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Riparian Ecosystems

Science Editor
Austin K. Andrews
text by
Gregor T. Auble
National Biological Service
Midcontinent Ecological Science Center
Fort Collins, CO 80525

Overview

The strict definition of riparian is "streambank," but riparian ecosystems are often broadly defined to include riverine floodplains. In the broad sense, the riparian zone is both a transition and interface between riverine and upland systems. Functionally and structurally, riparian areas are different from surrounding uplands because of proximity to a water course. In the eastern United States, the upland landscape is generally moist enough to support woody vegetation while the often extensive bottomland forests comprise only those plants able to tolerate flooding and excessive moisture. In much of the West, areas near water courses are often the only places with sufficient moisture for trees. Thus, western riparian ecosystems are often relatively narrow ribbons of trees in a generally unforested landscape.

We lack good estimates of the status or historical changes in area for riparian ecosystems of the West as a whole, although we do know that they have always represented a very small fraction of the land area because of their dependence on water in a dry region. Their importance stems from the unique features that they provide, representing desirable habitat for a variety of species. Many of the same features that make these systems relatively rare and important also make them relatively sensitive.

Western riparian systems have been massively altered in the last 200 years; the history of development in the West is to a large extent one of water development. As the articles in this section illustrate, it is hard to make a hydrologic change without also altering the associated riparian ecosystem. Busch and Scott (this section) show how hydrologic changes can influence the long-term species composition by altering soil salinity and changing the nature of disturbances that create opportunities for regeneration. Some changes described in Roelle and Hagenbuck's article (this section) on the Middle Rio Grande are relatively straightforward: riparian vegetation is inundated by a reservoir or a channel narrows with lower streamflow. Other effects of hydrologic alteration are more complex and may be played out over many decades. As the authors note, the absence of a change in net area may mask dramatic shifts in the location of different vegetation types.

Although hydrology is the dominant factor shaping these ecosystems, it is not the only one. In all the riparian systems described in the following articles, invasions of non-native plants have changed the composition of the communities and the way the systems will likely respond in the future. Timber clearing, overgrazing by livestock, agricultural conversion, and urban growth are other important causes of change in these ecosystems.

Western Riparian Ecosystems

by

David E. Busch
National Park Service

Michael L. Scott
National Biological Service

In much of western North America, riparian (streamside) environments are the only part of the landscape moist enough to allow survival of trees (Fig. 1). Riparian landscapes are usually defined as ecotones or corridors between terrestrial and aquatic realms (Malanson 1993). In spite of their limited areal extent, riparian ecosystems are essential habitat for many vertebrate species and provide critical physical and biological linkages between terrestrial and aquatic environments (Gregory et al. 1991).

Because of their association with scarce surface water resources, western riparian ecosystems have long been influenced by human activities. Human-caused perturbations can alter energy and material flow in riverine ecosystems, thus modifying riparian plant communities (Brinson 1990). Among the most serious impacts to riparian ecosystems are water impoundment and diversion, groundwater pumping from alluvial aquifers, livestock grazing, land clearing for agriculture or to increase water yield, mining, road development, heavy recreational demand, fire, the elimination of native organisms (e.g., beaver [*Castor canadensis*]) or the introduction of exotics, and overall watershed degradation (Stromberg 1993).

Courtesy M.L. Scott, NBS

Fig. 1. A cottonwood-willow riparian ecosystem illustrating how trees are closely associated with a water source in an arid landscape. Arikaree River, Colorado.

Riparian ecosystems along most major western rivers have changed as the result of water development and flood control. Losses of riparian forest downstream of dams have been reported from throughout western North America (Rood and Mahoney 1990). In contrast, woodland expansion in other dam-regulated riparian ecosystems provides evidence that the interrelationships between plant communities and hydrogeomorphic processes are complex (Johnson 1994). As the result of widespread, human-induced changes in hydrology and land use, native cottonwood-willow stands are being replaced by non-native woody species such as Russian olive (*Elaeagnus angustifolia*) and tamarisk (*Tamarix ramosissima*) throughout the West (Olson and Knopf 1986; Knopf and Scott 1990; Stromberg 1993).

