2006

Riparian grazing in the northern intermountain region: Impacts and strategies for management

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RIPARIAN GRAZING IN THE NORTHERN INTERMOUNTAIN REGION: IMPACTS AND STRATEGIES FOR MANAGEMENT

by

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Presented in partial fulfillment

of the requirements

for the degree of

Master of Science

The University of Montana

May 2006

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5-31-06
Date

Oestreich, Jon P. M.S., May 2006 Forestry

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Literature related to livestock grazing in riparian areas was reviewed especially as is relates to the northern intermountain region. Primary objectives included reviewing various definitions given for "riparian health", reviewing assessment protocols used to measure riparian health, review and organize literature concerning the effects of livestock grazing in riparian areas, and discussing the "state of the art" in terms of our understanding of livestock impacts and current strategies used to reduce negative impacts. A conceptual framework was developed to help understand how the direct physical impacts of livestock in riparian areas relate to a number or riparian functions and qualities. Conclusions were provided for each of the primary objectives as well as recommendations for future research related to this topic.

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Introduction

"Riparian" is a word that strikes fear in the hearts of many, anger in some and feelings of peaceful surroundings to others" (Elmore 1989 pg.93). This sentiment likely reflects a set of conflicting values surrounding the unique qualities of these ecosystems. Riparian areas are important for aesthetics, water quality, water quantity, streambank stability, and fish and wildlife habitat, but at the same time they are vital to the livestock grazing industry, have the potential to be developed as high-quality farmland, and are capable of producing timber (Hansen 1992). The potential uses of riparian areas and associated aquatic ecosystems can often interfere with the important ecological functions that they provide. Grazing in riparian areas has been one of the most important and controversial range management issues, especially on public lands. The importance of this issue is reflected in the amount of literature that has been developed on riparian issues since the 1970s.

Riparian areas can be simply defined as the "green zones" that lie between aquatic and upland ecosystems (Ehrhart and Hanson 1998). The National Research Council's Committee on Riparian Zone Functioning and Strategies for Management developed a more comprehensive definition:

> ...transitional between terrestrial and aquatic ecosystems and distinguished by gradients in biophysical conditions, ecological processes, and biota. They are areas through which surface and subsurface hydrology connect waterbodies with their adjacent uplands. They include those portions of terrestrial ecosystems that significantly influence exchanges of energy and matter with aquatic ecosystems (i.e., a zone of

influence). Riparian areas are adjacent to perennial, intermittent, and ephemeral streams, lakes, and estuarine-marine shorelines (NRC 2002 pg. 3).

Two types of riparian areas are often distinguished. Lentic riparian areas are those adjacent to still water such as a lake or pond and lotic riparian areas are those adjacent to streams and rivers. As ecotones, riparian areas encompass sharp gradients of environmental factors, ecological processes, and plant communities (Gregory et al. 1991).

Of the 70.4 million hectares (ha) of Bureau of Land Management lands, only about 40,000 ha (<1%) are considered riparian (U.S. Department of the Interior 1994). But from an ecological perspective, riparian areas are far more important than would be suggested by the relatively small proportion of the landscape they occupy. The supplemental surface and groundwater in a relatively arid landscape contributes to the unique character of riparian areas in the western United States (Patten 2000). Frequent disturbance associated with highly variable hydrologic regimes also sets riparian ecosystems apart from those in surrounding areas.

In-depth reviews have been conducted that describe the unique characteristics and processes associated with riparian ecosystems (ex. Gregory et al. 1991, Naiman and Decamps 1997, NRC 2002). Some characteristics of riparian areas relative to adjacent upland areas include more diverse plant communities (Thompson et al. 1998), high primary productivity (Naiman and Decamps 1997), more frequent disturbance (NRC 2002), unique microclimate (Naiman and Decamps 1997), and high heterogeneity (Naiman and Decamps 1997). A summary of important functions of riparian areas is shown in Table 1.

Table 1—Summary of ecosystem functions occurring in riparian areas.

Functions	Filter sediment	Naiman and Decamps 1997, Corley et al. 1999, Hook 2002
	Stabilize banks	Winward 2000, Gregory et al. 1991
	Groundwater recharge	NRC 2002, Hauer et al. 2002, Elmore 1989, Belsky 1999
	Regulate stream temperature	Gregory et al. 1991, NRC 2002, Naiman and Decamps 1997
	Provide nourishment at various trophic levels	Naiman and Decamps 1997
	Provide wildlife habitat	Naiman and Decamps 1997, Tewksbury et al. 2002, Ohmart 1996
	Nutrient Cycling	Naiman and Decamps 1997, Corley et al. 1999, Gregory et al. 1991, Green and Kauffman 1989
	Influence aquatic habitat	Gregory et al. 1991, Platts 1991, NRC 2002

When properly functioning, riparian areas can also support various human uses and values such as aesthetics, quality water for consumptive use, fishing, and other recreational pursuits. Human land use and use of aquatic resources across the United States has significantly affected the hydrologic, geomorphic, and biological structure and functioning of riparian areas (NRC 2002). Some of the most common sources of disturbance in the western United States include water development, stream channelization, agricultural practices, grazing, logging, and mining (Goodwin et al. 1997). A review of impacts caused by these activities is provided in Appendix A.

Livestock grazing has been identified as one of the most widespread causes of riparian degradation in the western U.S. (Elmore 1992). The lack of water, high temperatures, and relatively low forage production in uplands can cause cattle to concentrate in riparian areas leading to highly disproportionate use relative to upland areas (Skovlin 1984). The abundance of forage produced in some riparian areas can be a major asset to livestock producers (Schulz and Leininger 1990, Roath and Krueger 1982).

Historically, stocking rates where often high, and cattle were allowed access to riparian areas for the entire growing season or year-long (NRC 2002). Until the late 1960s and even later, western riparian areas were often viewed as "sacrifice" areas (e.g., Stoddart and Smith 1955) (Kauffman and Krueger 1984). There is undeniable evidence that early livestock grazing management practices have led to negative impacts on watershed hydrology, stream channel morphology, soils, vegetation, wildlife, fish, and water quality adjacent to these areas (Belsky et al. 1999).

Growing recognition of the importance of streams, rivers, and riparian habitats to western ecosystems has led to increased scientific investigation and discussion surrounding riparian areas (Belsky et al. 1999). During the last three decades, major concerns have been raised about the impacts of livestock grazing in particular (Armour and Elmore 1994). In an annotated bibliography on the topic of managing riparian and wetland areas in the western United States, approximately 350 sources had "grazing impacts" as a key word (Koehler and Thomas 2000).

Many studies, especially those by wildlife and fisheries biologists, often compared the effects of extreme intensities or heavy use to exclusion from grazing (Skovlin 1984). More recent studies have investigated the effects of grazing on many variables such as riparian vegetation, water quality, bank stability, wildlife populations and habitat, fish populations and habitat, and channel morphology. These effects have been measured on multiple stream types, at different seasons, and with varying intensities of grazing. Studies have also been conducted to understand behavior of cattle relative to riparian areas, and to test strategies for altering their behavior to reduce the associated impacts.

An important part of managing riparian areas, or identifying those in need of improvement, is the ability to identify the current condition or "health". A number of different parameters related to habitat, biological indicators, soils and geomorphology, hydrology, vegetation, and water quality can be quantified to assess riparian areas (U.S. EPA 1993, USDA Forest Service 1992). The use of these parameters usually requires an interdisciplinary team of experts to interpret the results for each parameter at whatever the investigation scale. A number of assessment protocols have also been developed which incorporate monitoring methods to provide a qualitative rating of stream/riparian health compared to the potential for that site (Miller 2005). Depending on the variables used in each protocol, results may reflect varying degrees of influence between actual riparian conditions and conditions throughout the watershed.

Objectives

The overall objective of this paper is to review riparian grazing effects and management. Specific objectives include determining:

1) How is riparian health defined, and what definition of riparian health is most useful for evaluating the effects of grazing on riparian health?

2) What common protocols are used in the northern intermountain region to assess the health of riparian areas, and how useful are these protocols in terms of measuring riparian health and their sensitivity to the impacts of riparian grazing?

3) What are the impacts of livestock grazing on riparian areas, and how do the parameters measured in various studies relate to these impacts?

4) What is the "state of the art" with respect to understanding of grazing impacts on riparian areas, and strategies for managing grazing in order to reduce the negative impacts on riparian health?

In order to meet these objectives, this paper is organized into four main sections. The first section, "Riparian Health", focuses on the first two objectives by providing a definition of riparian health and discussing the use of protocols to measure riparian health. The second section, "Effects of Livestock Grazing in Riparian Areas", reviews the effects of grazing on riparian areas in order to meet the third objective. A review of "Management Strategies" for grazing in riparian areas is provided in section 3 and this information is important to meet the fourth objective. In the final section, "Conclusions and Recommendations", previously presented information is synthesized in terms of the four primary objectives.

There is a specific scope to this paper in terms of the type of riparian area, the type of grazing animal, and the geographical area included in this paper. While livestock effects on riparian areas can be due to a combination of local grazing (in the riparian zone) and off-site grazing (throughout the watershed) (Trimble and Mendel 1995), the scope of this analysis is limited to the effects of grazing in the riparian area (local). This analysis is also limited to lotic riparian areas. While cattle can also have significant impacts on lentic riparian areas, the response is different and therefore should be analyzed separately. There is an overwhelming concentration of literature on lotic riparian areas compared to lentic. This is likely due to factors such as the sensitivity of lotic systems to grazing, and highly valued resources associated with them (i.e., salmonid fisheries, wildlife habitat, down-stream water quality).

Cattle are the primary type of livestock considered in this analysis. Cattle are also the herbivores used in the vast majority of riparian grazing studies. Cattle increasingly are the primary livestock consumer of forage on public lands in the western U.S. Of the ~25 million animal unit months (AUMs) of grazing on Bureau of Land Management and U.S. Forest Service lands in 1960, about 75% were from cattle (Holechek et al. 2001). By 1998 the total AUM's decreased to ~18 million but about 90% were from cattle use. Throughout this document, the term "livestock" refers to cattle and "grazing" refers to cattle grazing. In the few cases studies used other animals, the type or species of animal will be identified.

This analysis is primarily focused on the northern intermountain region. Most sources used in this analysis either treat riparian areas generically, in terms of the western U.S., or within the northern intermountain region. Specific results from studies come from an area roughly bounded by southern Alberta and Saskatchewan to the north, central Colorado to the south, central Oregon to the west, and central Montana and Wyoming to the east. If studies outside this area were discussed I included the location.

