DISSERTATION

LARGE UNGULATE EFFECTS ON NITROGEN DYNAMICS IN RIPARIAN ECOSYSTEMS OF COLORADO

Submitted by

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In partial fulfillment of the requirements

For the Doctor of Philosophy

Colorado State University

Fort Collins, Colorado

Summer 2008

COLORADO STATE UNIVERSITY

May 9, 2008

WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY AGNIESZKA PRZESZLOWSKA ENTITLED LARGE UNGULATE EFFECTS ON NITROGEN CYCLING IN RIPARIAN ECOSYSTEMS OF COLORADO BE ACCEPTED AS FULLFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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ABSTRACT OF DISSERTATION

LARGE UNGULATE EFFECTS ON NITROGEN CYCLING IN RIPARIAN ECOSYSTEMS OF COLORADO

Feedbacks between plant species and soil nitrogen (N) pools affect primary production, vegetation nutrient content, nutrient use efficiency, and soil carbon (C) storage potentials. Large herbivores can affect feedbacks between aboveground and belowground N pools, nutrient mineralization rates, soil food webs, and turnover rates of N pools at different temporal and spatial scales. Studies of terrestrial ecosystems have shown either accelerating or decelerating effects of ungulates on N cycling. Acceleration of nutrient cycling by ungulates has been proposed in fertile, productive ecosystems where herbivores promote compensatory plant growth, enhance nutrient concentration in living plant tissue, stimulate microbial activity and mineralization which results in a positive feedback of high nutrient supply rates to plants. In contrast, the decelerating nutrient scenario is more prevalent in ecosystems with low fertility and low production. Ungulates feed selectively on palatable plants leaving unpalatable species with poor litter quality. This results in a negative feedback of slow decomposition and low nutrient supply rates to plants.

Most studies have focused mainly on wild ungulates (elk, bison) or livestock (cattle, sheep) in grasslands, shrublands, or pasturelands and only few studies have investigated the effects of ungulates on nutrient dynamics in riparian zones. Although

riparian zones and wetlands cover only 1-2% of forest and rangeland landscapes in the western United States (US), they are important ecosystems from both a biological and economic perspective. Riparian zones are highly productive, provide habitat for fish and wildlife, and act as buffers between terrestrial and aquatic ecosystems by reducing sediment and N inputs from upland ecosystems to surface waters. Livestock grazing is a predominant land use on public and private lands in the western US. Grazing by bison is more prevalent in National Parks and Monuments. Alteration of N cycling by either ungulate may have significant feedbacks to plant communities and could alter the buffering potential of riparian zones.

The main goal of my studies was to investigate if large ungulates, bison and cattle, alter N dynamics in riparian ecosystems of Colorado. In the first study, I tested whether bison and cattle accelerate or decelerate soil N mineralization in riparian corridors and wet meadows of the Great Sand Dunes region in south-central Colorado where elk populations are high. In the second study, I evaluated the effects of long-term cattle grazing on N dynamics in soils, groundwater, and stream water of the Sheep Creek montane riparian ecosystem in north-central Colorado. Bison grazing in Great Sand Dunes riparian corridors and wet meadows did not accelerate net N mineralization. Cattle grazing also did not have a significant effect on mineralization parameters because variation was high within mean estimates of net N mineralization. However, I observed highest net N mineralization in soils from cattle grazed wet meadows which might result from a long contemporary history of cattle grazing in the Great Sand Dunes region compared with only 15 years of bison grazing (and 3 years of bison exclosure treatments) at the time of the study.

Cattle grazing in the Sheep Creek montane riparian zone did not significantly increase aboveground production, aboveground or belowground plant N pools, soil N pools, soil microbial biomass, litter decomposition, potential net N mineralization or denitrification in the riparian zone as a whole. Signs of accelerated N cycling were detected only at streambank sites where potential net N mineralization in incubated soils was 35% higher in cattle grazed compared with excluded streambank sites. Cattle grazing did not affect stream or groundwater NO_3^- and NH_4^+ concentrations. However, NO_3^- and NH_4^+ sink-source relationships changed temporally: the riparian zone may serve as a potential sink for NO_3^- and NH_4^+ during spring gaining streamflow conditions and a potential source of NO_3^- and NH_4^+ to the stream during summer losing streamflow conditions. In conclusion, current season-long, light-to-moderate cattle grazing does not appear to alter N cycling in the Sheep Creek montane riparian zone at the landscape scale.

Although I did not find strong evidence for accelerated N cycling (increased plant and soil N pools and increased microbial activity and N mineralization) in riparian zones grazed by large ungulates, results of my studies suggest that acceleration of N cycling in riparian ecosystems is more likely in sites that have a long history of grazing or are grazed frequently at low to moderate intensity. Future studies should better account for variability in ungulate use of riparian sites, especially in the context of different temporal and spatial scales.

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ACKNOWLEDGEMENTS

My greatest thanks go to my family, Alicja, Andrzej, Aleksandra, Adam and Andrzej Jr., for their continuous support, love, and patience throughout my PhD trials and tribulations … but, most importantly for not exiling me as the only non-engineer in the family. Special thanks also to close friends Jared, Shannon, Monte, Melody, Angie, Jen, Phillip, Melissa, Lisa, Christine, and Blair for their laughter, numerous adventures, inspiration and emotional support. A sincere "dziękuje" to Jared who was always willing to help me with fieldwork, edit my papers, listen to my scientific ramblings, and feed me gourmet meals.

I extend my gratitude to committee members Dr. Joe Trlica, Dr. Jean Reeder, Dr. Mary Stromberger, and Dr. John Stednick. Many thanks to Dr. Trlica for his continued support throughout my graduate studies, his mentorship, trust, patience, and friendship. Special thanks are also extended to Dr. Reeder and Dr. Stromberger for their discussions, sharing a woman's perspective, and the use of their labs for various analyses. Thank you to Dr. Stednick for his input on my groundwater studies but most importantly, thanks for the Polish comradery.

Colorado State University Agricultural Experiment Station and US Geological Survey provided financial support. My dissertation research would not have been possible without the help of many individuals. Humongous thanks to my extraordinary technicians: Melissa Reyes and Anna Hansen for their perseverance through hours of fieldwork, tedious sample preparations, analyses, and data entry. Also instrumental in many field efforts were: Jared Coburn, Beckie Hemmerling, Greg Fox, Tom Bates, Dani Mazzotta, Jeff Trlica, Angie Moline, Alicia Urbiztondo, Shannon Sokolow, Dana Bishop, Samantha Stiffler, Carly Dorman, Francis Rengers, and Maureen O'Mara. I would also like to thank Dr. Joe von Fischer and Anita Kear as well as Dan Reuss and Colin Pinney of the Natural Resource Ecology Laboratory for sharing their wealth of knowledge and assisting with numerous analyses. Kate Schoenecker and Chris Pauge were helpful in design of my Great Sand Dunes study. Lastly, my sincere thanks go to Dr. Greg Auble for his encouragement, valuable insights and discussions of riparian ecology.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Background

Riparian zones are focal points for maintenance and restoration of biological diversity, wildlife habitat, and water quality throughout forest and rangeland landscapes of the western United States (US). Although riparian zones and wetlands only cover 1-2% of these landscapes, they are critical ecosystems from both a biological and economic perspective (Kauffman and Krueger 1984). They are complex systems characterized by high productivity, high plant and wildlife diversity, zones of soil erosion and deposition, and temporally and spatially variable biogeochemical cycles (Kauffman and Krueger 1984; Gregory et al. 1991; Clary and Leininger 2000; Blank et al. 2006). Riparian zones are also important aquatic-terrestrial interfaces because they have the potential to reduce sediment and nitrogen (N) inputs from upland ecosystems to surface waters and act as a N sink (Tilton and Kadlec 1979; Seitzinger 1994; Griffiths et al. 1997).

Numerous studies have considered the ability of riparian zones to retain or lose N, especially nitrate (NO_3^-), to the aquatic system (Simmons et al. 1992; Irons et al. 1994; Seitzinger 1994; Groffman et al. 1996; Griffiths et al. 1997; Verchot et al. 1997; Spruill 2000; Dhondt et al. 2006). The main mechanisms for NO_3^- removal in riparian zones include denitrification, plant uptake, microbial immobilization, and dissimilatory NO_3^- reduction to ammonium NH_4^+ (Groffman et al. 1992; Simmons et al. 1992; Verchot et al. 1997; Dhondt et al. 2006). Denitrification is the prominent agent of NO_3^- attenuation during the dormant season (winter) when groundwater table is high and soils are anaerobic (Lowrance 1992; Haycock and Pinay 1993; Jacks et al. 1994). Plant uptake is usually the dominant groundwater NO_3^- sink during the growing season (summer) when the water table is generally low and the soils are aerobic (Groffman et al. 1992; Verchot et al. 1997; Van der Putten et al. 2001). Since the end product of denitrification are nitrogenous gases (N_2O, N_2), denitrification removes NO_3^- from an ecosystem and should not cause this sink to become saturated with chronic inputs of N (Groffman et al. 1991; Dhondt et al. 2006). Nitrogen species taken up by plants, however, can eventually be recycled back to an ecosystem through decomposition and mineralization of plant litter (Groffman et al. 1991; Groffman et al. 1992; Hanson et al. 1994; Dhondt et al. 2006).

The economic value of riparian zones to human society stems from their nutrient rich soils that are very productive for agriculture, forage for livestock and wildlife, and growth of forest products (Kauffman et al. 2001; Kauffman et al. 2004). Livestock grazing is a predominant land use in the interior Pacific Northwest and Intermountain West (Kauffman and Krueger 1984; Dwire et al. 2004). Historically, riparian and stream ecosystems were viewed as "sacrifice" areas dedicated primarily to providing forage, shade, and water for domestic livestock (Kauffman and Krueger 1984). Even though most grazing plans were designed for extensive uplands, management of riparian zones was limited and cattle concentrated along stream banks. Consequently, historical heavy grazing often resulted in severe degradation of many riparian zones in the US West

(Chaney 1990). Cattle grazing in riparian zones can affect plant diversity and community structure (Kauffman et al. 1983; Schulz and Leininger 1990; Clary 1995), forage quality (Phillips et al. 1999), soil physical properties (Wheeler et al. 2002; Kauffman et al. 2004), stream bank stability, soil organisms, and nutrient cycling. High inputs of N to riparian zones from ungulate movements and fecal material could lead to higher N production and export from the riparian zone to surface waters if plant and microbial pools become enriched and lose their capacity to retain N.

Alteration of biogeochemical processes by ungulate grazing may have significant feedbacks to plant productivity, community structure, buffering potential of riparian zones and overall ecosystem health (Bardgett et al. 1998). Large ungulates can alter N inputs and outputs in aboveground and belowground N pools, and thus affect nutrient mineralization rates, soil food webs, and turnover rates of these pools at different temporal and spatial scales (Hobbs 1996; Bardgett and Wardle 2003; Singer and Schoenecker 2003). Most studies have focused mainly on wild ungulates (elk, bison) or livestock (cattle, sheep) in grasslands, shrublands, or pasturelands and only few studies have been conducted to investigate the effects of ungulates on nutrient dynamics in riparian zones (but see: Trlica et al. 2003; Kauffman et al. 2004; Blank et al. 2006). Studies in upland ecosystems have shown either positive, negative, or neutral effects of ungulates on ecosystem N dynamics (McNaughton 1985; De Mazancourt et al. 1998; Frank and Groffman 1998; Ritchie et al. 1998; Tracy and Frank 1998; Phillips et al. 1999; Augustine et al. 2003; Singer and Schoenecker 2003).

Ungulate herbivory can increase, decrease, or have no significant effect on plant fitness and production by affecting any of the three main components of the N cycle: 1) plant and soil N pools, 2) annual N fluxes (e.g., NO_3^- leaching, NH_4^+ volatilization, denitrification, ecosystem N transport by ungulates), and 3) daily N fluxes (e.g., plant uptake of N, N mineralization, fecal and urine N deposition, ungulate N transport between habitats). Although ungulates can have neutral effects on these components, alternative ungulate feedback scenarios (positive vs. negative) have been generalized in an accelerating – decelerating nutrient scenario framework (Fig. 1.1). The accelerating nutrient scenario often occurs in fertile, productive ecosystems where selective consumption of plants by herbivores is low, plants exhibit compensatory growth, and input of labile fecal material by herbivores is high. This stimulates nutrient concentration in living plant tissue and results in high quality litter which stimulates microbial activity, litter decomposition, nutrient mineralization and leads to high nutrient supply rates to plants; a positive feedback. The decelerating nutrient scenario is more prevalent in ecosystems with low fertility and composed of plant species less resilient to grazing. Selective feeding of ungulates on palatable plants results in dominance of unpalatable species and poor litter quality which slows decomposition and results in low nutrient supply rates to plants; a negative feedback (Ritchie et al. 1998; Wardle et al. 2004).

In a study of Yellowstone National Park (YNP) grasslands, Frank and Groffman (1998) compared the effects of native ungulates (elk and bison) and landscape variables on soil C and N processes. They found that herbivores doubled net N mineralization in grazed plots compared with ungrazed plots, and that they improved soil organic matter quality by increasing labile fractions and decreasing recalcitrant organic matter fractions. They attributed ungulate acceleration of net N mineralization to stimulated gross

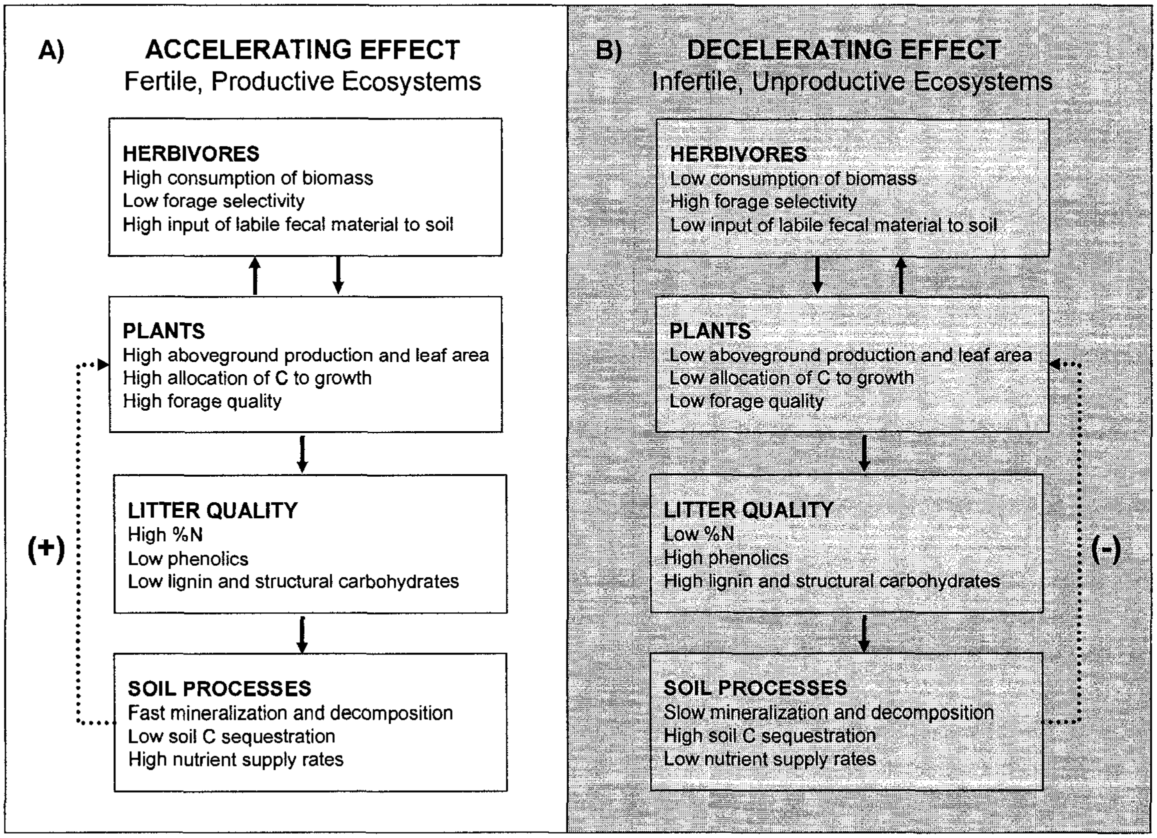

Figure 1.1. Influence of herbivores on plant and soil nutrient pools and soil processes summarized in the accelerating – decelerating nutrient scenario framework. Acceleration of N cycling generally occurs in A) fertile, productive ecosystems, while deceleration of N cycling is more common in B) infertile, unproductive ecosystems (After: Ritchie et al. 1998; Wardle et al. 2004).

mineralization and concluded that variation in N availability among diverse landscape sites was primarily a function of differences in microbial immobilization rates. These results were supported by Tracy and Frank (1998) who concluded that N mineralization and microbial activity were strongly influenced by grazers in YNP grasslands while landscape topography affected soil microbial biomass. The findings of Frank and Groffman (1998) and Tracy and Frank (1998) indicate that ungulates and landscape variables influence microbial activity which in turn regulates soil mineral fluxes.

