DOI: 10.1007/s00267-002-2608-8

Riparian Livestock Exclosure Research in the Western United States: A Critique and Some Recommendations

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ABSTRACT / Over the last three decades, livestock exclosure research has emerged as a preferred method to evaluate the ecology of riparian ecosystems and their susceptibility to livestock impacts. This research has addressed the effects of livestock exclusion on many characteristics of riparian ecosystems, including vegetation, aquatic and terrestrial animals, and geomorphology. This paper reviews, critiques, and provides recommendations for the improvement of riparian livestock exclosure research. Exclosure-based research has left considerable scientific uncertainty due to 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 upon the site conditions when and where livestock exclosures are established, postexclusion dynamics may vary considerably. Systems can recover quickly and predictably with livestock removal (the "rubber band" model), fail to recover due to changes in system structure or function (the "Humpty Dumpty" model), or recover slowly and remain more sensitive to livestock impacts than they were before grazing was initiated (the "broken leg" model). Several initial ideas for strengthening the scientific basis for livestock exclosure research are presented: (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/design; and (5) a stronger commitment to collection of pretreatment data.

As western land managers, scientists, and ranchers began to understand and appreciate the exceptional biodiversity of riparian ecosystems (Carothers and others 1974, Brode and Bury 1984, Naiman and others 1993), and the strong tendency for livestock to congregate in these habitats (Bryant 1982, Roath and Kreuger 1982, Platts and Nelson 1985, Rinne 1988b), riparian protection and restoration became a common conservation goal. Managers and scientists, in particular, began to look for reference systems in which natural ecological processes and patterns could be observed. It soon became clear, however, that very few riparian systems had escaped impact, and pristine sites were exceedingly rare or unavailable in most landscapes. As a result, many analyses of livestock grazing effects on riparian and aquatic habitats have been based on comparisons of grazed and ungrazed areas using livestock exclosures (Leege and others 1981, Rickard and Cushing 1982, Bowns and Bagley 1986, Brand and Goetz 1986, Schulz and Leininger 1990, Green and Kauffman 1995, Knapp and Matthews 1996).

This paper outlines the origin of a typical riparian livestock exclosure presented in the literature, summarizes and critiques some recurrent assumptions in exclosure-based research, and presents recommendations to improve future work in this area.

KEY WORDS: Livestock exclosures; Riparian ecosystems; Ecological restoration

Origin and Types of Riparian Livestock Exclosures

In much of the West, heavy, unregulated livestock grazing preceded the establishment of federal land management agencies by 50 years or more. As managers attempted to develop a quantitative basis for range management of public lands, many exclosures and other restoration projects were initiated by the late 1930s in federal lands, primarily on upland range (Sneva and others 1980, Sanders and Voth 1982), but occasionally in meadow or riparian ecosystems (Bowns and Bagley 1986, Sarr 1995). In the decades following, livestock exclosures were occasionally erected by managers or scientists, or occurred accidentally, due to nonuse of government or private pastures, land-use changes, or sequestering of national park or military lands (Rickard and Cushing 1982). In describing the California Rangeland Reference Area Inventory and Database, Holzman and Isaacs (1999) noted age, geographic location, size, and range cover type for the 193 riparian and upland exclosures listed for the state. They noted that most exclosures were <20 ha in size and <15 years old.

Livestock exclosures have been constructed by land management agencies or private landowners for a variety of reasons. Many exclosures have been built with the intent of providing "reference areas," naturally functioning systems to serve as targets for resource management. Fencing has also been advocated as a protective measure to minimize impacts of livestock on riparian and aquatic habitats (Platts and Rinne 1985). A third approach has been to use exclosures as a tool for "passive" restoration of degraded stream reaches (Kauffman and others 1997). Finally, some exclosures have been built with experimental research as the sole purpose.

Reference exclosures are the most typical exclosures encountered in the riparian range management literature. They are usually located in low-gradient alluvial basins of public land grazing allotments, centered on an intermittent or perennial stream channel, rectangular (with the long axis parallel to the stream), and between 0.5 and 4.0 km in length and 0.05 to 0.5 km wide (Rinne 1988a, Schulz and Leininger 1990, Kondolf 1993, Sarr and others 1996). Exclosures are usually of barbed wire or solar-electric construction, and of adequate height (1–1.5 m) to exclude livestock without overly obstructing movements of native ungulates and other animals. The areal dimensions are typically sufficient to encompass an average western headwater stream, its active floodplain, and up to a dozen full stream meanders. Since nearly all reference exclosures were grazed previously, they are also viewed by managers as a tools for passive restoration in degraded watersheds.