One reason to focus on the northern intermountain region is the difference in hydrologic factors that control riparian processes. Snow accumulation and melt in the north create a predictable hydrologic peak in May or June, while high flows in the south occur earlier and are more strongly influenced by localized storms (Patten 2000). While there are structural and functional similarities in riparian areas across the West, latitudinal differences in climate and streamflow make comparisons of studies more appropriate within similar latitudinal ranges (Patten 2000).

Riparian Health

The term "health" may take on a different meaning depending on the management objective for a given area, but in recent literature, it generally involves the processes and functions that are characteristic of riparian areas. The condition or health of riparian areas has been assessed using different methods such as measuring plant community composition, assessing function of riparian areas, making inferences based on water quality, or simply observing trends in acreage over time (NRC 2002). Multiple protocols have also emerged in an attempt to provide a basic measure of the overall health of a riparian area. This section provides a discussion of definitions for riparian health, a description of protocols that have been developed, a comparison of these protocols, a discussion on the use of reference sites, and a discussion of the effectiveness of these at measuring the impacts of riparian grazing.

Successional status has often been used as a major indicator of riparian health (Winward 2000, Clary and Webster 1989). Since riparian areas are dynamic, Gebhart and others (1990) argue that riparian health should not be confused with ecological site status. Natural disturbance in a properly functioning riparian area can lead to the presence of plant communities with early and mid-successional status. Hansen (1992) describes how human and non-human disturbances are capable of completely changing the potential for a site leading to a different climax vegetation type (association). Observations from 30 years of photomonitoring in Oregon led Hall (2005) to conclude that 30 years of flooding and the influence of beaver (*Castor canadensis*) activity led to dynamic conditions that seriously challenged the concepts of "condition and trend" and "climax good condition". There appears to be a need for a more dynamic picture of riparian areas rather than a single static picture of a "healthy" riparian area.

Medina and others (1996) propose that the condition of riparian areas and other ecosystems be measured in terms of "desirable functional processes" or DFP. This definition recognizes varying degrees of functionality where "processes observed are those that move the system to a higher state of dynamic equilibrium, as opposed to a state that is dysfunctional and demonstrates a trend towards system degradation." The idea that function equals health is common throughout riparian literature and commonly used for assessment protocols (Elmore 1992, Medina et al. 1996, Prichard 1998, Thompson et al. 1998, Hauer et al. 2002).

Assessment protocols

Numerous methods/protocols have been developed that provide both a definition of riparian health and some type of protocol or methods for evaluating health across a variety of riparian/stream ecosystems. The results from these methods and protocols can be largely quantitative or qualitative. Quantitative methods used to evaluate and monitor riparian conditions provide reliable base line data, which can be used to assess riparian areas and to identify significant change over time. Some of these methods include the Integrated Riparian Evaluation Guide (USDA Forest Service 1992), Monitoring Protocols to Evaluate Water Quality Effects of Grazing Management on Western Rangeland Streams (U.S. EPA 1993), and Monitoring the Vegetation Resources in Riparian Areas (Winward 2000). These methods provide quantitative data for various riparian attributes, but each parameter may be subject to interpretation by individuals or interdisciplinary teams. There are also several assessment protocols that have been developed to incorporate a number of variables in an attempt to provide a largely qualitative measure of overall riparian health. The remainder of the discussion focuses on these largely qualitative protocols.

Five of the protocols that have potential applicability to the northern intermountain region, and are discussed below, are the U.S. Department of Interior Bureau of Land Management's (BLM) "Proper Functioning Condition" (PFC), the Montana Riparian and Wetland Research Program's "Assessing the Health of a Riparian Site", the U.S. Department of Agriculture Natural Resources Conservation Service's (NRCS) "Riparian Assessment Method", the "Hydrogeomorphic Approach" (HGM), and the NRCS "Stream Visual Assessment" (SVAP). The definition of riparian health and indicators used in each method are shown in Table 2.

In determining Proper Functioning Condition (PFC), the function of a riparian area is evaluated relative to the potential natural community (PNC), which is the highest ecological status an area can attain given no political, social, or economic constraints (Prichard 1998). The PFC protocol was stated to have "improved the efficiency of riparian assessment by using a rapid, qualitative approach that focuses primarily on physical geomorphology and vegetation structure to distinguish the most altered stream reaches so that appropriate management actions can be undertaken" (Stevens et al. 2002).

Similar to PFC, Assessing the Health of a Riparian Site (Thompson et al. 1998) defines riparian health as the ability of a stream and the associated riparian area to perform certain functions. This method is intended for use as a "coarse filter" for identifying stream segments that need closer attention. This protocol has been adapted for use by Montana NRCS (NRCS 2004) and the Alberta Cows and Fish Program (Fitch et al. 2001).

Table 2—Summary of major components for 5 riparian/stream assessment protocols.

Protocol	Definition of Health	Indicators used
PFC (Prichard et al. 1998)	Veg., land form, and woody debris to perform 6 functions: dissipate stream energy, filter sediment, retain floodwater/recharge groundwater, stabilize streambanks, diverse habitat, support biodiversity	17 attributes base on hydrology, vegetation, and erosion/deposition. observations used to answer 17 yes/no questions
Assessing the Health of a Riparian Site (Thompson et al. 1998)	ability to function: sed. trapping, bank building/maint., water stor., aquifer rech., dissipate flow energy, biotic diversity, primary production	observations judged on numeric scale: plant cover on stream banks, % bank roots, noxious weed cover, diturb. induced undes. herb. sp., utiliz of woody veg, est. and regen. woody veg., human caused bare ground, human caused bank damage, channel incisement
NRCS Assessment Method (NRCS 2004)	Stability and Sustainability	Observations judged on numeric scale: stream incisement, human caused lateral cutting, balance with water and sed., binding root mass along banks, vet. cover on floodplain, noxious weeds, non-riparian introduced vet., est. and regent. of woody veg., utiliz. of woody veg., floodplain charact.
HGM (Hauer et al. 2002)	function within a range of variability in: surface-groundwater storage and flows, nutrient cycling, retention of organic and inorganic particles, generation and export of organic carbon, characteristic plant community, characteristic aquatic invertebrate food webs, characteristic vertebrate habitats, and, floodplain interspersion and connectivity	functional capacity models (3-7 variables) for each of the 8 functions listed
SVAP (NRCS 1998)	physical, chemical, and biological condition/processes relative to a reference site	numeric rating based on observations for: channel condition, hydrologic alteration, riparian zone, bank stability, water appearance, nutrient enrichment, fish barriers, in-stream fish cover, pool, invertebrate habitat

The NRCS Riparian Assessment Method was developed drawing from both PFC and Assessing the Health of a Riparian Site. This method was designed for use by field staff, consultants, and landowners to identify and stratify stream reaches requiring further study, and to prioritize reaches for treatment and directing resources (NRCS 2004). In the documentation for this method, it is emphasized that this method is only designed to evaluate stability and sustainability and it is not a comprehensive analysis of all ecological and physical processes. "Sustainability is the ability of a stream and associated riparian area to perform specific physical and biological processes over time"(NRCS 2004 p. 2). The final rating is given as a percent of the total potential score.

The Hydrogeomorphic approach (HGM) is a collection of concepts and methods developed from an interagency effort to assess the functional capacity of riparian wetlands relative to similar reference wetlands in a region (Hauer et al. 2002). The method is based on: a) classification of wetlands based on geomorphic and hydrographic regime, b) development of assessment models used as indicators of function, and c) comparison to reference areas that represent an expected range of conditions (Hauer and Smith 1998). The important functions identified for unconfined river reaches in the northern Rocky Mountains that have expansive floodplains are shown in Table 2. While the smaller size and landscape position of many grazed riparian areas may cause them to fall outside the scope of this approach, many of the primary functions of riparian areas are consistent throughout the northern Rocky Mountain region. Though originally developed for wetlands, this protocol has considerable potential for assessing riparian areas (NRC 2002).

The Stream Visual Assessment Protocol was developed by the U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS) for conservationists, with land owners present, to obtain a basic evaluation of stream health. This method uses 15 elements, which may or may not all be used, observed and ranked on a numeric scale relative to a reference condition. Scores are then averaged to provide an overall assessment. While some elements are closely tied to riparian function, this protocol was primarily developed to evaluate the condition of aquatic ecosystems associated with streams (NRCS 1998).

Comparison of Assessment Protocols

Miller (2005) suggests that Proper Functioning Condition (PFC) (Prichard 1998) and the NRCS Rapid Assessment (NRCS 2004) may give valuable information on proper functioning condition and sustainability of riparian communities, but lack the ability to reflect water quality and aquatic biotic integrity. Ward and others (2003) found that results from the Stream Visual Assessment Protocol (SVAP) and the EPA Habitat Assessment Field Data Sheet were strongly correlated (R= 0.81), while much weaker correlations were found between BLM's PFC and the EPA (R= 0.54) or SVAP (0.58) protocols. The authors attributed the lack of agreement with PFC to a difference in focus, where SVAP and the EPA method rely more on aquatic habitat features, and PFC targets features that reflect hydrologic function.

Conditions outside the riparian area can influence the quality, abundance, and stability of downstream resources by controlling production of sediment and nutrients, influencing stream flow, and modifying the distribution of chemicals throughout the riparian area (Prichard 1998). The difference in influence between local (riparian) conditions and those on a catchment (watershed) scale can be a source of bias in assessments of riparian or stream health (Miller 2005). This difference will affect the ability of various assessment methods to measure the effects of grazing in the riparian zone, a local activity, with variables that are affected by off-site conditions.

Some riparian functions and conditions can reflect local processes and disturbance. Instream habitat, organic matter input, and shade can be determined largely by local vegetative cover (Allan et al. 1997). Riparian vegetation can also be important for stabilizing streambanks, sediment entrapment, and fulfilling the ecological needs of an array of wildlife species (Clary and Leininger 2000, Ohmart 1996). Nutrient cycling is largely dependent on local conditions since it is influenced by floodplain vegetation, complexity of the floodplain mosaic, and decomposition of organic matter (Hauer et al. 2002).

In contrast, other characteristics largely reflect catchment or watershed conditions that have a substantial influence on the structure and function of riparian areas (USDA Forest Service 1992). Unfortunately, there are few empirical studies that assess relationships between land use and other environmental variables operating at different temporal and spatial scales (Richards et al. 1996). DeBano and Schmidt (1989) describe the interdependency between processes occurring on upland slopes and the stability of downstream riparian areas in the southwestern United States. In southeastern Michigan, Richards and others (1996) found that catchment-scale land use had stronger correlations to channel morphology than conditions closer to the stream. Allan and others (1997) suggest sediment delivery and channel maintenance depend on factors influencing the delivery of water over some large area, and identify a need to further research and understand the spatial scale of landscape influences.

Reference Condition/Sites

PFC, Assessing the Health of a Riparian Site, and HGM all rely on reference sites/conditions to provide a basis upon which the health of a riparian area is assessed.

