SURVEY OF LIVESTOCK INFLUENCES ON STREAM AND RIPARIAN ECOSYSTEMS IN THE WESTERN UNITED STATES

(Published by *Journal of Soil and Water Conservation*, 1999, Vol. 54, pp. 419-431)

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Acknowledgments: We thank R. Amundson, H. Campbell, D. DeLong, T. Dudley, D. Ferguson, N. Ferguson, S. Fouty, A. Kerr, T. Myers, M. O'Brien, E. Painter, R. Phillips, W. Platts, and J. Rhodes for providing insightful comments on drafts of this paper, as well as Northwest Fund for the Environment and the Bullitt Foundation for financial support.

Interpretive Summary

Livestock grazing has damaged approximately 80% of stream and riparian ecosystems in the western United States. Although these areas compose only 0.5-1.0% of the overall landscape, a disproportionately large percentage (~70-80%) of all desert, shrub, and grassland plants and animals depend on them. The introduction of livestock into these areas 100-200 years ago caused a disturbance with many ripple effects. Livestock seek out water, succulent forage, and shade in riparian areas, leading to trampling and overgrazing of streambanks, soil erosion, loss of streambank stability, declining water quality, and drier, hotter conditions. These changes have reduced habitat for riparian plant species, cold-water fish, and wildlife, thereby causing many native species to decline in number or go locally extinct. Such modifications can lead to large-scale changes in adjacent and downstream ecosystems.

Despite these disturbances, some people support continued grazing. These advocates argue that most of the damage occurred 50-100 years ago; however, recent studies clearly document that livestock continue to degrade western streams and rivers, and that riparian recovery is contingent upon total rest from grazing.

Abstract

This paper summarizes the major effects of livestock grazing on stream and riparian ecosystems in the arid West. We focused primarily on results from peer-reviewed, experimental studies, and secondarily on comparative studies of grazed vs. naturally or historically protected areas. Results were summarized in tabular form. Livestock grazing was found to negatively affect water quality and seasonal quantity, *stream channel morphology, hydrology, riparian zone soils, instream and streambank vegetation, and aquatic and riparian wildlife. No positive environmental impacts were found. Livestock were also found to cause negative impacts at the landscape and regional levels. Although it is sometimes difficult to draw generalizations from the many studies, due in part to differences in methodology and environmental variability among study sites, most recent scientific studies document that livestock grazing continues to be detrimental to stream and riparian ecosystems in the West.*

Introduction

Grazing by livestock has damaged 80% of the streams and riparian ecosystems in arid regions of the western United States (U.S. Department of the Interior (USDI) 1994a). A number of symposia (e.g. Warner and Hendrix 1984, Johnson et al. 1985, Gresswell et al. 1989, Meehan 1991, Clary et al. 1992) and reviews (Platts 1981b, 1982, 1991, Kauffman and Krueger 1984, Skovlin 1984, Chaney et al. 1990, 1993, Armour et al. 1994, Fleischner 1994, Rhodes et al. 1994, USDI 1994a, Kattelmann and Embury 1996, Ohmart 1996) describe this degradation. Livestock grazing affects watershed hydrology, stream channel morphology, soils, vegetation, wildlife, fish and other riparian-dependent species, and water quality at both local and landscape scales. Because riparian and stream ecosystems represent only 0.5-1% of the surface area of arid lands of the eleven western United States (U.S. General Accounting Office (US-GAO) 1988, Chaney et al. 1990, Ohmart 1996), they were historically ignored by land managers. In fact, riparian habitats in the West were viewed until the late 1960s as "sacrifice" areas (e.g., Stoddart and Smith 1955), being dedicated primarily to providing food and water for domestic livestock.

Recently, both critics and advocates of arid-land livestock grazing have focused their attention on western streams and their associated riparian zones, especially those in shrublands, grasslands, and deserts of the Southwest, Great Basin, and Pacific Northwest. Critics of grazing emphasize damage to riparian habitats to illustrate the unsuitability of cattle grazing in the arid West, while advocates of grazing argue that most of the damage to land and streams occurred 50-100 years ago, before modern grazing systems were instituted.

The evidence is undeniable that early grazing practices -- before the Taylor Grazing Act in 1934 established some control over livestock grazing in the public domain -- were highly destructive (Duce 1918, Bryan 1925, Leopold 1946). However, recent studies document that livestock grazing remains a key factor in the continued degradation of riparian habitats (US-GAO 1988, Szaro 1989, Platts 1991, Elmore and Kauffman 1994, Fleischner 1994, McIntosh et al., 1994, USDI 1994a, Ohmart 1996). As recently as 1990, Chaney et al. (1990) wrote in a U.S. Environmental Protection Agency (US-EPA) report on livestock grazing that "extensive field observations in the late 1980s suggest that riparian areas throughout much of the West were in their worst condition in history" (p.5). A joint Bureau of Land Management (BLM) and US Forest Service Report (USDI 1994a) also concludes that "riparian areas have continued to decline [since 1934]" (p.25) and estimates that 20% of the riparian areas managed by BLM are "non-functioning" and 46% are "functioning at risk." Altogether, less than 20% of potential riparian habitat in the western United States still exists (USDI 1994a). This continued decline has been attributed, in part, to increased numbers of cattle in western rangelands (Trimble and Mendel 1995); between 1940 and 1990, the number of cattle in the western United States increased from 25,500,000 to 54,400,000.

Recent scrutiny by scientists reflects a growing recognition by the public, land managers, and scientific community of the importance of streams, rivers, and riparian habitats to western ecosystems. One reason for this interest is the high productivity and biodiversity of riparian systems, which is due, in part, to their high soil moisture and fertility levels (Hubbard 1977, Meehan et al. 1977, Thomas et al. 1979, Knight and Bottorff 1984, Fleischner 1994, Ohmart 1996). Riparian areas in arid and semi-arid regions are composed of complex edaphic and vegetation mosaics because of high variability in landforms, soil types, and location of surface and subsurface water (Thomas et al. 1979, Green and Kauffman 1995, Lee et al. 1989, Gregory et al. 1991). These mosaics, plus extensive borders (ecotones) between moist streamsides and arid uplands, result in high species diversity (Thomas et al. 1979, Lee et al. 1989). An estimated 60-70% of western bird species (Ohmart 1996) and as many as 80% of wildlife species in Arizona and New Mexico (Chaney et al. 1990) and in southeastern Oregon (Thomas et al. 1979) are dependent on riparian habitats. Consequently, riparian ecosystems are considered to be important repositories for biodiversity throughout the West.