Protective exclosures are usually constructed around areas of special concern (e.g., active headcuts or deeply incised stream channels, springs, revegetation projects, rare plant or animal habitats, etc.) and have a local management focus. They are generally smaller than the typical reference exclosure, and since they are built to protect unique sites or projects, usually do not have equivalent grazed sites for comparison. Although protective exclosures typically offer less opportunity for inferential research, pre/post treatment comparisons may yield important insights for local adaptive management.

Research exclosures vary greatly in size and design, depending on the goals of the study and kinds of animals being excluded. They range in size from small exclosures to remove native rodents to large livestock or native ungulate exclosures covering many hectares. Research exclosures most often meet the requirements of a rigorous experimental design, but they are often clustered in research rangelands, and much less widespread than protective or reference exclosures.

A Review of Exclosure Studies

Exclosure studies have become an integral part of western range management and ecological research. Investigations have studied riparian vegetation, fisheries and aquatic biota, big-game and other mammals, and avifauna. Yet others have focused on physical structures and processes of streams, including stream channel morphology and substrate composition, bank stability, and erosion or sedimentation dynamics. Given the haphazard origins of most existing riparian livestock exclosures, it is perhaps not surprising that few studies were initiated at the time the exclosures were established (Anderson and Holte 1981, Leege and others 1981). Researchers have overwhelmingly initiated studies after the fact, and compared riparian sites inside versus outside exclosures without premanipulation data. With the broad array of site conditions, organisms, and the very real inferential challenges posed by exclosures, research results have been varied and often controversial.

Riparian Vegetation

Most studies tracking responses of riparian vegetation to cattle exclusion have noted rapid increases in height and vigor (Odion and others 1988, Kondolf 1993, Knapp and Matthews 1996, Kauffman and others 1997, Dobkin and others 1998), increased leaf litter accumulation, and decreases in bare substrate (Odion and others 1988, Schulz and Leininger 1990, Popolizio and others 1994, Dobkin and others 1998). Compositional changes from forb- or nonnative grass-dominated communities towards native grass- and sedge-dominated communities have also been widely documented in montane riparian meadows following rest from cattle grazing (Hayes 1978, Leege and others 1981, Kauffman 1983, Odion and others 1988, Schulz and Leininger 1990, Green and Kauffman 1995, Sarr 1995). Long-term exclusion of sheep, in contrast, has been reported to increase cover of native forbs (Bowns and Bagley 1986). Effects of exclusion on plant species richness have been less conclusive, with authors reporting increases (Winegar 1977, Bowns and Bagley 1986), decreases (Ratliff 1985, Green and Kauffman 1995), or no change (Sarr 1995). Belsky and others (1999) noted that riparian plant diversity is often inflated by invasion of nonnative or upland species in the presence of livestock disturbance, and overall species richness can decline with exclusion as the system recovers and native sod-forming graminoids attain dominance (Green and Kauffman 1995). Numerous studies have documented rapid and dramatic increases in willow or cottonwood densities and/or cover with exclusion (Marcuson 1977, Crouch 1978, Kauffman and others 1982, Rickard and Cushing 1982, Taylor 1986, Schulz and Leininger 1990, Green and Kauffman 1995, Sarr 1995, Dobkin and others 1998).

Aquatic Organisms

Responses of native fishes and their habitat have been well studied in exclosed stream reaches but remain problematic. Studies of riparian exclosures often indicate rapid responses in most elements of aquatic and fisheries habitat, such as decreased streambank angles, increases in shading from riparian and emergent vegetation, water column depth, and substrate quality (for salmonids) (Rinne 1988a,b, Knapp and Matthews 1996). The responses, in terms of actual fish populations, appear to be less conclusive; numerous studies have documented greater biomass and abundance of trout in livestock exclosures (Van Velson 1979, Bowers and others 1979, Keller and Burnham 1982, Knapp and Matthews 1996), but others have shown little or no difference (Rinne 1988b, Rinne and LaFayette 1991). Responses of nongame fish and aquatic invertebrates have received much less study (Rinne 1988a, Sarr and others 1996) and remain poorly understood. Platts (1991), in summarizing a large number of fisheries studies, noted that many of the most widely cited studies failed to prove that the observed differences inside and outside exclosures were due entirely to livestock exclusion. In addition, it is very likely that fish or other highly mobile aquatic organisms move freely between grazed and ungrazed stream reaches and use habitat features in both areas.