These sites ideally represent large intact riparian systems that are self-sustaining and not markedly influenced by anthropogenic influences (NRC 2002). Identifying reference conditions may include locating relic areas, seeking historical information, identifying habitat needs of certain species, and examining other characteristic such as soils, hydrology, and watershed condition (Prichard 1998). Beschta and Kauffman (2000) suggest that local reference areas that continue to function without significant modern anthropogenic impacts could provide important information regarding targets for restoration, but they acknowledge that these areas are uncommon throughout the western United States.

Though many consider the condition of western riparian areas at the time of Euro-American settlement to represent "natural" or "pristine" conditions, there is still some debate surrounding this topic. Some reports have suggested that large herbivores were not prevalent in the pre-European intermountain west (Mack and Thompson 1982, Daubenmire 1985). However, Burkhart (1996) argues that the intermountain region evolved in the presence of large herbivores and that the biologic conditions experienced at the time of European contact represented a period of flux following massive extinction of these herbivores at the close of the Pleistocene era. He suggests that a lack of large herbivores at the time of European contact has led some rangeland managers, plant ecologists, and environmentalists to assume that large herbivore grazing is an unnatural impact on the plant community.

Riparian and stream ecosystems in the western United States have also been altered by widespread removal of beavers. Fouty (2003) suggests that beaver trapping by Euro-Americans lead to geomorphic, hydrologic, and vegetative effects that pre-date grazing, logging and other settlement activities. Beaver activities likely had a significant effect on riparian function through modification of channel geomorphology and hydrology, retention of sediment and organic matter, creation of wetlands, modifying nutrient dynamics, and modifying water and sediment fluxes (Ohmart 1996).

Evaluation of Protocols

Most assessment protocols for riparian areas are relatively new, having been developed within the last 10-15 years. All current assessment methods for riparian areas are in need of independent testing and evaluation to ensure accuracy, usability, and credibility across a variety of riparian areas in a variety of regions (NRC 2002). Other factors that make the use of protocols difficult is the influence of disturbance at various scales, and identifying what is truly the natural condition for any given riparian area.

Based on the available information, there does not appear to be any single assessment method that would be particularly useful at measuring the effects of grazing on riparian areas. The specific parameters used in an assessment protocol would likely affect the sensitivity of the protocol to local versus catchment scale disturbances. To measure the effect of riparian grazing (a local activity), an assessment protocol would likely need to be sensitive to this disturbance. None of the protocols specifically addressed the scale at which they are most effective. There were no studies found that specifically attempted to test the usefulness of an assessment protocol at measuring the effects of grazing-induced disturbance on riparian areas.

Effects of Livestock Grazing in Riparian Areas

Livestock management has often been shown to have negative impacts on the structure and function of riparian areas. A primary reason cattle can have a major impact on riparian areas is disproportionate use relative to upland areas. Higher use of riparian areas by cattle can be attributed to: (1) higher volume and palatability of forage relative to uplands, (2) close proximity to water, (3) distance to, and slope of, upland grazing sites, and (4) microclimatic features (Skovlin 1984, Bryant 1982). One commonly cited 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). While this may be an extreme example, many studies have shown that cattle have a preference for riparian areas and have documented significant impacts on these ecosystems. This section provides a conceptual framework for organizing literature related to riparian grazing, reviews many of these studies within that context, and includes a discussion of research methods and study designs.

Organization of Literature

The effects of grazing and associated activities on riparian areas are the result of five primary physical impacts. They include the mechanical disturbance of soil on floodplains and streambanks (hoof shear), soil compaction, consumption of vegetation, physical damage to vegetation, and deposition of manure (Kauffman and Krueger 1984, Gary et al. 1983, Marlow et al. 1987, Obedzinski et al. 2001, Trimble and Mendel 1995, Wheeler et al. 2002). The degree of impact is highly dependent on multiple variables including characteristics of the stream channel, riparian area, adjacent uplands, timing (season) of grazing, and intensity of grazing.

The function of riparian areas has been identified as a common measure of riparian health, as discussed in the Riparian Health section. While many riparian functions have been described, five have been frequently described and researched for their importance and potential to be affected by livestock grazing. These include nutrient/sediment filtering (Gregory et al. 1991, Ehrhart and Hanson 1998, Hook 2003, Pearce et al. 1998a, Elmore 1989), bank stability (Elmore 1989, Gregory et al. 1991, Naiman and Decamps 1997, Marlow et al. 1987), groundwater recharge (Hauer et al. 2002, Elmore 1989, Prichard 1998, Ehrhart and Hansen 1998), stream energy dissipation (Gregory et al. 1991, NRC 2002, Belsky 1999, Ehrhart and Hansen 1998), and regulation of stream temperature (Naiman and Decamps 1997, Gregory et al. 1991, Maloney et al. 1999, Kauffman and Krueger 1984). With the number of different variables measured in grazing studies, it may be difficult to draw conclusions or identify the mechanisms involved in creating the measured effect. As such, when discussing the effects of grazing in the context of these riparian functions it provides a useful context for evaluating the effects of grazing and how they interact with other variables and processes. An understanding of various riparian processes, non-grazing variables, and how they interact is critical when investigating the effects of livestock grazing.

Studies can be placed into three categories relative to their affect on riparian function;

(1) *Controlling Variables*- variables closely tied to the direct physical impacts of grazing and combine with other variables to affect various riparian functions.

(2) *Riparian Functions*- ecosystem functions that may be affected by multiple physical, chemical and biological variables, some of which are altered by grazing.

(3) *Integrating Qualities*- qualities of a riparian ecosystem that are dependent on controlling variables, the ability of riparian areas to perform certain functions, and off-site contributing factors.

A conceptual model of this relationship is shown in Figure 1. Research on the effects of grazing on riparian areas in the northern intermountain region will be further discussed in the context of these three categories.

Controlling Variables

A number of controlling variables will be discussed. These include the effects of grazing through impacts on vegetation, influences on soil characteristics, physical damage to stream channels and banks, and deposition of manure. A large portion of this discussion is focused on vegetation since it has been the subject of a relatively large proportion of scientific studies related to riparian grazing.

Vegetation

Effects of grazing on vegetation are decreased vigor and biomass, alteration of species composition and diversity, and loss of some vegetation components, especially trees and shrubs (Fitch and Adams 1998). Since vegetation in riparian areas influences multiple functions and processes, it is one of the most common attributes measured in riparian grazing studies. Vegetation is important for nutrient cycling, production of organic carbon, soil development, transpiration, hydraulic resistance during overbank

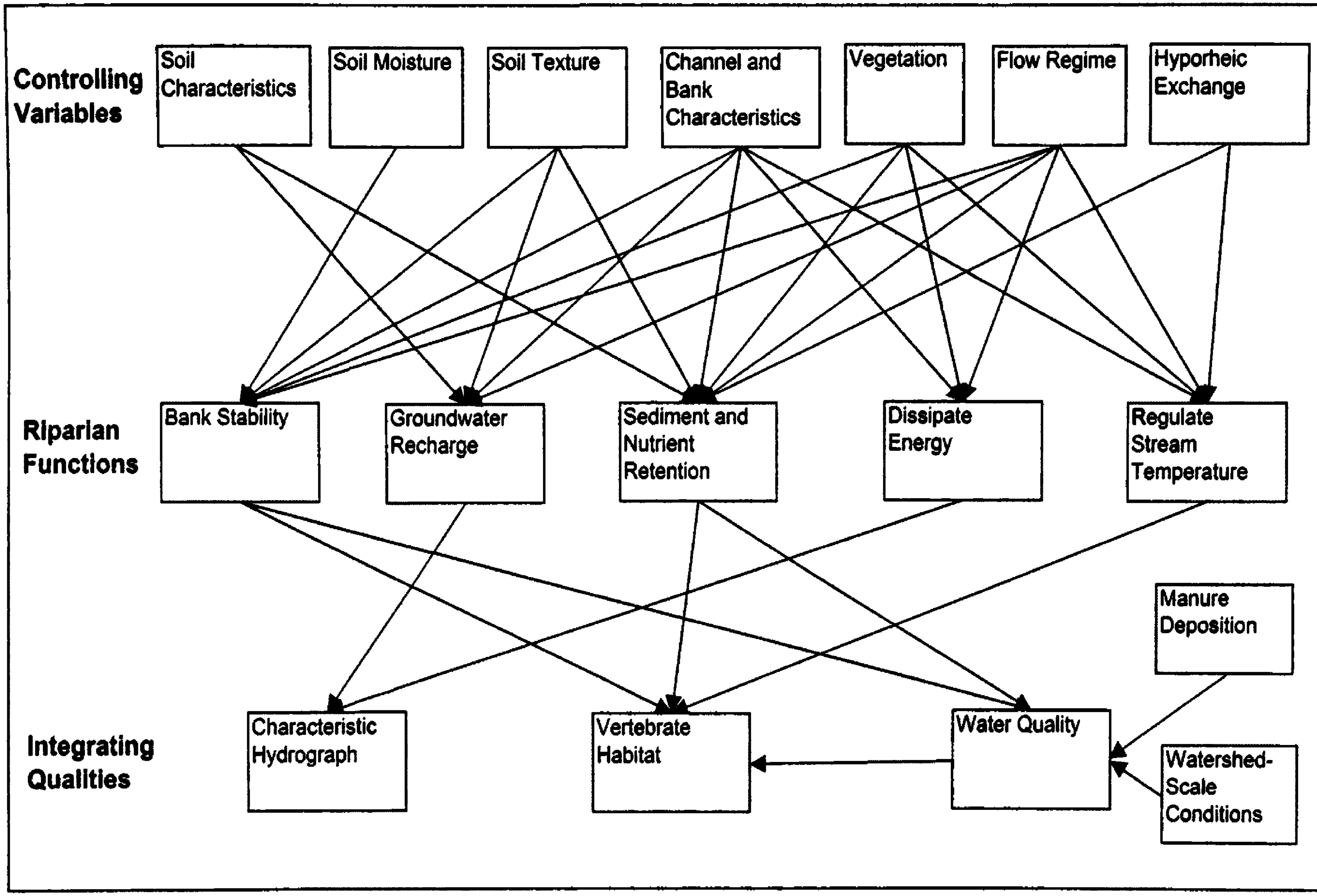

Figure 1- Representation of the cascading effects of grazing on riparian function. Not intended to represent all interactions and processes taking place in riparian areas.

flows, root strength for streambank stability, shading, and a food source for terrestrial and aquatic organisms (Beschta and Kauffman 2000). The importance of vegetation for bank stability (Winward 2000) and wildlife habitat (Ohmart 1996) has been well documented.