Riparian zones provide key services for all ecosystems, but are especially important in dry regions, where they provide the main source of moisture for plants and wildlife, and the main source of water for downstream plant, animal, and human communities (Meehan et al. 1977, Thurow 1991, Armour et al. 1994, among others). These services are highly dependent on streambanks and flood plains being in a vegetated and relatively undisturbed state. Rooted streamside plants retard streambank erosion, filter sediments out of the water, build up and stabilize streambanks and streambeds, and provide shade, food, and nutrients for aquatic and riparian species (Winegar 1977, Thomas et al. 1979, Kauffman and Krueger 1984). The ability of undisturbed plant communities to stabilize banks was notable during extensive floods in eastern Oregon in 1996, when shrubby vegetation in ungrazed sections of the Deschutes River "broke the flood's velocity and combed logs and mud from the river" (Meehan 1996).

Healthy riparian areas also act as giant sponges during flood events, raising water tables and maintaining a source of streamwater during dry seasons. The result is a more stable streamflow throughout the year (US-GAO 1988).

Cattle cause more damage to riparian zones than their often small numbers would suggest. Cattle tend to avoid hot, dry environments and congregate in wet areas for water and forage, which is more succulent and abundant than in uplands. They are also attracted to the shade and lower temperatures near streams, most likely because their species evolved in cool, wet meadows of northern Europe and Asia. In fact, cattle spend 5-30 times as much time in these cool, productive zones than would be predicted from surface area alone (Roath and Krueger 1982, Skovlin 1984). One study found that a riparian zone in eastern Oregon comprised only 1.9% of the grazing allotment by area, but produced 21% of the available forage and 81% of forage consumed by cattle (Roath and Krueger 1982).

Our goal is to summarize along biological and ecological lines the major effects of cattle grazing in stream and riparian ecosystems. We include only those studies that discuss the direct and indirect effects of livestock activities on stream and riparian habitats. We exclude other aspects of livestock production such as conversion of flood plains to cultivated fields for livestock feed, leaching of fertilizer from these fields into streams, and streamwater diversion for crop or pasture irrigation. We also do not include the effects of impounding streamwater for stock ponds or other activities that support livestock production, although these activities contribute significantly to stream degradation.

Methods

We searched the scientific literature for peer-reviewed empirical papers and reviews of the biological and physical effects of livestock on western rivers, streams, and associated riparian areas. Because of the extensive literature on the subject, not all papers could be reviewed or cited. In choosing the papers to be included, we gave highest priority to recent papers in refereed journals presenting experimental manipulations such as paired samples from grazed vs. ungrazed areas or from heavily grazed vs. lightly grazed pastures (when ungrazed controls were not included in the experimental design). Many of these studies used sites recently protected from grazing as controls (e.g., Kauffman at al. 1983a, Schulz and Leininger 1990), but a few used previously ungrazed areas to which livestock were newly introduced (e.g., Sedgwick and Knopf 1987, Samson et al. 1988). Secondary priority was given to descriptive or comparative studies of grazed vs. naturally or historically protected areas where similarity of initial conditions could be inferred. Where there was a paucity of data, we also used non-peer-reviewed reports, usually from government documents or symposia. In no case were our general conclusions drawn from unrefereed reports or from studies showing anomalous results. Instead, we based our conclusions on what seemed to be the consensus of experts in the field.

We also identified and listed comprehensive review papers on each topic. Environmental impacts were defined as environmental changes that were significant at the $P < 0.1$ level (e.g., Peterman 1990) (discussed below) or those effects deemed significant by the authors.

Results

Damage caused by cattle to riparian and stream habitats in the arid and semi-arid West can be separated into two broad categories: impacts that occur at the local level (Table 1) and those that occur at landscape and regional levels (Table 2). Local impacts can be further segregated by their effects on water quality and seasonal quantity, stream channel morphology, hydrology, riparian-zone soils, instream and streambank vegetation, aquatic biota, and terrestrial wildlife (Table 1). Local impacts have been investigated in a large number of studies, but landscape-level impacts have received less attention.

Our search uncovered no systematic investigations showing positive impacts or ecological benefits that could be attributed to livestock activities when grazed areas were compared to protected areas (see also Bock et al. 1993, Ohmart 1996). Thus, we mostly present negative environmental impacts. In general, there was little debate about the effects of livestock grazing. Most authors tended to agree that livestock damage stream and riparian ecosystems.

Discussion

In the following, we discuss pertinent topics that have not been addressed in depth in recent reviews. These reviews, which are listed after each major category in Tables 1 and 2, should be consulted for additional discussion of other topics.

Positive and neutral effects of cattle grazing on riparian zones. An extensive literature search did not locate peer-reviewed, empirical papers reporting a positive impact of cattle on riparian areas when those areas were compared to ungrazed controls, but some studies reported no statistically significant effects due to riparian grazing (e.g., Buckhouse and Gifford 1976, Samson et al. 1988). The authors of these papers usually explained this absence of statistically significant impacts as being due to stochastic or design problems associated with their research, rather than to grazing having no effect on vegetation, fish, or stream hydrology. They described such problems as (1) high variability among treatment plots, which masked treatment effects (e.g., Tiedemann and Higgins 1989, Shaw 1992), (2) insufficient recovery periods after protection from grazing (e.g., Hubert et al. 1985, Sedgwick and Knopf 1991, Shaw 1992, Sarr et al. 1996), (3) heavy browsing and grazing by native herbivores (or trespassing cattle) on supposedly ungrazed control plots (e.g., Shaw 1992, Clary et al. 1996), (4) unplanned disturbances such as flooding (e.g., Sedgwick and Knopf 1991, Clary et al. 1996, Myers and Swanson 1996a), and (5) the unknown effects of a prior history of heavy grazing, which may have permanently altered stream function and prevented recovery of control plots (e.g., Tiedemann and Higgins 1989).