In this article, we contrast the roles played by natural and human-induced disturbances in structuring western riparian ecosystems. Our approach draws heavily on data from the lower Colorado and upper Missouri rivers, two large, diverse systems that showcase a range of natural and human factors influencing riparian ecosystems throughout western North America. We also focus on how water and land-use management may threaten these valuable ecological resources.

Most of the Missouri River, through the Dakotas to its confluence with the Mississippi River, is controlled by a series of large dams and reservoirs constructed between the 1930's and 1950's. These dams radically altered the magnitude, timing, and frequency of flood flows that formerly promoted regeneration and maintenance of extensive riparian cottonwood (*Populus deltoides*) forests (Johnson et al. 1976; Johnson 1992). Here, we examine the importance of flow variability and channel processes in creating and maintaining riparian cottonwood stands in one of the last relatively naturally functioning reaches of the upper Missouri River in Montana.

The lower Colorado River riparian ecosystem (Nevada, California, and Arizona) has also been affected by hydrologic change resulting from human activities. Declines in riparian forest dominated by cottonwood (*Populus fremontii*) and willow (*Salix gooddingii*) have been attributed to change in the physical environment and to the extensive invasion of tamarisk. Our evaluation of the Colorado River ecosystem centered on an investigation of surface water-groundwater linkages and how hydrologic factors affect water uptake and use in riparian trees and shrubs. We also examined how hydrologic perturbation and alteration of natural disturbance processes affect riparian community structure along the lower Colorado River.

Methods

Upper Missouri River

We intensively sampled nine sites between Fort Benton, Montana, and Fort Peck Reservoir. Sites were selected primarily to represent the range of geomorphic (*see* glossary) conditions observed within this reach. Channel movement is variously constrained through this portion of river; in some reaches the channel meanders whereas in other reaches lateral movement is limited to a narrow valley floor. Previous work demonstrates that the age structure of cottonwood populations is strongly influenced by aspects of flow that promote successful establishment. We determined the precise age and elevation of establishment of 151 plains cottonwood stems in the study site and related their years of establishment to the flow record from U.S. Geological Survey (USGS) gauges.

Lower Colorado River

We established three sites for an intensive ecophysiological analysis of riparian plant communities on the Havasu National Wildlife Refuge in the lower Colorado River floodplain. Our analyses were confined to stands of riparian vegetation that had been classified as cottonwood-willow habitats (Anderson and Ohmart 1984; Younker and Andersen 1986).

Hydrology and Riparian Ecosystem Dynamics

Reproduction and growth of riparian plant species are closely associated with peak flows and related channel processes such as meandering. Successful establishment of such plants typically occurs only in channel positions that are moist, bare, and protected from removal by subsequent disturbance (Sigafoos 1964; Everitt 1968; Noble 1979; Bradley and Smith 1986; Stromberg et al. 1991; Sacchi and Price 1992; Johnson 1994). If streamflow is diverted, young trees may die (Smith et al. 1991). Studies of plant water uptake in floodplain ecosystems indicate that maintenance of cottonwood and willow populations depends on groundwater moisture sources which, in turn, are closely linked to instream flows (Busch et al. 1992). Thus, the establishment and maintenance of riparian plant communities are a function of the interplay among surface water dynamics, groundwater, and river channel processes.

Maps and notes from the journals of Lewis and Clark (1804-06) suggest that the present distribution and abundance of cottonwoods along the Missouri River within the study reach are generally similar to presettlement conditions. Although flows through this reach are influenced by Canyon Ferry Dam on the mainstem and Tiber Dam on the Marias River, the gross seasonal timing of flows and the magnitude and frequency of daily maximum flows have not been greatly altered by dam operations. This is due in part to the dam's relatively small storage capacity and the presence of a number of unregulated tributaries below the dams. Thus, the study reach represents one, if not the last, semi-naturally functioning reach along the entire Missouri River.

In the Colorado River, the link of floodplain groundwater with instream flows is illustrated by the association of river discharge and fluctuations in water table depth in the adjacent floodplain (Fig. 2). Further evidence for this linkage comes from daily fluctuations in water table depth, which correlated closely with the Colorado River hydroperiod (Busch, unpublished data). Colorado River floodplain soils were dry. Volumetric soil moisture in the upper 1 m (3.3 ft) of the Colorado River soil profile averaged less than 4%, while that of the nearby and less heavily impacted Bill Williams River averaged 13%. Incision of stream channels, through either natural or human-induced causes, can lead to the depression of floodplain water tables (Williams and Wolman 1984). Channelization of the lower Colorado River appears to have led to floodplain groundwater declines, and this has tended to isolate riparian vegetation from its principal moisture source at or near the water table (Busch et al. 1992).