Due to varying season, intensity and duration of livestock grazing, as well as the diversity and influence of natural disturbance in riparian areas, the response of vegetation to grazing is highly variable. As an example, when compared to a 30-year exclosure, season long grazing in Eastern Oregon led to significant changes including decreased herbaceous and shrub cover, decreased litter cover, and increased bare ground (Schulz and Leininger 1990). In contrast, by comparing 3 year exclosures to fall grazing in 10 plant communities, Kauffman and others (1983b) found few significant changes in species composition, standing phytomass, and productivity. In spite of the high variability within and among riparian areas, there are some conclusions and generalities that may be drawn from research in riparian areas. Primary areas of focus for research include woody vegetation, herbaceous vegetation, and plant community characteristics. Each of these components will be discussed individually.

Grazing effects on willows (*Salix spp.*) and other woody vegetation have received much attention. This is likely due to the importance of woody vegetation in terms of bank stabilization, wildlife habitat, shade, and hydrologic processes (Holland et al. 2005). Cattle use of willows has been found to increase from spring to fall, but it is also related to the availability of herbaceous forage (Roath and Krueger 1982, Pelster et al. 2004, Evans et al. 2004). Cattle are more likely to increase willow consumption as stubble height of herbaceous vegetation decreases (Pelster et al. 2004).

Excessive or uncontrolled grazing will almost always have a negative effect on woody species in riparian areas (Kauffman and Krueger 1984, Skovlin 1984, Myers 1989). In northeastern Oregon, fall grazing led to significantly reduced growth of woody species especially in gravel bar communities (Green and Kauffman 1995). By studying elk (*Cervus elaphus*) browsing of willows in Yellowstone National Park, it was found that seed production was virtually eliminated on branches within browse height. Those branches above browse height (2.5 m) were found to produce an abundance of male and female aments (Kay and Chadde 1992). The authors suggest that if all willows are within reach of domestic livestock, and a large portion if annual growth is removed, a similar lack of seed production may result. By using photographic transects, Myers (1989) assessed the influence of 34 grazing systems on shrub dominated riparian areas. Those systems that were determined to be unsuccessful at maintaining or improving woody vegetation had significantly more grazing during the hot season (7/1-9/15) and longer treatments than grazing systems determined as "successful".

In some studies grazing and maintenance of willows has been shown to be compatible. By assessing historical air photos and grazing management, Manoukian and Marlow (2002) found that reduced stocking rate and a rest-rotation grazing system led to an increase in willow canopy cover and a fairly even stem-age population curve. Holland and others (2005) suggested that light to moderate season-long grazing may be compatible with increased canopy cover, diversity, stem height, and recruitment, as long as other ecosystem processes are maintained.

Herbaceous vegetation is also an important component of riparian vegetation since it plays a role in numerous riparian functions and provides forage and cover for wildlife and domestic livestock. Sedges can play an important role in riparian areas since their massive root systems and coarse crowns counteract the erosive forces of water, and even build/rebuild streambanks by filtering and retaining sediment (Winward 2000). The relative availability of herbaceous vegetation may also influence ungulate browsing of willows and other important riparian shrubs (Clary and Leininger 2000).

Along sedge (*Carex* spp.) dominated streambanks, treatments simulating two years of heavy season-long grazing resulted in significant reductions ($P < 0.05$) in above-ground biomass (51-87%) and root biomass (32.5%) (Clary and Kinney 2002). Kauffman and others (2004) found an even greater reduction when comparing grazed areas to exclosures. Based on results from a study in Oregon, Clary (1995) suggests that preventing a reduction in productivity may require maintaining a stubble height of 10 cm or greater, or not allowing for use to exceed 30% of annual biomass production.

There is evidence that herbaceous vegetation may be resistant to grazing in some cases. In southwestern Montana, 15 to 25% use of beaked sedge (*Carex rostrata*) in June followed by 41 to 44% use in September lead to higher shoot production than ungrazed plots, suggesting that this species may be tolerant to moderate to heavy controlled grazing on similar sites (Allen and Marlow 1994). Clipping herbaceous riparian vegetation to various stubble heights (5.1, 10.2, and 15.3 cm) in June and July all increased annual production relative to unclipped control sites (Boyd and Svejcar 2004). Since influences such as soil compaction, hoof shear, and foraging behavior of cattle were not included, these results would likely change under actual grazing.

Plant communities in riparian areas can be diverse, leading to highly variable responses to different grazing treatments. In Montana, Hansen (1992) identified 16 habitat types and 16 community types that could be used to develop management information, and Green and Kauffman (1995) identified 60 plant communities along a single creek in northeastern Oregon. The complexity involved in studying and managing riparian areas becomes apparent when each of these communities reacts differently to grazing and multiple communities may occur along a given stream reach. Numerous community characteristics have been studied to understand the influence of grazing including lifeforms (Popolizio et al. 1994, Schulz and Leininger 1990, Roath and Krueger 1982), species composition (Kauffman et al. 1983b), and species richness (Green and Kauffman 1985).

Some reviews have attempted to summarize the many influences of grazing on plant community characteristics (ex. Kauffman and Krueger 1984, Skovlin 1984). However, it is often difficult to make generalizations about the effects of grazing on plant communities. Along a 3 km stretch of riparian vegetation, Green and Kauffman (1995) studied differences between grazing and exclosures for the 8 most common communities. They reported that grazing affected community characteristics differently in each of the 8 plant communities. Two years of grazing on previously exclosed herbaceous dominated sites was found to stimulate foliar cover (Popolizio et al. 1994), while Schulz and Leininger (1990) found a decline in graminoid and shrub canopy cover in grazed areas relative to exclosures. At times total forb cover may not change significantly, even under numerous grazing treatments (Schulz and Leininger 1990, Popolizio et al. 1994)

Clary (1999) found an increase in species diversity in both streamside and adjacent meadow communities with late June grazing. Belsky (1999) notes that traditional evaluations of species-diversity are inadequate if the replacement of native species and riparian specialists by introduced or upland species is not considered. Green and Kauffman (1995) suggest disturbance from grazing creates conditions suitable for exotic and ruderal species. Non-native species such as Kentucky bluegrass (*Poa pratensis*) were shown to have greater abundance in grazed areas relative to exclosures (Schulz and Leininger 1990, Green and Kauffman 1995).

Soil Characteristics

The potential for cattle to compact soil and reduce infiltration has been well documented for upland areas (Trimble and Mendel 1995), but few soil compaction or infiltration studies have been conducted in riparian areas (Kauffman et al. 2004). Bohn and Buckhouse (1985) showed that soil compaction by livestock reduced the infiltration rates in riparian soils. Similarly, Kauffman and others (2004) reported an approximately 13-fold increase in infiltration in an exclosed dry meadow and a 3-fold increase in infiltration in an exclosed wet meadow relative to similar grazed meadows.

One-time heavy grazing events in spring and summer led to an increase in bulk density and a decrease in infiltration in northern Colorado, but there was no significant difference after one year of recovery (Wheeler et al. 2002). Clary and Kinney (2002) found similar results by simulating heavy season-long grazing. The authors suggest that freeze-thaw and wet-dry cycles may have reversed the compaction. Wheeler and others (2002) found similar effects of spring and summer grazing on soil properties, while Bohn and Buckhouse (1985) found that grazing in October led to greater compaction than in September. They suggest that increased compaction was a result of increased soil moisture.

Channel and Bank Characteristics

Cattle can break banks by trampling and create hydraulic roughness, which increases tractive force (Trimble and Mendel 1995). The force of a hoof can shear off slices of bank material, leading to setback banks (Trimble and Mendel 1995, Kauffman and Krueger 1984). Numerous studies have measured streambank loss and changes in channel characteristics associated with grazing, but the effects of grazing on streambanks are also associated with alteration of vegetation (Gregory et al. 1991). While there are anecdotal accounts and observation of cattle breaking streambanks, there is little quantification of these impacts (Clary and Kinney 2002). Clary and Leininger (2000) note that there is little specific information identifying a level of use that would lead to measurable damage.

Manure Deposition

Cattle feces and urine deposited in or near streams can cause elevated concentrations of nutrients such as nitrogen (N) and phosphorus (P), and may also affect the bacteriological quality of streamwater (Nader et al. 1998, Gary et al. 1983). As cattle use is concentrated in riparian areas, deposition of manure in the riparian area and stream is greater relative to upland areas. Gary and others (1983) observed that 6.7 to 10.5% of defecations and 6.3 to 9.0% of urinations were deposited directly in a small central Colorado stream. This can lead to elevated counts of indicator bacteria such as fecal coliforms and fecal streptococci (Gary et al. 1983). In Oregon, intense grazing led to fecal coliform levels 10 times greater than ungrazed control sites, while managed grazing led to levels 4-6 times higher than control (Tiedemann et al. 1987). However, increases in indicator bacteria may be poorly correlated with pathogenic bacteria (Nader et al. 1998). Trlica and others (2000) used a rainfall simulator to test the water quality impacts of a single 8-hour heavy grazing event. They found significant increases in nitrate-N, ammonia-N, phosphate-P, and fecal coliform associated with the grazing treatment.

Riparian Functions

Five riparian functions that may be significantly affected by livestock grazing include bank stability, sediment and nutrient filtering, groundwater recharge, temperature regulation, and energy dissipation. While the effects of livestock grazing on bank stability are well documented by scientific studies, evidence for the effects of grazing on other riparian functions is primarily anecdotal. The effects of grazing on each of these functions are described below.

Bank Stability

Important variables that affect bank stability in riparian areas include vegetation (Gregory et al. 1991), channel condition/morphology (Trimble and Mendel 1995), soil moisture (Clary and Kinney 2002), soil texture (Dunaway et al. 1994), and flow regime (Trimble and Mendel 1995). Of these variables, grazing activity most directly affects vegetation and channel condition/morphology.

Numerous studies have shown that cattle can have a significant impact on streambank stability. In northeastern Oregon, late summer grazing (August-September) at a stocking rate of 1.3-1.7 ha/AUM led to increased erosion and streambank disturbance relative to exclosures (Kauffman et al. 1983a). Annual streambank losses averaged 30 cm in grazed areas and 9 cm in ungrazed areas. Clary and Kinney (2002) found that two years of simulated heavy season-long grazing led to similar results with an average bank retreat of more than 12 cm reported compared to approximately 2 cm in untreated sites. It has been suggested that grazing can lead to severe incision of stream channels (Trimble and Mendel 1995, Platts 1991), but there appears to be little documentation of this in the northern intermountain region.

Marlow and others (1987) suggest a combination of high flow, moist streambanks, and cattle use in the spring, can lead to major streambank alteration. They found that, in spite of reduced use of the riparian area in spring treatments versus fall, streambanks in the spring were subject to significantly more alteration. Bank stability may also be highly variable between streams. Type A and B streams (as identified by Rosgen 1994) tend to be more resistant to erosion and trampling damage where channels are often armored by rocks. Some type B and most type C channels have medium and fine-textured materials, and a vigorous plant community might play a greater role in protecting the easily erodible streambanks (Clary and Webster 1989).

