



CHAPTER

# 5

## A Scientific Assessment of the Effectiveness of Riparian Management Practices

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## INTRODUCTION

This chapter evaluates the ecological effectiveness of the major purposes and expected benefits of 21 riparian management practices as described in the US Department of Agriculture, Natural Resources Conservation Service (USDA NRCS), National Conservation Practice Guidelines (Table 1). The ecological benefits described in the standards for these practices include the following:

- Wildlife habitat
- Water quantity and quality
- Stream bank and soil stability
- Carbon storage
- Plant and animal diversity

Riparian management encompasses many activities and practices that are applied directly to the riparian zone or that are applied in the uplands to influence the riparian zone. To meet numerous riparian management goals, conservation practices are often applied as a suite of practices called a resource management system. A resource management system may include several practices (e.g., prescribed grazing, stream crossing, riparian herbaceous cover) selected to meet site-specific conditions and objectives. Riparian areas occur along watercourses or near water bodies. They are different from surrounding lands because of unique hydrologic, soil, and plant characteristics that support important ecosystem functions and services.

Riparian areas occupy the transitional area between the terrestrial (dry) and aquatic (wet) ecosystems. Rangeland riparian areas include the stream, stream channel, and adjacent riparian vegetation. These areas also include seeps, springs, and small wetlands that have greater soil water relative to surrounding

uplands. This does not include marshes, impoundments, estuaries, and other wetland habitats. Although riparian areas constitute only a fraction of the total land area on western rangelands, they generally support greater overall plant and animal species diversity, richness, and productivity than adjacent uplands. Access to riparian areas in rangeland systems is usually critical to sustaining the productive potential of the surrounding landscape. Riparian areas are often relatively long and narrow in relation to other landscape features. This characteristic creates significant interaction with other ecological sites within the landscape, supporting the exchange of materials and energy within the landscape.

Numerous studies in the western United States have shown that riparian areas have been negatively impacted by timber harvest, road building, irrigation, grazing, and other human activities (Kauffman and Krueger 1984; Fleischner 1994; Magilligan and McDowell 1997; Belsky et al. 1999). In many cases, these systems have been altered (e.g., down-cutting, head-cutting, and stream bank alteration) to the point that past geomorphic structure and function cannot be restored and returned to former conditions. Additionally, installation of dams and diversion of water have altered runoff timing and amounts, often resulting in irreversible changes in riparian characteristics. Where irreversible changes have occurred, some new desired condition becomes the objective of restoration.

Because grazing is such a widespread practice on public and privately owned rangelands, assessment of grazing management practices is a significant part of this review. Platts (1978, 1990) rated the effect of several grazing strategies for stream-riparian habitat values based on his observations and professional



Riparian corridor in eastern Oregon. (Photo: Chad Boyd)

**TABLE 1.** List of 20 riparian practices and their expected ecosystem services.

Practice name	Code	Ecosystem services				
		Wildlife habitat	Water quality and quantity	Stable stream banks and soils	Carbon storage	Diverse plant and animal communities
Animal trails and walkways (feet)	575		X	X		
Brush management (acres)	314	X	X	X		X
Channel bank vegetation (acres)	322	X	X	X		
Conservation cover (acres)	327	X	X	X		
Critical area planting (acres)	342			X		
Fence (feet)	382	X	X	X		X
Filter strip (acres)	393		X			
Pest management (acres)	595	X	X			
Prescribed burning (acres)	338	X				X
Prescribed grazing (acres)	528	X	X	X		X
Range planting (acres)	550	X	X	X	X	X
Riparian forest buffer (acres)	391	X	X	X	X	X
Riparian herbaceous cover (acres)	390	X	X	X	X	X
Stream crossing	578		X	X		
Stream habitat improvement and management (acres)	395	X		X		
Stream bank and shoreline protection (feet)	580	X		X		
Tree/shrub establishment (acres)	612	X	X	X	X	X
Upland wildlife habitat management (acres)	645	X				
Use exclusion (acres)	472		X	X		X
Watering facility (no.)	614		X	X		

experience (Table 2). Similarly, Kovalchik and Elmore (1991) rated the compatibility of grazing systems with willow-dominated communities (Table 3). While the effects of many of these grazing systems on riparian areas have been documented in case histories, rarely have they been tested with rigorous experimental designs and appropriate statistical analyses (Larsen et al. 1998). Both of these evaluations indicate that continuous grazing is not compatible with riparian areas and that rest or deferment from grazing, inherent in various forms of rotational grazing, tend to improve the riparian habitat values addressed in Tables 2 and 3. Continuous grazing often results in

heavy grazing use of the riparian area because livestock are attracted to riparian areas from the adjacent uplands. Even if the pasture is lightly stocked, grazing may be heavy because livestock preferentially use the riparian zone. Improperly applied rotational grazing systems can also result in heavy grazing and damage to riparian habitat.

The objective of livestock grazing strategies and practices has been to increase plant and litter cover, encourage growth of desirable plant species, improve plant species composition, increase plant vigor, and protect riparian soil and stream banks from erosion. Grazing tactics or practices for maintaining

or rehabilitating riparian areas include 1) controlling the timing and duration of riparian grazing by fencing riparian pastures within existing pastures, 2) fencing riparian areas to exclude livestock from riparian areas, 3) changing the kind and class of livestock, 4) reducing duration of grazing, 5) reducing grazing intensity, and 6) controlling season of use (Clary and Webster 1989; Platts and Nelson 1989). Annual management objectives for vegetation attributes (e.g., herbaceous plant stubble height, woody plant utilization, and vegetative ground cover) are frequently recommended or required to guide year-to-year grazing management decisions (Bauer and Burton 1993; Hall and Bryant 1995; Clary and Leininger 2000). The assumption is that meeting annual management objectives will be compatible with long-term resource objectives (e.g., stream bank stability, recruitment of woody plants, clean water; Clary and Leininger 2000).

Scientific documentation that livestock grazing could damage riparian areas began in the 1980s (Skovlin 1984) and has been documented in numerous symposia (e.g., Warner and Hendrix 1984; Johnson et al. 1985; Gresswell et al. 1989; Meehan 1991; Clary et al. 1992), literature reviews (Platts 1981, 1982, 1991; Kauffman and Krueger 1984; Skovlin 1984; Chaney et al. 1990, 1993; Armour et al. 1994; Fleischner 1994; Rhodes et al. 1994; Kattelman and Embury 1996; Ohmart 1996), and government reports (US Department of the Interior, Bureau of Land Management [USDI BLM] 1994; US General Accounting Office [US GAO] 1988). Recognizing that riparian ecosystem services need to be protected, USDA NRCS, along with many other federal and state resources agencies, began to apply existing conservation practices and to implement new practices with the goal of protecting and improving riparian habitats.

### DESCRIPTION OF CONSERVATION PRACTICES AND BENEFITS

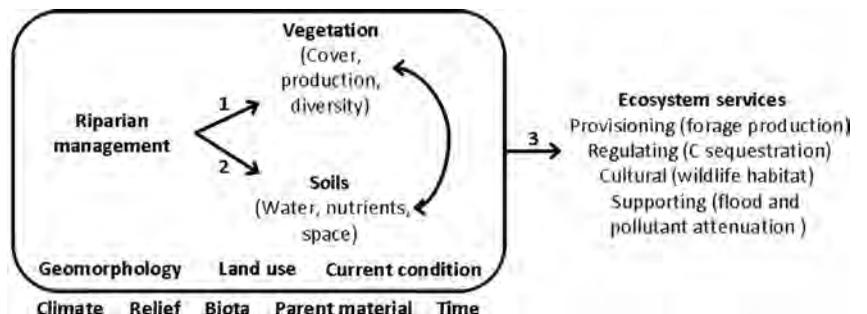
More than 40 practices in the USDA NRCS National Conservation Practice Guidelines (USDA NRCS 2003) were identified as having potential for application to riparian ecosystems. For this review, we narrowed the practices in

Appendix I to a shorter list of 20 that are often associated with rangeland or pasture systems (Table 1). The *purposes or anticipated benefits* stated in the practice standards for these 20 practices can be summarized into five main ecosystem services: 1) high-quality and abundant fish and wildlife habitat, 2) clean and plentiful water supply, 3) stable stream banks and riparian soils supporting hydrologic functions such as flood and pollutant attenuation, 4) carbon sequestration, and 5) diverse, rich, productive plant and animal communities (Table 1). However, the major objective of riparian habitat conservation practices is to effectively manage riparian vegetation, stream channel, and soil resources to protect or enhance these ecosystem services (Fig. 1).

### Objective and Approach

Recognizing that anticipated benefits of management practices applied to riparian habitats are mediated by resource availability, especially water, we developed a conceptual model that links management practices to vegetation attributes and resource constraints (Fig. 1). The model acknowledges the overriding importance of state factors such as climate, parent material, relief, geomorphology, past and contemporary land uses, and disturbances at the watershed and

**FIGURE 1.** Conceptual model of the effect of riparian conservation practices on vegetation, soils, stream banks, and ecosystem services. The outcome of conservation practices are contingent on the biophysical context, which is set at a coarse level by state factors such as climate, relief, parent material, and the age of the riparian area. These state factors interact to shape the geomorphology and current condition of the riparian zone. Land use at the landscape level of organization, including conservation practices in uplands, is considered a state factor because it is controlled by humans. Within the bounds set by a particular combination of state factors, riparian management can affect vegetation and soils. In addition to these direct effects, feedbacks exist between vegetation and soils that condition their individual and collective response to management. Ecosystem services in the form of forage production, carbon sequestration, wildlife habitat, and flood and pollutant attenuation emerge from these dynamics processes.





Practices such as fencing to manage grazing pressure on riparian vegetation and soils are anticipated to enhance riparian-based ecosystem services. (Photo: Ken Tate)

larger spatial scales on riparian vegetation and soils. It is widely documented that single or cumulative watershed-scale management practices (e.g., upland brush management, upland grazing management) and disturbances (e.g., fire, road construction) can affect riparian area functions, services, and response to site-specific management practices. For the purposes of this review, we focused on the interaction of various management practices with riparian soil and stream bank resource availability (i.e., water, nutrients, oxygen), and vegetation. We used the model illustrated in Figure 1 to generate 21 hypotheses that could be evaluated using published experimental data. The experimental data associated with these selected practices was identified by reviewing primarily peer-reviewed literature.

