Effects of Fire on Riparian Systems

Leonard F. DeBano[1] and Daniel G. Neary[2]

Abstract.—Riparian systems are a small but important resource in the southwestern USA and northern Mexico because of the diverse, dynamic, and complex biophysical habitats they provide. Wildfires have always produced the most significant impacts on riparian hydrology, geomorphology, and biology. Prescribed fires have not been used to any great extent in the Madrean Province for vegetation management in riparian systems. The unique geophysical characteristics of the Madrean Archipelago make it especially responsive to climatic events. Water yield, peakflow, and sediment yields after wildfires can be among the largest in North America, and can have a substantial impact on the watershed and associated riparian systems.

INTRODUCTION

Fire has occurred regularly in riparian and wetland environments for thousands of years. During the Holocene period, native Americans used fire in their hunting efforts to drive large mammoths into streams where they slew them for food (Dobyns, 1989). Later, hunter-gathers set fires to remove dead biomass from pond-marsh wetlands to improve game animal habitat and game bird productivity.

Today, both wildfires and prescribed fires occur in many riparian and wetlands systems. In riparian systems, fire is usually in the form of an unintentional invasion during a wildfire. Little prescribed fire in being used in the riparian systems for their management. However, some prescribed responses of fire in riparian systems can be gleaned from the experience with wildfires.

This paper reviews the limited studies reported on the effect of fire on riparian systems in the southwestern United States. This information is then used along with information from studies reported in other parts of the United States to assess the role of prescribed fire in riparian systems in the Madrean Province.

[1] *School of Renewable Natural Resources, University of Arizona, Tucson, AZ.*

[2] *USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Flagstaff, AZ.*

RIPARIAN SYSTEMS IN THE SOUTHWEST

Riparian systems are found in a wide range of elevations throughout the southwestern United States and Mexico. Their classification is complicated by variety of physical and environmental factors that have contributed to high plant species diversity. One classification system places riparian ecosystems into two general cover types - forest and scrub (Szaro, 1989). The riparian forests are further classified by different elevations, namely above 2000 m, below 2000 m, below 1500 m, and below 1000 m. Distinct scrub riparian areas have been broken into two categories, those above 1500 m and those below 1500 m. This classification scheme does not include marshlands and cienegas which can occur at both lower and higher elevations.

IMPORTANCE OF RIPARIAN SYSTEMS

Natural riparian systems are considered the most diverse, dynamic, and complex biophysical habitats in the Southwest. Because riparian systems act as interfaces between terrestrial and aquatic systems, they possess sharp environmental gradients, ecological processes, and biotic communities. Therefore, riparian ecosystems represent an unusually diverse mosaic of landforms, communities, and environments within a larger landscape setting. As such, they serve as a framework for understanding the organization, diversity, and dynamics of communities associated with fluvial systems (Naiman et al 1993). Under most conditions, riparian plant communities are best left alone or even protected from logging, grazing, and other types of exploitation. Unfortunately, the response and role of fire in riparian system dynamics is not well understood (Baker 1990).

Healthy riparian systems provide values and benefits far in excess of the land area they occupy. Healthy riparian systems provide water and soil to encourage vegetation growth for a more productive biotic community which has high biodiversity. They support a large diversity of insect, mollusk, and crustacean species that are key resources in the food chain. Healthy riparian systems also provide amenities for people by creating cool shade and general aesthetic beauty with their serene waters; and they provide prime areas for fishing, hiking, rafting, bird watching, water sports, picnicking, and camping. The lush vegetation improves water quality and removes sediment; rebuild flood plains and reduces erosion of stream banks; holds water in the streambanks which improves local ground water reserves; maintains instream biota; and stores flood waters, lessening the risk of flash floods (DeBano and Schmidt 1989).

ROLE OF FIRE IN RIPARIAN SYSTEMS

Riparian ecosystems are corridors streambank vegetation which interact continuously with the surrounding watershed, and represent a reservoir of disturbance-oriented species within the confines of a less frequently disturbed landscape. The edges of riparian ecosystems are often buffered from upland disturbances such as fire and to some extent, fluvial disturbances. Typical mid-sized riparian ecosystems, therefore, exhibit decreasing disturbance toward their core by processes common to uplands (e.g. overland flow,surface erosion, etc.) and increasing disturbance by fluvial processes (e.g. channel aggradation and degradation). Fire can affect both the channel processes in the riparian ecosystem and hillside processes on the surrounding watershed.