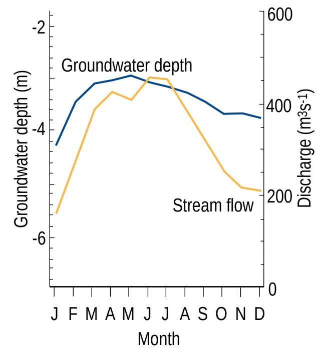
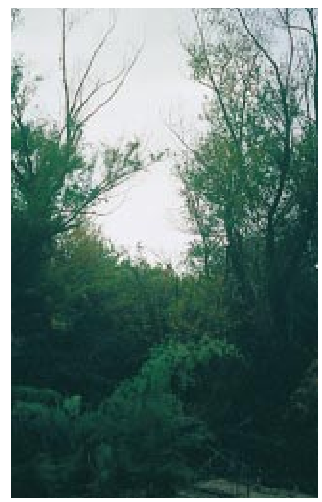


Fig. 2. Streamflow in the lower Colorado River and water table depth fluctuations in the adjacent floodplain.

Salinity and Alteration of Riparian Ecosystem Processes

In regulated rivers, a lack of flooding or infrequent groundwater incursion into surface soils can result in altered nutrient dynamics. The lack of an aqueous medium for salt dispersal may result in the elevation of soil salinity to levels that are stressful to some of the trees and shrubs native to southwestern riparian ecosystems (Busch and Smith 1995). Colorado River soils were significantly ($P < 0.05$) more saline than soils in the adjacent Bill Williams River floodplain. Salinities in Colorado River soils exceeded levels shown to inhibit germination, reduce vigor, and induce mortality in seedling cottonwood and willow (Jackson et al. 1990). Salt-tolerant species could thus benefit from elevated alluvium salinity. Evidence for salinity tolerance in both native and exotic halophytes (plants growing in salty soils or a saltwater environment) shows that arrowweed (*Tessaria sericea*) and tamarisk had significantly ($P <$ 0.05) higher leaf tissue sodium concentrations (11.2 and 18.1 mg/g [ppt], respectively) than did cottonwood (1.1 mg/g [ppt]) and willow (0.7 mg/g [ppt]).



Courtesy D.E. Busch, BOR

Colorado River study site with willow (note stress-induced canopy die back) and exotic tamarisk.

Courtesy M.L. Scott, NBS

Constrained reach of the Missouri River, Montana.

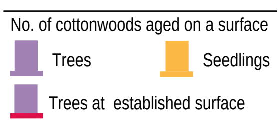
Establishment Patterns of Riparian Tree Populations

The structural diversity of riparian cottonwood and willow stands is a function of spatial and temporal patterns of occurrence. These patterns are largely determined by events during the establishment phase (Stromberg et al. 1991; Scott et al. 1993). Where stream regulation limits flooding and channel movement (e.g., the lower Colorado River), opportunities for seed germination are limited. In such systems, community structure may become less dynamic unless novel forms of disturbance such as fire increase in importance relative to the natural disturbance regime.

The magnitudes of flows associated with cottonwood establishment are influenced by local channel processes. Along the upper Missouri River, sections of meandering channel alternate with sections where lateral migration does not occur. In meandering sections, successful establishment occurs at relatively low elevations above the channel (Fig. 3a), producing several bands of even-aged trees (Bradley and Smith 1986).

If, however, lateral movement of the channel is constrained by a narrow valley, successful establishment occurs only at high elevations, often producing a single, narrow band of trees (Fig. 3b); seedlings initially established at lower positions are removed by water or ice scour. Where the channel is free to move, plant establishment occurs relatively frequently in association with both moderate and high river flows, but where the channel is constrained, plant establishment is associated with infrequent high flows in excess of 1,400 m^3/s (50,000 ft^3/s). Elimination of such high flows would largely eliminate cottonwood and willow stands from the constrained reaches of the upper Missouri River and decrease the frequency of stand establishment in the meandering reaches. From a water-management perspective, then, it is important to recognize how flow variability, including infrequent large flows, shapes the distribution and abundance of riparian tree populations.