The absence of significant effects may also be due to investigators setting statistical significance at arbitrarily low levels (i.e., at $P<0.05$). Peterman (1990) argues that many studies, such as those with few treatment replications or high spatial variability, have low power (i.e. poor ability) to detect environmental change. Because of the possibility that already depleted fish stocks could become endangered or important habitats become permanently altered, he argues that higher probability levels (i.e., $P<0.1$) are appropriate to test significance of hypotheses.

Authors have also attributed non-significant results to supplemental feeding of livestock (e.g., Sedgwick and Knopf 1991), which resulted in lower forage consumption levels than originally prescribed, and to high recreational fishing, which obscured the negative effects of grazing on fish populations (e.g., Hubert et al. 1985). Finally, severe environmental damage such as loss of native species or channel downcutting cannot be reversed in just a few years of protection. Streams may recover slowly or only over geological time scales (Sarr et al. 1996). Together, these circumstances have caused some (e.g., Platts 1982) to question the ability of many experimental techniques to adequately assess livestock impacts. Others (e.g. Peterman 1990) also question the statistical power of many experiments to accept or reject hypotheses.

Several recent papers (e.g., Clary and Webster 1989, Elmore and Kauffman 1994, Burton and Kozel 1996, Weller 1996) describe the benefits of reduced cattle stocking rates and newer grazing systems, such as seasonal grazing, rest-rotation, and deferred grazing. The authors also discuss examples of grazed riparian zones regaining their herbaceous and woody cover and water quality. These studies, however, only contrasted newer grazing systems with more traditional and destructive systems, such as year-long grazing and high stocking rates. They did not contrast these systems with no-grazing. The only conclusion that could be fairly drawn from these studies is that newer grazing systems improve streamside conditions relative to other grazing systems, not that cattle grazing truly benefit riparian zones. In fact, Meehan and Platts (1978) and Platts and Wagstaff (1984) found no grazing system that was compatible with healthy aquatic ecosystems.

In mid-western prairies, livestock have been reported to be useful at breaking up dense, rank vegetation near wetlands (Weller 1996). However, in the Intermountain West, where low densities of native grazers provided only light grazing and trampling disturbances during the last 10,000 years, riparian species have inherently lower tolerances for livestock disturbances (Mack and Thompson 1982). It is doubtful that grazing or trampling by cattle in this region would do more good than harm.

Problems in drawing generalizations from riparian studies. Although most research has shown grazing in streams and riparian zones to be deleterious, results have been variable (Platts 1982, Trimble and Mendel 1995). This has caused riparian specialists problems in drawing broad generalizations about the effects of cattle grazing. These problems can be attributed to several issues:

1. *Inadequacy of study design.* Most watershed-scale riparian management plans were not designed as experiments with the idea of researchers evaluating them years later.

2. *Inherent variability found between and within watersheds*. Streams are unique, having their own combination of channel morphology, soils, climate, riparian species, geology, and hydrology (Elmore and Beschta 1987, Myers and Swanson 1991, Trimble and Mendel 1995). One management strategy may have a particular effect in one area, but a greater or lesser effect elsewhere.

3. *Insufficient study replication*. Lack of adequate replication of experimental treatments make data interpretation difficult (Matthews 1996).

4. *Ambiguities or differences in study design* (Platts 1982, Rinne 1985). In some cases, terms such as "heavy" and "light" grazing to describe grazing treatments are subjective, making comparisons within and between experimental studies difficult (Fleischner 1994, Trimble and Mendel 1995). In other cases, differences in research methodologies make comparisons unreliable (Trimble and Mendel 1995).

5. *Grazing inside exclosures by small mammals and invertebrates*. Small animals often congregate inside exclosures where food and cover are abundant. Increases in grazing inside exclosures by grasshoppers, rabbits, and rodents may reduce differences between treatments, thus masking the effects of cattle grazing outside the exclosure.

6. *Prior grazing history*. Many pastures now protected within exclosures were grazed at some time in the past and thus do not accurately fall within a truly ungrazed (i.e. "pristine") landscape. In fact, many older exclosures were purposely erected in severely overgrazed and eroded areas in order for investigators to monitor recovery and successional processes. Since many of these protected stream segments may have been deeply downcut previously, their recovery may take hundreds to thousands of years. These exclosure studies, therefore, may underestimate the true extent of livestock damage because they fail to take into account the damage that occurred before the exclosures were erected (Fleischner 1994).

7. *Variable time lags.* Recovery of different ecological, hydrological, and geomorphologic processes require different amounts of time, often longer than the average research grant and sometimes longer than the life-span of the researcher. Recovery of herbaceous and woody vegetation along stream sides may begin immediately after grazing is terminated, while the recovery of channel form may take hundreds of years (Kattelmann and Embury 1996, Trimble and Mendel 1995, Clary et al. 1996).

8. *Influences from outside the study area*. Stream channel morphology and aquatic organisms respond not only to factors occurring inside the study area, but to those occurring outside as well (Rinne 1985). Soil compaction and reduced infiltration of rainwater due to cattle trampling on slopes above riparian exclosures may increase the volume of water flowing over soil surfaces and into protected research sites. In addition, grazed streambanks upstream from exclosures may fail, releasing sediments into protected segments. Together, these factors may contribute large amounts of sediment to the stream system, inhibiting stream recovery (Kondolf 1993). Similarly, water flowing out of exclosures may be cleaner, cooler, and produce better spawning habitat downstream than that inside the exclosures (Duff 1977, Rinne 1985). Conditions over the larger landscape, therefore, minimize differences in grazed/ungrazed comparative studies.

In spite of numerous problems in experimental design and difficulties in interpreting earlier studies, Platts (1982) concluded that livestock grazing was the major cause of degraded stream and riparian environments and reduced fish populations throughout the arid West. In an extensive review of the literature, he found that 85% of the studies demonstrated that livestock negatively impacted riparian and stream ecosystems, which he concluded was a sufficiently powerful statistic to override inadequacies in individual experimental design.

Effects of riparian grazing on channel morphology and water tables. Plants on undisturbed uplands and streamsides slow the downhill flow of rainwater, promoting its infiltration into soils. Water that percolates into the ground moves downhill through the sub-soil and seeps into stream channels throughout the year, creating perennial flows. But as upland and riparian vegetation is removed by livestock and as hillsides and streambanks are compacted by their hooves, less rainwater enters the soil and more flows overland into streams, creating larger peak flows. This was illustrated in a simulation by Trimble and Mendel (1995), who estimated that peak storm runoff from a 120 ha basin in Arizona would be 2-3 times greater when "heavily" grazed than when "lightly" grazed. Moderate and high rainfall events in grazed sites are, therefore, more likely to result in high energy and erosive floods, which deepen and reshape stream channels (Fig. 1, USDI 1994a).