Both wildfires and prescribed burns can affect riparian systems directly and indirectly. If fires burn in the riparian area itself, direct effects such as the consumption of part or all of the vegetation is immediately obvious. However, subtle indirect effects such as stream temperature increases, alterations in the quantity and quality of organic matter inputs to streams, aquatic macroinvertebrate population changes, and fish migration can occur long after the fire. When fire burns the surrounding watershed, direct effects such as excessive surface runoff, increased streamflow, higher peakflows, and sediment movement into and through downstream riparian ecosystems are readily apparent. Nutrient cycling changes, plant and animal community shifts, population declines, and other indirect effects can occur but are not easily visible.

Fire decreases basin stability on steep topography, debris flows along with dry ravel and small landslides are a common occurrence after fire. The recovery of vegetation following fire reflects the combined disturbance of both fire and flooding. The direct effects of fire on riparian ecosystems consists mainly of damage to the vegetation (trees, shrubs, and grasses) and partial consumption of the underlying litter layer. The severity of the damage depends largely upon the intensity of the fire. Intense wildfires can cause severe damage to plant cover as contrasted to low intensity cool- burning prescribed fires which have less severe consequences.

Both wildfires and prescribed fires on the watershed affect the downslope riparian ecosystems indirectly by changing the fluvial processes on a watershed. The most obvious change involves the removal of protective vegetative and litter cover which intercepts precipitation. When the protective soil cover is removed, the soil surface becomes subjected to raindrop impact and as a result both surface and rill erosion can increase. The increased erosion is related to the amount of protective cover removed. The effects of fire are variable and depend partly on the severity of the fire. Cool burning prescribed fires have little impact whereas intense wildfires may have substantial impact on the stormflow, erosion, sedimentation, and quality of the streamflow. The duration of these effects is affected by the rate of post-fire revegetation.

RESPONSE OF RIPARIAN SYSTEMS TO FIRE

The biotic communities that make up the Madrean Province floristic province consists of montane coniferous forests, oak-pine woodlands, tropical deciduous forest, savanna, short-grass prairie, subtropical thornscrub, and subtropical desert (Brown 1982; Warshall 1995). The specific responses of these Madrean ecosystems to fire have been reasonably well-studied in northern end of the Province (central and southern Arizona), but are limited in the southern end (Sierra Madre Occidental). Information from other better studied but comparable floristic zones (Californian oak-woodlands and chaparral) are used in this discussion.

Vegetation

Impacts on riparian vegetation can range from small effects with prescribed fires to severe effects associated with wildfires. The recovery of vegetation following fire reflects the combined disturbance of both the fire and any subsequent flooding. In southern California, post-fire recovery processes in the herbaceous layer were closely linked to geomorphic location in the riparian zone, and to the density of seeded, non-native ryegrass (Davis et al. 1989). Annuals became well-established on higher geomorphic locations less prone to flooding, but often in loose soil subject to dry ravel. Perennials, on the other hand, grew better on lower, more disturbed geomorphic locations near the stream. The overall species richness of annuals decreased in the second year after fire due to the redominance of ryegrass, although perennials took over the riparian area to a large extent. Sprouting is the dominant means of recovery of the tree species due to the lack of viable seeds following fire. Species such as sycamore (*Platanus racemosa*) showed rapid recovery, while others such as alder (*Alnus rhombifolia*) were slow to reestablish in the absence of a viable seed source. Full recovery of the alder canopy after unusually hot fires can take many years or decades.

Some riparian areas recover rapidly following wildfires, whereas others undergo slow recovery. The rate of recovery depends largely on the environment. A study on Marble Cone fire near Carmel, California after a intense wildfire showed that large amounts of sediments were deposited in riffle areas immediately following the fire (Hecht 1984). However, repeated measurements following the fire showed that habitat values of riffles were largely restored by vegetative growth by the end of the first year, and had undergone virtually complete recovery after three years. In contrast, fire in desert riparian environments might show prolonged effects. Although fire is not a common occurrence in desert riparian ecosystems, the riparian communities can be ignited by rolling firebrands from the surrounding desert grasslands (Miller et al. 1995). Although many riparian plant species can re-establish after fire, recovery of the vegetative structure may take a long time.