Meandering reach of the Missouri River, Montana.



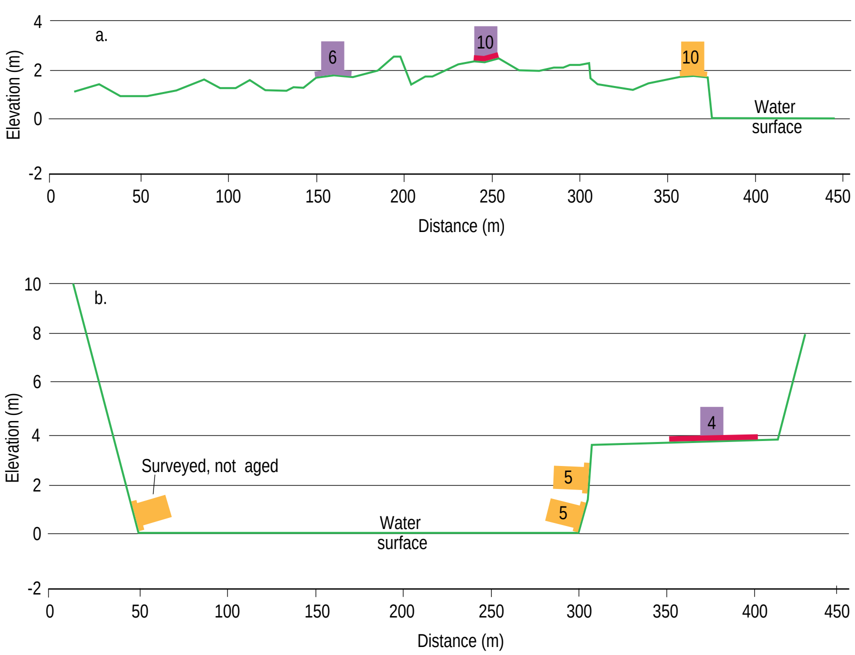


Fig. 3. Cross section in the (a) meandering channel reach, Missouri River, Montana, and (b) the constrained channel reach. All seedlings established within 10 cm (3.9 in) of the present surface (from Scott et al. 1994). For (a), at 160 m (525 ft) six trees were aged, but depth to establishment surface was measured for only one.

Disturbance Regimes and the Invasion of Non-native Species

Riparian ecosystems are dependent upon disturbance caused by occasional high flows. Along rivers where these flows have been reduced in frequency and magnitude, natural riparian ecosystems are being lost along with associated invertebrate and vertebrate species. Resource managers concerned with maintaining floodplain ecosystems need to consider ways of preserving flows that produce establishment, growth, and survival of native riparian species. If not, species such as tamarisk can exploit resources more efficiently than native riparian species, thereby altering whole ecosystem properties (Vitousek 1990). Thus, as Hobbs and Huenneke (1992) suggest, modification of the historical disturbance regimes will result in a decline in native species diversity. Although successful plant invasions are often associated with increased disturbance (Hobbs 1989; Rejmanek 1989; Hobbs and Huenneke 1992; Parker et al. 1993), in situations where the frequency or intensity of a natural disturbance is decreased, the invasion of competitively superior non-natives may be promoted (Hobbs and Huenneke 1992).

Although most riparian plants are adapted to flooding, the frequency, timing, and duration of floods may be highly altered on regulated stream reaches. Fire appears to have increased in importance relative to flooding as a form of disturbance affecting regulated southwestern rivers, including the Colorado. Colorado River cottonwood and willow canopy cover decreased only slightly following fire, but burned cottonwood-willow stands had significantly greater cover of both arrowweed and tamarisk ($P < 0.005$). Efficiency in water uptake, transport, and use are among the mechanisms responsible for superior post-fire recovery of halophytic shrubs compared with trees native to the Colorado River ecosystem (Busch and Smith 1993).