Riparian-Dependent Birds

Studies of riparian birds have shown that densities and diversity increase with exclusion, largely as a result of increased height, volume, and structural diversity of vegetation (Duff 1979, Crouch 1982, Taylor 1986, Schulz and Leininger 1991, Dobkin and others 1998). In a review of the effects of livestock on birds in western riparian areas, Saab and others (1995) noted that livestock exclusion appeared to have varied effects on different foraging guilds. Of 68 species of neotropical migrants, 46% increased in abundance with exclusion of livestock, 29% decreased, and 25% showed no clear response.

Geomorphology

Although many studies document recovery of riparian vegetation, and vegetation has been demonstrated to be critical in promoting bank stability (Smith 1976, Kleinfelder and others 1992, Dunaway and others 1994), studies of exclusion effects on stream geomorphology have yielded conflicting results. Many authors have noted decreased bare banks, narrowed wetted channels, and greater proportions of overhanging bank in excluded areas, which they ascribe to increased vigor of streamside vegetation (Kauffman and others 1983, Platts 1983, Knapp and Matthews 1996). Others, however, have documented no recovery in channel and floodplain form following apparent vegetation recovery and up to 30 years of exclusion (Kondolf 1993). Incised (downcut) stream channels are particularly common legacies of past overgrazing and present unique restoration challenges because of changes in flooding and sedimentation dynamics and bank stability. Zonge and Swanson (1996) determined that rapid vegetation establishment during drought years along a nongrazed riparian reach could not stabilize vertical streambanks during a subsequent high-flow year in the eastern Sierra Nevada. The apparently conflicting geomorphic responses reported with exclusion may become more meaningful as we develop a greater understanding of the relationships between riparian vegetation, stream geomorphology, and watershed processes (Rosgen 1994, Myers and Swanson 1991, 1996). Recovery of stream geomorphology appears to be hierarchical; hydraulic controls on stream form supercede vegetation controls beyond certain energy/structure thresholds, such as potential maximum discharge to floodplain capacity (Swanson 1989). These relationships complicate the interpretation of ecosystem recovery trends. Even in riparian systems that are not deeply incised, evaluation of recovery in channel and floodplain form may be limited by the episodic nature of channel development and its dependence upon watershed scale dynamics (Kondolf 1993, Sarr 1995, Zonge and Swanson 1996). Figure 1 illustrates hypothetical differences in recovery dynamics in incised and nonincised stream systems after historical degradation, a period of improved livestock management, and a period of livestock exclusion, based on field observations at several livestock exclosures in the southern Sierra Nevada (Sarr 1995).

A Critique of Livestock Exclosure Research

Scientific Uncertainty

Any review of the literature comparing grazed and ungrazed areas using riparian livestock exclosures reveals multiple layers of uncertainty. Many of the pri-