Where streams flow over deep soils or unconsolidated substrates, the erosive energy of floods cause channel downcutting, or incision (Fig. 1). As the channel deepens, water drains from the flood plain into the channel, causing a lowering (subsidence) of the water table. The roots of riparian plants are left suspended in drier soils. Eventually, riparian plants and their associated wildlife species are replaced by upland species such as sagebrush (*Artemesia* spp.) and juniper (*Juniperus* spp.), which can tolerate these drier soils. Additionally, with less water entering upslope and riparian soils, less is available to provide late-season flows. Consequently, the high intensity floods of the spring and early summer are often followed by low and no flow in late summer and fall.

Effects of riparian grazing on biodiversity. Most studies comparing grazed and protected riparian areas show that some plant and animal species decrease in abundance or productivity in grazed sites while other species increase. Plant species that commonly decline with livestock grazing are either damaged by removal of their photosynthetic and reproductive organs, or are unable to tolerate trampling or the drier conditions caused by lowered water tables. Plant species that commonly increase with livestock grazing are usually weedy exotics that benefit from disturbed conditions, upland species that prefer the drier conditions created by grazing, or sub-dominant species that are released from competition when taller neighbors are grazed down (Kauffman and Krueger 1984, Schulz and Leininger 1991, Stacy 1995, Green and Kauffman 1995, Ohmart 1996, Sarr et al. 1996).

Neotropical migratory birds (Bock et al. 1993, Saab et al. 1995) and prairie waterbirds (Weller 1996) are also variously affected by livestock grazing. After reviewing a large number of relevant studies, Saab et al. (1995) concluded that livestock grazing in the West led to a decline in abundance of 46% of the 68 neotropical migrant landbirds that utilize riparian habitat, an increase in 29% of the migrants, and no clear response in 25%. Those species that are grounded nesting or forage in riparian areas with heavy shrub or ground cover tended to decrease in abundance with grazing, while species that prefer open habitats, are ground foragers, or are attracted to livestock (i.e., cowbirds (*Molothrus* spp.), tended to increase in abundance in grazed riparian habitats (Bock et al. 1993, Saab et al. 1995). Cavity and canopy nesters were least affected. After a thorough analysis, Bock et al. (1993) concluded that few neotropical bird species actually "benefited from [cattle] grazing in riparian habitats, and that those that do are not restricted to riparian communities" (p.302). In other words, species that benefit from grazing are already widely distributed over the landscape and gain no extra benefit from additional habitat. Conversely, those species that are harmed by grazing are usually restricted to riparian habitats. Riparian grazing, therefore, makes them vulnerable to local extinction.

Fish populations are also differentially affected by livestock grazing. As stream waters become warmer and more sediment-laden due to streamside grazing (Table 1), trout, salmon, and other cold-water species decline in number and biomass. They are often replaced by less valued and more tolerant species. For example, Stuber (1985) found a higher biomass of game fish (predominantly brown trout (*Salmo trutta*)) in protected stream segments in Colorado, but a higher biomass of non-game species (predominantly longnose sucker (*Catostomys catastomus*)) in grazed segments. Similarly, Marcuson (1977) found that trout (*Salmo* spp.) were more abundant in an ungrazed stream segment in the Beartooth Mountains while mountain whitefish (*Prosopium williamsoni*) were more abundant in a grazed segment.

Changes in species composition due to cattle grazing should not be evaluated in conventional species-diversity terms, since even an influx of exotic weeds will increase species richness and diversity. These weeds may increase diversity, but they also alter wildlife habitat and ecosystem processes (i.e. erosion rates, seasonal flows) to which native species are adapted. Of greater importance than species diversity is whether grazing reduces the abundance or diversity of native species and riparian specialists, and whether these species are being replaced by introduced or upland species. In both cases, such changes lead to a reduction in native biological diversity, homogenization of the biotic landscape, and loss of high-value wildlife (i.e. game) species (Stuber 1985, Bock et al. 1993). Reductions in number, size, and productivity of native riparian or aquatic species are nearly always viewed as negative or as representing declining ecosystem health (Ohmart 1996).

Cattle grazing has converted many of the riparian habitats in the arid West into communities dominated by habitat generalists and weedy species such as dandelions (*Taraxacum officionale*), cheatgrass (*Bromus tectorum*), cowbirds, and small-mouth bass (*Micropterus dolomieu*), and by upland or abundant species such as sagebrush, juniper, and speckled dace (*Rhinichthys osculus*). As a result, both habitat quality and native species diversity have been severely reduced (Marcuson 1977, US-GAO 1988, Armour et al. 1994, Popolizia et al. 1994, Green and Kauffman 1995, Sarr et al. 1996). Consequently, a recent Forest Service report found livestock grazing to be the fourth major cause of species endangerment in the United States and the second major cause of endangerment of plant species (Flather et al. 1994). Within certain regions (i.e. Arizona Basin and Colorado/Green River Plateau), livestock grazing was listed as the #1 cause of species being federally listed as threatened or endangered.

Effects of riparian grazing on water quality. Bacterial contamination of drinking and surface water by domestic livestock is a significant non-point source of water pollution (George 1996). Although usually not considered pathogenic (Gary et al. 1983), fecal coliform (e.g., *Escherichia coli*), and enterococci bacteria are regularly monitored in surface waters because they are indicators of fecal contamination that may include pathogenic organisms such as *Cryptosporidium, Giardia, Salmonella, Shigella* and enteric viruses (Bohn and Buckhouse 1985b, George 1996). Because these organisms are carried by cattle and because fecal bacteria levels tend to increase with increasing grazing pressure (Gary et al. 1983, Owens et al. 1989, George 1996), the probability of disease-causing organisms contaminating swimming areas and entering human water supplies increases with intensity of cattle use.