Singer and Schoenecker (2003) also found an accelerating nutrient scenario in the grasslands of YNP where elk were abundant (i.e., doubled soil N mineralization, increased aboveground N yield, increased N in most plant species and enhanced aboveground production). But, they found decelerated nutrient cycling (i.e., declines in soil N mineralization rates, N pools, aboveground N yield and aboveground production) in willow and aspen vegetation communities utilized by elk in Rocky Mountain National Park (RMNP). They attributed nutrient deceleration in RMNP to higher ungulate densities and consumption rates in RMNP relative to YNP, coupled with a tendency of the ungulates to daily transport N from willow and aspen communities to other vegetation types in RMNP but not in YNP grasslands (Singer and Schoenecker 2003).

Ritchie et al. (1998) found that white tail deer decelerated N cycling in a Minnesota oak savanna by selectively decreasing the abundance of plant species with N-rich tissues. Herbivores also decreased soil NO_3^- and total available N but did not alter total soil or plant N. They also concluded that although herbivores alter available soil N pools, they might have little effect on short-term soil N accumulation because frequent fires prescribed for the savanna (two every three years) might mediate herbivore effects on long-term changes in N pools. Evidence of decelerated N cycling was also found by Kauffman et al. (2004) in riparian wet meadows of eastern Oregon. In this study, net potential nitrification rates and net potential mineralization rates were 149-fold and 32-fold lower, respectively, in cattle-grazed compared with cattle-excluded wet meadows. These parameters were not significantly different among cattle grazing treatments in dry meadow communities. Furthermore, the researchers expected lower N availability in exclosures but found no differences in N availability between grazed and ungrazed treatments. Thus, they hypothesized that alteration of soil physical properties (i.e., soil bulk density, pore space, infiltration) by cattle had stronger regulatory influence on N dynamics than cattle N inputs. In a study of soil-solution chemistry in a Sierra Nevada montane riparian meadow, Blank et al. (2006) observed that cattle grazing increased lysimeter-extractable NO_3^- but decreased NH_4^+ at the forest-edge. No differences in N species were found at stream edge and mid-floodplain locations. Grazing impacted soil N primarily at the forest-edge because cattle had access to trace-mineral salts placed along the forest edge which encouraged them to use these areas for loafing. Consequently, it is likely cattle transferred nutrients to these locations via urine and feces.

The discussed studies demonstrate that ungulates can have positive, negative, or neutral effects on ecosystem N cycling. Nitrogen responses to ungulate herbivory appear to be a function of landscape position and soil properties, ungulate preferences for certain sites, selective grazing of forage, grazing intensity, timing, and transfer of nutrients by ungulates between habitats and across a landscape. Since cattle and bison are common ungulate grazers in riparian corridors of the western US, the effects of these ungulates on N cycling in riparian ecosystems should be investigated further. Ungulate grazing in riparian zones could affect riparian functioning and potentials for nutrient retention by altering N inputs and outputs in aboveground and belowground N pools. Significant increase of N mineralization and nitrification by ungulates could enrich available soil N and microbial communities and accelerate N uptake by plants. If plant and microbial pools become enriched with N and lose their capacity to retain it, NO_3^- and NH_4^+ export from the riparian zone to stream water could increase (Aber et al. 1989; Hill and Shackleton 1989; Groffman et al. 1992). Because feedbacks between producers and decomposers occur in terrestrial ecosystems (Van der Putten et al. 2001; Bardgett and Wardle 2003), a combined aboveground and belowground approach is needed to understand how riparian zones respond to ungulate grazing (Kauffman et al. 2004).

Objectives

The main goal of my dissertation research was to investigate if large ungulates alter N dynamics in riparian ecosystems. I evaluated the effects of bison and cattle in two riparian systems of Colorado. In the first study, I tested whether bison and cattle accelerate or decelerate soil N mineralization in riparian corridors and wet meadows of the Great Sand Dunes region in south-central Colorado where elk populations are high. In the second study, I evaluated the effects of long-term cattle grazing on N dynamics in plants, soils, groundwater, and stream water of the Sheep Creek montane riparian ecosystem in north-central Colorado.

The specific objectives of my Great Sand Dunes study were to:

1. Determine the effect of bison grazing on potential N mineralization in riparian corridors and wet meadows.

2. Determine the effect of bison versus cattle grazing on potential N mineralization in wet meadows.

3. Assess soil properties (organic matter, total C and N, and soil texture) in riparian corridors and wet meadows.

The specific objectives of my Sheep Creek studies were to:

1. Determine if long-term moderate cattle grazing in montane riparian sites has accelerated or decelerated N cycling in comparison with sites that have been excluded from cattle grazing for 50 years.

2. Assess the effect of cattle grazing treatments by comparing N pools (plant, soil, and soil microbial N pools) and N fluxes (decomposition, mineralization, immobilization, and denitrification).

3. Compare N dynamics in aboveground and belowground ecosystem components at three locations in the riparian zone: streambank, middle of the riparian zone, and edge of the riparian zone adjacent to a forested upland to assess potential variation in N dynamics across the width of the riparian zone.

4. Measure stream stage and groundwater piezometric potentials to determine gaining and losing streamflow conditions.

5. Measure NO_3^- and NH_4^+ in stream water and groundwater in streambank, middle riparian, and riparian edge locations in both cattle grazed and excluded areas.

6. Relate NO_3^- and NH_4^+ concentrations to streamflow stage to determine sink-source relationships in sites with and without cattle grazing.

7. Measure N mineralization, nitrification, and denitrification in surface soils to better explain groundwater NO_3^- and NH_4^+ dynamics.

Hypotheses

I hypothesized that ungulate grazing has accelerated N cycling in the Great Sand Dunes riparian corridors and wet meadows and the Sheep Creek montane riparian zone. More specifically, I hypothesized that grazing by bison and cattle in addition to elk herbivory in the Great Sand Dunes riparian corridors and wet meadows would increase potentially mineralizable N pools and mineralization rates in comparison with communities utilized by elk only. I expected higher N mineralization rates and higher potentially mineralizable N pools in riparian corridors and wet meadows utilized by bison and cattle because these sites are more productive and provide more palatable forage than the surrounding xeric uplands. Areas on the landscape that have higher quantity and quality of forage are more likely to be re-grazed compared to the surrounding community and thus, receive more inputs of labile N through fecal material (McNaughton 1984; Singer and Schoenecker 2003). High quality litter and ungulate excretions in grazed areas are likely to increase litter decomposition and N mineralization. Furthermore, I hypothesized that cattle, rather than bison, would have a stronger effect on soil N mineralization in wet meadows because of their longer contemporary presence in the region.

I hypothesized that long-term cattle grazing in the Sheep Creek montane riparian zone of north-central Colorado also has accelerated N cycling because the riparian sites are highly productive and appear resilient to disturbances. The riparian zone adjacent to the stream provides more palatable forage than the surrounding sagebrush and lodge-pole pine uplands. Cattle tend to concentrate in the Sheep Creek riparian zone and do not appear to transport N to the surrounding upland communities. I hypothesized that the accelerating effect would be exhibited by greater aboveground and belowground N pools (plant, labile soil N, and soil microbial N pools), no significant alteration of plant species composition, and increased N processes (microbial respiration, decomposition, mineralization, nitrification, and denitrification) in the long-term grazed than excluded riparian sites. I expected a net increase in N of the system if N pools and processes were consistently higher in grazed than excluded sites.

I did not expect to find significantly higher N concentrations in stream water near sites grazed by cattle compared with excluded sites because, based on preliminary observations, there were no visible signs of ecosystem degradation or streambank instability within the Sheep Creek study allotment. Also, previous studies at Sheep Creek did not find elevated NO_3^- or NH_4^+ concentrations in stream water near cattle grazed riparian pastures (Stednick and Fernald 1999). I hypothesized that cattle grazing would not have an effect on groundwater NO_3^- and NH_4^+ during gaining (spring snowmelt) streamflow conditions when the groundwater level is elevated across all landscape locations. Under gaining conditions, NO_3^- could be denitrified and NH_4^+ immobilized by plants or soil microorganisms (unless plant growth was low during gaining streamflows). However, I hypothesized that cattle would increase groundwater NO_3^- and NH_4^+ at the middle and edge of the riparian zone during losing (late summer) streamflow conditions when the groundwater level declined. I did not expect cattle grazing to alter groundwater NO_3^- or NH_4^+ concentrations at streambank sites during losing streamflow conditions if the groundwater level remained elevated at the streambank late in the growing season.

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CHAPTER II

EFFECTS OF LARGE UNGULATES ON SOIL NITROGEN MINERALIZATION IN RIPARIAN CORRIDORS AND WET MEADOWS OF THE GREAT SAND DUNES, COLORADO.

Abstract

Large ungulates can affect N cycling and ecosystem processes by regulating N inputs and outputs in above- and belowground N pools. I conducted a study in the Great Sand Dunes region of Colorado to determine if grazing pressure by ungulates, bison or cattle, accelerates or decelerates soil N mineralization rates in riparian corridors and wet meadows where elk populations are high. I hypothesized that N cycling would be accelerated in riparian and wet meadow soils grazed by bison or cattle compared with sites utilized by elk only, because the riparian and wet meadow communities are more mesic and productive than the surrounding uplands.

I did not find statistically significant changes in soil N mineralization as a result of bison or cattle. Significant differences might have been masked by high variation in mean estimates of N mineralization obtained during soil incubations. I attributed the high variance to difficulty in maintaining constant soil moisture in incubated samples, differences in fine root or litter among subsamples, and variable leaching efficiencies of the vacuum manifold. Inferences about bison vs. cattle effects were further limited by

unequal grazing treatments. At the time of this study cattle had a longer contemporary history of grazing in the region than bison and cattle exclosures had been in place 5 times longer than bison exclosures. This study should be repeated after longer bison exclosure and include analyses of plant communities, litter quality, and ungulate utilization at different times of the growing season to better account for variation in soil N mineralization. Nevertheless, the results of this study could be considered in conjunction with currently on-going estimates of elk populations, bison movements, forage offtake, plant production and species composition to understand ungulate effects on riparian and wet meadow ecosystem dynamics.

Introduction

Feedbacks between plant species and soil nitrogen (N) dynamics affect primary production, vegetation nutrient content, nutrient use efficiency, and soil carbon (C) storage potentials (Pastor and Post 1986; Wedin and Tilman 1990; Phillips et al. 1999; Wardle et al. 2004). Large herbivores can alter N inputs and outputs in aboveground and belowground N pools, and thus affect nutrient mineralization rates, soil food webs, and turnover rates of these pools at different temporal and spatial scales (Hobbs 1996; Bardgett and Wardle 2003; Singer and Schoenecker 2003). Studies have shown either positive or negative effects of ungulates on ecosystem N dynamics (McNaughton 1984; McNaughton 1985; Frank and Groffman 1998; De Mazancourt et al. 1998; Phillips et al. 1999; Augustine et al. 2003; Bardgett and Wardle 2003).

Ungulate herbivory can increase or alternatively decrease plant fitness and production. The accelerating nutrient scenario often occurs in ecosystems where plants exhibit compensatory growth as a result of high nutrient use efficiency, enhanced nutrient uptake, and compensatory photosynthesis. The decelerating nutrient scenario is more prevalent in ecosystems where plant species are less resilient to grazing, selective feeding of sensitive plants occurs, and decomposition is slow (Ritchie et al. 1998; Bardgett and Wardle 2003). For example, Singer and Schoenecker (2003) found an accelerating nutrient scenario in the grasslands of Yellowstone National Park (YNP) where elk are abundant (i.e., doubled soil N mineralization, increased aboveground N yield, increased N in most plant species and enhanced aboveground production). However, they found nutrient cycling to be decelerated by elk in willow and aspen vegetation communities of Rocky Mountain National Park (RMNP): declines in soil N mineralization rates, N pools, aboveground N yield and aboveground production. Nutrient deceleration in RMNP was attributed to higher ungulate densities and consumption rates in RMNP relative to YNP, coupled with a tendency of the ungulates to daily transport N from willow and aspen communities to other vegetation types within RMNP (Singer and Schoenecker 2003).

The accelerating – decelerating framework of N cycling could be used by resource managers to assess impacts of herbivores on aboveground and belowground ecosystem feedbacks. In the Great Sand Dunes region of south-central Colorado, natural resource managers are faced with a challenge to increase the current bison population while not negatively affecting rangeland conditions, especially since elk populations in the area exceed Colorado Division of Wildlife management goals. Currently, the elk population is estimated at 3,955 ± 304 animals (Schoenecker et al. 2006). The Nature Conservancy (TNC) manages a herd of 1,500 bison on the Medano-Zapata Ranch that is adjacent to the Great Sand Dunes National Park. In the future, TNC would like to increase the bison herd to a population of 1,800–3,000 bison, or more. Currently, the impacts of ungulate grazing on plant communities and especially nutrient cycling are not well known in the Great Sand Dunes region.