Support for most hypotheses is summarized and incorporated into appendices to provide an evidence-based assessment of the effectiveness of these riparian management practices.

### EVALUATION OF RIPARIAN MANAGEMENT PRACTICES

We classified 21 hypotheses into three riparian management purposes: 1) protection or restoration of vegetation attributes, 2) protection or restoration of stream channel and riparian soil stability, and 3) direct or indirect protection or improvement of ecosystem services (Fig. 1). In this section, each of the 21 hypotheses is evaluated against the supporting experimental data.

## Practices That Protect or Restore Vegetation Attributes

### *Hypothesis 1: Management of Time, Intensity, Season, and Duration of Grazing Affect Herbaceous Species Composition.*

Grazing systems facilitate control of season of use, frequency of use, duration of use, grazing intensity, and livestock distribution. However, herbaceous plant community response to grazing management is often difficult to predict because the responses are contingent on resource availability, namely, water (Stringham et al. 2001; Poole et al. 2006). Resource availability is moderated by the biophysical characteristics of the riparian area and its watershed (Fig. 1; Goodwin et al. 2008). In general, increasing grazing intensity results in a reduction of slower-growing, larger-seeded plant species (i.e., competitive species sensu Grime 1979) that are often considered desirable, depending on management objectives. As grazing intensity increases, the abundance of faster-growing, small-seeded species (i.e., ruderals) increases; however, this response may be less prominent where water is in abundant supply. Moreover, where water is limiting or the supply is erratic, ruderals may dominate even with little or no grazing. This model is an oversimplification because in many riparian systems, resource limitations (e.g., moisture, nutrients, and temperature) occur in transient pulses (Seastedt and Knapp 1993). Flooding events may create microsites where only species tolerant of anoxia can persist.

Lucas et al. (2004), working in New Mexico, found little effect of grazing intensity (no, low, and moderate) on herbaceous structure (cover, biomass) and composition (diversity). However, cool-season grazing promoted herbaceous diversity over warm-season grazing. The authors were adamant that grazing management affects streams in site-specific ways; hence, no single prescription is warranted for riparian management. This echoes findings of Jackson and Allen-Diaz (2006), who found highly variable interannual community characteristics in spring-fed wetlands that appeared unrelated to grazing intensity, while subsequent first-order streamside vegetation appeared directly linked to grazing treatments.

Lunt et al. (2007), working in a southeastern Australian riparian forest, showed that grazing

exclusion had minimal impacts on understory composition and structure over a 12-yr period, attributing this to the fact that their system was nonequilibrium and responded more to abiotic factors than to biotic factors, such as grazing management. Clary (1999) found that all grazing treatments (0, 20–25%, and 35–50% utilization) resulted in increased plant species richness on streamsides and meadows as the systems recovered from historic heavy grazing. This indicates that the ecological condition of the riparian habitat at the onset of the study has important implications for the potential outcomes that may result from various management practices.

Kauffman et al. (1983a) observed a phenological shift in the herbaceous plant community of mesic and hydric riparian zones in eastern Oregon that they ascribed to quicker drying of grazed soils resulting from greater solar insolation incident on the soil surface. Their data showed an increase in undesirable plant species with grazing compared to exclosures, though the experimental design was weak and no estimate of uncertainty was reported. The grazing prescription during this study was 75% utilization of bluegrass (*Poa* spp.) meadows.

Lyons et al. (2000a) focused on the effects of different types of riparian vegetation on small streams in central North America and indicated that without grazing, these zones will become dominated by woody species that reduce stream bank stability. Paine and Ribic (2002) found more diverse plant communities and wildlife habitat when grassy buffer strips were present along riparian zones compared to woody-dominated riparian zones. In contrast, Carline and Walsh (2007) show that in Pennsylvania, exclusion of grazing for 3–5 yr, from formerly heavily stocked pastures, resulted in vegetation cover increases from 50% to 100%.

Our review of 11 reports found substantial support for the hypothesis that grazing intensity influences herbaceous species composition. However, managers should be aware that grazing effects on species composition may be influenced by the availability of resources, such as water and nutrients. Three of these studies (Lucas et al. 2004; Jackson and Allen-Diaz 2006; Lunt et



Eleven studies supported the hypothesis that grazing intensity influences herbaceous species composition however, grazing effects on species composition may be influenced by the availability of resources, such as water and nutrients”

**TABLE 2.** Evaluation and rating of grazing strategies for stream–riparian-related fisheries values based on observations of Platts (1990).

Strategy	Level to which riparian vegetation is commonly used	Control of animal distribution (allotment)	Stream bank stability	Brushy species condition	Seasonal plant regrowth	Stream–riparian rehabilitative potential	Rating
Continuous season-long (cattle)	Heavy	Poor	Poor	Poor	Poor	Poor	1 <sup>1</sup>
Holding (sheep or cattle)	Heavy	Excellent	Poor	Poor	Fair	Poor	1
Short duration–high intensity (cattle)	Heavy	Excellent	Poor	Poor	Poor	Poor	1
Three herd–four pasture (cattle)	Heavy to moderate	Good	Poor	Poor	Poor	Poor	2
Holistic (cattle or sheep)	Heavy to light	Good	Poor to good	Poor	Good	Poor to excellent	2–9
Deferred (cattle)	Moderate to heavy	Fair	Poor	Poor	Fair	Fair	3
Seasonal suitability (cattle)	Heavy	Good	Poor	Poor	Fair	Fair	3
Deferred rotation (cattle)	Heavy to moderate	Good	Fair	Fair	Fair	Fair	4
Stuttered deferred rotation (cattle)	Heavy to moderate	Good	Fair	Fair	Fair	Fair	4
Winter (sheep or cattle)	Moderate to heavy	Fair	Good	Fair	Fair to good	Good	5
Rest–rotation (cattle)	Heavy to moderate	Good	Fair to good	Fair	Fair to good	Fair	5
Double rest–rotation (cattle)	Moderate	Good	Good	Fair	Good	Good	6
Seasonal riparian preference (cattle or sheep)	Moderate to light	Good	Good	Good	Fair	Fair	6
Riparian pasture (cattle or sheep)	As prescribed	Good	Good	Good	Good	Good	8
Corridor fencing (cattle or sheep)	None	Excellent	Good to excellent	Excellent	Good to excellent	Excellent	9
Rest–rotation with seasonal preference (sheep)	Light	Good	Good to excellent	Good to excellent	Good	Excellent	9
Rest or closure (cattle or sheep)	None	Excellent	Excellent	Excellent	Excellent	Excellent	10

<sup>1</sup>Rating scale based on 1 (poorly compatible) to 10 (highly compatible) with fishery needs.

al. 2007), which were conducted in semiarid rangeland, concluded that grazing intensity effects were either nonexistent or overwhelmed by abiotic drivers. There was some support for a season, duration, or frequency of grazing effect on herbaceous species composition, but these studies were conducted mainly in the mesic upper Midwest or eastern grasslands (Lyons 2000b; Carline and Walsh 2007), where resources such as water and nutrients

are typically in greater and more consistent supply. Studies that focused on mesic systems supported an increase in woody species with grazing exclusion.

*Hypothesis 2: Management of Time, Intensity, Season, and Duration of Grazing Can Influence Aboveground Herbaceous Productivity.* Compensatory growth is the stimulation of net primary productivity (NPP)

by defoliation such that regrowth compensates for the biomass removed by the defoliation process (Bartolome 1993). Overcompensation occurs when defoliation results in production that exceeds that of undefoliated plants. Riparian herbaceous vegetation is often very productive since riparian areas usually possess abundant nutrients and water. Hence, it is plausible that grazing management that does not degrade resource availability may also result in compensatory growth, as was found by Boyd and Svejcar (2004) in eastern Oregon. This mechanism was implicated by Jackson et al. (2006) as the reason for greater nitrate loss from spring-fed wetlands of the Sierra Nevada foothill oak woodlands. In this study, grazing stimulated production compared to no grazing, which promoted uptake of nitrate entering the wetlands from the surrounding landscape. Alternatively, removal of grazing resulted in an immediate increase in total standing biomass, but this biomass accumulated, as dead plant material, on the surface and suppressed subsequent productivity, a phenomenon also observed by Popolizio et al. (1994) in a Colorado riparian zone.

Huber et al. (1995) observed lower standing biomass under moderate grazing intensity compared to low and no grazing treatments, which were not different from each other. Caution must be used when interpreting peak standing biomass data because it is difficult to know whether a response to the treatment or the treatment itself is being measured. Productivity could be equal to or greater than the control, but standing biomass may be lower because of livestock utilization.

Studying grazing effects of pack stock in Sierra Nevada mountain meadows, Cole et al. (2004) found reduced vegetation productivity over 5 yr in three meadow communities. Stohlgren et al. (1989) conducted a clipping experiment on high-elevation subalpine meadows of the Sierra Nevada. They found that clipping for 5 yr to simulate heavy grazing negatively affected productivity in wet and mesic meadows but not in dry *Carex exserta* meadows. The authors caution that these results cannot be extrapolated to address grazing at light or moderate levels. However, these results support the general notion that

grazing effects on productivity are likely to be more pronounced in systems where resource availability is relatively high, such as mesic compared to dry meadows, where environmentally driven resource limitation has a stronger influence. This is to say not that grazing management has no effect in resource-poor systems but rather that productivity is inherently low or variable and therefore less coupled to management.

Late-season clipping in a Sierra Nevada mountain meadow had no consistent effects on above- and belowground response variables, such as root growth and photosynthetic rates (Martin and Chambers 2002), similar to the late-season clipping results of Clary (1995, 1999). Kluse and Allen-Diaz (2005) clipped Sierra Nevada meadows dominated by *Deschampsia caespitosa* and *Poa pratensis* early in the growing season and found reduced productivity in both species but no shift in relative species abundance. Huber et al. (1995) found that light grazing of a Sierra Nevada meadow resulted in vegetation biomass similar to ungrazed meadows but encouraged cattle to graze away from streamside edge compared to heavy grazing. Allen and Marlow (1994) found that beaked sedge (*Carex rostrata*) tolerated light to moderate grazing in early summer and fall if there was at least 60 d of rest between grazing periods to allow production of new photosynthetic tissue.