Another concern is that nutrients found in animal wastes stimulate algal and aquatic plant growth when they are deposited directly or washed into streamwater. If resulting plant growth is moderate, it may provide a food base for the aquatic community. If excessive, these nutrients stimulate algal blooms. Subsequent decomposition of the algae leads to low dissolved oxygen concentrations (US-EPA 1995), which endangers aquatic organisms.

Landscape and regional effects of riparian grazing. The impacts of grazing on local riparian and stream environments and on stream morphology may be acute, but they also often extend far beyond their immediate surroundings (Table 2). Streams connect uplands to lowlands, terrestrial ecosystems to aquatic, and arid ecosystems to moist (Gregory et al. 1991, Knopf and Samson 1994). They act as corridors for migrating animals, provide moisture for aquatic, riparian, and upland species, and distribute sediments and nutrients downstream (Table 2; Thomas et al. 1979, Lee et al. 1989). In the case of anadromous fish, nutrients that are consumed in the ocean are brought inland, where they are distributed throughout the landscape as the fish are consumed by predators or decompose along streambanks after spawning.

By degrading water supplies and reducing the area of healthy riparian habitat, livestock fragment these landscape-level connections. They also damage the connection between natural and human communities, since degraded streams reduce the potential for recreational fishing and swimming, degrade municipal water supplies, provide less water for reservoirs, and damage coastal commercial fishing.

Neither are streams isolated from their adjacent uplands. Heavy grazing on upland communities impacts riparian areas primarily by increasing runoff and erosion. Blackburn (1984) and Trimble and Mendel (1995) summarized the negative impacts of heavy grazing on watersheds. They listed the erosive force of raindrops on denuded surfaces, the shearing force of hooves on slopes, decreased soil organic matter, and increased soil compaction as primary impacts. Together, these lead to reduced water infiltration and increased runoff, soil bulk density, erosion, and sediment delivery to streams. In addition, cattle form trails and terracettes (Trimble and Mendel 1995) (also called bovine terraces), which are also subject to erosion (Rostagno 1989).

Other factors contributing to riparian degradation. Cattle grazing is not the only factor damaging stream and riparian habitats in the arid West. Urban development, mining, damming for hydroelectric power, road construction, local eradication of beaver, logging, agricultural activities, and water diversions for industry, irrigation, and municipal water supplies have also exacted heavy tolls on riparian and aquatic ecosystems (Skovlin 1984, Szaro 1989, USDI 1994b). These factors acting alone and in combination have caused devastating cumulative impacts on western streams (Lee et al. 1989). Despite this, livestock grazing is still considered to be the most pervasive source of upland and riparian habitat degradation in the arid West (Elmore and Kauffman 1994, USDI 1994a, Ohmart 1996, among others).

Effects of riparian grazing in humid environments. Most investigations of the effects of livestock grazing on streams, rivers, and riparian zones have been located in arid regions. Although empirical studies from more humid (mesic) regions, such as western Oregon and Washington, the mid-West, and the eastern United States, are not as numerous (Trimble and Mendel 1995), available evidence suggests that environmental impacts of grazing in these regions are similar to those in drier areas. In all environments, cattle consume streamside vegetation, disturb soils, destabilize streambanks, deposit manure and urine, and churn up channel sediments (Trimble 1994, Armour et al. 1994, Trimble and Mendel 1995). Similar to arid areas, cattle were found to reduce overhead cover, herbaceous cover on banks, and woody vegetation in western Washington and Wisconsin (Chapman and Knudsen 1980, White and Brynildson 1967). Livestock also increased concentrations of ammonia, nitrate, soluble phosphate, chemical oxygen demand, and total organic carbon in runoff in Nebraska (Schepers and Francis 1982), increased concentrations of organic nitrogen, organic carbon, and sediment in runoff in Ohio (Owens et al. 1989, 1996), caused streambank erosion in Pennsylvania (Davis et al. 1991) and Tennessee (Trimble 1994), and increased soil loss in North Dakota (Hofmann and Ries 1991).

In some cases grazing may be even more damaging in wetter than in drier environments because moist soils are more vulnerable to compaction and disturbance than dry soils (Marlow and Pogacnik 1985, Trimble and Mendel 1995, McInnis 1996). In other cases, damage to riparian and stream habitats may be less severe in wetter climates because cattle may be less attracted to streamsides in areas where upland grasses are green and palatable for more months of the year.

Conclusion

The current debate over the environmental impacts and suitability of livestock grazing in arid western ecosystems has resulted in supporters declaring that livestock sometimes benefit streams (Savory 1988). Nearly all scientific studies, both observational and experimental, refute this claim. Livestock do not benefit stream and riparian communities, water quality, or hydrologic function in any way (Table 1). However, their damage can be reduced by improving grazing methods, herding or fencing cattle away from streams, reducing livestock numbers, or increasing the period of rest from grazing (Armour et al. 1994, Elmore and Kauffman 1994). The conclusion that all grazing practices detrimentally affect riparian areas (Elmore and Kauffman (1994) is to be expected since traditional grazing systems were developed for protecting upland grasses, not for protecting riparian plants and streamsbanks (Platts 1991, Saab et al. 1995).

With improved livestock management, previously denuded streambanks may revegetate and erosion may decline (Elmore and Kauffman 1994), but recovery will take longer than if grazing were terminated completely (Myers and Swanson 1995, 1996a, Ohmart 1996). Trimble and Mendel (1995) concluded that "although there may have been improvements in grazing management, the increase of cattle in the West [a doubling over the last 50 years] suggest that grazing impacts will continue into the foreseeable future" (p 233).

New studies go even further by suggesting that new grazing systems have only served to slow the rate of degradation, not reverse it. Sarr et al. (1996), for example, found that ten full years of livestock exclusion was necessary to reverse a negative trend and allow stream conditions to begin to improve. Elmore and Kauffman (1994) best summed up available evidence by stating that "livestock exclusion has consistently resulted in the most dramatic and rapid rates of ecosystem recovery " (p. 216).

Although the possibility of streams recovering their plant cover and ecological functions while providing food and water for livestock use is appealing (i.e. a win-win situation), it is largely contradicted by existing evidence (Table 1). Riparian specialist Robert Ohmart of the University of Arizona questions whether weakened and degraded riparian communities throughout the arid West can "hang onto their thread of existence for another 30-50 years" (Ohmart 1996, p. 272) while waiting for grazed systems to recover.