My goal was to determine whether additional ungulates, bison and cattle, accelerate or decelerate soil N mineralization rates in riparian and wet meadow communities where elk populations are high. These results could be used to better understand potential aboveground plant community responses to belowground N dynamics and provide a more integrated and process oriented approach to resource management. My specific objectives were to 1) determine the effect of bison grazing on potential N mineralization in riparian corridors and wet meadows, 2) determine the effect of bison versus cattle grazing on potential N mineralization in wet meadows, and 3) assess soil properties (organic matter, total C and N, and soil texture) in the two communities. Cattle were included in my study because they might be included in future management plans for this region. I hypothesized that grazing by bison and cattle in addition to elk herbivory in the Great Sand Dunes riparian corridors and wet meadows would increase potentially mineralizable N pools and mineralization rates in comparison with riparian corridors and wet meadow communities utilized by elk only. I expected that cattle, rather than bison, would have a greater effect on soil N mineralization in wet meadows because of their longer contemporary presence in the region. Bison were present in the San Luis Valley until extirpation in the 1840s. They were reintroduced on the Medano Ranch in the Great Sand Dunes region in the late 1980s. Cattle grazing in the valley had been practiced at high levels since European settlement until the 1970s (Schoenecker 2004). Current management of cattle on the Zapata Ranch is an intensive approach based on high densities of animals for short duration with adequate rest of grazed areas between May and September (J. Gossage, personal communication, February 2006). Thus, I hypothesized that the largest grazing effect on soil properties would occur in wet meadows with the longest history of cattle grazing.

To test my hypotheses, I conducted 6-month laboratory aerobic incubations of riparian and wet meadow soils. Soil incubations have been used to compare N mineralization and nitrification potentials as well as soil microbial activity (i.e., C mineralization) of soils from different regions and ecosystems (Stanford and Smith 1972; Nadelhoffer 1990; Wedin and Pastor 1993; Franzluebbers 1998). Laboratory incubations compared to *in situ* soil incubations, allow for control of microclimate and severed root effects (Binkley and Hart 1989; Wedin and Pastor 1993).

Methods

Study Site

The Great Sand Dunes National Park is located at the eastern edge of the San Luis Valley in south-central Colorado (Fig. 2.1). The park ranges in elevation from 2,300 m at its western boundary to over 4,000 m in the eastern Sangre de Cristo Mountains. My study sites were located at a 2,300 to 2,400 m elevation. Annual precipitation in the area averages approximately 200 mm, with 60% occurring as convective thunderstorms associated with the southwest monsoons between July and September. Mean daily temperatures range from 10°C in January to 32°C in July and total annual potential evapotranspiration is about 950 mm (Huntley 1976). The national park and my study sites were located in the closed basin portion of the San Luis Valley and have no surface water outlets. During spring, snowmelt from the mountains flows down streams into the closed basin and seeps into alluvial fans which in turn recharge deep and shallow aquifers. In the summer, fall, and winter the streams on the alluvial fans carry little or no water (Chimner and Cooper 2004). The surface and groundwater hydrology greatly influences vegetation communities in the Great Sand Dunes complex which are comprised of three major types: 1) active dunes and swale areas, 2) ephemeral wetlands, and 3) the sand sheet.

My study sites were located in wet meadows and riparian corridors west and south of the active dune field. The wet meadows are ephemeral and are fed by spring snowmelt or an elevated ground water table in the swale areas. They are dominated by *Juncus balticus* Willd., *Potentilla anserina* L., *and Distichlis spicata* (L.) Greene. *Carex* spp. are less prominent in wet meadows in comparison with the riparian corridors that I sampled. The vegetation in my riparian sites is dominated by *Carex nebrascensis* Dewey and *Carex aquatilis* Wahlenb., with some *Potentilla anserina* L. and patches of *Juncus balticus* Willd. near edges of the riparian corridors. Soils in all my study sites are sandy, ranging from sandy loams to loamy sands.

Experimental Design and Soil Sampling

I used a randomized complete block design with two treatment levels (grazing and control) replicated in two types of communities (riparian and wet meadow). The grazing treatments were elk only (the control), bison + elk, and cattle + elk. Bison exclosure treatments were established three years prior to this study while cattle exclosures had been in place for 15 years.

To determine the effect of bison grazing on potential soil N mineralization in riparian corridors and wet meadows, I chose two sites (i.e., blocks) in riparian corridors, Little Spring Creek and Big Spring Creek, and two sites in wet meadows, Elk Springs and Twin Lakes. To evaluate the effect of bison versus cattle grazing on N mineralization rates in wet meadows, we sampled two wet meadow sites frequented by bison, Elk Springs and Twin Lakes, and two wet meadows utilized by cattle near the Medano-Zapata (MZ) Ranch headquarters, South MZ and West MZ (Fig. 2.1).

I collected soils from four locations within each of the respective sites and grazing treatments in October 2004 ($n = 48$). The four sampling locations were chosen at random from six randomly selected locations on either side of the fence in both control and grazed treatments. Sampling locations in the riparian sites were along the stream bank within a 100-m reach that started 50 m away from the fence, while sampling locations in wet meadows were within a 50-m radius, also 50 m away from the fence. The 50-m setback from the fence eliminated an area along the fence where ungulate traffic is typically high. Since no soil or vegetation data were collected when exclosure fences were built, sampling in control and adjacent grazed treatments separated by a fence line allowed us to make the best possible assumption that both areas were similar in terms of vegetation, slope, aspect, drainage and soil type when the exclosure fence was constructed. At the time of my sampling I did not observe any visual differences in plant species composition, topography, drainage, or soil type between the two paired treatments at each site. Soils in the paired control and grazed treatments were the same at each riparian and wet meadow site: Medano fine sandy loams at Little Spring and Big Spring Creeks, Cotopaxi sands at Elk Springs and West MZ wet meadows, Hooper clay loams at Twin Lakes wet meadows, and Zinzer loams at South MZ wet meadows (USDA-NRCS 2007).

I collected 10 soil cores at each sampling location below the soil organic (O) horizon, to approximately a 10-cm depth. The soil samples were stored in plastic bags and transported on ice to the Natural Resources Ecology Laboratory (NREL) at Colorado State University (CSU), Fort Collins, CO. In the lab, I prepared the soil samples by immediately air drying the soil, passing it through a 2-mm sieve, and removing visible roots and litter. The dried soil samples were stored at room temperature before incubation and other soil analyses.

Incubations

I used the microlysimeter method developed by Nadelhoffer (1990) to measure 1) soil microbial respiration by sampling respired carbon dioxide (CO_2) in the microlysimeter headspace and 2) N mineralization by repeated leaching of soil. I mixed 20 g of soil samples with 20 g of washed sand to facilitate periodic leaching of N. The samples were then placed in the upper chambers of microlysimeters (two-chambered plastic filter units) and incubated in the dark at 25°C. I pre-leached all the soil samples on day 0 of the incubation with a micronutrient solution described below to remove initial mineral N. During the initial and all subsequent N extractions, I allowed a 100-ml aliquot of micronutrient solution to equilibrate with the soil samples for 0.5 h before extraction with a 0.02-MPa vacuum. The samples were vacuumed for 1 h and weighed. These weights were used to calculate the initial soil moisture content that was maintained for each sample during the 6-month incubation. It was difficult to establish consistent moisture content across all incubated samples because the suction in my vacuum manifold was unequal in all the valves (29% ± 9 SD gravimetric water content). Soil moisture might have been too high especially in very sandy soils. I monitored the soil moisture content of each sample by reweighing the assembled microlysimeters after each leaching (Appendix A). Sample moisture contents of individual samples were adjusted over time by addition of de-ionized water or additional evacuation with the vacuum to maintain constant moisture for each respective sample. There was little change in water contents of respective samples over the course of the entire incubation period, water contents changed from 0 to 5 SD of each sample mean.

To determine soil microbial respiration, I measured CO_2 accumulation in microlysiemeter headspaces after a short, 2-h incubation during which the microlysimeters were capped. I sampled the headspaces with a syringe at 0 and 2 h and immediately analyzed CO_2 concentrations with a LI-COR LI-2400 CO_2 gas analyzer (LI-COR Biosciences, Lincoln, NE) at day 3, 6, 10, 13, 20, 34, 48, 69, 89, 116, 140, and 164 of the incubation. I then used the Ideal Gas Law to convert CO_2 concentrations to C mineralization rates, normalized the rates by soil C, and expressed them as mg CO_2-C g^{-1} of soil C d^{-1} (Appendix B). I extracted N from the soil samples by leaching them with a micronutrient solution comprised of 4.0 mM $CaCl_2$, 2.0 mM KH_2PO_4, 1.0 mM K_2SO_4, 1.0 mM $MgSO_4$, 25 μM H_3BO_3, 2.0 μM $MnSO_4$, 2.0 μM $ZnSO_4$, 0.5 μM $CuSO_4$, and 0.5 μM Na_2MoO_4. I analyzed the extracts colorimetrically for NO_3^- and NH_4^+ on an Alpkem segmented flow autoanalyzer (OI Analytical, College Station, TX) and calculated relative N mineralization in incubated samples for each incubation period as mass of total inorganic N (NO_3^- plus NH_4^+) leached from a sample divided by total soil N (mg N g^{-1} soil N) (Appendix C). I utilized relative N mineralization rates (i.e., per g soil N) because I observed a wide range of indigenous soil N content across my sites, 0.07%–0.61% N. Net N mineralization at the end of the incubation period was the sum of N mineralized during all sampling periods.

Modeling Potential N Mineralization

I considered two models to estimate potentially mineralizable N from our aerobic laboratory incubations. The model proposed by Stanford and Smith (1972) estimates soil

N mineralization potential as the quantity of soil organic N that could be mineralized according to first-order kinetics:

$$N_t = N_o(1 - e^{-kt}) \quad (1)$$

where N_t is the cumulative amount of N mineralized at time t, N_0 is potentially mineralizable N, and k is the mineralization rate constant (Appendix D). This model has been used to describe N mineralization dynamics of soils under different land use and climatic conditions (Campbell et al. 1981; Hadas et al. 1986; Cabrera and Kissel 1988).

Bonde and Rosswall (1987) modified the first-order model to a mixed first- and zero-order kinetic model which defines two pools of soil organic N, a labile and a recalcitrant pool:

$$N_t = N_l(1 - e^{-ht}) + ct \quad (2)$$

N_l and h represent the pool size and rate constant for the labile N pool, and c is the mineralization rate constant for the recalcitrant N pool (Appendix E). I considered this model in addition to the first-order model because N mineralization rates in my aerobic soil incubations did not converge to zero (Bonde and Rosswall 1987).

I fitted the experimental results to the two models with the NLMIXED procedure in SAS for non-linear curve fitting (SAS 2003) and evaluated model adequacy on the basis of model convergence and Akaike's information criterion (AICc) for small data sets (Burnham and Anderson 1998). The model with the lowest values of AICc is considered to be the best model.

Soil Properties

I conducted several soil analyses to determine soil organic matter, C and N content, C:N ratio, clay, silt, and sand fractions (Appendix F). Soil organic matter (SOM) was determined by ashing 1.0 g of soil material in a 500°C muffle furnace for five hours. Percent SOM was calculated from differences in pre- and post-ashing weights (Nelson and Sommers 1996). Total C and N soil contents were determined with a dry combustion method (Nelson and Sommers 1996). Soil samples were combusted in a LECO CHN-1000 Carbon Hydrogen Nitrogen Analyzer (Laboratory Equipment Corp, St. Joseph, Michigan) and converted into gases that passed through an infrared cell to determine C content (% C) and a thermal conductivity cell to determine percent N. Lastly, I used the standard hydrometer method to determine clay, silt, and sand soil fractions (Elliott et al. 1999).

Statistical Analyses

I used SAS for all statistical analyses (SAS 2003). I conducted an analysis of variance (ANOVA) with multiple comparison tests to determine the effects of additional ungulates on soil N mineralization and soil properties. My response variables for these analyses were first-order model parameters (N_t, N_o, k), net N mineralization, soil quality (% C, % N, C:N, SOM), and clay content. I used log-transformed data in cases where variance increased as a function of the mean and accepted significant differences at $P <$ 0.05. Lastly, I conducted simple linear regressions to evaluate the relationships between first-order model parameters (N_o, k), net N mineralization, and different soil properties and to determine how much variability in N mineralization parameters could be explained by linear regression on the different soil properties. Summary statistics of all analyses are presented in Appendix G.

Results

N Mineralization Kinetics

The mixed model (Eq. 2), which defined a labile and a recalcitrant pool of soil organic N, produced lower AIC_c values than the first-order model (Eq. 1; Table 2.1) which estimated N mineralization according to first-order kinetics. The mixed model (Eq. 2) had 27 lower AIC_c values while the first-order model (Eq. 1) produced 18 lower AIC_c values. However, for 15 samples the values differed by ≤ 5. Although the fit statistics were better for the mixed model (Eq. 2), this model failed to meet convergence criteria for 9 out of 48 samples. The first-order model (Eq. 1), on the other hand, failed to converge for only 3 samples. Consequently, I selected the first-order model (Eq. 1) to estimate potentially mineralizable N. Estimates of potentially mineralizable N (N_o) in 48 soil samples ranged from 30.2 to 609.0 mg N g^{-1} soil N. Mineralization rate constants (k) ranged from 0.0014 to 0.0237 wk^{-1}. Model estimations of cumulative N mineralized at the end of the incubation (N_t) ranged from 27.7 to 157.8 mg N g^{-1} soil N, and underestimated measured net N mineralization by an average of 2.5 mg N g^{-1} soil N (Appendix E, Table E-1a).

Nitrogen mineralization (N_t at time t of incubation period) was significantly greater ($P < 0.04$, on average 39% higher) in bison grazed riparian sites than riparian control sites during the first 70 days of incubation (Fig. 2.2A; Appendix G, Table G-1a and G-1b). However, bison grazing did not have a significant effect on N mineralization in wet meadows ($P > 0.41$, Fig. 2.2B; Appendix G, Table G-1a and G-1b). Nitrogen mineralization was significantly greater at the end of soil incubations in wet meadows grazed by cattle ($P < 0.05$, on average 139% higher, Fig. 2.2C; Appendix G, Table G-1a and G-1b), but there were no significant differences in N mineralization attributed to bison vs. cattle grazing treatments in wet meadows ($P > 0.54$, Fig. 2.2D; Appendix G, Table G-1a and G-1b). The incrementally smaller increases in net N mineralized (i.e. declines in N mineralization rates, data not shown) in all treatments during the first 3 weeks of incubation corresponded to a sharp decline in microbial respiration at the beginning of soil incubations (Fig. 2.3). Elevated microbial respiration rates in wet meadow soils after day 70 of the incubation period (Figs. 2.3B–3D) corresponded to higher N mineralization in wet meadows (Fig. 2.2B–2D), especially in cattle grazed sites.

Grazer Effects on Potential N Mineralization

There were no overall significant grazing treatment effects by additional ungulates on potentially mineralizable N (N_o, $P = 0.32$; Appendix G, Table G-2a), mineralization rates (k, $P = 0.78$; Appendix G, Table G-3a), nor net N mineralized during aerobic soil incubations ($P = 0.23$; Appendix G, Table G-4a). Net N mineralized (total N leached from soil samples) ranged from 30.0 to 160.5 mg N g^{-1} soil N across 48 incubated soil samples.

