation (Briggs 1996). This type of analysis allows managers to design and implement effective remedial treatments. Unconventional techniques involving groundwater recharge using imported and effluent waters are providing potential opportunities to enhance existing riparian and wetland ecosystems and create new ones (Karpiscak and Gottfried 1998).

SUMMARY

Although riparian and wetland ecosystems occupy only a small portion of the land area in Arizona, they make up a valuable landscape component. As such, they have historically received concentrated human use and will be increasingly important in the future. The pleasant Southwestern climate, particularly during the winter, encourages large influxes of both winter visitors and permanent residents. The rapidly growing population will further intensify the demands placed on riparian areas and will require implementation of new and inventive management and policies. A list of present and future activities that will likely affect riparian ecosystems throughout Arizona includes continued groundwater withdrawal (Wirth and Hjalmarson 2000), grazing (Rinne 2001), recreation, use of dams and reservoirs, and urbanization. The number of threatened and endangered plant and animal species will continue to grow. Additional stresses from diminished streamflow and the spread of introduced fish species will continue to challenge native fish populations, particularly in the low-elevation riparian ecosystems in the Southwest.

The equitable treatment of instream flow rights is another rapidly emerging issue that will increase the competition for water between offsite and onsite water uses. Instream flow has important biological, geomorphologic, and legal implications when managing streamflow for fisheries, wildlife, vegetation, and, particularly, threatened and endangered plant

and animal species. Instream flow requirements affect streamflow regimes and the important links among the stream, floodplain, riparian and upland zones, and watershed geomorphology.

All these factors combine to create a sense of urgency to preserve existing riparian and wetland ecosystems and to develop an aggressive program to enhance and rehabilitate areas already depleted. The past loss of this unique resource emphasizes the need for a closely coordinated effort among land planners; land managers; scientists; developers; local, state and federal governments; and the public to ensure that present and future generations can share in the diverse benefits provided by Arizona's unique riparian and wetland ecosystems.

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