Sediment and Nutrient Filtering

Riparian areas filter sediment and nutrients from upland areas and from streamflow. Filtering from upland areas is largely dependent on vegetation (Naiman and Decamps 1997), infiltration capacity (NRC 2002), and soil texture (Corley et al. 1999). Sediment and nutrients already in streams can also be filtered by riparian vegetation along banks or on the floodplain. For this to occur, channel/bank characteristics

(Gregory et al. 1991), flow regime (Hauer et al. 2002), and streambed composition (Dahm et al. 1998) are also important as they influence the stream/floodplain connection. As previously discussed, grazing can have direct effects on vegetation, infiltration capacity, and channel/bank characteristics. Biogeochemical processes such as denitrification can be further influenced by geology and hyporheic exchange (NRC 2002). While an understanding of riparian systems has led to descriptions of how grazing can affect nutrient and sediment balances, there have been few studies which have successfully quantified these effects.

Significant changes in runoff characteristics and vegetation resulted from 8 hours of heavily concentrated grazing and trampling in northern Colorado (Flinnekin 2001). The authors suggest these changes may have consequences for erosion and the effectiveness of riparian filters. Attempts have been made to relate the type and height of vegetation to the efficiency of riparian areas to filter sediment and nutrients (Corley et al 1999, Pearce et al. 1998b, Finck et al. 2000). This can be difficult due to the influence of other variables such as percent cover of vegetation, aboveground biomass, surface roughness, soil texture of sediment, vegetation density, length of slope, and type of vegetation (Pearce et al. 1998b).

In a review of literature on nutrient cycling in the riparian zone, Green and Kauffman (1989) describe how grazing and other land-use activities may alter important biogeochemical processes and especially cycling of nutrients such as nitrogen and phosphorus. They suggest this can have implications for composition and productivity of vegetation, aquatic ecosystems, and water quality. There is currently little information or quantitative data to help understand how grazing may affect biogeochemical processes such as nutrient cycling, and there is a need for additional studies to help understand these relationships.

Kauffman and others (2004) compared rates of net potential nitrogen mineralization and nitrification in wet and dry meadows that were grazed and exclosed from grazing, but provided no information regarding the intensity of the grazing treatment. No significant changes were found in the dry meadow, but potential mineralization and nitrification were significantly lower in the grazed wet meadow compared to the exclosure. The authors hypothesized that this was mainly caused by differences in soil characteristics between the two sites. Since denitrification can be significantly influenced by anaerobic conditions associated with an elevated water table, organic matter supplied by plants, and hydraulic residence time (Green and Kauffman 1989), it may be influenced by the effects of grazing on geomorphology and vegetation.

Groundwater Recharge

Belsky (1999) compares healthy riparian areas to giant sponges that raise water tables during flood events, and maintain streamflow during dry seasons. Elmore and Beschta (1987) have also described the potential for functioning riparian areas to maintain an elevated water table and slowly release water during dry summers. Flow regime, channel/bank characteristics, and infiltration capacity have been identified as important factors affecting groundwater recharge (Hauer et al. 2002, Fitch and Adams 1998). Grazing effects on infiltration and channel/bank characteristics may influence this riparian function. Since the relative importance of overbank flow versus hillslope runoff typically increases with increasing stream order (NRC 2002), this could have implications for the relative effects of compaction and channel alteration on groundwater levels at different landscape positions.

There do not appear to be any studies that directly relate grazing to changes in groundwater recharge. This would be difficult to quantify since interactions between groundwater and stream channels not only change according to landscape position, they can be heterogeneous at even smaller scales (i.e. feet to tens of feet) (NRC 2002). In eastern Oregon, Elmore and Beschta (1987) observed that recovery of vegetation and the associated aggradation of stream channels allowed for increased subsurface storage and reestablishment of perennial flow in degraded channels.

Temperature Regulation

Important variables controlling stream temperature include: vegetation; channel/bank characteristics; flow regime; and hyporheic exchange (Beschta and Kauffman 2000, Rosgen 1994, NRC 2002). Vegetation and channel characteristics have been described as the two most significant factors regulating stream temperature (Ohmart 1996), and grazing can affect both of these characteristics of riparian areas. Stream temperature has received considerable attention since it is critical for the survival, distribution, and productivity of salmonid populations (Meehan 1991, Ohmart 1996, Maloney et al. 1999).

While mechanisms for the effects of grazing on temperature have been described, grazing effects on stream temperature are not easily measured, and as such there is little quantitative evidence of these effects (Maloney et al. 1999). The effects of grazing on temperatures reported in reviews by Kauffman and Krueger (1984) and Ohmart (1996) are mainly from unpublished reports and personal communication. A significant correlation between increased grazing intensity and increased stream temperature was found in eastern Oregon, but the results are not definitive due to the influence of watershed characteristics and prior grazing management (Maloney et al. 1999).

Dissipate Energy

The energy associated with moving water has important implications for erosion on floodplains and along streambanks. The vegetation and channel/bank characteristics associated with riparian areas can have important impacts on the energy of streamflow and runoff from uplands (Beschta and Kauffman 2000, Rosgen 1994, Ohmart 1996). Vegetation and channel/bank characteristics are subject to change by grazing as previously discussed.

Vegetation has the potential to reduce stream velocity during floods, and therefore reduce damage associated with overbank flows (Ohmart 1996). Flenniken and others (2001) found that grazing can influence various hydrologic characteristics associated with overland flow from upland areas, but their results failed to show a significant increase in overland flow velocities.

In some cases height of vegetation remaining on a site may not be as important as the type of vegetation. Frasier and others (1998) found little difference in simulated runoff characteristics between plots that were unclipped, clipped to 10 cm, and clipped to the soil surface, but did find a reduction in equilibrium runoff percentages associated with sedge communities versus grass communities.

Integrating Qualities

As previously described, integrating qualities are those qualities of riparian ecosystems that are influenced by controlling variables, dependent on certain riparian functions, and influenced by off-site contributing factors. Integrating qualities discussed below include vertebrate habitat, the characteristic hydrograph for a particular stream, and water quality. A large amount of scientific investigation has been devoted to the effects of riparian grazing on vertebrate habitat and this is reflected in the following discussion.

Vertebrate Habitat

Riparian areas can provide important habitat for a variety of vertebrates including fish, herptiles (i.e., amphibians and reptiles), birds, and mammals (Hauer et al. 2002). Habitat for various classes of wildlife has frequently been described as a function of riparian areas (Naiman and Decamps 1997, Ohmart 1996, Prichard et al. 1998, Hauer et al. 2002). However, it could also be argued that vertebrate habitat is an integrating quality due to the influence of those variables most directly affected by grazing, the proper function of riparian areas, and off-site variables that are largely unaffected by the presence of cattle in the riparian zone (Figure 1). Elmore (1992) and Ohmart (1996) emphasize the importance of riparian function for wildlife habitat.

The majority of research on the effects of riparian grazing in the northern intermountain region has focused on birds, small mammals, and fish. Habitat requirements within and between species are highly variable, and changes that benefit one species may be detrimental to another (Skovlin 1984). In general, maintenance of a diverse vertebrate fauna is dependent on a diverse and productive habitat (Hauer et al. 2002). Determining the effects of grazing on bird and mammal habitat may be less complicated compared to fish since these communities are primarily influenced by changes in vegetation (Ohmart 1996). The vegetation components that are most important to wildlife include tree species and their densities, foliage height diversity, foliage volume, patchiness, and shrub species/densities (Ohmart 1996). However, small mammals may also be influenced by soil characteristics (Skovlin 1984). The following discussion will concentrate on small mammals, birds, and fish.

There is limited information on the effects of grazing on small mammals, and responses to grazing will vary by species and grazing treatment (Skovlin 1984). In Oregon, annual grazing was shown to reduce the numbers of all small mammal species (Cornely et al. 1983). When comparing heavy season-long cattle grazing to a 30-year exclosure, Schulz and Leininger (1991) found that, while the diversity of bird communities and small mammal communities was similar, the composition between grazing treatments was different. They suggested that grazing led to a shift from sensitive species to more common species that they attributed to a change in habitat structure. They also identified a need for more research that measured the effects of varying intensities and seasons of grazing on nongame wildlife communities. The beaver is likely the mammal most intimately connected to riparian areas through use and alteration (NRC 2002), but there appears to be little information on livestock-beaver interactions.

The effects of grazing on birds have received considerable attention. Poor grazing practices can lead to trampling of nests, reduced cover, and reduced food sources such as insects, fruits, and seeds (Skovlin 1984). In two studies, grazing has not been shown to affect bird densities, but has significantly influenced species composition and foraging guilds (Mosconi and Hutto 1982, Kauffman et al. 1982). Increased frequency of grazing in southeast Oregon was correlated with a decreased abundance and diversity of passerine birds (Taylor 1986). Conversely, increased time of grazing was correlated with an increase in bird abundance. Scott and others (2003) infer a relationship between cattle grazing and decreased bird diversity and abundance by showing an increase in vegetation strata diversity in ungrazed patches. Information on grazing history was limited, and the correlation was made between grazing and habitat, not bird data. Along the Missouri River in Montana, bird populations in areas that have had moderate to heavy grazing for over 50 years were compared to those that were free of grazing for 25 years, and significant differences in bird communities were reported (Tewksbury et al. 2002).

Based on the known effects of grazing and requirements for quality fish habitat, the potential for grazing to negatively impact fish habitat cannot be denied. Skovlin (1984) describes four major causes of habitat degradation from heavy or uncontrolled grazing: 1) excessive erosion and sedimentation that damages spawning beds and reduces invertebrate food sources, 2) wider and shallower stream channels from bank damage and vegetation removal, 3) increased stream temperature from loss of vegetation, and 4) reduced hiding cover along streambanks and fish food from herbaceous plants.

While cattle can impact some habitat components, many can be influenced by watershed characteristics and water quality upstream. Water velocity, annual discharge and flow, temperature, sediment load, and dissolved oxygen are important for fisheries (Ohmart 1996), but can be largely determined by upland conditions and upstream influences (Richards et al. 1996, Rinne 1988). This complex combination of multi-scale influences may be part of the reason many fish studies rely on comparing heavy mis-managed grazing to exclosures, and are plagued by biases and ambiguities (Skovlin 1984, Platts 1991).

In spite of the complexity, some studies have shown grazing impacts on fisheries in the northern intermountain region. After a 30-year exclosure, there was an improvement in various trout habitat parameters and a significant increase in estimated trout standing crop (Stuber 1985). An overgrazed section of Rock Creek, Montana supported 71 kg of brown trout (*Salmo trutta*) compared to 238.8 kg in an ungrazed section (Marcuson 1977).