More specifically, I did not find significant bison grazing effects (Fig. 2.4A–4C) on potentially mineralizable N ($P = 0.99$; Appendix G, Table G-2b), mineralization rates ($P = 0.17$; Appendix G, Table G-3b), nor net N mineralization in riparian soils ($P = 0.68$; Appendix G, Table G-3b) or wet meadows: potentially mineralizable N, $P = 0.86$

(Appendix G, Table G-2b), mineralization rates, *P* = 0.28 (Appendix G, Table G-3b), net N mineralization, *P* = 0.75 (Appendix G, Table G-4b). Similarly, there were no significant differences in these response variables between bison and cattle grazed wet meadow soils (potentially mineralizable N, *P* = 0.23; mineralization rates, *P* = 0.89; net N mineralization, *P* = 0.48; Fig. 2.4A–4C; Appendix G, Table G-2b, G-3b, G-4b). Although N mineralization parameters in cattle grazed wet meadows were not significantly different from other treatments, these sites had the largest potentially mineralizable N pool (336.4 mg N g^{-1} N, Fig. 2.4A) which resulted in highest net N mineralization (96.5 mg N g^{-1} soil N, Fig. 2.4C) at the lowest N mineralization rates (0.0045 wk^{-1}, Fig. 2.4B). These parameters did not differ significantly from cattle control treatments or bison grazed treatments in wet meadows because of high variation in their mean values (high standard error of the mean = SE): potentially mineralizable N SE = 95, net N mineralized SE = 19, and mineralization rate SE = 0.001.

Soil Properties

Soil C:N ratios were significantly lower in wet meadows than in riparian sites (P < 0.02; Appendix G, Table G-5b). Soil C:N ratios in wet meadows averaged 10.8 and 13.1 in riparian sites. Lower C:N ratios in wet meadow soils may help to explain relatively higher N mineralization in wet meadow soils compared with riparian soils (Fig. 2.2). Other soil properties did not differ significantly between riparian and wet meadow soils when averaged over grazing treatments: total C, *P* = 0.99; total N, *P* = 0.92; SOM, *P* = 0.98; clay content, *P* = 0.43; sand content, *P* = 0.37; silt content, *P* = 0.34 (Appendix G, Table G-5a).

There were no significant differences in any soil property between control and bison grazed riparian sites, control and bison grazed wet meadow sites, or control and cattle grazed wet meadow sites ($P > 0.11$, Table 2.2). This suggests that additional grazing by bison or cattle has not altered soil texture, soil organic matter, or C and N pools.

Soil C:N ratios did not help to explain variation in mineralization parameters (N_o or k) or net N mineralized at the end of the incubation period ($R^2 = 0.03$, 0.04, 0.09, respectively, $P > 0.05$, Table 2.3; Appendix G, Table G-6). Soil C also was not a significant predictor of these N mineralization variables ($P > 0.05$). Soil organic matter was only significant for potentially mineralizable N ($P < 0.04$), explaining 9% of variation. Soil N was a better predictor of potentially mineralizable N ($P < 0.02$), and mineralization rates ($P < 0.03$), respectively explaining 12% and 11% of variation in these variables, but not net N mineralization. Soil sand and silt fractions were the most significant predictors of the 3 mineralization parameters ($P < 0.04$), and explained the most variation: 14% and 17% in potentially mineralizable N, 22% and 24% in mineralization rates, and 10% and 12% in net N mineralization (Table 2.3). Greater silt fractions were positively correlated with potentially N mineralizable pools and net N mineralization (inverse was true of sand content).

Discussion

Despite differences in N mineralization at certain periods of the soil incubations, I did not find overall significant effects of grazing by bison or cattle on soil N dynamics. This suggests that in addition to elk herbivory, bison and cattle do not accelerate or decelerate N cycling in riparian or wet meadow sites in the Great Sand Dunes region. However, significant grazing effects might have been masked in my data by high variance in mineralized N among replicates within respective community type and grazing treatment levels. The high variance could be attributed to my difficulty in maintaining constant soil moisture in samples during the long-term incubation, differences in fine root or litter among replicates, and variable leaching efficiencies with the vacuum manifold. Furthermore, I conducted my incubations on soils collected only at the end of the growing season. Patterns in N mineralization could be different at other times of the growing season, especially if grazers utilize my study sites differentially over time.

I expected increased N mineralization in riparian and wet meadow sites utilized by bison and cattle because Great Sand Dunes riparian corridors and wet meadows are more productive and provide more palatable forage for herbivores than the surrounding uplands and sand sheet characterized by *Ericameria nauseosa* Pallas ex Pursh (rubber rabbitbrush) and *Sarcobatus vermiculatus* Hook (greasewood). Areas on the landscape that have higher quantity and quality of forage are more likely to be regrazed compared to the surrounding community (Singer and Schoenecker 2003). This could have a positive feedback of increased nutrient cycling and primary productivity because N cycling is generally accelerated in urine and fecal patches which contain labile N that is more available to plants and soil microorganisms (Coppock et al. 1983; Hobbs 1996; Ritchie et al. 1998; Bardgett and Wardle 2003; Singer and Schoenecker 2003). Furthermore, according to De Mazancourt et al. (1998), nutrient acceleration is likely to occur only when herbivores transport nutrients into an ecosystem from other areas on the landscape. I did not measure N imports or exports by ungulates in my study. Analysis of daily bison movements and utilization being conducted in another study should help to determine whether bison are transporting N to riparian or wet meadow communities from other vegetation types or if they are moving N out of these communities.

Although my data did not support the accelerating effect scenario, I observed highest values of potentially mineralizable N and net N mineralization in soils from cattle grazed wet meadows. Potentially mineralizable N and net N mineralization were also considerably higher (130% and 28%, respectively) in cattle grazed wet meadows than bison grazed meadows. This might be a result of a long history of cattle grazing in the Great Sand Dunes region compared with only 15 years of bison grazing (and 3 years of bison exclosure treatments) at the time of this study. However, the cattle grazing effect was not statistically significant because of high variation in the mean value of mineralization parameters (high SE).

The high variance in N mineralization estimates might potentially be attributed to errors in laboratory incubation procedures, such as difficulty in maintaining constant moisture in the microlysimeters, or differences in site characteristics that I did not measure in this study. For example, the magnitude of grazer effects on mineralization rates and N availability could have varied at my sampling locations as a result of plant community structure, aboveground plant production, litter quality, water availability, and presence of mineral licks (McNaughton 1990; Tracy and McNaughton 1995; Frank and Groffman 1998; Augustine et al. 2003; Singer and Schoenecker 2003). Nitrogen mineralization is also mediated by the structure and functional attributes of the soil microbial community (Brussaard et al. 1997; Frank et al. 2000). Soil microbial community patterns are related to the history and intensity of grazing. For example, Bardgett et al. (2001) found that phenotypic evenness of soil microbial communities declines with increased intensity of grazing. They found that soil microbial communities of sub-montane ecosystems were dominated by bacteria in heavily grazed sites while fungi were more predominant in less intensively grazed sites. Such shifts in microbial communities can regulate ecosystem soil processes and energy flows (Brussard et al. 1997; Bardgett et al. 1998, 2001).

Although I found significantly lower C:N ratios in wet meadow soils than in riparian soils, soil C:N was not significantly correlated with any N mineralization parameter. Other factors such as litter quality and recalcitrant plant residues (i.e., plant lignin content or lignin:N ratios) could be more important controls of mineralization and turnover rates of soil organic matter (Melillo et al. 1982; Schimel et al. 1996) than soil C:N ratios. Although I did not measure species composition in this study, I observed higher abundance of *Carex* spp. such as *C. aquatilis* in riparian corridors compared with wet meadows that were characterized by relatively more *J. balticus* and *D. spicata.* Review of the literature suggests that *C. aquatilis* litter might have lower tissue N than *J. balticus* and *D. spicata* in my sites, thus, potentially contributing to slower N mineralization in riparian corridors compared with wet meadows. Chapin and Shaver (1989) reported 2.16% N ± 0.02 SE in mid-summer leaf blades of *C. aquatilis* collected from a wet meadow tundra in Alaska. Phillips et al. (1999) estimated tissue N of *C. aquatilis* in a montane riparian zone of Colorado at 2.5% N in early summer. In a study of stable C and N isotope composition of plants in San Francisco Bay, Cloern et al. (2002) reported seasonal averages of 5.6% N for *J. balticus* and 8.8% N for *D. spicata.*

However, they observed large variability in individual species over different seasons and geographic regions. In future studies of Great Sand Dunes riparian and wet meadow systems, litter quality of dominant species and soil N mineralization should be measured through the growing season to help explain variation in N dynamics.

Although my results do not suggest changes in soil N dynamics from current grazing management, ecosystem level N processes might be significantly altered if the carrying capacity for all ungulates (bison, cattle, and elk) is exceeded in the Great Sand Dunes region. For that reason, questions regarding the carrying capacity for ungulates and plant community dynamics in the region are currently being investigated in a collaborative effort by the US Geological Survey, The Nature Conservancy, and the National Park Service (Schoenecker et al. 2006). Therefore, the results of my study will be further considered in conjunction with currently on-going estimates of elk populations, bison movements, cattle grazing intensity and seasonality, forage offtake, plant production and species composition.

Implications

My results suggest that presence of additional herbivores, bison or cattle, in Great Sand Dunes riparian corridors and wet meadows frequented by elk, does not significantly alter potential soil N mineralization. But, potentially mineralizable N and net N mineralized at the end of my soil incubations appeared higher in cattle grazed meadows. These patterns could be a result of longer history of cattle grazing in the region compared with bison grazing. Although these effects were not statistically significant, they might become more apparent after longer exclosure time from grazing. At the time of this study cattle had been exclosed from control sites for 15 years while bison had been excluded from control sites for only three years. Thus, the regulatory influence of additional herbivores on soil N dynamics may be underestimated in my study. This study should be repeated after longer bison exclosure to better inform management decisions. It should also include analyses of soil microbial communities, plant community composition, plant litter quality, and ungulate utilization estimates at different times of the growing season to better account for variation in soil N mineralization.

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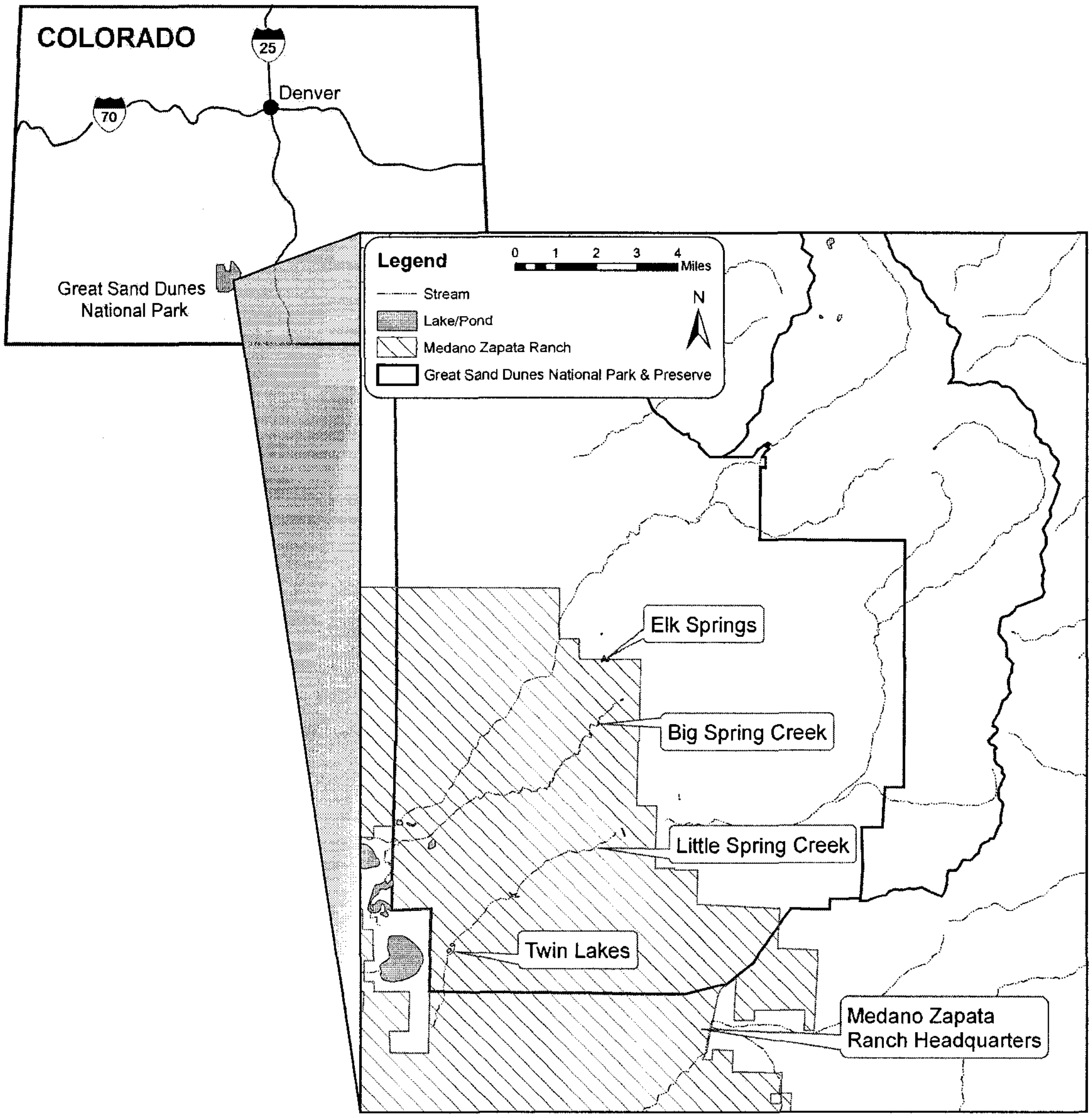

Figure 2.1. Location of the Great Sand Dunes National Park and riparian corridors and wet meadows sampled in this study.

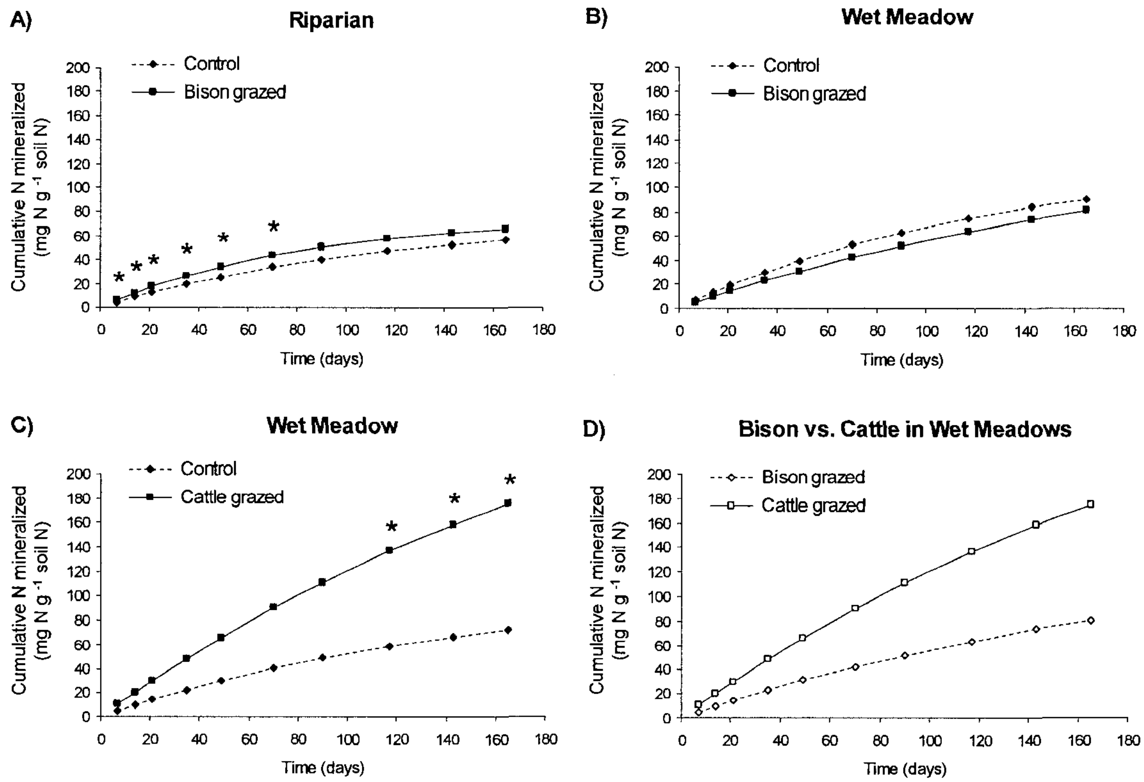

Figure 2.2. Cumulative N mineralization (mg N g^{-1} soil N) estimated with the first-order model for 165-day laboratory incubations of soils. Points labeled "*" indicate significant pairwise differences between grazing treatments for log transformed data at a given incubation period at $P < 0.05$, n = 8. **A)** Bison grazing effect on N mineralization in riparian soils. **B)** Bison grazing effect on N mineralization in wet meadow soils. **C)** Cattle grazing effect on N mineralization in wet meadows. **D)** Bison vs. cattle grazing effect on N mineralization in wet meadows.