Nine peer-reviewed reports support that grazing intensity can influence herbaceous productivity. Two reports (Boyd and Svejcar 2004; Jackson et al. 2006) support a compensatory grazing effect on productivity, and two reports (Popolizio et al. 1994; Jackson et al. 2006) found that exclusion resulted in an accumulation of standing biomass that subsequently suppressed productivity. One report (Kluse et al. 2005) concluded that early-season clipping reduced productivity of two grasses. Three of these studies (Stohlgren et al. 1989; Huber et al. 1995; Cole et al. 2004) concluded that resource availability mediated the effect of grazing intensity on herbaceous productivity. Three studies in *Rangelands* found that late-season clipping had no consistent effect on above- and belowground productivity (Clary 1995, 1999; Martin and Chambers 2002).



The peer-reviewed literature generally supports the effectiveness of water developments, supplement placement and herding for reducing riparian vegetation utilization, or time spent in riparian areas”



Cattle grazing a small riparian patch within a sagebrush community. (Photo: Chad Boyd)

We can conclude that there is no universal riparian herbaceous production response to the complex elements (time, intensity, season, or duration) of grazing management. Consequently, what a manager learns on one site may not be transferable to another site.

### *Hypothesis 3: Livestock Distribution Practices Reduce Time Spent in Riparian Zones or Riparian Vegetation Utilization.*

The peer-reviewed literature generally supports the effectiveness of water developments, supplement placement and herding for reducing riparian vegetation utilization, or time spent in riparian areas. Bailey (2004, 2005) and George et al. (2007) have reviewed practices that attract livestock to underused areas and away from riparian habitats. Abiotic and biotic characteristics of landscapes and pastures influence the effectiveness of these practices. A few studies document the effectiveness of drinking-water developments, herding, and strategic placement of supplemental feeds for reducing grazing use and the time spent in riparian areas. Nine out of 10 studies (seven peer reviewed, one thesis, and two in rangelands) report that development of off-stream stock water reduces grazing use or time spent in riparian areas. Six of these studies were conducted in eastern Oregon. McGinnis and McIver (2001) reported that the extent to which livestock can be enticed away from riparian areas depends on season, topography, vegetation, weather, and behavioral differences among animals. Ehrhart and Hansen (1998) evaluated ecological function on 71 streams in Montana and found that off-stream water developments resulted in improved ecosystem health. A few studies have shown that most grazing use occurs within 400 m of stock water sources (Pinchak et al. 1991). Thus, water developments placed at this distance or beyond may be more effective at reducing livestock use in riparian areas than closer installations. Two studies in California (McDougald et al. 1989; George et al. 2008) and one in Montana (Bailey et al. 2008a) have demonstrated the effectiveness of strategic supplement placement for attracting livestock away from riparian areas, and one study in Montana documented the effectiveness of herding with or without supplementation for reducing grazing use in the riparian area.

Additional studies in Montana have shown the effectiveness of supplement as a cattle attractant. One study in Nevada documented the effectiveness of shade structures for reducing riparian use. The results of these studies are reinforced by studies in California and Montana that found that riparian health was related to time invested in management by the landowner or manager (Ehrhart and Hansen 1998; Ward 2002; Ward et al. 2003).

Most of the data supporting these findings come from Oregon (Great Basin or forest), California (oak-woodland and annual grassland), or Montana (plains). We conclude from these studies that water developments, strategic supplement placement, and herding can effectively reduce time spent in riparian zones and riparian vegetation use by livestock. Because the effectiveness of these practices is often controlled more by abiotic (topography and distance from water) landscape characteristics than by biotic characteristics, we believe that they can be generalized to other rangeland ecosystems. Livestock attraction practices work best on gentle slopes and become less effective as slope increases. Narrow riparian corridors that are bound by steep slopes with limited available high-quality forage or water are generally not good candidates for these practices.

### *Hypothesis 4: Under Initially Degraded Conditions, Grazing Exclusion Can Promote Recovery of Riparian Plant Community Composition.*

The peer-reviewed literature generally supports the hypothesis that grazing exclusion can promote recovery of riparian plant community composition in degraded riparian systems. Fencing and use exclusion are commonly used to remove grazing from riparian areas permanently or during recovery periods. Many reports of the impacts of grazing on riparian areas and associated aquatic ecosystems come from comparisons of grazed and ungrazed areas (Larsen et al. 1998; Sarr 2002). Working in north-central Colorado on montane riparian areas, Popolizio et al. (1994) showed that long-term grazing altered plant community composition and cover characterized by more bare ground, dandelion (*Taraxacum officinale*), and clover (*Trifolium repens*) compared to ungrazed areas. Similar findings were reported

by Schulz and Leininger (1990) within the riparian zone bordering Sheep Creek in north-central Colorado. Compositional changes from forb- or nonnative grass-dominated communities toward native grass- and sedge-dominated communities have been widely documented in montane riparian meadow with grazing exclusion (Leege et al. 1981; Kauffman 1983b; Schulz and Leininger 1990; Green and Kauffman 1995).

We can conclude from these studies that grazing exclusion can promote recovery of initially degraded riparian plant community composition. However, plant species richness has not shown a clear response to grazing exclusion, though a few experimental results have been reported in the peer-reviewed literature (Bowns and Bagley 1986; Green and Kauffman 1995).

*Hypothesis 5: Livestock and Other Large Herbivores Modify Structure and Composition of Woody Plant Communities.*

The literature clearly indicates that livestock and native ungulates can modify the structure and composition of woody plant communities in riparian habitats. The vast majority of papers dealing with woody plants were from the western and northwestern United States; work from the southwestern United States was limited, and southern Plains publications were lacking. Fourteen of 16 papers (Appendix V) indicated structural or compositional modification of woody plant communities as a result of livestock grazing (Green and Kauffman 1995; Samuelson and Rood 2004; Holland et al. 2005). Papers by Sedgwick and Knopf (1991) and Lucas et al. (2004) did not clearly show structural or compositional effects of grazing on woody plant communities. Two papers indicated negative effects of deer (*Odocoileus hemionus*) browsing (Opperman and Merenlender 2000; Matney et al. 2005), two papers indicated negative impacts of elk (*Cervus canadensis*) or moose (*Alces alces*) herbivory (Kay 1994; Zeigenfuss et al. 2002) on woody plants, and Case and Kauffman (1997) reported reductions in woody plant abundance as a result of combined deer and elk herbivory.

Establishment and maintenance of woody plants can be associated with episodic

disturbance events (Rood et al. 2007; Bay and Sher 2008); therefore, evaluation of the effects of grazing on establishment and maintenance of woody plants should ideally occur over a sufficient time interval to encompass critical disturbance events. Auble and Scott (1998) reported that recruitment of cottonwood decreased with cattle grazing but that recruitment was highly dependent on infrequent high flow conditions that created suitable habitat for seedlings. Conversely, Sedgwick and Knopf (1991) thought grazing to be a relatively minor impact on willows (*Salix* spp.) and cottonwoods (*Populus* spp.) in comparison to periodic catastrophic flooding (which washed out woody plant habitat). Manoukian and Marlow (2002) concluded that willow canopy cover fluctuated along streams from 1942 to 1985 but that the trend was upward in a USDA Forest Service grazing allotment. They concluded that extended periods (>3 yr) of rest were not necessary for willow recovery if livestock or wildlife use was closely controlled. In many cases, livestock use of woody plants may constitute only a portion of total use when native ungulates are considered. For example, Kay (1994) reported that tall willows had disappeared from 41 of 44 historical photo sets in Yellowstone National Park in association with elk and moose herbivory. Grazing can also affect woody plants through alterations in site hydrology. Such alterations may take the form of direct alterations in physical characteristics of the stream channel associated with changes from high- to low-root-density vegetation as discussed under hypothesis 8. These modifications could indirectly decrease site availability for riparian woody plants by decreasing available water.

The influence of livestock on woody plant structure is complex and dependent on a variety of management and environmental site factors. Hypothesis 3 makes clear that livestock usage of riparian areas is variable and predicated on a variety of management and environmental factors. From hypothesis 5, we can conclude that livestock and other large herbivores can modify the structure and composition of woody plant communities, but the impacts of livestock on woody plant resources are likely to be highly variable from location to location and within a given location over time.



Based on these studies, there is sufficient evidence to conclude that fall livestock use of riparian areas can lead to increased utilization of woody plants”

*Hypothesis 6: Late-Growing-Season Livestock Use Increases Utilization of Woody Plants.* Eleven of the 17 papers associated with livestock impacts on woody plants reported on the effects of late-season use. Of those 11 papers, nine reported negative structural or compositional modification associated with late-season livestock utilization of woody plants (Schulz and Leininger 1990; Clary et al. 1996; Holland et al. 2005), and four papers specifically noted increased use during the late-season period (Roath and Krueger 1982; Kauffman et al. 1983a; Conroy and Svejcar 1991; Green and Kauffman 1995). One paper found that dormant-season clipping had less negative impact on woody plant abundance than continuous elk use (Zeigenfuss 2002), and another paper reported decreased willow

abundance associated with late-season deer use (Matney et al. 2005). Roath and Krueger (1982) reported an inverse relationship between degree of woody plant utilization and phenological maturity of herbaceous cover. Kauffman et al. (1983a) and Matney et al. (2005) noted that woody plant utilization by mule deer did not begin until herbaceous availability became limiting. Clary et al. (1996) concluded that spring grazing was less detrimental to woody plants than fall grazing.

Based on these studies, there is sufficient evidence to conclude that fall livestock use of riparian areas can lead to increased utilization of woody plants. This temporal pattern of woody plant utilization is generally associated with reduced herbaceous plant availability or forage quality.

For streams with the site potential to support riparian woody plants, consistent late season grazing can reduce woody plant recruitment and extent. (Photo: Ken Tate)



**Hypothesis 7: Riparian Burning Can Reduce Undesirable Woody Species and Restore Desired Herbaceous or Woody Vegetation.** Few studies have addressed the effects of fire on riparian ecosystems (Dwire and Kauffman 2003). However, riparian species exhibit adaptations that facilitate rapid recovery following fire. Several species resprout following fire, including quaking aspen (*Populus tremuloides*), cottonwood, and willows. To the extent that fire can remove competition from undesirable species, desirable resprouting species may be restored.