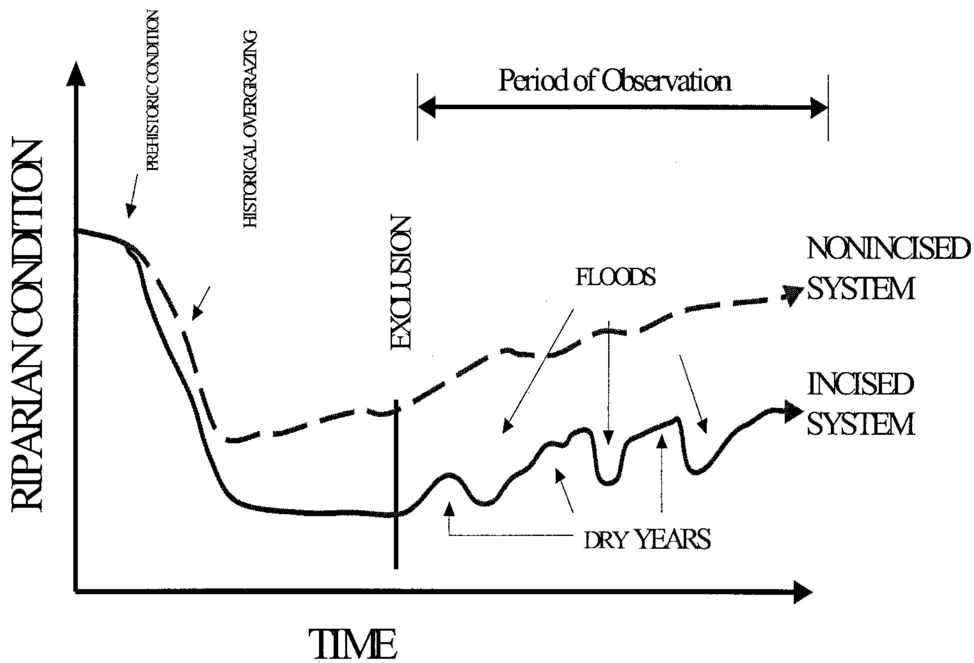

Figure 1. Diagram comparing changes in riparian condition during historical overgrazing, a period of moderate intensity grazing, and a period of livestock exclusion in incised and nonincised riparian ecosystems. In the more severely degraded incised system, recovery is minimal in the presence of moderate livestock use and is strongly controlled by flooding disturbances after exclusion. In the nonincised system, recovery may begin with improved grazing management, and accelerate with exclusion. Flooding has less of a constraining effect on early recovery in the nonincised system, and it may actually facilitate recovery.

mary studies are descriptive and popularized, and the authors often reach conclusions on often circumstantial data (Platts 1991). The literature is uneven in its emphasis, with many more studies addressing salmonid fishes than all other forms of riparian fauna combined. These weaknesses have been noted by others (Platts 1991, Rinne and LaFayette 1991, Larsen and others 1998). Moreover, in literature reviews there is often a tendency to marshal evidence advocating for or against the use of public rangelands by domestic livestock interests. Rather than focusing on building a quantitative understanding of the recovery dynamics in exclosures, reviews of exclosure studies have often emphasized the severe impacts of ongoing livestock grazing on vegetation, geomorphology, and aquatic organisms (Kauffmann and Kreuger 1984, Fleischner 1994, Belsky and others 1999). Other reviews have emphasized the design weaknesses in many of the most often cited papers (Larsen and others 1998), concluding the reported detrimental effects are largely unsubstantiated. Given the rapidly growing body of research suggesting that riparian recovery does occur in exclosures (Kauffman and others 1983, Platts 1983, Knapp and Matthews 1996, Sarr and others 1996), and the very real design problems with most exclosure studies (Rinne and LaFayette 1991, Platts 1991, Larsen and others 1998), it is likely that researchers of differing opinions on public lands livestock grazing will continue to draw their own conclusions.

Research Assumptions and Interpretive Challenges

Studies seeking to evaluate the effects of livestock grazing at a given locale often use observations of recovery processes in one or several nearby excluded areas as a benchmark. Although grazed/excluded comparisons remain an important research path, researchers using this approach have often used a number of untested assumptions. The following assumptions are especially common:

1. Studies of recovery dynamics are suitable ways to acquire knowledge about past and present degradational pathways and have special applicability to current grazing management.
2. Recovery of natural floodplain or stream structure, function, and communities can occur within small (several dozen hectares or less) and replicable exclosures.
3. Recovery processes observed at one site can be accurately generalized to sites in other ecosystems.

4. Long-term exclosures represent suitable examples of historical conditions.

Each of these four assumptions may hold true and provide important insights in specific situations, but the limitations of each must be considered in turn.

1. Recovery studies to understand past and present degradational pathways. Many of the studies using livestock exclosures contain language and reasoning implying that postexclusion responses are the reverse of those caused by livestock grazing and, therefore, represent a test of the grazing effect. For example, a study that shows no evidence of geomorphic recovery along a floodplain after several years of grazing exclusion may be interpreted to mean that grazing has no effect upon erosion rates at the paired grazed site. This reasoning assumes both that there is a symmetry of degradational and aggradational geomorphic processes and that these processes operate on the spatial and temporal scales of the exclosure treatment. Both assumptions are tenuous. The concept of hysteresis, or asymmetry, in pathways of degradation and recovery, is critical in understanding and thoughtfully interpreting recovery dynamics of degraded ecosystems (Friedel 1991, Laycock 1991).