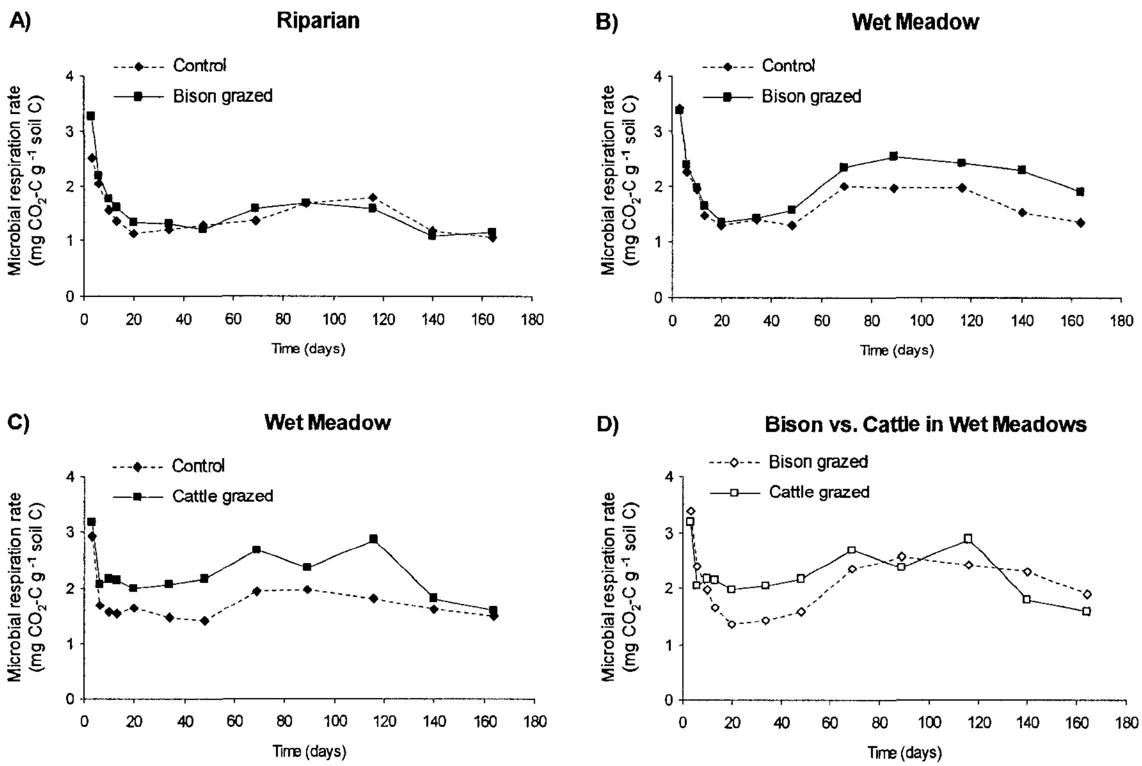

Figure 2.3. Microbial respiration rates during 165-day laboratory incubations of soils. Values are daily respiration rates calculated as relative C respired per g soil C. **A)** Bison grazing effect on microbial respiration rates in riparian soils. **B)** Bison grazing effect on microbial respiration rates in wet meadow soils. **C)** Cattle grazing effect on microbial respiration rates in wet meadows. D) Bison vs. cattle grazing effect on microbial respiration rates in wet meadows.

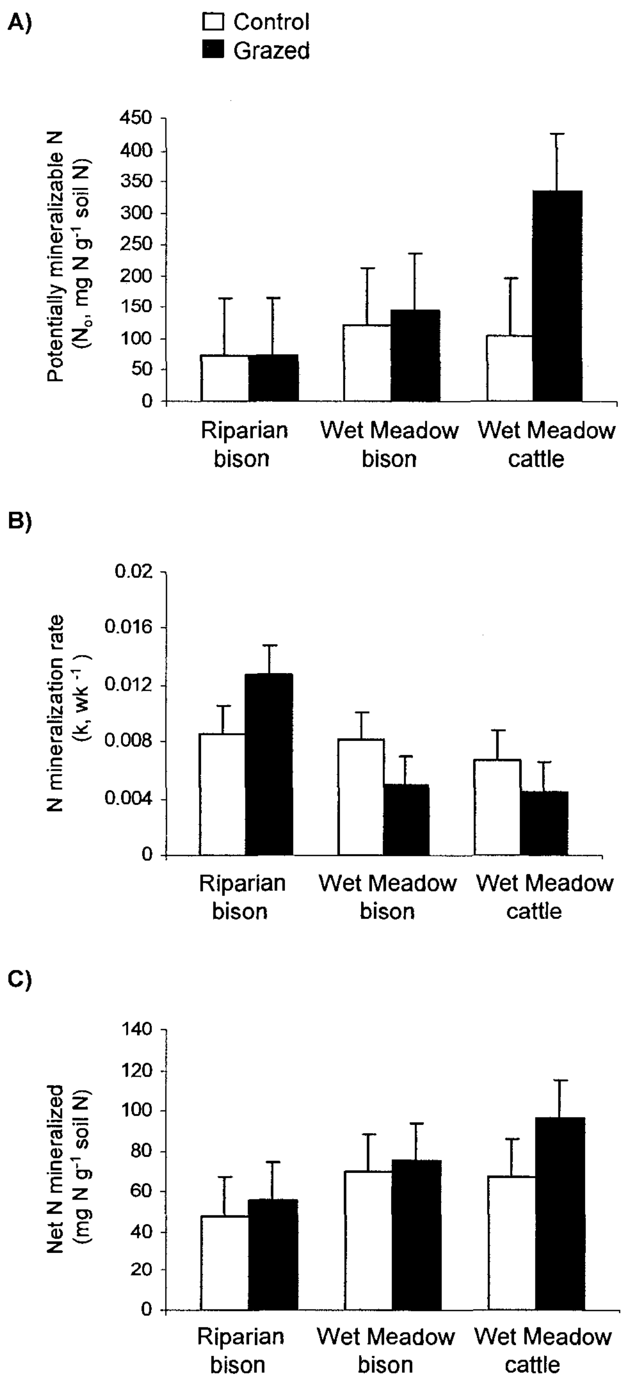

Figure 2.4. Pairwise comparisons of means for ungulate grazing effects on **A)** potentially mineralizabe N (N_o, mg N g^{-1} N), **B)** N mineralization rates (k, wk^{-1}), and **C)** net N mineralized at the end of incubation period (mg N g^{-1} N). There were no significant differences for any pairwise comparisons at $P < 0.05$, n = 8. Bars above paired means represent standard error of the mean (SE).

Table 2.1. Model performance based on convergence and Akaike's information criterion for small data sets (AIC_c) for model fitting of 48 soil incubations. Lower value of AIC_c is considered to be the better model. Replicates are 4 replicate soil samples collected at each site by treatment type.

				Convergence		AIC_c	
Site	Wetland Type	Treatment	Replicate	First-order	Mixed	First-order	Mixed
Big Spring Creek	riparian	control	1	Yes	No	53	—
Big Spring Creek	riparian	control	2	Yes	Yes	51	14
Big Spring Creek	riparian	control	3	Yes	Yes	50	58
Big Spring Creek	riparian	control	4	Yes	Yes	44	39
Big Spring Creek	riparian	bison	1	Yes	Yes	68	50
Big Spring Creek	riparian	bison	2	Yes	Yes	70	64
Big Spring Creek	riparian	bison	3	Yes	No	50	—
Big Spring Creek	riparian	bison	4	Yes	Yes	46	52
Little Spring Creek	riparian	control	1	Yes	Yes	59	52
Little Spring Creek	riparian	control	2	Yes	Yes	53	50
Little Spring Creek	riparian	control	3	Yes	Yes	56	42
Little Spring Creek	riparian	control	4	Yes	Yes	72	54
Little Spring Creek	riparian	bison	1	Yes	Yes	50	54
Little Spring Creek	riparian	bison	2	Yes	Yes	42	31
Little Spring Creek	riparian	bison	3	Yes	Yes	53	31
Little Spring Creek	riparian	bison	4	Yes	Yes	53	42
Elk Springs	wet meadow	control	1	Yes	Yes	54	51
Elk Springs	wet meadow	control	2	Yes	No	53	—
Elk Springs	wet meadow	control	3	Yes	Yes	72	55
Elk Springs	wet meadow	control	4	Yes	Yes	49	40
Elk Springs	wet meadow	bison	1	Yes	Yes	54	55
Elk Springs	wet meadow	bison	2	Yes	Yes	58	58
Elk Springs	wet meadow	bison	3	Yes	Yes	58	64
Elk Springs	wet meadow	bison	4	Yes	Yes	70	69
Twin Lakes	wet meadow	control	1	Yes	Yes	38	40
Twin Lakes	wet meadow	control	2	Yes	Yes	52	52
Twin Lakes	wet meadow	control	3	Yes	Yes	57	51
Twin Lakes	wet meadow	control	4	Yes	Yes	50	43
Twin Lakes	wet meadow	bison	1	Yes	Yes	59	53
Twin Lakes	wet meadow	bison	2	Yes	Yes	56	46
Twin Lakes	wet meadow	bison	3	Yes	Yes	50	55
Twin Lakes	wet meadow	bison	4	No	Yes	—	44
South MZ Ranch	wet meadow	control	1	Yes	Yes	51	57
South MZ Ranch	wet meadow	control	2	Yes	No	57	—
South MZ Ranch	wet meadow	control	3	Yes	Yes	51	56
South MZ Ranch	wet meadow	control	4	Yes	Yes	52	52
South MZ Ranch	wet meadow	cattle	1	No	No	—	—
South MZ Ranch	wet meadow	cattle	2	No	Yes	—	67
South MZ Ranch	wet meadow	cattle	3	Yes	No	55	—
South MZ Ranch	wet meadow	cattle	4	Yes	Yes	48	63
West MZ Ranch	wet meadow	control	1	Yes	Yes	51	39
West MZ Ranch	wet meadow	control	2	Yes	Yes	48	40
West MZ Ranch	wet meadow	control	3	Yes	Yes	54	51
West MZ Ranch	wet meadow	control	4	Yes	No	50	—
West MZ Ranch	wet meadow	cattle	1	Yes	No	51	—
West MZ Ranch	wet meadow	cattle	2	Yes	Yes	41	42
West MZ Ranch	wet meadow	cattle	3	Yes	No	39	—
West MZ Ranch	wet meadow	cattle	4	Yes	Yes	47	46

Table 2.2. Soil property means ± 1 standard error of the mean (SE) by community type and grazing treatment: soil C:N, total C (% C), total N (%N), soil organic matter (% SOM), and particle size distribution (% sand, clay, and silt). *P* are *P*-values of least square differences in soil property means (n = 8) between grazing treatments in each community type.

	Riparian			Wet Meadow			Wet Meadow		
	control	bison	*P*	control	bison	*P*	control	cattle	*P*
Soil C:N	13.4 ± 0.6	12.8 ± 0.3	0.45	10.9 ± 0.7	10.7 ± 0.2	0.71	10.9 ± 0.4	10.8 ± 0.2	0.93
% C	2.62 ± 0.41	2.25 ± 0.35	0.63	2.64 ± 0.72	3.40 ± 0.82	0.25	2.13 ± 0.34	3.20 ± 0.53	0.17
% N	0.20 ± 0.03	0.18 ± 0.03	0.72	0.23 ± 0.06	0.32 ± 0.08	0.22	0.20 ± 0.03	0.29 ± 0.04	0.16
% SOM	6.5 ± 1.0	5.6 ± 0.8	0.65	6.2 ± 1.4	8.3 ± 1.6	0.23	5.7 ± 0.8	7.9 ± 1.1	0.25
Sand	81.0 ± 1.3	84.2 ± 0.1	0.46	73.3 ± 5.8	65.0 ± 7.2	0.46	56.5 ± 3.1	56.0 ± 1.3	0.11
Clay	9.5 ± 1.2	7.9 ± 0.6	0.63	11.3 ± 1.8	12.7 ± 2.4	0.59	16.1 ± 1.2	15.7 ± 0	0.41
Silt	9.5 ± 0	7.9 ± 0.6	0.58	15.3 ± 4.0	22.3 ± 4.8	0.50	27.4 ± 1.9	28.3 ± 1.2	0.11

Table 2.3. Regression of mineralization parameters estimated with the first-order model (potentially mineralizable N $=N_o$, mineralization rate = k) and net N mineralized during incubation period with soil properties: soil C:N, total C (% C), total N (% N), soil organic matter (% SOM), and particle size (% sand, clay, and silt). R^2 are coefficients of determination and P are P-values for dependent variables in regression models based on n = 48.

	N_o		k		net N mineralized	
	R^2	P	R^2	P	R^2	P
C:N	0.03	0.23	0.04	0.20	0.09	0.05
% C	0.09	0.05	0.08	0.06	0	0.99
% N	0.12	0.02	0.11	0.03	0	0.73
SOM	0.09	0.04	0.09	0.05	0	0.94
Sand	0.14	0.01	0.22	0.001	0.10	0.04
Clay	0.07	0.08	0.16	0.01	0.05	0.15
Silt	0.17	0.01	0.24	0.001	0.12	0.02

CHAPTER III

LONG-TERM EFFECTS OF CATTLE GRAZING ON NITROGEN CYCLING IN A MONTANE RIPARIAN ZONE OF NORTH-CENTRAL COLORADO

Abstract

Although relatively small in area, riparian zones in the western US are characterized by high productivity, high plant and wildlife diversity, zones of soil erosion and deposition, and temporally and spatially variable biogeochemical cycles. Historically, heavy cattle grazing resulted in severe degradation of many riparian zones, but a change in livestock management since the late 1950s (i.e., livestock exclusion and reduced stocking rates) has resulted in rapid recovery of many western riparian zones. Numerous studies have illustrated the effects of ungulate herbivory on aboveground ecosystem dynamics and soil properties, but less consideration has been given to nutrient cycling and belowground nitrogen (N) dynamics in riparian zones grazed by cattle. The goal of this study was to determine if long-term cattle grazing in a montane riparian zone of north-central Colorado has altered ecosystem N cycling. Since herbivory can affect producer-decomposer feedbacks in an ecosystem, I assessed cattle effects on N dynamics by investigating both aboveground and belowground N pools and N fluxes across a landscape gradient from the stream bank to the edge of the riparian zone. I expected to

find evidence of accelerated N cycling (i.e., increased aboveground N pools, inorganic soil N pools, soil microbial N pools and increased microbial respiration, mineralization, nitrification, and denitrification) because the Sheep Creek montane riparian sites are highly productive and appear resilient to disturbances.