In southeastern Arizona, the response of big sacaton (*Sporobolus wrightii*) grassland riparian sites to burning and mowing were studied Arizona (Cox and Morton 1985). Both burning and mowing reduced green biomass production, and stocking rates on the burned and mowed pastures were only one-third as high as on untreated areas. Cattle gains were also less on the treated sites.

Water Yield

Water yield increases from prescribed fires and wildfires in Madrean-type ecosystems are shown in Table 1. Where soil wettability becomes a problem, water yield increases can be high due to a greater contribution of surface runoff to stormflows. Overland flow that is usually low in most undisturbed forests can increase to 15-40% of total water yield after fires. If more precipitation leaves a watershed as surface runoff, baseflows will eventually decrease. Perennial streams become ephemeral in extreme conditions. The effect on biota in riparian and aquatic ecosystems then becomes devastating. Also, water supply for human use is impaired.

Peakflows and Flooding

The effects of fire on storm peakflows are variable and complex (Table 2). Storm peakflows can produce some of the most profound impacts that forest managers have to consider. The high velocities and flow volumes of peakflows are responsible for most sediment transport, and alteration of channel geomorphic characteristics. These flows also have profound influences on riparian biota. Thus, there has always been considerable concern that increases in annual flood peaks of 20+% could lead to channel instability and degradation, aquatic and riparian habitat deterioration, and increased property damage in flood-prone urban areas.

A wildfire in Arizona ponderosa pine produced a peakflow 58 times greater than an unburned watershed during record autumn rainfalls where the burn

Table 1. Increased Water Yield From Burned Watersheds In Madrean-type Ecosystems.

Watershed/ condition	Rain (mm)	Flow (mm\yr)	Increase (%)	Recovery (years)	Reference
AZ Chaparral	740				Davis (1984)
Control		64	—		
Burned		156	144	>11	
AZ Chaparral	655				Hibbert (1971)
Control		0	—		
Wildfire		124	9999+	9+	
Control		19	—		
Wildfire		289	1421	9+	
AZ Pinyon-Juniper	480				Hibbert et al (1982)
Control		34	—		
Burned		39	12	5	
TX Juniper-Grass	660				Wright et al. (1982)
Control		2	—		
Burned		25	1150	5	
Burned, Seeded	10	400	2		

was severe (Table 2). Watersheds in the Madrean Province are much more prone to these enormous peakflow responses due to geomorphology (high elevation ranges), climatic (monsoon weather conditions and a close source of moist, tropical air), and soil (shallow, clay-rich, and potentially hydrophobic) conditions (DeBano 1981; Swanson 1981).

Another concern is the timing of stormflows or response time. Burned watersheds respond to rainfall faster, producing more "flash floods". Hydrophobic and bare soils, and cover loss will cause flood peaks to arrive faster and at higher levels. Flood warning times are reduced by "flashy" flow and higher flood levels can be devastating to property and human life. As indicated in Table 2, the Southwest and the Madrean Archipelago is particularly vulnerable to changes in peakflow response time and volume. The responses are an interaction between intense rainfalls common in the region, steep terrain, and water repellency which often develops in shrubland vegetation typically found in the Madrean Province. Another aspect of this is the fact that recovery times can range from years to many decades.

So, the net effect on watershed systems and aquatic habitat of increased peakflows is very much a function of the type of fire, area burned, climate, watershed and soil characteristics, and the severity of the fire. Small areas in flat terrain subjected to prescribed fires will have little, if any, effect on water resources, especially if Best Management Practices are utilized. Peakflows after wildfires that burn large areas in steep terrain can produce significant impacts.

Table 2. Effects of Fire on Peakflows in Madrean-type Ecosystems.

Location	Treatment	Peakflow Control $m^3/s/km^2$	Peakflow Burn $m^3/s/km^2$	Reference
Chaparral, CA	Wildfire	0.051	1.169	Nasseri (1989)
Chaparral, AZ	Wildfire	0.008	7.800 a	Hibbert (1985)
		0.035	1.780 b	
Ponderosa Pine, AZ	Wildfire-Mod.	0.070	0.240	Campbell et al. (1977)
	Wildfire-Sev.	0.070	4.067	
Ponderosa Pine, AZ	Wildfire	0.060	1.400	Rich (1962)

a Summer storms; b Winter storms

Sediment

Total Yield

Some sediment yield baseline data are discussed by Neary and Hornbeck (1994). Natural erosion rates for forests in the western USA (0.001 - 5.530 Mg/ha) are higher than the East (0.110 - 0.220 Mg/ha) but do not approach the upper limit of geologic erosion (15.000 Mg/ha). Landscape disturbing activities like mechanical site preparation, agriculture, and road construction produce the most sediment loss and can match or exceed the upper limit of natural geologic erosion.