Depending upon the level of past damage, riparian systems may show very different recovery trajectories upon exclusion. Productive sites where soils and geomorphology are intact may have considerable resilience and recover vegetation vigor and composition rapidly when livestock stress is removed or diminished. Tall grass prairies or moist sedge meadows often show this response, and some observations in exclosures indicate vegetation recovery can occur fairly rapidly if the site hydrology is intact or restored simultaneously with exclusion (Schulz and Leininger 1990, Green and Kauffman 1995, Sarr 1995, Kauffman and others 2000). In these specific situations, there may be a rough symmetry in trajectories of recovery and degradation (i.e., little hysteresis), allowing development of predictive relationships between livestock disturbance levels and plant species composition. Early indices of range condition which classified plant species as "increasers" or "decreasers" with grazing pressure, hinged on a reversible model of response to grazing (Dyksterhuis 1949, Ratliff 1985). Such situations may be thought of as an elastic or "rubber band" model of stress and recovery (Figure 2a). In most restoration situations, where damage may have been severe, recovery probably does not parallel degradation. Laycock (1991) suggested that semiarid rangelands, for example, may actually have multiple stable states, and once moved by disturbance into a new state, may not recover to former conditions

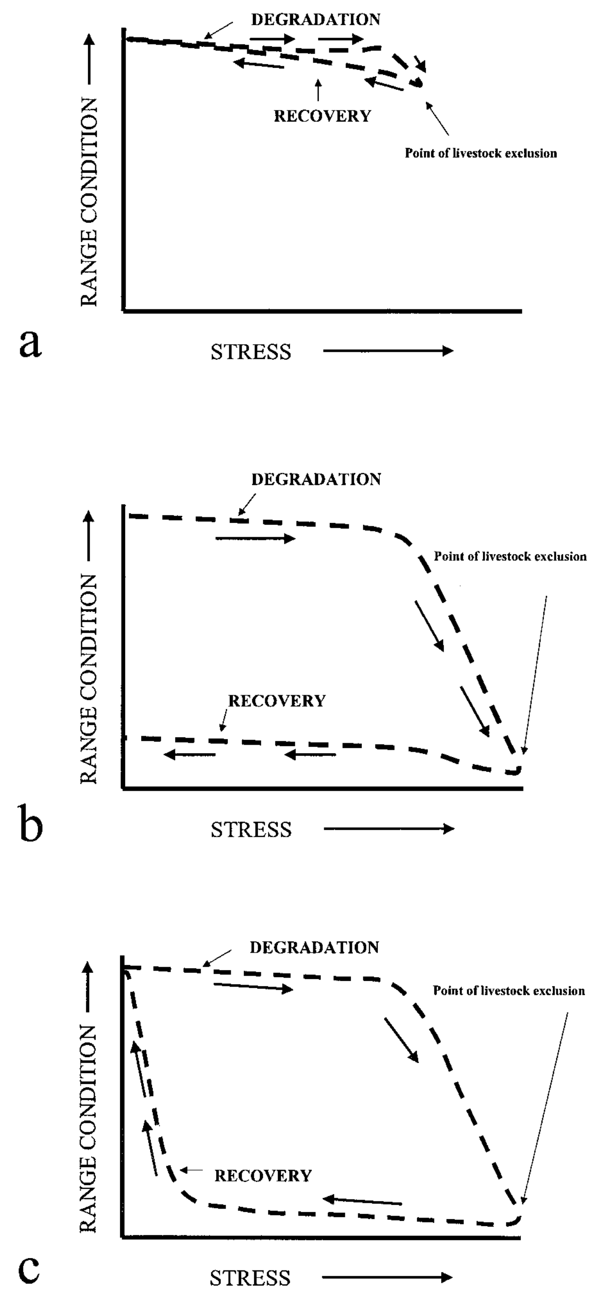

Figure 2. Diagrams displaying different relationships between range condition and livestock associated stress in a riparian area during degradation and recovery: (**a**) rubber band model system, where grazing-induced stresses are readily reversible; (**b**) Humpty Dumpty model system, where changes are irreversible; and (**c**) broken leg model system, where changes are reversible, but degradation and recovery follow distinct stress/condition pathways.

even if the initial stress is removed. He notes several dynamics that may preclude recovery to the initial state, including exotic species invasions, woody plant establishment in grasslands, and changes in fire regime. These situations may thought of as the "Humpty Dumpty" model (Figure 2b), (recalling the egg-shaped nursery rhyme character who fell off the wall and could never be put back together again). In such cases, recovery will probably not occur with any passive approach such as livestock exclusion. Most riparian systems, however, are probably somewhere between the two models above. Recovery is possible, but substantial reductions in grazing pressure may be necessary before the damaged system can begin recovery. Substantial time lags may also occur between the time stress is removed and the time the system begins to recover. This situation may be thought of as the "broken leg" model of recovery (Figure 2c).