Characteristic Hydrograph

While streamflow is largely determined by climate variables and watershed characteristics, it can also be determined by certain riparian functions. As previously shown, these functions can be indirectly affected by grazing (Figure 1). It has also been suggested that water retained during high flow events can be slowly released, thus contributing to baseflow during drier seasons (Belsky et al. 1999). Through the function of energy dissipation and groundwater recharge, riparian areas can reduce down-stream flooding (NRC 2002). However, this effect may be counteracted by transpiration of riparian vegetation (NRC 2002). Since grazing can affect riparian function, which in turn modifies the shape of the annual hydrograph, it could be suggested that grazing indirectly influences the hydrograph. There appears to be no empirical evidence of this effect, and this influence would likely be difficult to quantify.

Water Quality

In relation to riparian grazing, water quality is classified as an integrating quality since it can be largely affected by the direct influence of cattle grazing, proper functioning of riparian areas, and watershed-scale conditions that can be largely unaffected by riparian grazing (Figure 1). Grazing can directly influence water quality through deposition of manure and introduction of sediment through hoof shear. Water quality is also dependent on the proper function of riparian areas to filter sediment and nutrients and stabilize streambanks. Finally, water quality is significantly affected by conditions and land use at a watershed scale, but these are largely unaffected by riparian grazing. While this complex interaction of multiple influences does not reduce or negate the influences of grazing on water quality, it can cause difficulty in identifying the source(s) of water quality degradation.

Research Methods/Study Designs

Larsen and others (1998) suggest that research related to riparian grazing suffers from weak study designs, a lack of pre-treatment data, and inadequate description of practices or treatments. The dynamic and complex nature of riparian ecosystems leads to large experimental errors which can only be minimized by carefully designed experiments. Researchers often study the effects of grazing by comparing grazed areas with grazing exclosures. Sarr (2002) identifies four common assumptions that often go untested in exclosure studies:

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 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.

Many early studies of grazing only compared heavy long-term grazing to cessation of grazing, failing to identify the intensity or season of use (Ehrhart and Hanson 1997). When stocking rates are given, they are generally given for an entire pasture which can be misleading due to the tendency of cattle to congregate in riparian areas. In one example, Green and Kauffman (1995) provided a stocking rate for an entire pasture, but then fenced half of the riparian zone within 50 meters of the stream. This could seemingly double any negative impacts caused by concentrated use of the riparian area.

The result is that many of the studies reviewed in this section may present a "worst case" scenario for the effects of livestock grazing. Even those studies that attempt to define some degree of sensitivity to grazing disturbance are often difficult to interpret due to the interaction of variables such as the proportion of riparian to upland area, season of use, upland characteristics (i.e. slope, vegetation), and the high variability among stream and riparian characteristics. Regardless, these studies have played an important role in understanding and managing riparian areas. They identify and describe some of the common impacts of cattle grazing on riparian areas and they help explain the mechanisms that are involved.

Management Strategies

There are four basic components of grazing management as described by Holecheck and others (2001). They include: 1) proper stocking rate, 2) proper timing, 3) proper distribution, and 4) proper grazing system. Each of these components have received considerable research and discussion in riparian literature. Numerous reports suggest that the use of a particular management grazing system is not necessary if the other three components are controlled. Scientific and observational investigation into how these components can be effectively applied has provided knowledge that can be directly applied to meeting particular management goals. Other factors that are important for proper management of riparian areas throughout the western U.S. are a commitment to and involvement in proper management of riparian areas, and access to up-to-date knowledge. This section includes a discussion of grazing management strategies, distribution management strategies, and programs that are designed to encourage proper grazing management in riparian areas.

<u>Grazing Management</u>

Stocking Rate

Stocking rate is defined as the "amount of land allocated to each animal unit for the grazeable period of the year" (Society for Range Management 1989). For this discussion, stocking rate will be considered more generally as the amount of use by livestock. The three primary factors controlling use are the total area being grazed, the number of animals, and the amount of time spent in a given area (duration). Distribution within a pasture and season can lead to varying effects over space and time, but these will be discussed separately. Use has been described in terms of intensity (light, moderate, etc.), and common indicators of use include the percent loss of total forage produced (utilization), and height of remaining vegetation after grazing (stubble height).

Numerous impacts of grazing on riparian areas have been shown to be use dependent. That is, by reducing the amount of use, impacts will also be reduced. Clary and Webster (1989) suggest the level of utilization is the most important consideration when managing grazing in riparian areas, while Pelster and others (2004) identify intensity and season as the most important factors.

Bryant (1985) suggests that productivity of some floodplain plant communities may be enhanced if utilization is kept below 70 percent. Even season-long grazing may be compatible with improvement of willow canopy cover, species diversity, stem height, and stem recruitment if cattle use is switched from heavy to light or moderate (Holland et al. 2005). In western New Mexico, Lucas and others (2004) found that light or moderate grazing had limited impacts on riparian vegetation during any season.

Damage to streambanks may be reduced by switching from heavy use (Kauffman et al. 1983a) to moderate or light use (Buckhouse et al. 1981). Although results were not definitive, Maloney and others (1999) found a correlation between increased intensity of range management (stocking rate) and increased stream temperature. The impacts of cattle on water quality may also be reduced with decreased use by cattle (Gary et al. 1983).

In spite of failed attempts to show a direct influence of stubble height on sediment filtering and water quality (Pearce et al. 1998b, Finck et al. 2000), it may still have value as a management tool. Using stubble height to assess use can help preserve plant vigor, maintain forage to prevent browsing, indirectly influence riparian function, and it provides a management criterion that is easily understood and easily communicated (Clary and Leininger 2000). A stubble height of 3 inches for the most palatable species may be used to indicate a shift in preference and possible use of riparian shrubs (Hall and Bryant 1995). Pelster and others (2004) reached a similar conclusion, but warned that the required stubble height can vary by season. In a review article, Clary and Leininger (2000) describe how different stubble heights may be used to meet a variety of objectives under varying conditions.

Season

Numerous studies on seasonal impacts have led to a greater understanding of how riparian areas respond to grazing. This information improves the ability of managers to meet pre-determined objectives. Each season has advantages and drawbacks that must be considered when working toward objectives and both will be discussed for each season. The delineation of seasons will follow Ehrhart and Hansen (1998) with spring being late April/ early May to early/mid July, summer as early/mid July to mid/late September, fall as mid/late September to late December/early January, and winter as late December/early January to late April.

Spring

When the riparian area is part of a larger pasture, riparian areas may benefit from reduced grazing use in spring relative to other seasons. Cattle were shown to spend more time near the stream in late summer than early summer (Parsons et al. 2003). They suggest that early summer grazing is less detrimental because of improved livestock distribution and more uniform vegetation use between the riparian and upland areas. In June, with light and medium stocking rates, cattle were not noticeably attracted to streamside vegetation (Clary and Booth 1993). Beaked sedge (*Carex rostrata*) has been shown to increase shoot production while grazed in June and again in September (Allen and Marlow 1994). By grazing early in the spring and removing cattle, forage plants are allowed to regrow and provide streambank protection during the winter and following spring (Clary and Webster 1989).

Chaney and others (1990) present a case study where a period of rest, and then dividing a pasture to allow for spring grazing (mid February to mid April) led to increased bank stability and reduced erosion and sedimentation. The permittees licensed amount of forage increased from 72 animal unit months (AUM's) to 354 AUM's over a 13 year period. In central Idaho, 10 years of change from continuous summer use, to late-spring treatments of varying intensity, led to improvements in width-depth ratio, streambank stability, and willow (*Salix* spp.) height and cover. The results suggest the mountain meadow ecosystems that were studied are compatible with light to medium late spring cattle grazing (Clary 1999). However, there are potential disadvantages to grazing during this season. Due to high flows and moist streambanks, cattle-induced streambank alteration may be high during this time period (Marlow et al. 1987).

Summer

Use of riparian areas by cattle during the summer is beneficial in terms of livestock production because the forage in riparian areas is generally more palatable and of higher nutritive quality than upland forage, potentially allowing for improved condition of mother cows and increased calf gains (Kauffman et al. 1983b). Compaction effects due to grazing on riparian soils may be reduced compared to seasons when soil moisture is greater (Bohn and Buckhouse 1985). However, the beneficial effects of reduced soil moisture may be offset by higher usage rates as cattle tend to congregate in riparian areas during the hot summer months (Clary and Webster 1989, Parsons et al. 2003). The increase in use may intensify both physical disturbance and vegetation consumption in riparian areas (Clary and Webster 1989, Parsons et al. 2003).

As palatable herbaceous forage begins to cure, use may shift from herbaceous species to riparian shrubs (Hall and Bryant 1995). Grazing systems that Meyers (1989) identified as successful had significantly less days of hot season (7/1-9/15) grazing than those considered successful. The bulk of forage consumption may come for riparian zones during this season, and stocking rates may need to be based on forage in the riparian zone rather than total forage in the pasture or allotment (Marlow and Pogacnik 1987).

Fall

Streambanks may be less susceptible to damage by cattle in the fall due to decreased soil moisture (Marlow et al. 1987), but this may not apply in some areas if the soil moisture remains well above 10% throughout the growing season (Clary and Kinney 2002). Clary and Webster (1989) suggest fall grazing can be successful if utilization is controlled to leave enough vegetation to protect streambanks during high flows of the following spring. Relative to summer grazing, perennial warm-season plants may be less impacted since storage of carbohydrates is nearing completion and maintenance of leaf area may be less critical (Leonard et al. 1997).

There are also disadvantages associated with fall grazing. Grazing systems considered successful in terms of maintenance or recovery of willows had significantly fewer days of fall grazing (8/15-1/10) than those considered "unsuccessful" (Meyers 1989). With the onset of fall rains, soil moisture may increase significantly, leading to increased alteration during grazing (Bohn and Buckhouse 1985). There have also been inconsistent reports of increased use of willows in the fall (Evans et. al. 2004). Pelster and others (2004) suggest maintaining adequate herbaceous stubble height may control use of willows.

Winter

Use of riparian areas in the northern intermountain region during the winter can be severely limited by a lack of usable forage and the restrictions associated with snow (Leonard et al. 1997). This limited use of riparian areas in winter is likely the reason for limited scientific research and discussion of grazing affects during this season. Based on personal observations, Platts (1989) gave winter grazing a rating of 5 on a scale of 1 to 10 (1-poorly compatible with fishery needs, 10-highly compatible). The author suggests it may be compatible since frozen streambanks are more resilient to mechanical damage, and plant carbohydrates are stored in the roots systems. When soils are frozen and herbaceous vegetation is dormant, impacts of grazing can be minimal (Leonard et al. 1997). If winter grazing is used, browsing of shrubs and small trees should be closely monitored (Ehrhart and Hansen 1998)

Growing season/Year-long

Grazing the entire growing season, or year-long, has been described as devastating to riparian areas (Elmore and Beschta 1987, Platts 1991). Others have suggested that light to moderate season-long grazing may be compatible with sustainable management of riparian ecosystems (Holland 2005). Clary and Webster (1989) caution that season-long grazing should only be used where animal use can be carefully controlled.