All discussions of improved grazing systems allude to the fact that the best prescription for stream recovery is a long period of rest from livestock grazing. Even those who strongly believe grazing to be compatible with healthy riparian ecosystems point out that 2-15 years of total livestock exclusion is required to initiate the recovery process (Duff 1977, Skovlin 1984, Clary and Webster 1989, Elmore 1996, Clary et al. 1996). Consequently, streams that are permanently protected from grazing have the highest probability of successful recovery (Claire and Storch 1977, Chaney et al. 1990, Bock et al. 1993, Armour et al. 1994, Fleischner 1994, Rhodes et al. 1994, Ohmart 1996, Case and Kauffman 1997).

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Table 1: Effects of livestock grazing and trampling on aquatic and riparian species and habitats in the western United States.

Influence on	Response	Causes	Impacts	References
Water quality				
Nutrient concentrations	Increase	Runoff from disturbed stream banks; livestock urine and manure deposited into stream; nutrients concentrated in reduced quantity of water	Reduced dissolved oxygen and possible water salinization in isolated pools and downstream lakes; alteration of instream species composition	Schepers et al. 1982 Taylor et al. 1989
Bacteria/ protozoa	Increase	Direct fecal deposition into water; fecal material in runoff; sediments containing buried microorganisms churned up by hoof action	Higher human and wildlife disease-producing potential from pathogens; human health endangered by swimming and other contact	Johnson et al. 1978 Stephenson and Street 1978 Stephenson and Rychert 1982 Tiedemann and Higgins 1989 Tiedemann et al. 1987
Sediment load and turbidity	Increase	Instream trampling; disturbance and erosion from denuded banks; reduced sediment trapping by streambank and instream vegetation; loss of bank stability; increased peak flows from compaction	Sediments blanket spawning gravel, entombing or suffocating fish embryos and juveniles; reduced dissolved oxygen levels in substrate; reduced foraging success by aquatic organisms; disruption of fish migration and respiratory systems of invertebrates; pool infilling; alteraton of benthic food web; reduction of human reservoir storage capacity more rapidly than projected; increased costs for filtraton of domestic water supplies	Lusby 1970 Winegar 1977 Johnson et al. 1978 Stevens et al. 1992

Water temperature	Increases	Increased solar exposure due to reduced shade from streamside vegetation and loss of undercut streambanks, and to widened stream channel that exposes greater water surface to solar radiation; lower summer flow	Increased evaporation and salinity; poor to lethal environment for salmonids and other temperature-sensitive, cold-water species; reduces fish growth due to increased metabolic rate and suppression in appetite; increased competition from warmwater fish; shift from salmonids to non-game fish; increased predation on fish; changes in growth rate and population size of cyanobacteria, algae and other aquatic organisms; increased incidence of lethal water-borne diseases; higher decomposition rates	Duff 1977 Tiedemann and Higgens 1989 Platts 1991 Li, et al. 1994 Tait, et al. 1994 Maloney et al. 1998
Dissolved oxygen levels	Possibly decline	Higher water temperatures; high biological oxygen demand of fecal material and algal blooms	Insufficient oxygen in spawning gravels; reduced rate of food consumption, growth and survival of salmonids and other aquatic species, especially at their early life stages; reduced prey items for fish; reduced decomposition rates; increased toxicity of toxicants	
General reviews of topic	Meehan and Platts 1978, Reiser and Bjornin 1979, Kauffman and Krueger 1984, Skovlin 1984, Bohn and Buckhouse 1985b, Haveren et al. 1985, Ongerth and Stibbs 1987, Platts 1991, USDI 1993, Rhodes et al. 1994, ODEQ 1995a, b, US-EPA 1995, Atwill 1996, Ohmart 1996			

Stream channel morphology				
Channel depth	Increases	Downcutting (incision) due to higher flood energy in high gradient, erosional stream regimes	Lowered groundwater table; narrowing of riparian zone; high flows contained within channel, thus precluding build-up of flood plain; more downstream sedimentation	Winegar 1977 Overton et al. 1994 Knapp and Matthews 1996
Channel width	Increases	Breakdown of streambanks by trampling; increased erosion from greater flood velocity; erosion of stream banks due to reduced resistance from riparian vegetation	Further loss of riparian vegetation; higher water temperatures; decreased water depth	Duff 1977 Marcuson 1977 Platts 1981a Kauffman et al. 1983b Hubert et al. 1985 Stuber 1985 Overton et al. 1994 Matthews 1996
Channel stability during floods	Decreases	Bare streambanks and channel bed easily eroded	Widening of channel; loss of pools and meanders	Marcuson 1977
Water depth	Decreases (except during peak flow)	Wider stream bed	Higher water temperatures; reduced habitat for aquatic organisms	Platts 1981a Hubert et al. 1985 Stuber 1985 Matthews 1996
Channel bed				
--Gravel	Lost in erosional environment	Increased flood velocity and energy; reduction in large woody debris	Reduced spawning habitat and habitat for benthic organisms	Duff 1977
--Fine sediments	Increase in depositional environment	Increased streambank erosion	Suffocation of fish eggs and fry due to low intragravel oxygen levels; degraded stream habitat for benthic organisms; filling in of pools	Duff 1977 Hubert et al. 1985 Owens et al. 1996 Myers and Swanson 1996a,b

Streambank stability	Reduced	Fewer plant roots to anchor soil; less plant cover to protect soil surface from disturbance; shear force of trampling hooves	Increased streambank sloughing; increased erosion and water turbidity; increased channel width	Duff 1977 Gunderson 1968 Marcuson 1977 Platts 1981a Kauffman et al. 1983b Rinne 1985 Stuber 1985 Myers and Swanson 1991, 1992, 1996a Kleinfelder et al. 1992 Overton et al. 1994
Streambank angle	Laid back	Streambank sloughing; livestock trampling	Increased channel width; decreased water depth	Platts 1981a Myers and Swanson 1995 Knapp and Matthews 1996
Streambank undercuts	Reduction in quality and quantity	Streambank breakdown by livestock and loss of stabilizing vegetation	Fewer hiding spaces and pools for fish	Platts 1981a Kauffman et al. 1983b Hubert et al. 1985 Overton et al. 1994 Myers and Swanson 1995 Knapp and Matthews 1996
Channel form	Fewer meanders and unvegetated gravel bars	Increased water velocity; removal of stabilizing vegetation; erosion of stream bank	Increased erosion; fewer pools for fish; decreased streambank roughness	Marcuson 1977
Pools	Decrease in number and quality	Loss of large woody debris; increased sedimentation	Loss of fish habitat; loss of thermal refugia during temperature extremes, reduced salmonid productivity and survival	Duff 1977 Marcuson 1977 Hubert et al. 1985 Myers and Swanson 1991, 1994, 1996a McIntosh et al. 1994
General reviews of topic	Kauffman and Krueger 1984, Skovlin 1984, Armour et al. 1994, Platts 1982, 1991, Chaney et al. 1990, 1993, USDI 1993; Rhodes et al. 1994; Trimble and Mendel 1995; Sarr et al. 1996			