Nitrogen cycling in long-term cattle grazed sites of the Sheep Creek montane riparian ecosystem did not fit the accelerating nutrient scenario across all landscape positions compared with sites excluded from grazing for 50 years. Overall, cattle grazing did not increase aboveground plant production, aboveground or belowground plant N pools, soil N pools, soil microbial biomass, litter decomposition, potential net N mineralization or denitrification. And, there were no apparent differences in species composition between grazed and excluded treatments. The potential for accelerated N cycling was detected only near the stream bank where net N mineralization in incubated soils was 13.6 ± 1.6 mg N g^{-1}soil N in cattle grazed sites compared with 8.8 ± 1.3 mg N g^{-1}soil N in excluded sites, while the immobilization index (CO_2 respired : net N mineralized) was lower in grazed than excluded sites. This result was mainly attributed to higher nitrification at one out of 3 grazed streambank sites which also happened to be most utilized by cattle during the two field seasons. Because I did not have historical accounts of cattle utilization and frequency at my specific study locations, it is possible that streambank sites frequently grazed by cattle exhibit accelerated N cycling compared with other riparian locations less frequently grazed by cattle, but I was unable to fully capture the grazer-induced response because my study locations likely had unequal histories of cattle use. Nevertheless, the results of this study suggest that the Sheep Creek riparian zone is resilient and resistant to cattle grazing and that season-long, light-to-moderate grazing does not significantly alter ecosystem functioning. Livestock grazing under current management appears to be a viable land-use in this montane riparian corridor.

Introduction

Riparian zones, the interfaces between terrestrial and aquatic ecosystems, are complex systems characterized by high productivity, high plant and wildlife diversity, zones of soil erosion and deposition, and temporally and spatially variable biogeochemical cycles that vary over small scales (Kauffman and Krueger 1984; Gregory et al. 1991; Clary and Leininger 2000; Blank et al. 2006). Riparian zones are often designated as multiple use areas that are managed for recreational activities, wildlife habitat, and livestock grazing. These different uses have been re-evaluated as economic and ecological values of the riparian zones become recognized. Chaney et al. (1990) suggested that most of the degradation of riparian areas in the West had been caused by improper cattle management. Historically riparian and stream ecosystems of the western US were viewed as "sacrifice" areas dedicated primarily to providing forage, shade, and water for domestic livestock (Kauffman and Krueger 1984). Even though most grazing plans were designed for extensive uplands, management of riparian zones was limited and cattle concentrated along stream banks. Consequently, historical heavy grazing often resulted in severe degradation of many riparian zones in the US West.

Cattle grazing in montane riparian zones can affect plant diversity and community structure (Kauffman et al. 1983; Schulz and Leininger 1990; Clary 1995), forage quality (Phillips et al. 1999), soil physical properties (Wheeler et al. 2002), stream bank stability, soil organisms, and nutrient cycling. Alteration of biogeochemical processes (i.e., litter decomposition, nutrient mineralization, nutrient turnover) by cattle grazing may have significant effects on plant productivity, community structure, buffering potential of riparian zones and overall ecosystem health (Bardgett et al. 1998). Although it has been demonstrated that ungulate grazing has indirect effects on nutrient cycling, soil microbial communities and their functions (Holland and Detling 1990; Bardgett et al. 1998; Tracy and Frank 1998; Frank et al. 2000; Bardgett et al. 2001; Bardgett and Wardle 2003; Binkley et al. 2003; Le Roux et al. 2003; Kauffman et al. 2004; Sankaran and Augustine 2004; Schoenecker et al. 2004), many of these studies have focused mainly on wild ungulates (elk, bison) or livestock (sheep, cattle) in grasslands, shrublands, or pasturelands and only few studies have investigated cattle grazing effects on nutrient dynamics in montane riparian zones (Groffman et al. 1992; Trlica et al. 2003; Kauffman et al. 2004; Blank et al. 2006).

Herbivory can indirectly affect nutrient cycling by affecting the quantity and quality of plant-derived nutrients available to soil microorganisms, rates of microbial litter decomposition and mineralization, and nutrient supply rates to plants (Phillips et al. 1999; Hamilton and Frank 2001). Ungulate grazing may alter any of the three main components of the N cycle:

a) N pools (aboveground and belowground plant N pools, inorganic soil N, and total soil N),

b) annual N fluxes (denitrification, NO_3^- leaching, NH_4^+ volatilization, N transport in or out of ecosystems by ungulate movements or wind and surface runoff), and

c) daily N fluxes (plant uptake and transport of N to aboveground tissues, consumption of plant N by ungulates, litter N deposition to soil, fecal and urine N deposition, litter decomposition and mineralization rates, and daily transport of N between habitats by ungulates) (Singer and Schoenecker 2003).

The potential effects of ungulate grazing on N cycling in upland ecosystems have been summarized into an accelerating – decelerating nutrient cycling scenarios framework. The accelerating nutrient scenario has been proposed for fertile, productive ecosystems. In productive ecosystems, selective consumption is low and herbivores promote compensatory plant growth while returning some organic matter as labile fecal material to the soil. There is an acceleration of N uptake by plants which enhances nutrient concentration in living plant tissue. The resulting high quality litter stimulates microbial activity which has a positive feedback of high nutrient supply rates to plants (Ritchie et al. 1998; Bardgett and Wardle 2003; Wardle et al. 2004). According to De Mazancourt et al. (1998), grazing optimization and nutrient acceleration are likely to occur when herbivores move nutrients into an ecosystem from areas outside of the ecosystem (i.e., herbivores redistribute N across a landscape). The decelerating nutrient scenario is more prevalent in ecosystems that are infertile and unproductive. In infertile ecosystems, plant species are not resilient to grazing and selective feeding on palatable plants results in dominance of unpalatable species with poor litter quality. Litter decomposition and mineralization rates are slowed, nutrient supply rates to plants are lower and, eventually, labile N pools decline (Ritchie et al. 1998; Bardgett and Wardle 2003; Wardle et al. 2004). The accelerating – decelerating nutrient cycling framework has not yet been tested in montane riparian ecosystems grazed by cattle. A combined aboveground and belowground approach is needed to understand if N cycling in montane riparian zones is altered by cattle grazing (Kauffman et al. 2004).

The main goal of my study was to determine if long-term cattle grazing in a montane riparian zone has altered N cycling by changing N pools sizes (aboveground and belowground N, soil N) and N fluxes (microbial respiration, mineralization, nitrification, immobilization, denitrification). Since the magnitude of herbivory effects on N cycling appears to depend on soil fertility (Olff et al. 2002; Bardgett and Wardle 2003), I assessed aboveground and belowground N pool sizes and fluxes across a landscape gradient from the stream bank to the edge of the riparian zone. The specific objectives of my study were to:

1. Determine if long-term moderate cattle grazing in montane riparian sites has accelerated or decelerated N cycling in comparison with sites that have been excluded from cattle grazing for 50 years,

2. Assess cattle grazing effects on N pools (plant, soil, and soil microbial N pools) and N fluxes (litter decomposition, mineralization, nitrification, immobilization, and denitrification), and

3. Compare aboveground and belowground N pools and N fluxes at three locations in the riparian zone: streambank, middle of the riparian zone, and edge of the riparian zone adjacent to a forested upland to assess potential variation in N dynamics across a landscape gradient.

I hypothesized that long-term cattle grazing in the Sheep Creek montane riparian zone of north-central Colorado has accelerated N cycling because the riparian sites are highly productive and appear resilient to disturbances. I hypothesized that the accelerating effect would be exhibited by greater aboveground and belowground N pools (i.e., plant N, inorganic soil N, soil microbial N) and increased N fluxes (i.e., microbial respiration, litter decomposition, mineralization, and denitrification) in the long-term grazed compared with excluded sites of the Sheep Creek montane riparian ecosystem. I expected increases in N cycling to be especially apparent at streambank sites because cattle generally concentrate near stream banks where forage and water are abundant.

Methods

Study Site

The Sheep Creek riparian ecosystem is located in north-central Colorado, approximately 80 km northwest of Fort Collins, CO, within the Roosevelt National Forest (Fig. 3.1). Sheep Creek is a first-order stream that flows southeasterly into the North Fork of the Cache la Poudre River. Eaton Reservoir is located in the headwaters of the stream, 5 km upstream of my study sites which were located at 2,500 m elevation. The annual hydrograph is characterized by a snowmelt-driven peak in early spring and a second peak in late July or August when about 1.5 $m^3 s^{-1}$ are released from the reservoir for three to four weeks (Stednick and Fernald 1999). Limited weather data exist for this site, but available data indicate mean annual precipitation of 400 mm with 240 mm average precipitation during the growing season from May to September. Average daily temperatures range from 0° to 25°C during the growing season (Holland et al. 2005).

Soils in the Sheep Creek riparian zone are Naz sandy loams (Pachic cryoboroll) that occur to depths of 76-154 cm. Sandy loams characterize the upper 12 cm of the soil, while coarse and gravelly sandy loams are more common deeper in the soil profile. These soils are well-drained, have high hydraulic conductivity and medium water-holding capacity (Stednick and Fernald 1999; USDA-NRCS 2008). Willows dominante the overstory vegetation along Sheep Creek and include planeleaf willow (*Salix planifolia* Pursch var. *planifolia*), Geyer willow (*Salix geyeriana* Andersson), peachleaf willow (*Salix amygdaloides* Andersson), coyote willow (*Salix exigua* Nuttall ssp. *exigua*), and mountain willow (*Salix monticola* Bebb) (Holland et al. 2005). The herbaceous understory is comprised of several sedge species (*Carex aquatilis* Whalenb., *Carex utriculata* Boott, *Carex praticola* Rydb.), rushes (*Juncus arcticus* Willd., *Juncus balticus* Willd.), numerous forbs (*Erigeron formossisimus* Greene, *Fragaria vesca* L., *Fragaria virginiana* Duchesne, *Potentilla diversifolia* Lehm., *Potentilla pulcherrima* Lehm., *Taraxacum officionale* Weber, and *Trifolium repens* L.) and grasses (*Agrostis stolonifera* L., *Deschampsia caespitosa* L., *Phleum alpinum* L., *Phleum pratense* L., *Poa pratensis* L., *Poa palustris* L.) (Schulz and Leininger 1990; Popolizio et al. 1994). My study locations were in riparian meadows dominated by herbaceous cover and very few willows.

Grazeable range in the Sheep Creek allotment consists of 1,050 ha which had been heavily grazed from the 1890s to 1950s (Fig. 3.2). In an effort to protect fish habitat, the U.S. Forest Service (USFS) and Division of Wildlife constructed two exclosures in 1956 and one in 1959. A total of 40 ha of the riparian zone and 2.5 km of stream were fenced to protect the areas from livestock grazing. Cattle stocking rates by this time were reduced to about 1,000 animal unit months (AUMs) from 1,800 in late 1930s. Forage utilization continued at 70-80% until mid-1980s, when utilization was reduced to 40-60%, fluctuating at 100-300 AUMs (Schulz and Leininger 1990; Phillips et al. 1999; Stednick and Fernald 1999; Wheeler et al. 2002). According to Shaw (1992), streamside forage utilization is light at 20-35%, moderate at 36-55%, heavy at 56-75%, and very heavy at greater than 75%. The ecological condition of Sheep Creek was classified in 1991 by the USFS as excellent and range forage value as good (USFS, unpublished data). Current livestock grazing is season long from 21 June until 25 September.

Experimental Design

I located control study plots (i.e. exclosure treatments) in sites excluded from cattle grazing since the late 1950s and grazed treatment study plots in areas that have been grazed heavily until mid-1980s and moderately since then. I designed my study as a split-plot factorial experiment (Fig. 3.3) with grazing treatment (2 levels: exclosure and control) as the whole-plot factor and landscape location (3 levels: streambank, middle riparian, and edge of riparian) as the subplot factor. Within each landscape location I established 4, 1-m^2 permanent plots which I subsampled and then pooled for statistical analyses. I used 3 blocks as replicates and repeated measures over time for some variables. Types of data and year in which they were collected are summarized in Table 3.1 and presented in methods and results in two parts as Aboveground Plant Dynamics and Belowground Soil Dynamics.

Aboveground Plant Dynamics

<u>*Aboveground Primary Production and Plant C and N Pools*</u>

I used the standard harvest method to estimate aboveground primary production (APP) by clipping a given year's standing biomass at the end of each growing season (Appendix H). The vegetation samples were oven-dried at 60°C for 48 h and weighed. Subsamples of the dried vegetation were ground with a Wiley mill and analyzed for total plant carbon (C) and N with a dry combustion method (Sollins et al. 1999) in which ground samples (~0.1 g) were combusted in a LECO CHN-1000 (Laboratory Equipment Corp, St. Joseph, Michigan) analyzer and CO_2 and N gases were analyzed with an infrared gas analyzer and gas chromatograph, respectively. I multiplied plant %C and

%N by APP to calculate plant C and N pools (g C m^{-2} and g N m^{-2}) for each sampling location (Appendix I).

To obtain estimates of root C and N, I sorted roots from soil cores collected for soil analyses in June, August, and October 2006. I washed the roots, dried them at 60°C for 48 h, ground them in liquid N in a mortar and pestle, and analyzed them with the dry combustion method on a LECO CHN-1000 analyzer. I converted root %C and %N to C and N pools by adjusting the percentages by soil bulk density estimates described below (Appendix J).

Species Composition and Plant Cover

In August 2005, I characterized plant species composition with the point-intercept method using a laser point frame (Appendix K). The laser point frame was placed 5 times, at 20 cm intervals, across 1-m^2 plots to obtain readings for 50 laser positions. At each position, multiple hits on vegetation were recorded by species to obtain absolute cover of each species. I summed absolute cover for each species to obtain total plant cover for each sampling location and measured species richness as the number of different species at each sampling location (Appendix L). I also grouped species by functional groups (forb, sedge, grass, rush, shrub, tree, moss) to determine if there were differences in plant functional groups between grazing treatments or across landscape locations.

Belowground Soil Dynamics

I used composite soil samples from each sampling location for all soil analyses. At each sampling location, I composited 10 soil cores (2-cm diameter) collected to a 10 cm depth below the soil O horizon from 4 permanent, 1-m^2 plots within each sampling location. Soils were stored in plastic zip-lock bags and transported on ice to the laboratory where subsamples of field moist soil were taken for analyses of soil moisture, water-soluble organic C (WSOC) and water-soluble total N (WSTN), denitrification potential, and soil microbial biomass. Field moist soils were stored in a refrigerator until these analyses were completed. The remaining soil samples were air-dried, passed through a 2 mm sieve to remove rocks and gravel, and visible roots and litter were removed.