Sediment Yields From Fires

The regions where fire accounts for the highest portion of total sediment yield in North America, include the Madrean Archipelago and the chaparral steeplands of Southern California (Swanson 1981). Sediment yields are usually higher immediately following a fire and then decline rapidly in subsequent years as vegetation is reestablished. All fires increase sediment yield, but it is the wildfires that produce the biggest amounts (28 - 369 Mg/ha). Slope plays a major role in determining the amount of sediment yield, but *Best Management Practices* are useful in reducing sediment loss in steeplands (Heede 1988).

Debris Flows

Observations in southern California show that wildfires (e.g. Wheeler Fire) decrease basin stability. In steep erodible topography, debris flows along with dry ravel and small landslides off hillslopes are a common occurrence (Davis et al 1989). Debris flows are the largest, most dramatic, and main form of mass wasting which delivers sediment to streams. They can range from slow moving earth flows to rapid avalanches of soil, rock, and woody debris. Debris avalanches occur when the mass of soil material and soil water exceed the sheer strength needed to maintain the mass in place. Steep slopes, logging, road construction, heavy rainfall, and fires all aggravate debris avalanching potential.

Most mass failures after fire are associated with development of water repellency in soils. Chaparral and other sclerophyllous vegetation in the southwestern USA and the Madrean Archipelago are high debris flow hazard areas because of the tendency for water repellency to develop in soils of these ecosystems after fires (DeBano 1981). Debris flows can be 50% of the total post-fire sediment yield in some ecosystems. In Southern California chaparral, sediment yields from debris flows increased from 7 to 1907 m3/km2/yr the first year after a wildfire (Wells 1981).

The impacts of debris flows on riparian ecosystems are multiple. Large, sudden inputs of sediments into streams cause rapid aggradation of channels. A stable stream channel reflects a dynamic equilibrium between incoming and outgoing sediment and streamflow. Increased erosion after fires can alter this equilibrium by transporting additional sediment into channels (aggradation). Although increased peakflows that result from fires can also produce channel downcutting (degradation), the process of aggradation from debris flows dominates in the short-term. Narrow, distinct channels turn into broad, braided systems. The consequences are destroyed aquatic habitat, damaged riparian vegetation, devastation to aquatic biota, deteriorated water supply systems, and spreading and elevating of flood flows.

Buffer Strips

Riparian systems along rivers in the Madrean Province serve an important function as buffer strips which capture sediment and nutrients, thereby preventing them from entering the stream. Buffer strips are protective areas adjacent to an area requiring special attention. Filter strips are buffer strips specifically designed to trap sediment.

An important part of developing any prescribed burning program in riparian areas is recognizing their importance as buffer areas for adjacent streams. Guidelines on buffer strip widths for prescribed fires have been established for other parts of the United States. For low intensity fires, less than 0.6 m high that does not kill stream-shading shrubs and trees, fire can be used throughout the riparian area without creating substantial damage (Neary et al 1993). Where fire damages woody vegetation, the width should be proportional to the size of the contributing area, slope, cultural practices in the upslope area and the nature of the drainage below (Cooper et al 1987). Buffer widths should increase as higher order streams are encountered and deposition opportunities within the zone decrease. A general rule of thumb for the width of the buffer strip which should be planned for is 9 meters plus (0.46 X % slope) (USDA Forest Service 1989).

Large Woody Debris

Large organic debris is recognized as an increasingly important component of watersheds and river systems in the western United States. Large woody debris plays an important role in hydraulics, sediment routing, and channel morphology of streams flowing through riparian systems (Smith et al. 1993). Woody debris increases the complexity of stream habitats by physically obstructing water flow. Trees extending partially across the channel deflect the current laterally, causing it to widen the streambed. Sediment stored by debris also adds to hydraulic complexity, especially in organically rich channels that are often wide and shallow and posses a high diversity of riffles and pools in low gradient streams of alluvial valley floors. Stream stabilization after major floods, debris torrents, or massive landslides is accelerated by large, woody debris along and within the channel. After wildfire, while the post-fire forest is developing, the aquatic habitat may be maintained by large, woody debris supplied to the stream by the prefire forests.