As the result of ecosystem change over the last century, cottonwoods have become rare along the lower Colorado River, and most remaining stands are dominated by senescent (i.e., in decline) individuals (Fig. 4). Although a senescent segment was also a substantial portion of the willow population, this species is still relatively abundant in stands classified as cottonwood-willow habitat. Even so, salt-tolerant or water stress-tolerant shrubs such as tamarisk and arrowweed now dominate these habitats.

Similar to tamarisk, the non-native Russian olive is a shrubby tree that has become naturalized throughout the western United States (Olson and Knopf 1986), forming extensive stands in some areas (Knopf and Olson 1984; Brown 1990), particularly where historical river flow patterns have been altered by water development, such as along the Platte River in Nebraska (Currier 1982) and the Bighorn River in Wyoming (Akashi 1988). Such conversion of riparian vegetation from native to non-native species may have profound wildlife management implications. Bird species richness and density, for example, are higher in native riparian vegetation than in habitats dominated by tamarisk or Russian-olive (Knopf and Olson 1984; Brown 1990; Rosenberg et al. 1991).

Future

The health of natural riparian ecosystems is linked to the periodic occurrence of flood flows, associated channel dynamics, and the preservation of base flows capable of sustaining high floodplain water tables. The establishment of native riparian vegetation is diminished when the frequency and magnitude of peak river flows are reduced. Water uptake and water-use patterns indicate that native trees are replaced by non-native species in riparian ecosystems where streamflows are highly modified. Although riparian ecosystems are most directly affected by altered streamflow, additional factors threaten their integrity, including groundwater pumping (Stromberg et al. 1992), grazing (Armour et al. 1991), timber harvest and land clearing (Brinson et al. 1981), and fire (Busch and Smith 1993). Studies are under way to evaluate whether exotic plants will encroach further into riparian ecosystems, given conditions predicted under global climate change scenarios.

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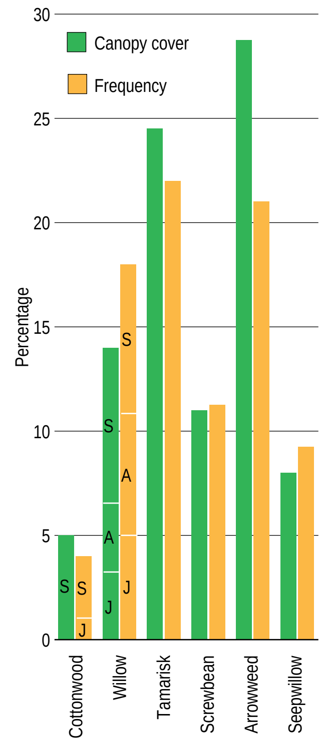

Fig. 4. Relative plant canopy cover and relative frequency percentages for woody riparian species of the lower Colorado River floodplain. Cottonwood and willow populations are grouped into juvenile (J), adult (A), and senescent (S) age segments.

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For further information:

David E. Busch
South Florida Natural Resources Center
National Park Service
Everglades National Park
4001 State Rd. 9336
Homestead, FL 33034

Surface Cover Changes in the Rio Grande Floodplain, 1935-89

by

James E. Roelle
National Biological Service

Warren W. Hagenbuck
U.S. Fish and Wildlife Service

Riparian (streamside) vegetation communities provide valuable habitat for wildlife, particularly in the arid and semi-arid Southwest, where such communities make up less than 1% of the landscape (Knopf et al. 1988). Agricultural conversion, urban and suburban expansion, water development, recreation, and invasion by non-native species such as Russian olive (*Elaeagnus angustifolia*) and saltcedar (*Tamarix* spp.) have severely reduced the extent and quality of these habitats. Despite such impacts, the floodplain of the Rio Grande in central New Mexico supports one of the most extensive cottonwood (*Populus fremontii*) gallery forests (bosque) remaining in the Southwest (Howe and Knopf 1991), and interest in ensuring the long-term health and viability of native communities along the Rio Grande has been steadily increasing (Crawford et al. 1993). This article documents changes between 1935 and 1989 in cover types of the floodplain of the Rio Grande in central New Mexico.