Reviews by Dwire and Kaufman (2003) and Pettit and Naiman (2007) point out that the effectiveness of riparian burning may be mediated by resource availability and grazing management. Riparian burning is not well studied, but these reviews offer several hypotheses related to interactions among climate, disturbance regime, landscape position, and fire frequency and intensity. They point out that even in fire-driven landscapes (e.g., savannas), riparian plant community composition and productivity is more likely to be controlled by water and nutrient availability afforded by the lower landscape position. The effects of burning will likely interact with grazing management with higher grazing intensities, reducing the effects and the likelihood of fire in riparian zones (Dwire et al. 2006). That said, if sufficient fuel is available, the effects of burning may depend on depth to the water table. Blank et al. (2003) burned riparian sites dominated by big sagebrush (*Artemisia tridentata*) to reduce its cover and favor herbaceous species in areas with shallow and deep water tables. Herbs that were present at the time of burning resprouted and contained higher nutrient concentrations following burning. However, herbs were less abundant where the water table was deeper prior to burning, so the postburn response was more favorable with shallower water tables. Proportionally more of the surface soil nutrients were lost from the riparian zones with deeper water tables, which does not bode well for the growth of herbs in these habitats. Thus, recovery from fire depends on the presence of residual herbaceous species and an adequate water table to support these species.

**TABLE 3.** Grazing system compatibility with willow-dominated plant communities in riparian habitats (Kovalchik and Elmore 1991).

Grazing practice	Compatibility with willows
Corridor fencing	Highly
Riparian pasture	Highly
Spring (early-season) grazing	Highly
Winter grazing	Highly
Two-pasture rotation	Moderately
Three-pasture rest rotation	Moderately
Three-pasture deferred rotation	Moderately
Spring-fall pastures	Incompatible
Deferred grazing	Incompatible
Late-season grazing	Incompatible
Season-long grazing	Incompatible

Literature concerning use of prescribed fire to control undesirable woody species in riparian zones relates mainly to the genus *Tamarix*. Three of four studies that incorporated fire as a treatment reported successful control of *Tamarix* with mortality rates up to 95% (McDaniel and Taylor 2003; Harms and Hiebert 2006; Bateman et al. 2008; Appendix VII). One study found that control of *Tamarix* was not related to burning or mechanical removal but instead was most closely associated with site and year factors, the most important of which was precipitation, with no *Tamarix* regrowth occurring on sites receiving less than 20.8 cm of annual precipitation (Bay and Sher 2008). Busch and Smith (1993) urged caution in the use of fire to control both *Tamarix* and *Tessaria*, as these genera possess ecophysiological adaptations that may favor their abundance over historically dominant willow and cottonwood in the postfire environment. A study in the Great Basin on riparian areas affected by stream incision and decreased water tables examined the use of prescribed fire to remove sagebrush and restore riparian obligate herbaceous species. Desired plant species increased and herbaceous biomass tripled on sites with residual riparian species and adequate water tables, but sites that

lacked residual species and had significantly lowered water tables were dominated by annual weeds postfire (Chambers and Linnerooth 2001; Wright and Chambers 2002; Blank et al. 2003). Fire has been used as an effective form of control for nonsprouting conifer species on upland sites (e.g., Bryant et al. 1983; Engle and Stritzke 1995; Miller et al. 2005) and may play an important role in controlling encroachment of those species into riparian areas.

While there are insufficient experimental data to thoroughly evaluate this hypothesis, current literature suggests that fire can be used to control some species of woody plants; however, the success of fire-based restoration may relate strongly to the availability of propagules of desired species, which can be depleted if riparian degradation has led to decreased soil water availability.

### Scientific Uncertainty and Livestock Exclosure Studies

Comparison of grazed areas with ungrazed areas (exclosures) is a common practice that has the potential for erroneous interpretations. Sarr (2002) reviewed exclosure studies and reported that exclosure-based research has left considerable scientific uncertainty because of the popularization of relatively few studies, weak study designs, a poor understanding of the scales and mechanisms of ecosystem recovery, and selective, agenda-laden literature reviews advocating for or against public lands livestock grazing. Exclosures are often too small (<50 ha) and improperly placed to accurately measure the responses of aquatic organisms or geomorphic processes to livestock removal. Depending on the site conditions when and where livestock exclosures are established, postexclusion dynamics may vary considerably. Systems can recover quickly and predictably with livestock removal, fail to recover because of changes in system structure or function, or recover slowly and remain more sensitive to livestock impacts than they were before grazing was initiated. Sarr presents suggestions for strengthening the scientific basis for livestock exclosure research, including 1) incorporation of meta-analyses and critical reviews, 2) use of restoration ecology as a unifying conceptual framework, 3) development of long-term research programs, 4) improved exclosure placement

and design, and 5) a stronger commitment to collection of pretreatment data. Properly designed exclosure studies could provide useful insights into grazing effects, but few meet these criteria.

### Practices That Protect or Restore Stream Bank and Riparian Soil Stability

*Hypothesis 8: Riparian Management That Affects Plant Species Composition, Plant Vigor, Rooting Densities and Depth, and Ground Cover and Influences the Stability of Stream Channel and Riparian Soils That Derive Their Stability from Riparian Vegetation.*

The linkage between riparian management, riparian vegetation, and stream channel and riparian soil stability is complex (Fig. 1). Stream systems themselves are complex; Rosgen (1994) describes almost 100 stream channel categories. State factors such as watershed size, geomorphology, parent material, climate, and site-specific riparian vegetation attributes interact to define the structure and function of each stream segment (reach). Each stream reach may support and be supported by different riparian plant communities. Each reach may respond differently to watershed- or landscape-scale disturbances, and each may exhibit differing response to riparian management practices. Gordon et al. (1992), Leopold (1994), and Rosgen (1996) are excellent applications of our basic understanding of stream hydrology and applied river morphology from a watershed perspective.

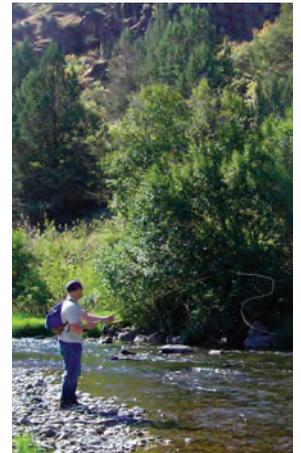
Eight studies and six reviews provide evidence of the importance of riparian plant communities and grazing management to stream bank and soil stability. Thorne (1982, 1990), Gregory (1992), and Trimble and Mendel (1995) discuss and document the general importance of riparian plant communities on stream channel and riparian soil stability. In the Sierra Nevada, Michelli and Kirchner (2002a) found that the 50-yr rate of stream channel migration and erosion was 6 and 10 times lower on stream banks and associated “wet” riparian areas covered with sedge (*Carex* spp.) and rush (*Juncus* spp.) compared to grass-dominated “dry” stream banks and associated riparian areas. In a companion study, Michelli and Kirchner (2002b) found that the tensile strength of wet

riparian soils supporting sedge (*Carex* spp.) and rush (*Juncus* spp.) plant communities were five times stronger than dry riparian soils dominated by grass and shrub species. Soil tensile strength was positively correlated to plant density, biomass, and the ratio of root to soil mass. In northwestern Nevada, Manning et al. (1989) compared root mass and root length density across a soil moisture gradient represented by four herbaceous riparian plant communities. They found both root metrics to increase with soil moisture availability, indicating superior site-stabilizing capacity in the wetter plant communities. Klienfelder et al. (1992) report similar findings for riparian areas from central Nevada and eastern California.

Research introduced to test hypotheses 1, 2, 4, and 5 in this document establishes the capacity for riparian grazing, along a gradient of heavy to minimal grazing, to have primary effects on riparian plant composition, biomass, and cover. Combined with the discussion above, the capacity for riparian grazing management practices to have secondary effects on stream channel and riparian soil stability can be established. In general, it has been well documented (e.g., Kauffman and Krueger 1984; Sarr 2002) that incorrectly managed livestock grazing in riparian areas can 1) reduce plant root mass and rooting depth, which is critical for stabilizing riparian soils and stream banks against stream flow, and 2) shift plant community composition from high-root-density species to low-root-density species. The subsequent potential effects include: 1) stream banks and riparian soils becoming unstable; 2) stream channels with “hard” bottoms eroding laterally and widening; and 3) stream channels with “soft” bottoms eroding vertically to down-cut the channel and lowering the riparian water table. A positive feedback loop exists between lowered water tables and stream bank stability as it becomes increasingly difficult for high-root-density species that require wet habitats to reestablish (Toledo and Kauffman 2001). There are significant limitations with the literature addressing grazing impacts on stream channel and riparian soil stability and associated ecosystem services (e.g., aquatic habitat, flood attenuation). Several

comprehensive reviews of essentially the same literature base substantiate the generally negative effects of “heavy” grazing, the generally positive response of riparian areas to complete removal of heavy grazing, the need for further research on “proper” grazing management strategies for riparian areas, and the need for increased rigor and consistency in case studies and experiments examining these riparian grazing strategies (Rinne 1988; Platts 1991; Ohmart 1996; Larsen et al. 1998; Allen-Diaz et al. 1999; Sarr 2002).

Based on these reviews and studies, there is sufficient evidence that riparian grazing management that maintains or enhances key riparian vegetation attributes (i.e., species composition, root mass and root density, cover, and biomass) will enhance stream channel and riparian soil stability, which will in turn support ecosystem services, such as flood and pollutant attenuation and high-quality riparian habitat. Lacking in the literature are watershed-level, statistically robust examinations of how stream channel and riparian soil stability are correlated with grazing management components, such as intensity, frequency, season, and duration of grazing across a set of riparian conditions. These should be compared for a variety to conditions, including degraded and undegraded riparian systems, herbaceous-dominated and woody-dominated systems, and alluvial channel substrates versus bedrock-dominated substrates. It is difficult to predict the specific impacts of riparian grazing management practices under differing levels of state variables (Fig. 1) as indicated in the results of Lucas et al. (2004) and Jackson and Allen-Diaz (2006) for hypothesis 1. However, it is clear that riparian grazing can be managed to enhance and protect primary riparian vegetation attributes that are strongly correlated to stream channel and riparian soil stability, which support ecosystem services provided by riparian areas (e.g., hypotheses 3 and 4). There may be highly degraded riparian conditions, such as down-cut channels, under which riparian grazing management practices alone cannot restore the site’s former soil moisture regime that supported riparian plant communities with high rooting densities and their associated ecosystem services (Chambers and Miller 2004).