Grazing Systems

A grazing system can be defined as "A specialization of grazing management which defines systematically recurring periods of grazing or deferment for two or more pastures or management units"(Society for Range Management 1974). Grazing systems often involve common treatments such as rest (non-use for a full year) and deferment (delayed grazing until seed maturity of key forage species), and movement of livestock from one pasture to another on a scheduled basis (Holechek et al. 2001). Platts (1991) provides useful definitions of individual grazing systems, and provides a rating of compatibility with fisheries needs based on personal observations.

Numerous studies have investigated the compatibility of various grazing systems with riparian areas but results are highly variable, making it difficult to draw many sound conclusions. Much of the information on grazing systems consists of opinion, personal experience, and observations. Upon reviewing literature on the effectiveness of grazing systems for riparian management, Clary and Webster (1989) concluded that, as long as good management is practiced, the specific grazing system used may be insignificant. Similarly, Skovlin (1984) suggests intensity of grazing may be of more importance than the actual grazing system used.

There appears to be agreement among many that grazing systems can be compatible with riparian areas, but that success is still dependent on proper control of certain variables. Based on a literature review and personal experience, Kovalchik and Elmore (1982) identify the compatibility of various grazing systems with willow dominated riparian communities. Those systems that avoided late summer use were considered most compatible. Rest-rotation and deferred-rotation were considered compatible only when adequate forage was left to prevent browsing, and systems featuring late-season grazing were considered incompatible. Successful regeneration of willows may be achieved with rest-rotation and reduced stocking rates (Manoukian and Marlow 2002). Kauffman and Krueger (1984) suggest that grazing systems, such as rest-rotation, can be successful for rehabilitation and maintenance if riparian areas are treated as special use pastures.

Others suggest less consistent benefits with grazing systems. After evaluating the response of riparian vegetation to 34 grazing systems in Montana, Myers (1989) found that while most systems improved watershed characteristics in the uplands, 74% of riparian areas showed no improvement. The author suggests that the importance of riparian areas was not considered when these grazing systems were developed and they "were not designed to be responsive to floodplain function, riparian area livestock behavior, nor riparian plant phenology". Marlow and others (1989) found no significant difference between the effects of season-long, deferred rotation, high-intensity short-duration, and livestock exclusion on streambank stability and trout habitat conditions.

Distribution Management

Riparian Pasture

Riparian pastures are generally smaller areas of rangeland that contain riparian and upland vegetation, but are managed as a unit to reach riparian objectives (Leonard et al. 1997). Fencing riparian areas so as to be managed as separate pastures allows for control of use and season of grazing while reducing concerns about disproportionate use between riparian areas and upland areas. Platts (1989) describes this as one of the most promising grazing strategies for maintaining riparian systems. A riparian pasture allows for optimized use of riparian and upland vegetation, and flexibility in achieving management goals (Kauffman et al. 1983b). Development of riparian pastures on intermountain rangelands may be prohibitive due to cost of fencing and labor (Leonard et al. 1997).

Offsite Water and Minerals

Since the availability of free water is one of the factors that cause cattle to concentrate in riparian areas, the use of off-stream water sources has been suggested as a means of luring cattle away from riparian areas and improving distribution throughout an allotment. Off-site water may be used alone or in combination with mineral supplements. In some cases, water and salt may not be enough to lure cattle away from attractive riparian areas, especially if placed in areas of steep slopes (Bryant 1982). Important considerations when using off-site water and minerals include location and availability of water, shade, and trace-mineral salt, season, time of day, temperature, and vegetation type/abundance (Porath et al. 2002).

In eastern Oregon, Chaimberlain and Doverspike (2001) observed an upward trend in riparian condition by using solar power to pump water to a trough adjacent to the riparian area, and to power a temporary electric fence to keep cattle away from sensitive areas. There is also some evidence that off-stream water may be useful in reducing water quality impacts in small commercial and non-commercial animal enterprises (SCAEs) (Godwin and Miner 1996), but this may have limited applicability to larger-scale rangeland settings.

In eastern Oregon, McInnis and McIver (2001) found that the use of offsite water and mineral supplements led to a significant decrease in uncovered/unstable streambanks form 9% to 3%. Although, the influence of offsite supplements on cover, stability, frequency of hoof prints, and their "erosion index" were not found to be significant. In a northeastern Oregon study, off-stream water and trace-mineral salt were shown to significantly increase time spent in upland areas compared to riparian areas, and improved weight gain by 11.5 kg/cow over a 42 day period (Porath et al. 2002). The effect of the off-stream treatment on distribution was significant in late July but not in late August. Stillings and others (2003) developed a bioeconomic model to demonstrate the potential economic benefit to using off-stream water and salt to improve distribution in northeastern Oregon. They suggest annual net returns between $4,500 and $11,000.

Other Techniques

Other techniques that have been identified as possible tools for managing livestock distribution include altering turn-in location, herding livestock, culling individual animals, and improving upland forage (Ehrhart and Hansen 1998). Gillen and others (1985) suggest that altering the turn-in location in large pastures may delay use of riparian meadows by as much as 2 weeks, but provided little evidence to support this recommendation. Daily herding of livestock can be successful at reducing livestock use of riparian areas and improve utilization of upland areas (Kauffman and Krueger 1984). Ohmart (1996) suggests that cattle herding by a permittee is currently the most viable approach to reducing the impacts of grazing. Finally, significant differences have been found in the tendency of individual cows within a herd to spend more or less time on uplands versus lowlands (perennial stream) (Bailey et al. 2004). Although culling of "bottom-dwelling" cows may reduce impact to riparian areas, the author suggests this would require a large commitment of labor. While many of these strategies show promise for reducing the impacts of grazing on riparian areas, there appear to be few studies to test the effectiveness of these techniques.

Total Exclosure

In some cases, total exclusion of cattle grazing may be the easiest, most economical, and ecologically feasible method for restoring previously degraded riparian areas (Ehrhart and Hansen 1998). Livestock exclosure may lead to improvements in a variety of riparian characteristics and functions (see review of effects). While total exclosure may be appealing to some, these areas are important to livestock producers because of the abundant forage they produce (Schulz and Leininger 1990, Roath and Krueger 1982). Other factors such as cost of fencing and impacts on the movement of some wildlife species may also be prohibitive.

Programs

The sustainable management of riparian areas will depend on extension of available knowledge to those who will be actively involved in the management of these areas. Programs have been established in the United States and Canada in order to provide this function. Best management practices (BMP's) for grazing have been established in Idaho (Johnson 1992) and Montana (Lee 1999). In Alberta, Canada, the "Cows and Fish" Program (Fitch and Adams 1998) has had a major impact on management of riparian areas. There have also been numerous documents produced by the USDI Bureau of Land Management.

The Alberta Riparian Habitat Management Project (aka "Cows and Fish") was established as a partnership between the Alberta Cattle Commission, Trout Unlimited Canada, the Canadian Cattlemen's Association, Alberta Environmental Protection, Alberta Agriculture, Food and Rural Development, and Fisheries and Oceans Canada (Fitch and Adams 1998). Development of this program involved three major steps: 1) gathering of technical knowledge; 2) development and demonstration of key strategies; and, 3) extension of information and key strategies through a variety of groups and organizations. Publications such as *Caring for the Green Zone: Riparian Areas and Grazing Management*" (Fitch et al. 2003), now in its 3rd edition, provide science-based information on riparian areas and their management in a form that is accessible to farmers, ranchers, and livestock producers. This and many other resources are available at www.cowsandfish.org. Bateman (2001) found that this program was reasonably successful in delivering awareness programming related to sustainable resource management, and that locally-based and locally-paced awareness initiatives were most effective at building ecological literacy.

The USDI Bureau of Land Management (BLM) has produced multiple documents pertaining to management of grazing in riparian areas. In 1997, the BLM produced a document describing principles, concepts, and strategies for managing grazing in riparian-wetland areas (Leonard et al. 1997). The scope of this document would make it applicable across the northern intermountain region. The following year, the Montana BLM produced *Successful Strategies for Grazing in Riparian Zones* (Ehrhart and Hansen 1998). In this document, principles and techniques for riparian grazing are provided with support from scientific literature and examples from study reaches across Montana.

Best management practices (BMP's) can be an important source of information for managing grazing in riparian areas. BMP's are strategies for managing the use of a resource that is based on study and experience, and promotes ecological and economic stability (Johnson 1992, Lee 1999). These practices include many of the principles and strategies already discussed, but they have been identified as BMP's for their potential to reduce nonpoint source water pollution associated with grazing activities. Rather than providing a single approach that will work in all situations, the aim of BMP's is to provide a number of tools to help meet management objectives (Lee 1999)

Conclusions/Recommendations

Riparian Health

The most common definition of riparian health appears to be based on the ecosystem function of riparian areas. Determining the health of a riparian area by comparing it to a static image fails to acknowledge the dynamic nature of these ecosystems (Medina et al. 1996). Vegetation alone has also been shown to be a poor surrogate for riparian health (Hansen 1991, Hall 2005, Gebhart et al. 1990, Medina et al. 1996). Proper function of riparian areas accounts for the interaction of components such as vegetation, soils, and hydrology. Riparian health in terms of function provides a useful framework for evaluating the effects of cattle grazing since the impacts of grazing are not limited to impacts on vegetation.

When measuring impacts of grazing on riparian function, it is important to consider watershed characteristics and other human disturbances taking place throughout the watershed. The condition of upland areas and activities taking place throughout a watershed can have significant effects on riparian function (Appendix A, USDA Forest Service 1992, Debano and Schmidt 1989, Richards et al. 1996, Allan et al. 1997). Riparian vegetation is a critical component for riparian function (Winward 2000), but it should be considered an independent indicator of riparian function.

Protocols

With the exception of a few studies (Ward 2003, Miller 2005, Whitacre 2004) there is little information documenting the effectiveness of various protocols for assessing riparian health or comparing the level of agreement between methods. Ideally, proper management throughout an entire watershed would allow for riparian ecosystems to function at or near full potential (Ohmart 1996), but given the amount of human impact taking place throughout western watersheds (see Appendix A), this is often unrealistic. One problem with assessment protocols is the inability of the protocols to distinguish between various types of disturbance occurring at various spatial scales.