The broken leg model almost certainly applies in overgrazed riparian systems of alluvial basins, where several positive feedback mechanisms may act to inhibit recovery. Where overgrazing has initiated channel incision or gully erosion, water tables decline, and mesic or xeric upland species invade former riparian wetlands, wetlands constrict in area, and streams lose access to their floodplains. When streams are decoupled from their floodplains in grazed watersheds, three positive feedback loops are set into play: entrapment, impoverishment, and convergence. In entrapment, floods that would normally escape the baseflow channel and dissipate sediment and energy over the floodplain are trapped in the gully and highly scouring flows occur. In impoverishment, the floodplain, which would normally be provided with organic debris and fine sediment at relatively short flood intervals, is either deprived of these inputs entirely or inundated with very coarse alluvium at relatively long flood intervals. Either situation produces floodplain terrace soils that are coarse, nutrient- and moisture-poor, and inhospitable for many riparian plant species. These skeletal soils are more likely to remain unvegetated and prone to movement during subsequent long-interval floods. Further, in gullied watersheds that continue to be grazed even lightly, xerification of the former floodplains and constriction of palatable wetland species to gully bottoms leads to convergence of livestock, and their impacts, into increasingly smaller areas of suitable forage. This increases livestock trampling on steep gully banks and favors further erosion even with low livestock numbers. Even when grazing is excluded from the affected drainage, two of the three pathways set in motion by the initial disturbance will likely remain in effect for some time. Full recovery of stream/riparian conditions will only occur after the stream, sediment, and vegetation can reequilibrate, which may require many years.

2. Riparian ecosystem recovery can occur within small and replicable exclosures. Researchers conducting investigations of exclusion dynamics in riparian systems are in a double bind. Recovery of ecosystems requires exclosures to be large enough to encompass the ecological processes supporting the system of concern (Bock and others 1993, Fleischner 1994), yet to achieve conclusive results scientists require adequate replication and spatial interspersion of exclusion treatments (Hurlbert 1984). Although certain riparian elements may respond quite well in small exclosures (e.g., vegetation), others may not respond unless the protected area is large enough to include landscape processes. Geomorphology and aquatic fauna may require protection of entire watersheds for full recovery (Rinne 1988a,b, Kondolf 1993). Protected areas large enough to allow recovery of watershed processes are difficult to replicate, since they often require taking rangelands out of production. Moreover, the system of interest may be inherently unique, and increased spatial scope would add unwanted variation in biota, geology, or management history (Dobkin and others 1998). To further complicate things, populations of riparian/aquatic organisms are often highly variable in time and space, making change detection difficult (Rinne 1988a, Knapp and Matthews 1996).

Typically, the net result of these logistical constraints is low statistical power, and the probability of committing a type II error, or accepting the null hypothesis (no recovery), when it is false, is usually substantial. Exclosures often provide locally compelling case studies of stream channel and vegetation recovery, but fail to fulfill statistical requirements due to low power. Such ambiguous results have hampered scientific consensus about both exclusion and livestock grazing effects in riparian environments.

3. Recovery processes can be generalized across diverse ecosystems or geographic areas. A clear lesson from the intensive study of three, and repeated field observations of four more, newly exclosed areas of the Kern Plateau of the southern Sierra Nevada (Sarr 1995, Sarr and others 1996) is that generalizations that could be made from each exclosure would be limited. Each of the sites appeared to be recovering, especially in regard to willow and sedge (*Carex* spp.) growth. The rate and magnitude of vegetation change, however, was very different across the seven exclosures. Factors such as watershed stability, climate, subsurface moisture availability, soil organic content, condition, and proximity of propagule sources (especially for willows), and degree of channel incision appear to strongly affect the rate of vegetation and channel recovery along a given stream reach (Swanson 1989, Sarr and others 1996).

In a meta-analysis of global effects of livestock grazing, Milchunas and Lauenroth (1993) noted that grazing effects on ecosystems vary strongly from site to site depending on productivity, evolutionary history of grazing, and site environment. It seems probable that site differences are highly influential on recovery processes in riparian systems as well. It is likely that many of the differences noted in exclosure studies will become less incongruous as we develop a stronger predictive basis for comparing recovery trajectories across gradients of hydrology, geomorphology, soils, climate, and disturbance history.