Riparian corridors are important for recreation. (Photo: Chad Boyd)



Healthy riparian plant communities are effective at attenuating pollutants carried in runoff. (Photo: Ken Tate)

### Practices That Protect or Enhance Ecosystem Services

*Hypothesis 9: Riparian Vegetation Can Attenuate Pollutants Transported in Runoff, and Buffer Strip Effectiveness Is Dependent on Site-Specific Factors.* The management of riparian vegetation to trap waterborne pollutants is commonly referred to as a vegetative “buffer” or “filter” strip. Small wetlands, either natural or constructed, can also provide this service. Reviews of research relevant to the implementation of vegetative buffers in riparian habitats of rangeland ecosystems and pastures can be found in Castle et al. (1994), Schmitt et al. (1999), Dosskey (2002), Dorioz et al. (2006), and Mayer et al. (2007), among others.

Attenuation efficiencies ranging from ~0 to greater than 99% have been reported for pollutants common to rangelands and livestock-grazed systems, primarily nutrients, sediment, and indicator bacteria and pathogens (Dillaha et al. 1989; Pearce et al. 1998b; Atwill et al. 2002, 2005; Bedard Haughn et al. 2004; Tate et al. 2004a, 2005; Dosskey et al. 2007; Knox et al. 2007, 2008). The variation observed across these studies can partially be attributed to site-specific differences in biophysical factors, such as buffer width, slope, vegetation attributes within the buffer, pollutant type and attributes, pollutant load entering the buffer, overland or flood flow rate entering the buffer, hydrologic residence time within the buffer, riparian soil attributes within the buffer, and

buffer vegetation management (Castelle et al. 1994; Schmitt et al. 1999; Mayer et al. 2007). A significant number of studies have focused on determination of optimal buffer widths. No single buffer width can be prescribed for all scenarios, and there is increasing demand for decision support tools that develop first approximations of required buffer widths based on site factors (e.g., Dosskey et al. 2005, 2006, 2008; Parajuli et al. 2008). While biophysical site factors determine buffer efficiency, the manager must also decide on an acceptable level of water quality degradation risk in the determination of buffer width. As risk tolerance decreases, buffer width must increase (Castelle et al. 1994; Atwill et al. 2005; Tate et al. 2005). Varying results have been reported for the effect of stubble height of herbaceous riparian vegetation on sediment and nutrient deposition and retention, indicating that this metric may not consistently impact, or predict, buffer efficiency (Abt et al. 1994; Clary et al. 1996; Pearce et al. 1997, 1998a, 1998b; Thorton et al. 1997; Fraiser et al. 1998; Skinner 1998; Clary and Leininger 2000; Marlow et al. 2006). There is a consistently positive correlation between vegetative ground cover, plant stem density, and buffer filtration efficiency for several pollutants (e.g., Larsen et al. 1993; Corley et al. 1999; McEldowney et al. 2002; Davies et al. 2004; Tate et al. 2005). It is important to note that these same plant attributes are important for determining stream channel and riparian soil stability (H 8). Defoliation to manage buffer vegetation biomass accumulation, growth stage, and nutrient demand affects the nitrogen attenuation efficiencies of buffers (e.g., Mendez et al. 1999; Matheson et al. 2002; Bedard-Haughn et al. 2005; Jackson et al. 2006). As overland and flood flow rates entering a buffer increase and hydrologic residence times decrease, buffer attenuation and retention capacities can be reduced, if not completely eliminated (e.g., Bedard-Haughn et al. 2004; Tate et al. 2004a, 2005; Knox et al. 2007, 2008). Biomass accumulation in buffers can create human health concerns. Excessive organic carbon near surface drinking water sources may lead to formation of carcinogenic–mutagenic by-products during chlorination (Krasner et al. 1989; Jassby and Cloern 2000; Bull 2001).

Based on 41 peer-reviewed reports, the overriding message is that 1) vegetative buffer

strips can attenuate some portion of most waterborne pollutants transported by overland and flood flow events, and 2) there is significant variation in buffer attenuation efficiency attributable to site-specific factors. Supporting research ranges across a wide range of systems (e.g., urban, agricultural, rangeland), regions of the United States and the world and for a wide suite of pollutants, including sediment, nutrients, microorganisms, and pesticides. There is strong evidence supporting the overall assertion that riparian vegetation can function to attenuate waterborne pollutants in overland and flood flow events.

*Hypothesis 10: Practices That Reduce Livestock Densities, Residence Time, and Fecal and Urine Deposition in Riparian Areas and Stream Flow Generation Areas Can Reduce Nutrient and Pathogen Loading of Surface Water.* In conjunction with implementation and management of vegetative buffers in riparian areas, additional water quality protection can logically be derived from implementation of livestock management strategies that distribute livestock fecal material and urine away from riparian areas, stream flow generation areas, and surface waters. In essence, this will create additional buffering length and capacity. Recent research on rangelands supports that livestock distribution practices can be applied to modify the spatial distribution of feces and urine deposition, creating buffering distances between feces and water bodies with minimal establishment of fences (Miner et al. 1992; Clawson 1993; Bailey et al. 1996; Bailey and Welling 1999; Bailey et al. 2001; Tate et al. 2003; Blank et al. 2006; Bailey et al. 2008a, 2008b). Cattle feces and urine distribution patterns on rangelands are significantly associated with location of livestock attractants, aspect, topographic position, and season (Tate et al. 2003; Bailey et al. 2008a). Strategic location of livestock attractants, including stock water, mineral supplements, and protein supplements, can have strong influences on patterns of cattle fecal and urine loads on watersheds.

There is evidence to support the assertion that practices that reduce livestock densities, residence time, and fecal and urine deposition in riparian areas and stream flow generation



There is strong evidence supporting the overall assertion that riparian vegetation can function to attenuate waterborne pollutants in overland and flood flow events”



We conclude that grazing can decrease populations of riparian obligate avifauna but has variable effects on generalist species”

areas can reduce nutrient and pathogen loading of surface water. In addition, reducing livestock densities and residence time also reduces the negative effects of livestock on riparian vegetation attributes (e.g., stem density, cover) and soil hydrologic attributes (Gifford and Hawkins 1978; Tate et al. 2004b; e.g., bulk density, infiltration capacity). Thus, reducing livestock densities and residence time can benefit buffer efficiency (H 9) and site stability (H 8). To reduce livestock impacts in the riparian zone, stocking rate reductions are not the universal solution. The key is implementing practices that reduce livestock density in the riparian zone. These can be distribution practices, fencing to increase control of time and duration of grazing, and, in some cases, stocking rate reductions.

*Hypothesis 11: Riparian Grazing Decreases Habitat Quality for Prairie Wetland Avian Species.* Nine of 28 avian references provided information on grazing management of wetland or prairie wetland habitat and associated avian species. In seven studies focusing on waterfowl (Duebber et al. 1986; Ignatiuk and Duncan 2001; Murphy et al. 2004), only four had ungrazed controls. Habitat quality was unchanged in two studies (Barker et al. 1990; West and Messmer 2006), decreased in a third (Kruse and Bowen 1996), and was unreported in a fourth (Littlefield and Paulin 1990); nesting success was unchanged, decreased, increased, or was not measured. One of three studies without controls indicated that heavy stocking rates did not provide adequate nesting cover (Duebber et al. 1986), and two studies found no difference in nest success or habitat quality between season-long and rotational grazing strategies (Ignatiuk and Duncan 2001; Murphy et al. 2004). One of two passerine studies indicated decreased habitat quality and bird diversity with grazing (Taylor 1986), and a second study found that avian abundance and diversity were unaffected by grazing (May et al. 2002).

The references reviewed here suggest that with the exception of heavily grazed areas, grazing in wetland habitat does not decrease habitat quality for waterfowl. Insufficient data exist to determine the influence of grazing on habitat quality for wetland passerine species.

*Hypothesis 12: Riparian Grazing Decreases Populations of Riparian Avifauna.* Effects of livestock grazing on riparian avian habitat have been reviewed or summarized (Szaro 1980; Bock et al. 1993; Fleischner 1994; Belsky et al. 1999). The importance of riparian vegetation as avian habitat has been described by numerous authors (Bull and Skovlin 1982; Douglas et al. 1992; Sanders and Edge 1998; Deschenes et al. 2003). Knopf et al. (1988a) reported that riparian vegetation attracts over 10 times the number of spring migrant birds found in upland sites and has 14 times more species during fall migration. References were fairly well distributed geographically except literature for the southern Plains, which was generally lacking. Evaluating the influence of grazing management practices on riparian wildlife was limited by insufficient details in many of the studies reviewed. These limitations relegated our assessment of grazing responses to a presence-and-absence standpoint.

Nineteen studies report dynamics of riparian avifauna as a function of grazing. Of those, eight found no change in abundance (Kauffman et al. 1982; Sedgewick and Knopf 1987; Knopf et al. 1988b; Schulz and Leininger 1991; Warkentin and Reed 1999; Stanley and Knopf 2002; Scott et al. 2003; Martin and McIntyre 2007), five did not report or did not clearly report abundance (Neel 1980; Crawford et al. 2004; Martin et al. 2006; Brodhead et al. 2007; Hall et al. 2007), and five found decreased abundance (Popotnik and Giuliano 2000; Tewksbury et al. 2002; Krueper et al. 2003; Earnst et al. 2005; Fletcher and Hutto 2008). Four studies reported a decrease in species diversity or richness of riparian avifauna (Popotnik and Giuliano 2000; Stanley and Knopf 2002; Scott et al. 2003; Hall et al. 2007), and four reported static values (Kauffman et al. 1982; Schulz and Leininger 1991; Warkentin and Reed 1999; Earnst et al. 2005). Bock et al. (1993) reviewed abundance data for 63 neotropical migrant bird species in grazed and ungrazed environments. Of these species, three declined in abundance in grazed areas, and seven additional species were thought to be negatively influenced by grazing. These species were either shrub, ground, or near-ground nesters.