Hydrology (stream flow patterns)				
Overland flow (runoff)	Increases	Reduced water infiltration into soils due to compaction and loss of streamside vegetation	Increase in sheet and rill erosion; increased flooding; reduced groundwater recharge; lowered water table	Orr 1975 Meehan and Platts 1978 Stevens et al. 1992
Peak flow	Increases	Larger volume of runoff flowing directly into channel	Increased stream energy for channel erosion, downcutting of channel bed and gully formation	Platts 1991
Flood water velocity	Increases	Reduced resistence from streambank and instream vegetation and from downed woody debris; increased flood water volume	Increased erosive energy and downcutting; removal of submerged vegetation and woody debris for pool formation; reduced habitat diversity; fish vulnerable to flash floods	Platts 1981a Li et al. 1994
Summer and late-season flows	Decrease	Less water stored in soil; lowered water table	Aquatic organisms stressed by reduced water quantity; less aquatic habitat; higher water temperatures	Ponce and Lindquist 1990 Kovalchik and Elmore 1992 Li et al. 1994
Water table	Lowered	Reduced water infiltration and increased runoff; groundwater drains into incised streambed; deeper channel reduces recharge by stream	Loss of aquatic and riparian species; perennial streams become ephemeral; loss of ephemeral streams	Kovalchik and Elmore 1992 Li et al. 1994
General reviews	Platts 1981b, 1991, Thurow 1991, Chaney et al. 1990, 1993, USDI 1993, Fleischner 1994, Rhodes et al. 1994, Trimble and Mendel 1995			

Riparian zone soils				
Bare ground	Increases	Vegetation consumed and trampled by livestock	Drier soil surfaces; higher erosion and sediment delivery to streams and aquatic habitats	Lusby 1970 Marcuson 1977 Hubert et al. 1985 Schultz and Leininger 1990 Clary and Medin 1990 Stevens et al. 1992 Popolizia et al. 1994
Erosion (water, ice, and wind)	Increases	Soil compaction; removal of vegetational cover; trampling disturbance	Increased sediment load to receiving stream; loss of fertile topsoil; suffication of fish eggs; loss of pools and pool volume; reduction of reservoir capacity	Lusby 1970 Bohn and Buckhouse 1985a Kauffman et al. 1983b
Litter layer	Decreases	Removal of aboveground plant biomass by livestock	Lower infiltration rates; greater runoff and erosion; reduced soil organic matter; warmer, drier soils	Marcuson 1977 Kauffman et al. 1983a Shultz and Leininger 1990 Popolizia et al. 1994 Green and Kauffman 1995
Compaction	Increases	Trampling by livestock on wet, heavy soils; reduced litter and soil organic matter	Decreased infiltration rates and more runoff; reduced plant productivity and vegetative cover	Orr 1975 Clary and Medin 1990 Clary 1995
Infiltration	Decreases	Increased soil compaction from hoof action; reduced plant cover, litter, and organic matter	Increased overland flow and erosion; reduced soil water content and plant growth; lowered water table	Orr 1975 Gifford and Hawkins 1978 Bohn and Buckhouse 1985a
Fertility	Declines	Less soil organic matter; loss of top soil; loss of soil strucure due to trampling	Fewer soil organisms; reduced plant growth	Marcuson 1977
General reviews of topic	Kauffman and Krueger 1984, Skovlin 1984, Chaney et al. 1990, 1993, Thurow 1991, Fleischner 1994, Rhodes et al. 1994; Trimble and Mendel 1995, Belsky and Blumenthal 1997			

Instream vegetation				
Algae	Increase	More sunlight; higher temperatures; higher concentrations of dissolved nutrients	Low levels of dissolved oxygen, especially when algal blooms collapse	Tait et al. 1994 Li et al. 1994 US-EPA 1995
Higher plants (submerged and emergent)	Often decline in abundance	Trampled; buried in deposited sediments; uprooted by strong flows	Reduced trapping of sediments; less food for aquatic organisms; higher water velocity and erosive force	
General reviews	Knight and Bottorff 1984			
Streambank vegetation				
Herbaceous cover, biomass, productivity, and native diversity	Decline	Grazing and trampling by livestock; selective grazing on palatable species; loss of vulnerable species; lowered water table; drier, warmer, more exposed environment	Less detritus (food inputs) for stream and aquatic organisms; higher water temperatures in summer and cooler temperatures in winter; degraded habitat for fish and wildlife; reduced biodiversity; loss of moisture- and shade-dependent species; replacement of riparian specialists with weedy generalists; loss of ecosystem resiliency; higher water velocities during floods; reduced sediment trapping	Duff 1977 Marcuson 1977 Winegar 1977 Kauffman, et al. 1983a Elmore and Beschta 1987 Medin and Clary 1989 Schultz and Leininger 1990 Clary and Medin 1990 Stevens, et al. 1992 Popolizia et al. 1994 Clary 1995 Green and Kauffman 1995 Clary et al. 1996 Knapp and Matthews 1996
Overhanging vegetation	Declines	Grazing and browsing by livestock	Less shade; higher water temperatures; less detritus for stream organisms	Marcuson 1977
Tree and shrub biomass and cover	Decline	Browsing by livestock on shrubs and tree saplings when they are most vulnerable	Decline in streambank stability; increased erosion; reduced stream shade and higher water temperatures; reduction in detritus and essential nutrients; loss of complex vegetation structure for wildlife	Marcuson 1977 Kauffman et al. 1983a Taylor 1986 Schulz and Leininger 1990 Sedgwick and Knopf 1991 Boggs and Weaver 1992 Kovalchik and Elmore 1992 Green and Kauffman 1995