Soil Physiochemical Properties

To gain insight into potential differences in soil physiochemical properties and sizes of soil N pools across sampling locations, I conducted several different soil analyses. In 2005, I characterized soil particle size distribution (Appendix M) with the hydrometer method that is adequate for particle size analysis of soils with a clay content of 5-50% (Elliott et al. 1999). I used the core method to obtain estimates of soil bulk density (Elliott et al. 1999). I collected bulk density cores to a 10 cm depth with 7.3 cm diameter corer in mid-August 2005 when the riparian soils were drier than at the beginning of the growing season and less susceptible to compaction by the corer (Appendix M).

Soil pH was measured in June, August, and October 2005 with a standard pH meter that measured hydrogen ion activity in the soil samples (Robertson et al. 1999) (Appendix N). I measured soil organic matter (SOM), total C and N, inorganic N and soil moisture in June, August, and October of both 2005 and 2006. I ashed 1.0-g soil samples in a 500°C muffle furnace for 5 hours and calculated %SOM from differences in pre- and post-ashing weights (Nelson and Sommers 1996). I used soil bulk density to convert % SOM to pool sizes (Appendix P). Similarly to plant and root litter, I used the dry combustion method to measure soil %C and %N (Elliott et al. 1999) and then converted them to pool sizes by adjusting the percentages by soil bulk densities (Appendix O). I measured available inorganic nitrate (NO_3^-), ammonium (NH_4^+), and total inorganic N ($NO_3^- + NH_4^+$) with the exchangeable ion technique where I used 2M KCl to liberate NH_4^+ into solution by allowing K^+ to exchange for NH_4^+ and Cl^- for NO_3^- (Robertson et al. 1999). I then analyzed the extracts colorimetrically for NO_3^- and NH_4^+ on an Alpkem segmented flow autoanalyzer (OI Analytical, College Station, TX) and converted concentrations to pool sizes by adjusting the percentages by soil bulk densities (Appendix P). I assessed soil moisture at the time of each sampling event by oven-drying samples at 105°C for 24 h and reweighing them to obtain soil gravimetric water content (Jarrell et al. 1999) (Appendix O).

Lastly, I measured WSOC and WSTN in June, August, and October 2006 (Appendix Q). These C and N fractions represent water-extractable C and N pools that are an estimate of organics from root exudates, leachates from litter, and organic decomposition by-products (Davidson et al. 1987). Water-solubles can be used as an index of potential soil microbial activity because they represent the availability of labile

C and N available for microbial metabolism. I used a 5:1 ratio of deionized water to soil sample weight to extract WSOC and WSTN from soils. Samples were shaken for 30 min on a rotary shaker, centrifuged at 10,000 rpm, filtered through a Whatman GF/A glass microfiber filter, filtered again with a vacuum extractor through a 0.45 μ nylon acrodisc before analysis on a Shimadzu TOC-V instrument (Shimadzu Instruments, Inc. Columbia, MD).

Litter Decomposition

To assess possible differences in litter decomposition between grazing treatments and locations across the riparian zone, I conducted a decomposition experiment with litter bags containing senesced *Carex* spp. blades cut to 10 cm lengths. In October 2004, I buried 4 litter bags in each of the 4, 1-m^2 plots at each sampling location at a 10-15 cm depth. At the end of April 2005, as well as June, August, and October I removed one bag from each 1-m^2 plot for a total of 4 replicates per sampling location. The litter bags were emptied in the laboratory, the litter was then washed, oven dried at 60°C for 48 h and weighed. Subsamples of the dried litter (0.5 -1.0 g) were ashed in a muffle furnace at 500°C for 5 hours to obtain ash-free litter weights which were then used to calculate % ash-free dry mass (AFDM) remaining of initial litter mass (Harmon et al. 1999) (Appendix R).

Soil C and N Mineralization

Soil microbial respiration, N mineralization and immobilization are processes that control ecosystem-level patterns of C and N cycling, and I measured them to assess potential differences in ecosystem function associated with long-term cattle grazing or landscape position. I used aerobic soil incubations to measure potential N mineralization and soil respiration potentials of riparian soils. Net mineralization potentials are often a better indicator of site fertility than extractable inorganic soil N which is largely immobilized by soil microorganisms and plants, leached, adsorbed to soil or reduced to other forms. Thus, potential mineralization estimates are a good index of the capacity of a soil to provide inorganic N to plants (Robertson et al. 1999).

I conducted 21-day aerobic incubations of soils collected in both 2005 and 2006 (June, August, October) (Robertson et al. 1999). I incubated 30 g of dry soil (2 analytical replicates) in Mason jars at 55% WFPS which I calculated for each soil sample based on its bulk density and soil particle density of 2.65 g cm^{-3}. Moisture content of the incubated soils was monitored bi-weekly by reweighing and adding deionized water when necessary. I measured soil microbial respiration by measuring CO_2 accumulation in the headspace of each jar at day 3, 10, and 21 of the incubation period to make sure the headspaces did not saturate with CO_2 that could inhibit microbial activity. I analyzed CO_2 concentrations with a LI-COR LI-2400 CO_2 gas analyzer (LI-COR Biosciences, Lincoln, NE) and used the Ideal Gas Law to convert CO_2 concentrations to net C mineralization and express them as mg CO_2-C g^{-1} soil C (Appendix S). At the end of the incubation I extracted inorganic N with a 2M KCl solution as described above. I subtracted inorganic N measured at day 0 of the incubation from inorganic N measured at day 21 to obtain net N mineralized and expressed it as mg N g^{-1} soil N (Appendix S). Lastly, I calculated the immobilization index to gain insight into potential N immobilization of incubated soils by dividing soil CO_2 respiration (mg CO_2-C g^{-1} soil C) with net N mineralization (mg N g^{-1} soil N) (Appendix S). This metric has been used as an index of soil microbial N immobilization (Schimel 1986; Frank and Groffman 1998).

Denitrification Potential

Riparian zones are important buffers of runoff inputs from surrounding uplands to ground water and stream water (Lowrance et al. 1984; Groffman et al. 1996; Dhondt et al. 2006). Denitrification is an important process that contributes to the buffering capacity of riparian zones because it removes NO_3^- from soil and ground waters before they enter streams. Thus, significant alteration of denitrification by cattle grazing could affect the buffering capacity of a montane riparian zone. Since denitrification is spatially heterogeneous and in situ N_2O emissions are often below detection limits, I used a denitrification enzyme assay (DEA) to assess the denitrification potential in soils from the two grazing treatment levels and different riparian locations. The Tiedje (1994) method that I used estimates denitrifying enzyme concentration in a soil sample and since denitrifying enzymes are inducible, nitrous oxide production (N_2O) indicates conditions suitable for denitrification. I amended 25 g of field-moist soil (2 analytical replicates) with NO_3^-, glucose, and chloramphenicol, purged the incubation jars with N_2 gas to remove O_2, added acetylene (C_2H_2) to achieve a 10% (10 kPa) concentration in gas phase, and incubated the samples on a rotary shaker at room temperature for 60 min. I subsampled the headspaces every 15 min to establish linearity of N_2O production. The gas samples were analyzed for N_2O on an electron-capture detector (ECD) gas chromatograph, Shimadzu 14B (Shimadzu, Japan). I expressed the denitrification potential as N_2O production rate (μg N_2O-N g^{-1}soil h^{-1}) (Appendix T).

Soil Microbial Biomass

I used the chloroform-fumigation extraction (CFE) method to characterize soil microbial biomass C and N in soils collected in June, August, and October 2006. This method has been widely used for comparisons of temporal changes in microbial biomass in natural and disturbed systems (Horwath and Paul 1994). In this procedure, microbial constituents (soluble C, organic N and NH_4^+) are released by fumigation with chloroform and extracted directly to determine the size of soil C and N biomass. The CFE has an advantage over the chloroform fumigation incubation method because it prohibits NH_4^+ immobilization or denitrification activity, and has low interference from non-microbial labile C and N (Horwath and Paul 1994). I used 10 g of field-moist soil (2 analytical replicates) for un-fumigated and fumigated samples. The un-fumigated samples were extracted at day 0 of the incubation with a 0.5 M K_2SO_4 at a 5:1 ratio of extractant weight to dry soil weight to provide initial concentrations of soil microbial C and N. Fumigated samples were placed in 50-ml beakers and fumigated with ethanol-free chloroform. The chloroform-fumigated samples were incubated in the presence of chloroform fumes in a desiccator for 5 days to release soluble C, organic N and NH_4^+ from microbial biomass. The 5-day incubation period is recommended for release of potentially extractable microbial products until extracellular enzyme activity ceases or substrate becomes limiting (Horwath and Paul 1994). The fumigated samples were also extracted with a 0.5 M K_2SO_4 at a 5:1 ratio of extractant weight to dry soil weight and both fumigated and un-fumigated extracts were analyzed for microbial C and N on a Shimadzu TOC-V. I calculated microbial biomass C and N (Appendix U) by respectively differencing these constituents from fumigated and un-fumigated extracts and dividing them by extraction efficiency coefficients ($K_{ec} = 0.35$ and $K_{en} = 0.68$) (Horwath and Paul 1994).

Data Analysis

I used analysis of variance (ANOVA) to determine the influence of grazing treatments and landscape locations on aboveground plant dynamics and several belowground soil response variables (soil physiochemical properties and litter decomposition). Since these analyses revealed significant differences ($P < 0.10$) in soil particle size distribution, C, N, and SOM pools between landscape locations, I used these variables as covariates in an ANCOVA to determine the influence of grazing treatments and landscape locations on soil microbial respiration, N mineralization, immobilization, denitrification, and soil microbial biomass.

I used the mixed procedure in SAS 9.1 software (SAS Institute 2003) for both repeated-measures ANOVA and ANCOVA, and accepted significant differences at $P < 0.10$ (Appendix V). Random effects in the proc mixed procedures included block and block by location, grazing treatment, and time interactions while fixed effects included location, grazing treatment, and time. In some analyses, I used log or square-root transformed data to normalize data distribution and make statistical comparisons, but I reported untransformed least square means and standard errors in tables and figures. The appropriate data transformations for different response variables are stated in the results section.

In addition to the above analyses, I used non-metric multidimensional scaling (NMS), an ordination technique, to evaluate community relationships in species composition across the riparian zone (Kruskal 1964) (Appendix V). I used the Sorensen (BC) distance measure in PC-ORD software (Mather 1976; McCune and Grace 2002) with a random starting configuration and an instability criterion of ≤ 0.0005. I performed 10 runs with real data, 10 iterations for stability, 200 maximum iterations, and 20 randomized runs for the Monte Carlo test. I assessed dimensionality of the data by selecting the highest dimensionality (i.e. number of axes) that reduced the final stress by 5 or more (on a scale of 0-100) and where final stress was lower than $P < 0.05$ for the Monte Carlo test. I then used a joint plot overlay to describe plant functional group gradients in species composition where the cutoff criteria for key functional groups were $r^2 \geq 0.1$.

Results

Aboveground Plant Dynamics

Aboveground Primary Production and Plant C and N Pools

Cattle grazing did not have a significant effect on APP estimated by peak standing biomass ($P = 0.68$) in either 2005 or 2006 (Appendix V, Table V-1a). Forage utilization by cattle was low in both years. In 2005, cattle, on average, utilized 17% of biomass at streambank locations, 10% in the middle of the riparian zone, and 0% at the edge of the riparian zone. In 2006, cattle, on average, utilized 32%, 27%, and 10% of biomass at streambank, middle riparian, and edge of riparian locations, respectively. Although APP did not differ between grazing treatments, it was significantly higher at streambank and middle riparian locations than at the riparian edge ($P = 0.02$; Appendix V, Table V-1a and V-1b). Aboveground primary production at the streambank and middle riparian locations was 35% higher than at the edge of the riparian zone (Fig. 3.4A). Aboveground primary production was also 36% higher in 2005 than 2006 ($P < 0.0001$; Fig. 3.4B).

There were no significant differences in total plant C pools, total plant N pools, or plant C:N between exclosure and grazed treatments in 2006 ($P = 0.50, 0.51, 0.37$, respectively; Table 3.2, Appendix V, Table V-2a). Total plant C and N pools, however, were higher at streambank and middle riparian locations than at the riparian edge ($P = 0.03, 0.03$, respectively; Appendix V, Table V-2b). The total plant C pools were 34 to 41% higher at the streambank and middle of the riparian zone while total plant N pools were 35 and 44% higher at these two locations compared with the edge of the riparian zone.

Similarly to aboveground plant C and N pools, there were no significant differences in total root C pools, total root N pools, or root C:N between exclosure and grazed treatments ($P = 0.65, 0.90, 0.53$, respectively; Table 3.3). Furthermore, there were no differences in these root variables across riparian locations ($P \geq 0.41$; Appendix V, Table V-3).

Species Composition and Plant Cover

Ordination of sampling units in species space did not reveal any patterns in species composition associated with grazing treatment (Fig. 3.5A) or location (Fig. 3.5B). Stress was 20.5 and instability was 0.00046 for a two-dimensional NMS solution based on Kruskal's stress formula 1 (Appendix V, Table V-7). NMS axis 1 and 2, respectively, represented 48 and 24% of variance in ordination space. The joint plot with functional groups as predictors revealed three key functional groups (forb, grass, and sedge) that were most strongly related with the NMS axes. Forbs were better related with NMS axis 2 (r^2 = 0.12), grasses were equally related with axis 1 and 2 (r^2 = 0.12, 0.13, respectively), while sedges related best with axis 1 (r^2 = 0.32).

Subsequent analysis of variance on cover of the three functional groups did not reveal significant differences associated with grazing treatment ($P \geq 0.47$; Appendix V, Table V-4a). Grass cover, however, was significantly greater in streambank and middle riparian locations compared with the edge of the riparian zone ($P = 0.04$; Fig. 3.6B, Appendix V, Table V-4b). Grass cover was 42 and 47% higher in streambank and middle riparian locations than riparian edge. Sedge and forb cover did not differ significantly across locations ($P \geq 0.48$), however, forb cover exhibited a pattern opposite that of grasses since forbs were more prevalent at the riparian edge (Fig 3.6D). There were no significant differences across locations ($P = 0.25$) or grazing treatments ($P = 0.32$) in total plant cover which comprised of the three main functional groups and the less dominant cover classes: rushes, shrubs, moss, and tree saplings (Appendix V, Table V-5).

Similarly, there were no significant grazing treatment or location effects on species richness (Table 3.4) which ranged from 11 to 13 across all treatment levels (Appendix V, Table V-5). *Agrostis stolonifera* was the most abundant species across grazing treatments and riparian locations (Table 3.4). However, the only significant grazing treatment effect on the cover of a key species occurred for *Fragaria* spp. which were more abundant in excluded versus grazed sites ($P = 0.10$; Appendix V, Table V-6a and V-6b). The major species also differed little across the three riparian locations. Significant differences occurred for *Poa pratensis* ($P = 0.05$) which was most abundant in the middle of the riparian zone and *Erigeron formosissimus* ($P = 0.001$) that was most common at the edge of the riparian zone (Appendix V, Table V-6a and V-6b).

Belowground Soil Dynamics

<u>Soil Physiochemical Properties</u>

Soil physical properties (texture and bulk density) as well as pH, soil moisture, WSOC and WSTN did not differ between excluded and grazed sites (Table 3.5A). However, there were differences in soil texture and WSOC and WSTN associated with landscape location. Fine soil fractions (i.e., clay and silt) were significantly lower at streambank locations than the middle or edge of the riparian zone ($P \leq 0.08$), while the opposite occurred for sand fraction with sand being highest in streambank sites ($P = 0.02$; Appendix V, Table V-8a and V-8b). Soil moisture content was greater in 2005 than 2006 ($P = 0.0002$; Appendix V, Table V-11a and V-11b). In both years soil moisture was lowest in the middle of the growing season, August, relative to the beginning and end of the growing season, June and October.