Overall, where grazing induced changes in habitat structure and composition, avian populations tended to change from dominance by riparian obligate species to dominance by riparian generalists (e.g., Schulz and Leininger 1991; Martin and McIntyre 2007). Changes in avian abundance were often positively associated with habitat quality; however, assigning a habitat quality measure is somewhat subjective when dealing with avian species assemblages; some species may benefit from altered habitat, and some may be negatively impacted, depending on specific habitat requirements (Farley et al. 1994). The work of Martin and McIntyre (2007) suggests that species diversity may be maximized with heterogeneous grazing intensities over space. Tewksbury et al. (2002) suggested that avian species nesting below 2.5 m would be most negatively impacted by livestock grazing.

We conclude that grazing can decrease populations of riparian obligate avifauna but has variable effects on generalist species. Diversity of species may decrease in proportion to grazing-induced decreases in habitat diversity (Scott et al. 2003). One caveat to this conclusion is that determining

the specific influence of grazing on riparian avian assemblages is challenging and must take into account uses and changes in use within the surrounding landscape. Avian species are highly mobile, and some “riparian” species may depend on spatially distant habitat types and landscape attributes. In an extreme example, assessing the influence of management practices on abundance of riparian neotropical migrant avifauna should involve determination of vital rates (e.g., nesting success and juvenile survival) to help factor out the proportion of population change associated with nonbreeding habitat. Management of local-scale riparian issues (such as grazing) should be undertaken in conjunction with larger-scale efforts to create landscapes suitable for attaining conservation objectives for riparian avifauna (Martin et al. 2006; Fletcher and Hutto 2008).

*Hypothesis 13: Riparian Grazing Decreases Populations of Macroinvertebrates, Herpetofauna, and Salmonids.* Limited data suggest that grazing does not decrease the abundance or overall diversity of macroinvertebrates. However, some habitat specialists may decrease and be replaced with



Grazing should be managed to allow a site to meet its potential to provide in-stream aquatic habitat features such as over-hanging banks and clean gravel beds. (Photo: Ken Tate)

habitat generalists (Weigel et al. 2000; Bates et al. 2007). Data are insufficient to make general conclusions regarding the influence grazing on herpetofauna populations. Diversity of macroinvertebrates remained unchanged or increased with grazing in six of nine studies (Fritz et al. 1999; Weigel et al. 2000; Homyack and Giuliano 2002; Scrimgeour and Kendall 2003; Sada et al. 2005; Bates et al. 2007), decreased in one study (Foote and Rice Hornung 2005), and was not reported in two studies (Tait et al. 1994; Saunders and Fausch 2007). Macroinvertebrate abundance remained unchanged with grazing in seven studies (Tait et al. 1994; Fritz et al. 1999; Homyack and Giuliano 2002; Scrimgeour and Kendall 2003; Sada et al. 2005; Bates et al. 2007; Saunders and Fausch 2007), decreased in one study (Foote and Rice Hornung 2005), and was not reported in one study (Weigel et al. 2000). Two studies reported no effect of grazing on riparian herpetofauna (Bull and Hayes 2000; Homyack and Giuliano 2002), but a review by Brodie (2001) suggests that turtle populations may be negatively impacted by increased siltation associated with disturbances, such as livestock grazing.

Limited data suggest that livestock grazing can decrease salmonid populations, and the bulk of papers we examined suggested decreasing quality of habitat with livestock use. The specific grazing management scenarios under which salmonid populations may be negatively impacted by grazing are largely unknown given that most of the salmonid studies we reviewed did not report stocking rate or utilization information. Impacts of livestock grazing on salmonid habitat and populations have been summarized (Meehan and Platts 1978; Platts 1981, 1991; Armour et al. 1994; Fleischner 1994; Belsky et al. 1999). Three of six studies reported decreased salmonid abundance associated with livestock grazing (Keller and Burnham 1982; Tait et al. 1994; Knapp and Matthews 1996), one study reported no impact (Chapman and Knudsen 1980), and one did not report abundance as a function of grazing treatment (Platts and Nelson 1989). One study indicated that salmonid abundance was higher for areas grazed with a high-density, short-duration grazing system compared to season-long grazing (Saunders and Fausch 2007). Three of six studies reported decreased quality

of salmonid habitat with grazing (Chapman and Knudsen 1980; Platts and Nelson 1989; Knapp and Matthews 1996), one reported no effect (Tait et al. 1994), one did not report habitat effects (Keller and Burnham 1982), and one reported increased habitat quality with short-duration grazing compared to season-long grazing (Saunders and Fausch 2007).

We recognize that additional published references are available correlating fish abundance with grazing practices. However, much of this work has not undergone the scrutiny of peer review, suffers from major experimental design inadequacies (e.g., lack of replication, nonrandom treatment assignment, lack of pretreatment data), or has insufficient methodological description to determine the adequacy of experimental design (Platts 1982; Rinne 1985; Larsen et al. 1998). These problems render affected references useless for our purposes in determining the validity of hypotheses regarding management practices. That said, it should also be pointed out that ill-advised grazing practices can lead to loss of bank-stabilizing vegetation, resulting in altered channel morphology (see discussion for hypothesis 8) and that such alterations may have strong negative consequences for habitat of affected aquatic fauna (Fitch and Adams 1998).

#### *Hypothesis 14: Riparian Grazing Decreases Habitat Quality for Riparian Mammals.*

Data are insufficient to determine the impact of grazing on large mammal riparian wildlife species with two studies reporting either decreased quality of fawning habitat (Loft et al. 1987) or livestock-induced habitat avoidance (Loft et al. 1991). Three studies addressed the influence of grazing on riparian small mammal communities. Two studies found no change in diversity of species (Kauffman et al. 1982; Schulz and Leininger 1991), and one reported decreased diversity (Giuliano and Homyack 2004). Two of three studies reported decreased small mammal abundance with grazing (Kauffman et al. 1982; Giuliano and Homyack 2004), and one study was inconclusive (Schulz and Leininger 1991). A fourth study reported decreased small mammal biomass with heavy compared to light grazing, but responses varied by species, and ungrazed comparisons were not included (Johnston and Anthony 2008).

Available data are insufficient to draw general conclusions regarding the impacts of livestock on riparian small mammal communities. Realistically, a general conclusion for small mammals as a group may not be possible because of the inherent variability in habitat requirements between species and variability among years. Species that depend on herbaceous cover may decrease with heavy livestock use, while the same disturbance may increase habitat quality for species requiring reduced amounts of herbaceous ground cover (Hanley and Page 1982; Johnston and Anthony 2008).

**Hypothesis 15: Grazing Removal Will Increase Quality of Sage Grouse Brood-Rearing Habitat.** Because of a lack of experimental work on the subject, generalizations regarding the influence of grazing on sage grouse brood rearing habitat cannot be made at this time. Only one study, Neel (1980; see also Appendix VI) has addressed the influence of grazing on riparian brood-rearing habitat for sage grouse. This study found that 1 yr of rest from grazing increased abundance of forbs important in the diet of sage grouse. The author also reported that sage grouse selected lightly grazed riparian habitat for brood rearing as compared to nongrazed habitat.

**Hypothesis 16: Invasive Woody Plant Management Can Control Abundance of Undesirable Plant Species.** Literature relating to invasive species management and riparian woody plants deals mainly with populations of the invasive plant genera *Tamarix* and in some cases Russian olive (*Elaeagnus angustifolia*) in the southwestern United States. In three studies, various combinations of cutting, plowing, and burning were highly effective at removing both *Tamarix* and Russian olive (McDaniel and Taylor 2003; Harms and Hieber 2006; Bay and Sher 2008; Appendix VII). A fourth study reported that while *Tamarix* seedling density was initially higher than that of native woody plants, *Tamarix* seedlings were much more susceptible to mortality associated with overbank flooding in unregulated river systems (Sher et al. 2002). Much of the effort to control *Tamarix* remains unevaluated and unpublished. Bay and Sher (2008) reviewed

control projects ranging from 1 to 18 yr posttreatment. They reported that the degree of control was not related to time since restoration began or specific management treatments and that areas with less than 21 cm of annual precipitation had only limited long-term *Tamarix* control. Site factors played a strong role in influencing project success, and the degree of control was associated positively with proximity to perennial water, sufficient precipitation, recent flooding, and coarse soil texture. Shafroth et al. (2008) noted that success of *Tamarix* control projects was highly variable and proposed a framework for planning control efforts that focuses on using principles of adaptive management. These authors stressed that site conditions, including soil salinity and texture, current vegetation, and availability of desired propagules, have a strong influence on restoration success and highlighted the importance of considering both passive (e.g., flooding) and active (e.g., cutting and seeding) management options.

Because of the spatial and temporal variability associated with the success of *Tamarix* control projects, it is not possible to make general statements regarding the effectiveness of control programs. Future success in *Tamarix* management will likely hinge on effective application of adaptive management techniques (Reever Morghan et al. 2006).

**Hypothesis 17: Control of Invasive Woody Plant Species Increases the Abundance of Terrestrial Wildlife.** Most of the literature regarding invasive riparian woody plant control and wildlife abundance relates to the control of *Tamarix*. Four papers relating invasive woody plants to wildlife assemblages failed to uncover substantive benefit to abundance or diversity of avian, butterfly, or lizard assemblages (Knopf and Olson 1984; Bateman et al. 2008; Nelson and Wydoski 2008; Sogge et al. 2008). In a 2008 review, Sogge et al. found that not all avian species benefit from control of *Tamarix*, particularly when native vegetation does not reestablish in the postrestoration environment. These authors concluded that 49 avian species, including the endangered southwestern willow flycatcher, use *Tamarix* as breeding habitat. Van Ripper et al. (2008) reported that for most avian species, abundance was highest with a mix of native woody plants and *Tamarix*.



Seasonal riparian corridor in an oak-woodland in California's central Sierra Nevada foothills. (Photo: Melvin George)

Knopf and Olson (1984) reported increased avian diversity in native riparian communities compared to sites dominated by Russian olive but noted that Russian olive was used by avian species favoring tall shrub habitat and that the occurrence of Russian olive near the periphery of riparian areas could increase diversity of riparian habitats available to avian species.