Managers often debate the post-fire management practice of leaving burned and dead debris in channels following wildfires. The USDA Forest Service suggests that the *Best Management Practice* balances downstream value protection with the environmental implications of the treatment (Barro et al, 1988). To protect life and property, treatments generally involve channel clearing, necessarily at the expense of the riparian environment. Because living and dead trees in the riparian zone act as stabilizing elements in streambed configuration, their removal can provoke adjustments in channel morphology. In addition, removal of obstructions increases flow velocity which can scour the channel bed, increase the sediment load, degrade the water quality, export nutrients out of the system, and cause deterioration of the biotic habitat. Therefore, in the final analsysis it appears beneficial to maintain as much woody material as is possible in the ecosystem following fire.

Water Chemistry

Undisturbed forest, shrub, and range ecosystems usually have tight cycles for major cations and anions, resulting in low concentrations in streams. Fire interrupts or terminates uptake by vegetation and speeds up mineral weathering, element mineralization, microbial activity, nitrification, and decomposition. These processes result in the increased concentration of inorganic ions in soil solution and leaching to streams via subsurface flow.

Nutrients carried to streams can increase the growth of aquatic plants, reduce the potability of water supplies, and produce toxic effects. Anions like phosphate and cations such as calcium and potassium can be exported from watersheds at 10 times their normal rate immediately after severe disturbances, but do not significantly alter water quality.

Most of the attention relative to water quality after fires focuses on nitrate nitrogen (NO3- N), since it is highly mobile. High NO3-N levels in conjunction with phosphorus can also cause eutrophication of lakes and streams. Most studies of forest fires show increases in NO3-N concentrations with maximums in Madrean-type ranging from 0.6 to 12.0 mg/L. Losses of NO3- N would be higher if volatilization into the atmosphere was not a major pathway of nitrogen loss. Except for the municipal water quality implications of elevated NO3-N concentrations, water chemistry changes in Madrean Province ecosystems have not been a problem.

Temperature

Large fires can function like clearcuts in raising the temperature of streams due to direct heating of the water surface by solar radiation and increases in excess of 150 C have been measured .

The main concern relative to riparian ecosystems is the reduction in the concentrations of dissolved oxygen (O_2) available for aquatic biota that occurs with rising temperatures. Dissolved O_2 contents are affected by temperature, altitude, water turbulence, aquatic organism respiration, aquatic plant photosynthesis, inorganic reactions, and tributary inflow. Generally, O_2, concentrations <10 mg/L create problems for fish. Increases of 1-5 C that are not a problem at sea level become problematic at high altitudes of the Madrean Province .

Aquatic Macroinvertebrates and Fish

The most sensitive species in riparian ecosystems to fire effects are aquatic macroinvertebrates and fish. Rinne and Neary (This Volume) cover this topic in some detail so no further discussion is warranted here.

CONCLUSIONS

Fire has not been used extensively in management of riparian and wetland systems in the Madrean Archipelago region. Most fire in riparian areas occurs in the form of an unintentional invasion during a wildfire. Under these conditions, fires in the riparian area can be intense and cause extensive damage to the vegetation. However, even after severe fires, recovery to prefire conditions can be rapid—within a couple years in some environments. The recovery of vegetation following fire reflects the combined disturbance of both the fire and flooding.

Because of the high responsiveness of Madrean Province watersheds to climatic events, water yields, peakflows, and sediment yields measured after wildfires have historically been some of the largest in North America. Thus, the potential is always there for significant adverse impacts to riparian ecosystems and the biota that inhabit them.

Riparian areas provide buffer strips which trap sediment and nutrients that are released when surrounding watersheds are burned. The width of this buffer strip is critical for minimizing sediment and nutrient movement into the streams. The best available guidelines for buffer width associated with prescribed fire is that, low intensity fires that do not kill stream-shading shrubs and trees can be used throughout riparian areas without creating substantial damage. Where fire damages woody vegetation, the width should be proportional to the size of the contributing area, slope, cultural practices in the upslope area and the nature of the drainage below.

There are mixed concerns about leaving downed large woody debris in, or near, stream channels following fire. Large woody debris plays an important role in hydraulics, sediment routing, and channel morphology of streams flowing through riparian systems, thereby enhancing these systems. Sometimes, to protect life and property, debris is removed following wildfires. In general, large woody debris in streams after fire has numerous advantages and should be left on site unless downstream risks are readily identified.

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