4. Long-term exclosures represent suitable examples of historical conditions. Although, as stated previously, they are the best examples we have, the value of exclosures as reference sites must be viewed realistically. The heavy grazing of the previous century left an enduring mark on western landscapes (Wood 1975, Kauffmann and Krueger 1984, Odion and others 1988, Fleischner 1994). Exotic species invasions (D'Antonio and Vitousek 1992), vegetation type conversions (Miller and others 1994, Sarr 1995), and streambank and gully erosion (Odion and others 1988, Sarr 1995) were widespread in the West by the beginning of the 20th century. Local extirpations of species, introductions of nonnative species or shifts toward more grazing-tolerant organisms, and physical changes such as soil compaction and erosion probably occurred at almost all presently excluded sites. Moreover, few exclosures have been maintained and monitored closely enough to preclude occasional to frequent trespass by livestock. Even the oldest existing exclosures were likely subject to the abuses of early unregulated grazing and may still be in early stages of geomorphic recovery. Naturally isolated areas that never experienced livestock use are exceedingly unique and often show vegetation characteristics fundamentally different from those found in livestock exclosures (Jameson and others 1962, Fleischner 1994, Ambos and others 2000). Unfortunately, these sites are almost exclusively limited to isolated mesas or mountains, not valley bottom riparian habitats.

Conclusions and Recommendations

Livestock exclosure research has yielded essential insights into the effects of livestock on riparian ecosystems, as well as mechanisms of ecosystem recovery. At the same time, it has spawned uncertainty due to a proliferation of poorly replicated, conflicting studies, untested research assumptions, and a lack of understanding of the mechanisms and spatial and temporal scales of ecosystem recovery. To better address these issues, we must improve the way we conduct livestock exclosure research on the ground, develop methods to objectively assess a large number of individually inconclusive or conflicting studies, and develop a predictive framework to discuss the mechanisms of riparian recovery. Since exclosures are likely to serve as important benchmarks and research tools in the future, a stronger theoretical and operational foundation is needed. I propose several initial ideas for strengthening the scientific basis for livestock exclosure research: (1) incorporation of meta-analyses and critical reviews. (2) use of restoration ecology as a conceptual framework; (3) development of long-term research programs; (4) improved exclosure placement/design; and (5) a stronger commitment to collection of pretreatment data.

Meta-Analyses and Critical Reviews

Since it is unlikely that the logistical and interpretive constraints encountered in exclosure research will disappear overnight, meta-analysis techniques provide a means to assemble and analyze the many existing studies which, in themselves, are weakly replicated, inconclusive, or conflicting (e.g., Milchunas and Lauenroth 1993, Saab and others 1995). One of the strengths of this approach is its ability to document emergent patterns from a pool of smaller, perhaps even conflicting, studies. Equally important, it allows us to more thoughtfully evaluate the risk of type II errors. In systems as spatially and temporally variable, difficult to replicate, and biologically valuable as riparian ecosystems, the risk of type II errors requires careful consideration.

With the great controversy over livestock grazing on public lands in the western US, there has been an unmistakable tendency for literature reviews to take on the role of advocacy in this policy debate. Although debate is appropriate for such an important conservation issue, it sometimes inhibits thoughtful review of the dynamics of restoration. Regardless of one's opinion on public land grazing, it is safe to say that all concerned parties desire a better understanding of ecosystem recovery. The pursuit of quantitative ecological relationships, conceptual models of recovery, and their interactions with management, is the heart of livestock exclosure research. Particularly thoughtful reviews that balance criticism, objectivity, creativity, and ecological insight, will serve to strengthen this scientific basis (Rinne and LaFayette 1991, Platts 1991, Saab and others 1995, Kauffman and others 1997, Larsen and others 1998).

Restoration Ecology

This could provide a common language for parties on both sides of the public lands grazing controversy to share valuable information and insights. A shift in focus from simply documenting livestock effects to quantifying recovery dynamics may allow a more rigorous scientific foundation to develop from exclosure research, which will ultimately improve both biodiversity conservation and livestock management. Ideally, any developing science should aim to be predictive (Peters 1991). Few authors have focused on rigorously quantifying spatial or temporal dynamics of recovery in exclosures or on making initial predictions of recovery trajectories for different riparian elements (but see Beschta and Kauffman 2000). A scientific framework for predicting the recovery of these systems will require clear descriptions of the factors that are facilitating or impeding recovery, hypotheses about spatial and temporal scales of recovery, articulation of research assumptions and design limitations, and explicit recognition of the constraints of individual field sites. Such empirical or theoretical contributions have potential to further understanding of ecosystem recovery in both grazed and protected landscapes.