At this time, the complexity of wildlife responses to *Tamarix* and Russian olive control varies strongly across species and geographic location, making generalizations regarding the impact of these invasive species on terrestrial wildlife difficult (Shafroth et al. 2005; Sogge et al. 2008).

**Hypothesis 18: Upland Brush Management Can Decrease Riparian Erosion and Increase Stream Flow.** Nine studies addressed the influence of woody plant removal on watershed hydrology (Appendix VII). Three studies reported increased water yield (actual or modeled) or stream flow in pinyon-juniper (Baker 1984), chaparral (Davis 1993), or sagebrush (Sturges 1994) vegetation, and two reported no change in stream flow (Wilcox et al. 2005) or runoff (Dugas et al. 1998) for Ashe juniper (*Juniperus ashei*). One study found no change in basin-level water yield with removal of western juniper (*Juniperus occidentalis*; Kuhn et al. 2007). One study reported increased potential for deep drainage with burning in sagebrush-steppe (Seyfried and Wilcox 2006), a second found dramatically decreased runoff and erosion in sagebrush-steppe following juniper removal and (Pierson et al. 2007), and a third found increased runoff with chaining and windrowing of pinyon-juniper, but runoff was invariant when trees were left in place (Gifford 1975). Wilcox (2002) proposed that the influence of woody plants on stream flow will be a product of interactions between shrub characteristics, precipitation, soils, and geology. Under this conceptual framework, woody plant removal generally will not affect stream flow in areas receiving less than 500 mm of annual precipitation, and runoff will occur as overland flow in the absence of a subsurface connection between stream and hillslope. Without subsurface flow, water use by woody plants may have little impact on stream flow. Huxman et al. (2005) echoed the importance of subsurface flow for linking woody plants and stream flow.

Pierson et al. (2007) stressed that increases in herbaceous production associated with woody plant control can dramatically increase infiltration and decrease runoff.

Given that site characteristics strongly influence the relationship between woody plant cover and hydrology, definitive statements regarding outcomes of this interaction are not possible. Newman et al. (2006) argued that because of the variability and complexity of the relationship between woody plants and rangeland hydrology, efforts to manage woody plant issues will benefit from “place-based science” and an interdisciplinary focus on hypothesis testing.

**Hypothesis 19: Shading of the Stream Channel by Riparian Woody Vegetation Cover Influences Aquatic Ecology by Reducing Stream Temperature.**

Macroinvertebrates and fish are sensitive to dissolved oxygen content of streams, which is influenced by stream temperature. Thus, stream temperature is an important factor affecting the distribution of aquatic vertebrate and invertebrate species (Baltz et al. 1987; Lyons 1996; Hawkins et al. 1997; Jacobsen et al. 1997; Isaak and Hubert 2001). The distribution and abundance of native coldwater fisheries in the western United States has been reduced since European settlement (Nehlsen et al. 1991; Hunnington et al. 1996; Thurow et al. 1997), and land and water management practices that impact stream temperature are considered to be partly responsible for these reductions (Isaak and Hubert 2001; Poole and Berman 2001; Zoellick 2004). Water temperature is a particularly important habitat determinant for aquatic species in arid rangeland basins of the western United States.

A significant international research base indicates that water temperature is a spatially and temporally dynamic stream property controlled by a complex and interacting set of environmental factors, such as local air mass characteristics, solar radiation, vegetative and topographic shading, channel elevation and aspect, channel gradient, adiabatic rate, channel width and depth, hydrologic residence time, stream flow volume, and deep and shallow groundwater inputs (e.g.,

Constantz 1998; Ebersole et al. 2001; Liquori and Jackson 2001; Poole and Berman 2001; Ebersole et al. 2003; Johnson 2004; Malcolm et al. 2004; Moore et al. 2005; Tate et al. 2007). Management practices which affect these factors have the potential to secondarily affect stream temperature dynamics. There is clear evidence that shading provided by woody plant cover will have some effect on stream temperature dynamics.

There is also clear evidence that the relative importance of woody plant canopy cover, among the many factors, in determining stream temperature is variable across ecosystems, watersheds, streams, and stream reaches. Larson and Larson (1996) hypothesized that when air temperature is warmer than water temperature, water temperature will increase to approach thermal equilibrium with the surrounding air mass and that this basic relationship is unchanged by the presence of shade from woody plants. However, in a field study in arid northeastern California, Tate et al. (2005) found that daily maximum stream temperature was associated with air temperature, instantaneous stream flow volume, stream order and watershed position, and woody plant canopy cover. Increased woody plant cover was associated with decreased maximum daily stream temperature, and a significant interaction between canopy and air temperature indicated that the cooling effect of woody plant cover increased with increased maximum daily air temperature. One study (Meays et al. 2005) reported that a thermal gradient associated with variable elevation was the dominant factor controlling stream temperature and that exposure time (velocity and distance), discharge volume, rate of flow, and cool-water inputs had a greater influence on stream temperature than woody canopy cover. Poole and Berman (2001) found that the influence of shade on stream temperature was greatest in smaller (first and second order) streams and decreased with stream size. These authors hypothesized that reduced stream shading may lower the quantity of air trapped by vegetation, which can increase convective and advective transfer of heat to the stream surface. Both Liquori and Jackson (2001) and Malcolm

et al. (2004) determined that the type of riparian woody plant community affected the relationship between canopy cover and stream temperature. Stream channel protection from incoming radiation is one mechanism by which woody plant cover may influence stream temperature. In certain riparian areas, woody plants may play a role in maintaining channel structure (e.g., width:depth ratio) in the face of destabilizing flood flow events (Winward 2000). To the extent that maintenance of channel structure is related to stream temperature dynamics, woody plants may play an important role in moderating in-stream temperature fluctuations (Liquori and Jackson 2001).

There is strong evidence to support the assertion that riparian management to enhance and sustain riparian woody plants can moderate stream temperatures. The validity of this conclusion is conditional and dependent on 1) site conditions and potential and that management of factors such as stream flow volume may have a greater effect on stream temperature than management of woody plant cover; 2) the natural, or existing, potential of the riparian site to support woody plant communities; and 3) the likelihood that management to increase woody canopy above natural site potential can lead to overall reductions of in-stream primary production, diversity, and richness of aquatic species (Liquori and Jackson 2001; Broadmeadow and Nisbet 2004; Malcolm et al. 2004).

*Hypothesis 20: Prescribed Fire Can Increase Richness, Diversity, and Abundance of Native Riparian Plant and Animal Species.*

Because of the low number of published reports concerning prescribed fire in riparian habitat, we included wildfire-based publications in this discussion. Of seven papers documenting the effects of fire on native riparian vegetation, four reported little to no effect (Busch and Smith 1993; Gom and Rood 1999; Blank et al. 2003; Smith et al. 2007), and three reported an increase in desired species (Stein et al. 1992; Kay 1993; Rood et al. 2007; Appendix VII). In some cases, fire has been used as a tool to rejuvenate dense stands of mature woody plants, such as cottonwood, when reproduction became limited (Rood et al. 2007).



There is strong evidence to support the assertion that riparian management to enhance and sustain riparian woody plant cover or canopies can moderate stream temperatures”



Management which supports woody riparian plants and deep-rooted herbaceous vegetation may increase carbon sequestration in riparian soils. (Photo: Mel George)

Existing literature is not sufficient to generalize the effects of fire on riparian plant species richness, diversity, and abundance. The impact of fire on diversity of riparian animal species in native riparian habitat is practically unexplored. Literature documenting the response of riparian birds to fire is lacking (Bock and Block 2005; Smith et al. 2007).

*Hypothesis 21: Carbon Storage Is Enhanced by Establishment and Maintenance of Woody Species, Herbaceous Species with High Root Mass, and Dominance of Deep-Rooted Perennials.* Carbon accumulation in soils occurs when C inputs to the ecosystem as NPP exceed C outputs from the ecosystem as microbial respiration of soil organic matter (Post and Kwon 2000). Hence, any management that increases production and/or decreases microbial respiration on an annual basis should promote

soil C storage. Root detritus is a significant contributor to recalcitrant soil C pools (Rees et al. 2005), so promotion of belowground NPP is believed to be particularly important for C sequestration.

Nine to 18 yr of grazing exclusion from herb-dominated wet and dry meadows in eastern Oregon resulted in clear increases in belowground standing biomass (Kauffman et al. 2004). While these authors did not detect significant increases in soil organic matter, bulk densities decreased significantly, and one can infer that soil organic C would increase over a longer period of observation. One year of late-season clipping of mesic meadow species in central Nevada resulted in higher rooting activity in the surface 5 cm (Martin and Chambers 2002). These authors cite the overriding influence of water table depth as the reason that larger defoliation effects were

not observed. No significant effects on soil physical or chemical properties were found by Wheeler et al. (2002) as the result of a one-time intense grazing event. Clary and Kinney (2002) found that simulated season-long, heavy grazing significantly reduced root production, while simulated moderate seasonal grazing had no effect relative to unclipped control plots.

We cannot support or reject this hypothesis because few studies have investigated carbon storage in riparian zones. Two studies (grazing exclusion and late-season clipping) support increases in belowground biomass, one study found no grazing effect on soil chemical and physical properties, and one study found that season-long heavy grazing reduced root production in riparian systems.

### Incorporating Science into NRCS Conservation Practices and Systems

The evidence supporting conservation practice effectiveness is mixed with some practices being well documented and others poorly supported in peer-reviewed scientific publications. However, this is not the only source of evidence for practice effectiveness. Professional experience is also an important source of knowledge regarding practice effectiveness. Within NRCS and other agencies are conservationists who have learned to apply practices effectively by learning from others and by trial and error, much the way agricultural producers learn to adapt practices in their farming operations. Management based on trial and error is often called adaptive management. Adaptive management allows managers to monitor and evaluate management practices in the field as they go along. The nine steps of planning used by NRCS make up a form of adaptive management that allows conservationists and landowners to identify resource concerns and alternative practices. Following selection and implementation of practices, monitoring and evaluation provide feedback regarding progress toward objectives and practice effectiveness. The knowledge gained during planning, implementation, and evaluation is seldom reported in peer-reviewed journals. Occasionally, it appears in case study reports, but more often it goes unpublished (e.g., Wyman et al. 2006).