Species composition	Altered	Lowered water table; warmer, drier environment; livestock selection of palatable species; compacted and disturbed soils	Replacement of riparian species by upland species and exotic weeds; reduction in riparian area	Kauffman et al. 1983a Clary and Medin 1990 Schulz and Leininger 1990 Green and Kauffman 1995
Structure (vertical and horizontal)	Simplified	Loss of trees and large shrubs; reduced plant establishment in drier soils	Loss of sensitive bird species; reduction in wildlife habitat	Taylor 1986 Knopf et al. 1988 Medin and Clary 1989
Plant age-structure	Becomes even-aged	Reduced plant establishment and survival due to browsing, grazing, and trampling	Reduced wildlife habitat; loss of riparian-dependent wildlife	Kauffman et al. 1983a
Plant phenology	Altered	Less shade and soil litter create warmer, drier environments in summer and colder environments in winter	Increased frost damage to plants in fall	Kauffman et al. 1983a
Plant succession	Impeded	Late-successional species grazed and browsed	Retrogression	Kauffman et al. 1983a Green and Kauffman 1995
General reviews of topic	Kauffman and Krueger 1984, Knight and Bartorff 1984, Skovlin 1984, Thomas et al. 1979, Chaney et al. 1990, 1993, Fleischner 1994, Ohmart 1996			

Aquatic and riparian wildlife				
Fish				
Species diversity, abundance, and productivity	Decrease	Higher water temperatures increase salmonid mortality (by breaking down physiological regulation of vital processes such as respiration and circulation), and negatively affect fish spawning, rearing, and passage; greater water turbidity, increased siltation and bacterial counts, lower summer flows, and low dissolved oxygen in the water column and intragravel environment reduce fish survival; damage to spawning beds; less protective plant cover; fewer insects and other food items; streambank damage; decreased hiding cover; reduced resistance to water-bourne diseases	Loss of salmonids and other cold-water species; loss of avian and mammalian predators; replacement of cold-water, riparian species with warm-water species	Duff 1977 Marcuson 1977 Stuber 1985 Li et al. 1994 Tait et al. 1994 Dudley and Embury 1995 Knapp and Matthews 1996 Sarr et al. 1996
Behavior	Different use of different habitats	Reduction in preferred habitat types		Matthews 1996
General reviews of topic	Marcuson 1977, Meehan et al. 1977, Reiser and Bjornn 1979, Kauffman and Krueger 1984, Skovlin 1984, Platts 1982, 1991, Fleischner 1994, Rhodes et al. 1994, ODEQ 1995a,b, Ohmart 1996			
Invertebrates				
Diversity, abundance, and species composition	Altered	Higher water temperatures from loss of shade; lower dissolved oxygen levels; increased fine sediments; reduced plant detritus but higher algal biomass for food	Loss of species that require cleaner and colder waters and coarser substrates; increase in algae feeders; fewer palatable species and less food for higher trophic levels; reduced litter breakdown	Rinne 1988 Tait et al. 1994 Erman 1996

General reviews	Meehan et al. 1977, Knight and Bottorff 1984, ODEQ 1995a,b, Sarr et al. (1996)			
Amphibians and reptiles				
Diversity, abundance, and species composition	Decline	Decline in structural richness of vegetative community; loss of prey base; increased aridity; loss of thermal cover and protection from predators; water temperatures lethal to early life stages	Loss of biodiversity and prey for higher trophic levels; loss of native species	Jones 1981 Szaro et al. 1985 Dudley and Embury 1995 Jennings 1996
Birds				
Diversity, abundance and species composition	Altered	Reduction in food, water quality and water quantity; loss of perches, nesting sites, and protective plant cover; loss of complex vegetational structure	Reduction in biodiversity; replacement of riparian specialists by upland species and generalists; loss of some neotropical migrants	Taylor 1986 Sedgwick and Knopf 1987 Knopf et al. 1988 Schulz and Leininger 1991 Clary and Medin 1992 Stacey 1995
General reviews of topic	Kauffman and Krueger 1984, Skovlin 1984, Bock et al. 1993, Fleischner 1994, ODEQ 1995a,b, Saab et al. 1995, Ohmart 1996, Weller 1996			
Mammals (large and small)				
Diversity, abundance, and species composition	Altered (sometimes but not always)	Loss of riparian habitat and food sources; warmer, drier, more exposed environment; behavioral characteristics such as avoidance of livestock	Habitat-use shifts by wildlife; suboptimal nutrition for females and offspring; changes in predator-prey relations; altered herbivory and other ecosystem processes; lower beaver activity with their creation of wetlands; riparian species replaced by upland species and generalists	Winegar 1977 Samson et al. 1988 Medin and Clary 1989 Loft et al. 1991 Schultz and Leininger 1991 Clary and Medin 1992 Clary et al. 1996
General reviews	Thomas et al. 1979, Kauffman and Krueger 1984, Skovlin 1984, Ohmart 1996			
Threatened and endangered species				

Abundance	Reduced	Loss of habitat; disturbance; livestock herbivory; competition with livestock; habitat fragmentation	Possible extinction	Dudley and Embury 1995 USDI 1994a
General reviews	Flather et al. 1994, Horning 1994, Ohmart 1996			

Table 2. Landscape and regional consequences of livestock grazing in streams and riparian ecosystems in the arid West

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Downstream waters have higher temperatures and sediment loads
Downstream flood levels are higher
Quantity of water to downstream ecosystems is lower during low-flow periods
Forested connectors and wildlife migratory routes between high and low elevation ranges are lost
The diversity and abundance of migratory birds and wildlife are reduced
Habitat mosaic is homogenized
Corridors for migration of salmonids and other species are fragmented
Areas set aside for human recreation are reduced in quality
Commercial and recreational fishing opportunities are reduced
Domestic water supplies require more filtration and treatment by water-treatment plants, leading to higher utility rates
More sediment is deposited in lakes and reservoirs, thus reducing reservoir life and hydroelectric capacity
Sediments in water damage hydroelectric turbines
Higher sediment loads increase maintenance costs of irrigation canals