Based on the few studies that compare protocols and an understanding of local versus catchment influences on riparian function, it becomes apparent that the variables used in a protocol can largely dictate the sensitivity of that protocol to a particular scale of disturbance. Protocols such as PFC and The NRCS Riparian Assessment tend to focus on features related to hydrologic function and floodplain sustainability while SVAP focuses on water quality and biotic integrity, leading to inconsistencies between methods (Miller 2005, Ward 2003). This suggests that selection of a protocol to measure the effects of disturbance on riparian areas should be based on both the scale at which the disturbance is taking place, and the scale that any particular protocol may be sensitive to disturbance.

There should be continued study of assessment protocols to assess their usefulness, consistency, and applicability. More specifically, research directed toward testing existing protocols for sensitivity to grazing in riparian areas or development of a grazing-specific riparian assessment would be valuable to those managing for sustainable grazing in riparian ecosystems. Arguably, an assessment protocol to evaluate the effects of grazing in riparian areas would largely need to focus on local physical conditions, and require an interdisciplinary understanding of riparian functions and processes. Stevens and others (2002) argue that parameters such as streamflow, algal growth, turbidity, aquatic invertebrate and vertebrate populations, and multiple human impacts would increase the effectiveness of BLM's PFC. At the same time, aquatic ecosystems integrate a variety of physical, chemical, and biological conditions throughout the watershed (NRCS 1998). Therefore, it could be possible that the addition of such parameters would greatly increase the ability of this protocol to measure stream health, watershed conditions, and watershed-scale human disturbance, but would reduce the sensitivity of this protocol to riparian conditions at the local or reach scale. Any future assessment protocol should specifically address scale-related issues.

Effects of Grazing

Relating effects of grazing to riparian function provides a useful framework for organizing research on the effects of grazing on riparian health. Controlling the negative impacts of grazing on riparian areas requires an understanding of the mechanisms behind the observed impact. Viewing the effects of grazing within the context presented in this paper may be helpful in understanding the major variables that are involved in maintaining riparian functions.

The effects of grazing should continue to be evaluated in terms of riparian function and processes. As shown in Figure 1, grazing may affect multiple variables simultaneously. In some cases, dividing up the impacts of grazing into certain categories fail to recognize the complexity of grazing effects on riparian function (ex. Kauffman and Krueger 1984). Future discussion of grazing impacts on riparian areas should attempt to identify key variables involved in an observed effect. This includes those variables affected by grazing and those largely unaffected by grazing.

State of the Art

In the last few decades, a number of advances through research in riparian areas have led to a vastly improved understanding of riparian areas, and important information that can be used in their management. Important progress has included greater understanding of riparian structure and function, the effects of grazing, and strategies that reduce the negative impacts associated with grazing. A final step in managing for healthy riparian areas is the transfer of new scientific findings to those actively involved in managing these ecosystems.

Recent reviews, symposia, and books have emerged that summarize much of the available knowledge concerning riparian areas (Naiman and Decamps 1997, Gregory et al. 1991, NRC 2002, Clary et al. 1992). Numerous studies on the effects of riparian grazing have also been followed by reviews (Kauffman and Krueger 1984, Skovlin 1984, Ohmart 1996). Information used for managing grazing in riparian areas comes from two main sources. Many of the studies measuring the effects of grazing on riparian areas provide important information about season of use and grazing intensity. There are also studies designed specifically to better understand the behavior of cattle and to test management alternatives such as grazing systems and distribution techniques. The continued communication of updated science-based information to managers through vehicles such as BMP's, agency publications, and programs aimed at educating managers, is also important for successful management of riparian areas.

The present state of our knowledge is not sufficient to predict how a given riparian ecosystem would react to a grazing treatment. Even if it were possible to predict how a given site would react, there is not the potential to develop a single management strategy that would work in all situations. A management strategy must account for the natural variability within and between managerial units, account for the influence of any additional disturbances in the riparian area and throughout the watershed, and work within the context of an entire grazing operation. Riparian areas, the landscapes they exist within, and ranch operations have different features; each has unique qualities that, when combined, require solutions that are tailored to each situation (Fitch and Adams 1998). What the current body of literature has provided is a greater understanding of the processes that take place in riparian areas and the ecosystem functions that they provide. It is the improved understanding of riparian ecosystems, and an understanding of the mechanisms that lead to alteration of these ecosystems, that can allow managers to weigh the benefits of obtaining an agricultural commodity with the associated ecological costs.

One primary recommendation for future research related to riparian grazing is continued improvement in study designs. It could be argued that the usefulness of any future research comparing heavy season-long grazing to exclosures is severely limited. These studies have been useful in identifying some mechanisms for riparian degradation by cattle, and presented dramatic examples of impacts, but future research must continue to focus on the sensitivity of certain conditions and functions of riparian areas to grazing. Long-term, well replicated studies that study various levels of controlled grazing will provide an idea of tolerance to natural and human induced disturbance (Larsen et al. 1998), yet there are very few of these studies to date. Studies should provide detailed information regarding grazing treatments. This has improved in recent studies, but in some cases this information is still lacking (ex. Kauffman et al. 2004).

Certain impacts, such as stream temperature and water quality, have been repeatedly described in literature related to grazing, but there is still little quantitative evidence documenting these effects. Quantifying these effects might provide some threshold of impact that could be useful in management situations. Water quality and temperature are a result of complex interactions in riparian/stream ecosystems and would require careful study design.

Attention should also be brought to the focus and direction of riparian related research. Platts and Raleigh (1984) suggest that scientists involved in range conservation, wildlife, fisheries, and watersheds all approach problems with their own biases making agreement on grazing strategies difficult. Similarly, Skovlin (1984) identifies a lack of cohesiveness among disciplines. The degree to which so many disciplines are so intimately linked is probably greater in riparian areas than any other part of the landscape. "It is time for interstate, interagency, and interdisciplinary coordination or research activities" (Larsen et al. 1998).

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Appendix A

Influence of human activities on riparian areas

Riparian ecosystem conditions can reflect the cumulative effects of multiple activities in a watershed (Patten 2000). Critical ecosystem functions such as the cycling and chemical transformation of nutrients, water purification, flood attenuation, maintenance of stream flows and stream temperatures, groundwater recharge, and fish and wildlife habitat can be hindered by the degradation on riparian zones (Kauffman et al. 1997). For those involved in the research and management of riparian areas, it is important to identify potential impacts associated with human disturbance. Interactions of anthropogenic and natural disturbance regimes must also be incorporated into restoration planning (Ward and Stanford 1995).

Various alterations such as dams, industrial development, urbanization, agricultural practices, irrigation withdraws, grazing, forestry, and other land uses, can have negative impacts on riparian areas (Beschta and Kauffman 2000). In the western U.S., the primary impacts on low elevation riparian areas may be from water development, channelization, and agriculture while those at higher elevations may be from grazing, logging, and mining (Goodwin et al. 1997). Each of these are discussed below except riparian grazing, which is examined in greater detail in a separate section. Since relatively little of the western landscape has been urbanized (Goodwin et al. 1997), and information on the influence of industrial development in the intermountain region is lacking, these two impacts will not be discussed further.

Water development has been essential to the agriculture, population growth, and industrial development of the western United States (Goodwin et al. 1997). Dams and irrigation diversions are two common types of water development in the west. Dams have been used for hydropower, irrigation, flood control, domestic and industrial water, recreation, and navigation (NRC 2002). One immediate affect of dams is the loss of upstream riparian structure and function due to inundation (NRC 2002). Downstream from dams, riparian areas are affected by altered flow regime, changes in sediment loads, aggradation and degradation of the stream channel, and other changes in the size and shape of the stream channel (Williams and Wolman 1986). Diversions can also alter flow regimes and geomorphic conditions. Diversions can reduce floods, reduce seedbeds, and lower water table depths (Obedzinski 2001). Along the Carmel river in California, pumping of groundwater has led to a lowered water table, decreased riparian vegetation, and an increase in bank erosion (Groaneveld and Griepentrog 1985).

Maintaining or reestablishing the natural flow regime is of particular importance to riparian restoration (Beschta and Kauffman 2000). Many riparian species are sensitive to flood periodicity and water table depth associated with certain hydrologic regimes (Obedzinski 2001). Since riparian vegetation is especially sensitive to minimum and maximum flows, riparian vegetation may change substantially without changing mean annual flow (Auble et al. 1994). In some cases restoring a natural flow regime might be a simple solution but providing this flow regime might be more of a political-social-economic problem than a technical one (Goodwin et al. 1997).

Channelization is the modification of streams to make them deeper, straighter, and often wider (NRC 2002). It can affect riparian areas by reducing floodplain inundation, reduce or eliminate channel migration, eliminate sites for plant recruitment, and lower groundwater tables (Goodwin et al. 1997). Some effects of channelization are obvious, such as the mechanical alteration of streams and the associated destruction of riparian vegetation (NRC 2002), while other effects are more indirect. Riparian areas can become drier as channelization leads to lowered water tables and reduces the frequency of overbank flow (NRC 2002).

Riparian areas are often subject to conversion to cropland since they often contain some of the most fertile soils and they are often close to a convenient source of water (NRC 2002). In Iowa, a typical stream may have cultivation up to the streambank along as much as half its length (Lowrance et al. 2002). Willows and shrubs have been cleared for agricultural use in the northern Black Hills of South Dakota (Froiland 1962). The removal of riparian vegetation, or conversion to row crops, leads to a loss of all the important ecological functions it provides. The impacts of water development that were previously discussed can often be tied to agriculture since the development and use of surface and groundwater is often necessary for agricultural operations in the western United States. The fertilizers and pesticides used in agricultural operations can also have negative effects on riparian flora and fauna (NRC 2002).

Logging activities can impact riparian areas through tree falling, skidding, road construction, and removal of vegetation (DeBano and Schmidt 1990). Some effects of these activities include compaction and disturbance of soil, increased erosion, changes in cover and composition of vegetation, and changes in structural diversity (Obedzinski 2001). Numerous studies have documented the hydrologic effects of timber harvest, but responses are dependent on numerous factors including site characteristics, harvest activities, as well as others (NRC 2002).

The effects of mining on riparian areas can be highly variable based on the method that is used. In some cases, past mining operations have caused the complete obliteration of valley floors along with the aquatic and riparian ecosystems (Goodwin 1997, NRC 2002)

There are other human impacts that are either less studied or are less prevalent, but they can still lead to degradation of riparian areas. Some of these include bank stabilization structures, recreation, and introduction of exotic species (NRC 2002). Human activities with the watershed, but off-site relative to riparian areas, may also have impacts on stream and riparian ecosystems. Upland activities modify water and sediment yield from the watershed, which in turn can affect peak flows, low flows, timing of runoff, and sediment production. This modification can be manifested in various forms of riparian degradation (Goodwin et al. 1997).