Early in the planning process, NRCS conservationists document and analyze resource concerns, including those related to riparian systems and associated watersheds. This is followed by development of alternative practices that may address concerns. Based on this analysis, the landowner selects a mix of practices. For riparian areas, prescribed grazing (528), off-site water (614), fencing (382), and riparian herbaceous cover (390) are common conservation practices that are often applied together because they facilitate control of riparian use while enabling use of the broader landscape by livestock and wildlife.

While the effectiveness of these practices may not have been documented in the ecosystem or site being managed, there is often support for their effectiveness from other riparian ecosystems in the scientific literature. NRCS training programs expedite integration of results from other ecosystems into the planning process. Conservationists and landowners learn what works from these applications, and it becomes part of the individual's experience and the agency's institutional memory in the form of state practice standards and specifications.

### RECOMMENDATIONS

With more than 40 management practices (USDA NRCS 2003) available for application to riparian habitats, considerable overlap exists among the purposes and benefits stated in practice standards. Better riparian practice standards could be developed by the following:

- Initiating review teams of NRCS conservationists, biologists, and engineers to complete practice revisions
- Grouping practices that protect or restore vegetation to remove overlapping purposes (e.g., channel bank vegetation, conservation cover, critical area planting, riparian herbaceous cover, stream bank and shoreline protection, and tree and shrub establishment)
- Grouping and revising buffer and filter strip practices into those that apply to rangeland, forestland, or cropland
- Updating practice definitions, purposes and benefits, criteria and other practice standard sections to reflect current knowledge



Rigorous monitoring to document the effect of resource management systems can help resource professionals learn more about riparian processes and management interactions”

- Incorporating ecosystem services into revised practice purposes and benefits
- Separating structural practices from vegetation management practices
- Incorporating riparian purposes and benefits into upland practices, such as brush management, prescribed burning, and prescribed grazing

While there are opportunities to combine and clarify practices and there is evidence supporting the effectiveness of many riparian management practices, we can provide little evidence-based support to USDA NRCS for modifications of existing practice specifications (practice application) or initiation of alternative practices, with one exception in the following paragraph. We also recommend addition of a collaborative research and monitoring component to selected practice implementation plans so that the body of evidence supporting conservation practices and systems of practices can be strengthened.

We found sufficient evidence to recommend that NRCS increase the role of herding and supplement placement along with water development and fences for manipulating livestock distribution. These practices have a role where topography does not limit their effectiveness and total exclusion is not required. While it has not been the policy of USDA conservation cost-share programs to fund feed purchase or herding, placement of supplement and herding practices should be included in the overall ranch conservation plan. The USDA might consider allowing these “feeding” practices to be part of the rancher’s share of the cost in the Environmental Quality Incentives Program and other cost-share programs.

The need for more effective selection and application of management practices on a site-specific basis requires much greater attention. Recognizing that one practice or set of practices cannot meet the conservation requirements of biophysically diverse riparian habitats and stream systems, USDA NRCS applies resource management systems that are a flexible mix of practices selected for a specific set of site conditions and landowner management objectives during conservation planning. Rigorous monitoring to document

the effect of resource management systems can help resource professionals learn more about riparian processes and management interactions while maintaining feedback information to both land managers and conservation planners. The portfolio of research and case studies supporting the effectiveness of these practices is limited and commonly cannot be extended to other sites. Time and funds limit the ability of research institutions to investigate the seemingly infinite combination of site conditions that exist across US rangeland riparian zones. To accelerate these investigations, we recommend that a partnership of researchers and NRCS conservationists implement two complementary lines of investigation. In the first line of investigation, this team should 1) develop, implement, and maintain rigorous monitoring of selected practices in selected ecosystems and 2) implement monitoring systems that can be analyzed and meet standards of research peer review. The team would manage monitoring data collection and analyze the data at appropriate time intervals. In short, a research study design (monitoring plan) needs to accompany and be funded along with the conservation plan.

The second line of investigation is to develop testable hypotheses based on observations and findings resulting from team monitoring projects. The team can test these hypotheses in more controlled studies. These hypotheses should attempt to elucidate the intervening ecological processes between practice implementation and practice effect. Only then can we begin to understand relationships between grazing, riparian management practices, and riparian ecology at relevant scales and extrapolate results from one location to another. It is crucial that USDA NRCS and other agencies support such a monitoring partnership between researchers and conservationists.

Finally, we support the completion of riparian ecological site descriptions by USDA NRCS. It is important to recognize that not all riparian areas have the same potential or react to management in the same way. Therefore, they should be managed according to their unique characteristics as described in ecological site descriptions. State variables (soils, climate,

geomorphology, topography, vegetation, and wildlife), vegetation dynamics, and practices that have been effective on the site in the past are described in the ecological site description. We recommend completion of riparian ecological site descriptions as a means of documenting and communicating proven site-specific management practices to the NRCS planning process.

## KNOWLEDGE GAPS

Our assessment reveals limited controlled experimentation in support of many of our hypotheses, resulting in critical knowledge gaps across all riparian management practices and riparian ecosystems. Linking conservation planning and management to research in a collaborative program is crucial to filling these knowledge gaps.

Two substantial knowledge gaps exist in the riparian literature related to grazing and rangeland management. While there are many case studies comparing species (animal and plant) abundance within and outside riparian exclosures, they are often deficient in more rigorously designed experiments. For example, much of the case study literature concerning impacts of livestock on riparian wildlife suffers from experimental design inadequacies, including lack of pretreatment data, low sample size, and lack of randomization of treatments (Rinne 1985; Larsen et al. 1996). Additional research based on replicated experimental designs is needed to better understand the relationship between grazing and riparian ecology at scales relevant to determining the ecological consequences of grazing practices.

The second knowledge gap emphasizes ecological processes that mediate the effect of management actions on riparian ecosystem products and services. Without mechanistic understanding of the intervening ecological processes that mediate cause-and-effect relationships, we cannot generalize study results to other sites. This point is particularly important given the dependence of riparian plant species on groundwater resources that vary over both space and time (Stringham et al. 2001; Poole et al. 2006). Improving our knowledge of the effects of management on



ecosystem services will involve an expanded, research-based focus on the interaction between management activities and biophysical mechanisms responsible for provisioning ecosystem services.

## CONCLUSIONS

While the scientific evidence for many riparian management practices is inconclusive, there are several practice benefits that are well documented. There is strong evidence supporting the influence of management

Several riparian practices have been shown to enhance riparian functions and dependent ecosystem services. (Photo: Ken Tate)

practices on vegetation in riparian habitats, including the following:

1. Grazing intensity influences herbaceous species composition and productivity (H1, 2).
2. Livestock distribution practices, such as water developments, supplement placement, and herding, are effective means of reducing livestock residence time and utilization in the riparian zone (H3).
3. Grazing exclusion can promote recovery of riparian plant community composition in degraded riparian systems (H4).
4. Livestock and other large herbivores can modify the structure and composition of woody plant communities (H5).
5. Late-season (usually late summer and fall) livestock use of riparian areas can lead to increased utilization of woody plants, especially when herbaceous plants are limited in availability or forage quality (H6).
6. Grazing in wetland habitat does not decrease habitat quality for waterfowl except in instances of heavy grazing (H11).
7. Grazing can decrease populations of riparian obligate avifauna but may increase or have no effect on generalist species (12).
8. Shading provided by woody plant cover along with other factors (e.g., elevation, topography, and subsurface flow) will have some effect on stream temperature dynamics (19).
9. Fire can be used to control some species of woody plants, but success of fire-based restoration may be related to availability of water and the availability of propagules of desired species following years of limited water availability (H7).
10. Grazing does not appear to decrease the abundance or overall diversity of macroinvertebrates, but these data are limited (H13).
11. Limited data suggest that livestock grazing practices that are too long in duration and poorly timed can decrease salmonid habitat quality or populations (13).

There is also evidence supporting the influence of riparian management practices on riparian vegetation and soils (Fig. 1). Riparian grazing management that maintains or enhances key riparian vegetation attributes (i.e., species composition, root mass and root density, cover, and biomass) will enhance stream channel and riparian soil stability, and this in turn will support ecosystem services, such as flood and pollutant attenuation and quality of riparian habitats (H8).

Finally, limited evidence indicates that riparian habitat management can promote ecosystem services by enhancing vegetation and soil attributes (Fig. 1):

1. Riparian vegetation can function to attenuate waterborne pollutants in overland and flood flow events (H9).
2. The design and implementation of optimally efficient riparian buffers must incorporate site-specific biophysical factors, including buffer width, vegetation attributes and management, pollutant type, pollutant load and concentration, flow rate, hydrologic residence time, and soil attributes (H9).
3. Practices that reduce livestock densities, residence time, and fecal and urine

deposition in riparian areas and stream flow generation areas can reduce nutrient and pathogen loading of surface water (H10).

4. Grazing in wetland habitat does not decrease habitat quality for waterfowl except in instances of heavy grazing (H11).
5. Grazing can decrease populations of riparian obligate avifauna but may increase or have no effect on generalist species (12).
6. Shading provided by woody plant cover along with other factors (e.g., elevation, topography, and subsurface flow) will have some effect on stream temperature dynamics (19).
7. Fire can be used to control some species of woody plants, but success of fire-based restoration may be related to availability of water and the availability of propagules of desired species following years of limited water availability (H7).
8. Grazing does not appear to decrease the abundance or overall diversity of macroinvertebrates, but these data are limited (H13).
9. Limited data suggest that livestock grazing practices that are too long in duration and poorly timed can decrease salmonid habitat quality or populations (13).

For several hypotheses, the evidence supporting or refuting beneficial effects on ecosystem services was weak or inconclusive. These include 1) riparian grazing decreases habitat quality for riparian mammals (H14) and sage grouse (H15); 2) woody plant control can reduce undesirable plant species (H16) or increase the abundance of terrestrial wildlife (H17); 3) the influence of riparian burning (H7) on vegetation and animals; 4) prescribed fire can increase the richness, diversity, and abundance of native riparian plants and animals (H 20); 5) upland brush management can decrease erosion and increase stream flow (H 18); and 6) carbon storage can be enhanced by the establishment and maintenance of woody species, herbaceous species with high root mass, and dominance of deep-rooted perennials.

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