Study Area

The study area covers the historical floodplain of the Rio Grande from Velarde, New Mexico, to the narrows at Elephant Butte Reservoir, New Mexico, a distance of nearly 250 river mi (402 km; Figure). The historical floodplain in this reach encompasses more than 95,000 ha (nearly 236,000 acres); about 9,650 ha (24,000 acres) were omitted from the analysis because 1989 photography was unavailable.

Classification

Wetlands were classified according to the system used by the U.S. Fish and Wildlife Service's (USFWS) National Wetlands Inventory (Cowardin et al. 1979). Wooded riparian (nonwetland) areas were classified according to an unpublished system developed by the USFWS and the Arizona Riparian Council. The remaining uplands were classified according to a system developed by the U.S. Geological Survey (Anderson et al. 1976).

These classification systems provided more than 160 cover classes, an unmanageable number for an analysis of change. Thus, we aggregated the original classes in our geographic information system (GIS) into 11 broader types.

Expansion of saltcedar is of great concern in the Rio Grande valley in New Mexico, and

Figure. The Rio Grande study area.

separating saltcedar from other scrub-shrub types would have been desirable. Unfortunately, saltcedar could not be distinguished from other scrub-shrub types on the 1935 photography used to classify the area and was therefore included in the riparian scrub-shrub and wetland scrub-shrub classes.

Trends

Major changes in surface cover occurred on the floodplain of the Rio Grande between 1935 and 1989 (Table). Five of eight wetland or riparian types declined by about 17,000 ha (42,000 acres), including 5,453 ha (13,475 acres) of river or artificial channel; 4,015 ha (9,921 acres) of wet meadow, marsh, or pond; 2,638 ha (6,519 acres) of riparian scrub-shrub; 2,507 ha (6,195 acres) of riparian forest; and 2,482 ha (6,133 acres) of wetland scrub-shrub. Upland range also declined by 5,217 ha (12,891 acres).

The largest gains occurred in urban (11,389 ha; 28,143 acres) and agricultural (5,395 ha; 13,331 acres) cover types. Only three wetland or riparian cover types (lake, wetland forest, and dead forest or scrub-shrub) increased. Higher water levels in Elephant Butte Reservoir and construction of Cochiti Reservoir, New Mexico, produced a gain of 2,552 ha (6,306 acres) of lake. Wetland forests increased by 1,779 ha (4,396 acres). Most of this increase occurred between the levees and the stream channel, which has become narrower and straighter because of levee construction and channel stabilization. Dead forest or scrub-shrub increased by 1,197 ha (2,958 acres). Most of this mortality was at the upper end of Elephant Butte Reservoir because of high water in the mid-1980's.

The total forested area (wetland plus riparian) declined only slightly between 1935 (9,861 ha; 24,367 acres) and 1989 (9,133 ha; 22,568 acres), but this does not mean that concern for the long-term future of the woodlands is unwarranted. Only about 27% of the area forested in 1935 still supports forests, indicating that significant changes have occurred even in cases where the net change in area has been small. As noted before, much of the cottonwood forest is now confined between the levees and the river channel. The flow regime of the Rio Grande, however, has been altered significantly (e.g., lower peak flows) since most of these stands were established, and conditions favorable for germination and establishment of cottonwood now occur only rarely. Russian olive and saltcedar are likely to continue to replace cottonwood, especially under current hydrologic conditions (Howe and Knopf 1991).

Table. Surface cover changes in the Rio Grande floodplain, Velarde to Elephant Butte Reservoir, NM, 1935-89.

Cover type	Area (ha)		
	1935	1989	Change
Lake	32	2,584	+2,552
River or artificial channel	10,673	5,220	-5,453
Wet meadow, marsh, or pond	5,527	1,512	-4,015
Scrub-shrub (wetland)	9,070	6,588	-2,482
Scrub-shrub (riparian)	7,804	5,166	-2,638
Dead forest or scrub-shrub	0	1,197	+1,197
Forest (wetland)	4,683	6,462	+1,779
Forest (riparian)	5,178	2,671	-2,507
Agriculture	19,614	25,009	+5,395
Range	20,179	14,962	-5,217
Urban	3,006	14,395	+11,389

Courtesy R. Milhous, NBS

Rio Grande floodplain.

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For further information:

James E. Roelle
National Biological Service
Midcontinent Ecological Science Center
4512 McMurry Ave.
Fort Collins, CO 80525

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