Long-Term Research Program

As Larsen and others (1998) suggested, well-designed long-term studies of the dynamics of recovery in exclosures, as well as grazed areas, are needed if we are to develop a stronger predictive basis for the study of riparian ecosystem recovery. Beschta and Kauffman (2000) laid out some initial timelines for recovery of various elements during passive restoration of riparian ecosystems, and noted some essential habitat elements (e.g., large wood) may take several decades to respond. In addition, they stressed that the “range of natural variability” is an essential component to consider in interpreting recovery of riparian ecosystems. A geographically dispersed network of long-term riparian exclosures would allow us develop much greater insight into the regional differences in riparian structure and function, natural disturbance regimes, and temporal dynamics of ecosystem recovery.

Exclosure Placement

The haphazard spatial coverage of most existing exclosures has limited the generalizions that can be drawn from them. Future research is needed to develop exclosure strategies that address statistical requirements for replication and randomization of treatments, while protecting sufficently large areas to allow ecosystem recovery. The great majority of the exclosures that exist today are placed in low gradient alluvial reaches of stream basins. Some authors have recommended placing exclosures across the range of landscape types comprised in federal grazing allotments (Bock and others 1993). This proposal seems warranted given the large proportion of the land base utilized by livestock, the wide variety in ecosystem responses to grazing (Milchunas and Lauenroth 1993), and presumably, to exclusion. Efforts to catalog existing rangeland exclosures across ownerships and landscape gradients (Holzman and Isaacs 1999) provide a very useful step towards identifying important geographic and design gaps in existing exclosures. Placement of exclosures in a variety of hydrologic, structural, and physiographic settings will greatly facilitate development of a theoretical basis for recovery dynamics, and provide a frame of reference that will grow in value through time.

Building on the proposal of Bock and others (1993), I propose that not only are reference exclosures highly desirable across the full range of western public rangelands, but that a two-scaled approach could be used. First, on experimental rangelands at selected sites throughout the West, three watershed scale treatments could be applied: (1) livestock grazing at a typical season and intensity for the ecoregion; (2) exclusion of livestock and native ungulates, and (3) exclusion of livestock only. Recent evidence has demonstrated that native ungulates have a strong effect on vegetation, which complicates assessment of both the recovery of ecosystems and the ongoing effects of livestock use (Kay and Bartos 2000). Since this approach would require taking relatively large areas of rangeland out of livestock production, as well as removal of range for native ungulates, it could be applied as an experimental approach for specially designated representative rangelands in each ecoregion. Second, on a more operational level, the three treatments above should be established in modest-sized exclosures on all public land allotments as part of the ongoing adaptive management of these systems. This approach would allow managers and others to gain a base of reference of natural riparian recovery across geographic gradients. In addition, we could begin to gain insight into the functional scales of geomorphic and biological recovery and to more clearly differentiate livestock from native ungulate effects on riparian ecosystems.

Pretreatment Data

With the strong overlap in objectives of managers and scientists, it is likely that exclosure studies will continue to be conducted at sites exclosed for various management objectives and built by local or regional management entities. This is desirable in that it reduces duplication of efforts and provides information of direct use to managers. However, the establishment of accurate baseline data at the time of exclosure construction is absolutely essential to strengthen the inferential power of subsequent analyses for research or adaptive management at the exclosed site. Impact studies require pretreatment data to unambiguously document effects of spatially extensive and poorly or totally unreplicated management activities, such as livestock exclusion. Statistical analyses based in temporal changes in sites, such as before–after controlled-impact (BACI) designs, require one to several pre- and post-treatment measurements to evaluate the effect of the treatment (Stewart-Oaten and others 1986, Manly 2001). By establishing scientifically credible monitoring designs prior to exclosure construction, managers can help ensure that meaningful conclusions will be obtained.

Given the near absence of ungrazed riparian areas in the West, riparian livestock exclosures are essential research tools for the study of ecosystem processes, recovery, and to better inform livestock management. The critique and recommendations in this paper are intended to stimulate discussion and improvement of this increasingly important area of research.

Acknowledgments

I thank Del Hubbs, Terry Hicks, Tom Dudley, Dennis Odion, Keith Schulz, Terri Schulz, Wayne Leininger, Bob Beschta, Scott Cooper, Carl Bock, and Jane Bock for their support and creativity in helping me to develop these ideas. Roland Knapp, Jeff Shatford, *G. Matthias* Kondolf, *Virginia* Dale, and two anonymous reviewers provided many helpful comments that greatly improved the manuscript. Funding was provided by Inyo National Forest and The Aldo Leopold Wilderness Research Institute (grant INT-94942-RJVA). Support for the author during the preparation of this manuscript was provided by Cooperative Forest Ecosystem Research, USGS Forest and Rangeland Ecosystem Science Center, Corvallis, Oregon.

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