Differences in soil pools of organic matter, C, and N occurred between grazing treatments within each year and between treatments within landscape location (i.e., main effect interactions, Table 3.5B; Appendix V, Table V-12a, V-12b,V-13a, and V-13b). Grazing treatment did not have a significant effect on these properties in 2006, but in 2005 the soil C and N pools were respectively 27% and 18% higher in excluded than grazed sites. Soil C pools were also higher at excluded sites compared with grazed streambank and middle riparian sites ($P \leq 0.08$), while the soil N pool was higher only at excluded vs. grazed streambank sites ($P = 0.04$). There were no significant grazing treatment effects on SOM pools over time or in any of the landscape locations ($P \geq 0.11$). Soil C:N also did not differ between grazing treatments over time or at different sampling locations sites resulting in no significant treatment by year or location interactions ($P \geq 0.17$).

Soil C, N, and SOM pools also differed significantly across landscape locations ($P \leq 0.003$) and, in addition to clay content, were used as covariates in analyses of soil C respiration, N mineralization, denitrification, and soil microbial biomass. The three pools were lower at streambank locations compared with the middle and edge of the riparian zone (Fig 3.7). Water soluble organic C and total N were also significantly lower at streambank sites compared with the edge of the riparian zone (Table 3.5A).

With respect to time during the growing season, soil C, N, and SOM pools differed significantly over time ($P \leq 0.02$). The soil C pool increased from 3.9 to 4.3 kg m^{-2}, soil N pool increased from 0.27 to 0.29 kg m^{-2}, and SOM pool increased from 8.9 to 9.5 kg m^{-2} between June and October. However, these differences are small and probably not biologically significant. Soil C and SOM pools were also higher in 2005 than 2006 ($P \leq 0.003$) but no difference between the two years for soil N pool was found ($P = 0.38$).

Water soluble organic C and total N were measured only in 2006, but both of these pools were highest in August when soil moisture was also lower which suggests a concentration effect of organic C and total N ($P < 0.0001$; Appendix V, Table V-14a and V-14b). However, these differences were very small and might not be biologically important; WSOC was 3.9 g m^{-2} in August, 2.6 g m^{-2} in June and 3.3 in g m^{-2} October, while WSTN was 0.05 g m^{-2} in August compared with 0.03 g m^{-2} in June and 0.04 g m^{-2} in October.

Pools of inorganic N species and total inorganic N were not different between exclosure and grazed treatments ($P \geq 0.31$; Table 3.6, Appendix V, Table V-15a and V-15b). Ammonium and total inorganic N also did not differ between locations, however, the NO_3^--N pool at streambank sites was 75 and 33% lower than in the middle and edge of the riparian zone, respectively ($P = 0.02$). The soil NO_3^--N pool was highest in June and declined significantly over the course of the growing season ($P < 0.0001$). Ammonium did not differ in June and August; however, it declined significantly by October ($P = 0.06$). Since ammonium comprised 95 – 97% more of the total inorganic N pool than nitrate, the total inorganic N pool also decreased significantly from June to August and October ($P = 0.02$).

Litter Decomposition

There were no significant differences in litter decomposition between grazing treatments ($P = 0.43$) or riparian locations ($P = 0.34$; Appendix V, Table V-16a and V-16b). Over the course of the winter, litter mass decreased by 12% (88% AFDM at the end of April). Litter remaining in the litter bags declined another 10% by early June to 78% AFDM. Most decomposition of litter occurred between June and early August when litter mass decreased from 78 to 48% AFDM (Fig. 3.8). After one year, litter decomposed to 47% AFDM by October 2005.

Soil C and N Mineralization

Moderate (light over the 2 years of the study, light-to-moderate over the last 20 years) cattle grazing did not accelerate C or N mineralization when these estimates were pooled over landscape locations ($P > 0.28$; Table 3.7, Appendix V, Table V-17a and V-17b). However, there was a significant treatment by location interaction for nitrification, net N mineralization, and the immobilization index ($P \leq 0.05$) at streambank sites only. The long-term moderate cattle grazing increased nitrification potential by 72%, increased net N mineralization by 35% and decreased immobilization by 42% at the streambank (Fig. 3.9). This increase in N mineralization at streambank sites, however, was not reflected by soil CO_2 respiration which was similar between grazing treatments at all three locations ($P = 0.19$). Furthermore, raw data suggest that the significant increase in potential nitrification in soils from grazed streambank sites could be associated with much higher nitrification at one out of three grazed streambank sites. At this particular streambank site, nitrification was on average 97% higher compared with the two other streambank sites. This site was also utilized the most by cattle in 2005 and 2006.

Nitrification and net N mineralization were higher at the beginning and middle of the growing season compared with the end of the season in October ($P = 0.03$), whereas the immobilization index exhibited an opposite trend of low immobilization in June and August compared with higher immobilization at the end of the growing season ($P = 0.03$). There were no significant differences in soil microbial respiration over the course of the two growing seasons. Furthermore, only nitrification was higher in 2005 (when averaged over treatments, location, and time of growing season) compared with 2006 ($P = 0.007$), while immobilization was lower in 2005 compared with 2006 ($P = 0.02$; Table 3.7).

Denitrification Potential

Denitrification potential, measured as N_2O production rate, was 147 ± 49 SE μg N_2O-N g^{-1}soil h^{-1} in excluded sites compared with 227 ± 49 SE μg N_2O-N g^{-1} soil h^{-1} in grazed sites. But, this difference was not significant for log transformed data ($P = 0.38$, Appendix V, Table V-18a and V-18b). There were also no significant differences in denitrification potential across the riparian zone ($P = 0.02$). Nitrous oxide production rate at streambank sites was 194 ± 77 SE μg N_2O-N g^{-1} soil h^{-1}, 173 ± 57 SE μg N_2O-N g^{-1} soil h^{-1} in the middle of the riparian zone and 195 ± 61 SE μg N_2O-N g^{-1} soil h^{-1} at the edge of the riparian zone. Denitrification potential was similar when compared by treatment within each location (Fig. 3.10A). However, there was a significant location by time of growing season interaction ($P = 0.06$) which revealed highest denitrification potential at the beginning of the growing season, June, within each riparian location (Fig. 3.10B). Although mean denitrification potential at the riparian edge in June was 46% higher than mean denitrification potential in June at the streambank, this difference was not significant ($P = 0.44$).

Soil Microbial Biomass

Soil microbial biomass C , N or C:N ratios (Table 3.8) did not differ between grazing treatments ($P \geq 0.15$; Appendix V, Table V-18a and V-18b). Microbial C was greater at the streambank than at both middle riparian and edge of riparian locations ($P < 0.09$). Microbial N was also higher at the streambank than the edge of the riparian zone ($P < 0.07$), but not the middle riparian locations. Soil microbial biomass also changed over the course of a growing season ($P \leq 0.05$). The microbial C pool was 100 ± 4.30 SE mg C m^{-2} at the end of the growing season in October compared with 90 ± 4.04 SE mg C m^{-2} in June and 87 ± 4.24 SE mg C m^{-2} in August. Similarly, the microbial N pool was higher in October, 7.21 ± 0.63 SE mg C m^{-2}, compared with 5.52 ± 0.60 SE mg C m^{-2} in June and 5.72 ± 0.62 SE mg C m^{-2} in August. Soil microbial C:N ratios ranged between 15 and 19 across landscape locations (Table 3.8).

Discussion

Cattle Grazing Effects on N Dynamics

Overall, N cycling in long-term cattle grazed sites of the Sheep Creek montane riparian ecosystem did not fit the accelerating nutrient cycling scenario (Ritchie et al. 1998; Wardle et al. 2004). Cattle grazing did not enhance APP, aboveground or belowground plant N pools, soil N pools, soil microbial biomass, litter decomposition, potential N mineralization or denitrification in the riparian zone as a whole. Also, there were no apparent differences in plant species composition between grazed and excluded treatments.

The potential for accelerated N cycling was detected only near the stream bank where net N mineralization in incubated soils was 13.6 ± 1.6 mg N g^{-1}soil N in cattle grazed sites compared with 8.8 ± 1.3 mg N g^{-1} soil N in excluded sites, while the immobilization index was lower in grazed than excluded sites. Areas repeatedly and frequently grazed by large herbivores such as cattle have been shown to influence N cycling by increasing available N through urine and fecal inputs, lowering C:N ratios of plant litter and soil organic matter, increasing mineralization rates and reducing microbial immobilization of N (Risser and Parton 1982; Ritchie et al. 1998; Singer and

Schoenecker 2003). Studies reporting increased N mineralization in grazed sites were often conducted in upland sites grazed only by wild ungulates (Frank and Groffman 1998; Singer and Schoenecker 2003) or sites where domestic cattle grazing was light to moderate (Risser and Parton 1982; Shariff et al. 1994). A study of cattle grazing effects on belowground ecosystem responses in riparian wet and dry meadows of eastern Oregon reported lower net potential nitrification and mineralization in grazed compared with exclosed wet meadows (but not dry meadows), and lower aboveground and belowground production in exclosed than cattle grazed sites (Kauffman et al. 2004). Rates of N transformations are correlated with primary productivity (Vitousek and Howarth 1991; Hart et al. 1994). In my study, I did not observe significant differences in aboveground production between grazed and excluded riparian sites and net N mineralization was greater only in streambank grazed compared with excluded sites.

Increased net N mineralization only in the streambank grazed sites resulted from higher nitrification of mineralized NH_4^+ to NO_3^- in streambank grazed than excluded sites. Nitrification is accomplished by a small number of obligate aerobic bacteria and is generally optimized when bulk soils are near field capacity or about 60% WFPS (Myrold 2005). I measured potential mineralization in aerobic incubations under controlled abiotic conditions where soil moisture of incubated soils was optimized at 55% WFPS. Similar soil moisture in all incubated soil samples should have equally affected nitrification in soil samples, unless there were inherent differences in the soil environment or soil microbial communities of the incubated samples.

Data suggest that higher nitrification in grazed streambank sites could have been specifically associated with high nitrification (89% higher) at one out of the three grazed streambank sites I sampled. This particular site was unique because it had higher soil N pools than the other two grazed streambank sites: 48% more total soil N, 26% more inorganic N, 75% more water-soluble total N, 44% more microbial N, and 45% more soil organic matter. This site also had 21% higher APP, 33% higher aboveground C, and 30% higher aboveground N compared with the other grazed streambank sites. Although these differences were not statistically significant, the larger N pools do not suggest that N is being lost from this site. Rather, N cycling might be accelerated at this particular streambank site via higher N mineralization and plant uptake of N (i.e., higher aboveground plant N), especially since this site was utilized the most by cattle compared with all other study locations in 2005 and 2006.

Spatial heterogeneity of N distribution on a landscape can be amplified by ungulate selection of habitats and patches (Hobbs 1996). Since cattle tend to concentrate near the stream where forage and water are abundant (Kauffman and Krueger 1984), it is likely that they move N from surrounding areas to the streambank. Although I did not quantify cattle movements or inputs of labile fecal material in this study, I observed most cattle use and loafing near stream banks. In contrast, Blank et al. (2006) found cattle grazing effects on nutrient dynamics to be most pronounced at the forest edge of a Sierra Nevada montane riparian meadow, and attributed them to spatial transfer of nutrients via urine and feces to these locations. However, the forest edge in that study received a greater proportion of loafing use because cattle had access to mineral salts that were placed along the forest edge (Blank et al. 2006).

According to De Mazancourt (1998), grazing optimization and nutrient acceleration are likely to occur when herbivores transport nutrients from outside the ecosystem to areas that are being considered. The transport of a limiting nutrient, such as N, to a site reduces (or makes negative) the proportion of the nutrient lost when the herbivore leaves the system. For example, Singer and Schoenecker (2003) found an accelerating nutrient scenario in the grasslands of Yellowstone National Park (YNP) where elk are abundant (i.e., doubled soil N mineralization, increased aboveground N yield, increased N in most plant species and enhanced aboveground production). However, they found nutrient cycling to be decelerated by elk in willow and aspen vegetation communities of Rocky Mountain National Park (RMNP): declines in soil N mineralization rates, N pools, aboveground N yield and aboveground production. Nutrient deceleration in RMNP was attributed to higher ungulate densities and consumption rates in RMNP relative to YNP, coupled with a tendency of the ungulates to daily transport N from willow and aspen communities to other vegetation types in RMNP (Singer and Schoenecker 2003).

Because I did not find differences in N pools or N fluxes between cattle grazed and long-term excluded sites, the Sheep Creek riparian zone appears to be resilient and resistant to cattle grazing. Several studies have shown that riparian ecosystems exhibit signs of recovery within 5 to 20 years of livestock exclusion. Although data on soils and vegetation prior to the change in Sheep Creek livestock management in the late 1950s do not exist, historic photographs indicate that willow cover and streambank stability has recovered over the last 50 years. Signs of resiliency in herbaceous and shrub cover were observed 10-15 years after cattle exclusion from parts of the riparian zone (Trlica 2008, personal communication). Shulz and Leininger (1990) measured increased shrub and graminoid cover after 26 years of livestock exclusion in the Sheep Creek riparian corridor. Based on another study at Sheep Creek, Holland et al. (2005) concluded that livestock removal can be effective for initiating rapid recovery of willow canopy cover and height within 5 years of exclosure. Thus, the Sheep Creek riparian zone appears to have recovered from severe degradation from heavy livestock grazing in the early to mid-20th century.

Current cattle grazing does not appear to be detrimental to ecosystem functioning and suggests that the Sheep Creek montane riparian zone is resistant to change from light-to-moderate, season-long grazing. Other riparian ecosystems might not be as resistant to grazing especially if large herbivores affect soil physical properties. For instance, Kauffman et al. (2004) found that effects of cattle on soil physical properties in riparian meadows exerted stronger influences on N dynamics than did altered belowground production or fecal and urine inputs. They observed increased soil bulk density, decreased pore space and infiltration rates in grazed sites. Other studies have also reported increased bulk density and/or decreased soil pore space in cattle grazed sites (Orr 1960; Bohn and Buckhouse 1985; Clary 1995). The Sheep Creek montane riparian zone, however, is unique because seasonal changes in soil bulk density and infiltration rates are restored annually through freeze-thaw activity. Wheeler et al. (2002) found that a one-time heavy grazing event at Sheep Creek caused increase bulk density and decreased infiltration rates at 5-10 cm and 10-15 cm soil depths but not in the surface organic layer of 0-5 cm. These soil parameters returned to pre-disturbance values within one year and were attributed to frequent freeze-thaw activity and high soil organic matter in soils of this montane riparian zone (Wheeler et al. 2002). These soil structural properties likely contribute to the resiliency and resistance of the Sheep Creek riparian zone to cattle grazing.

Spatial Variation in N Dynamics

Aboveground and belowground ecosystem components associated with N dynamics varied across the Sheep Creek riparian zone from the streambank to sites near the edge of the riparian zone. In general, streambank sites were more productive and had greater aboveground plant C and N pools than sites at the edge of the riparian zone. My study locations were in sites dominated by herbaceous cover (i.e., meadows) with very few if any willows. Herbaceous vegetation near the streambank was dominated by grasses and sedges whereas forbs were more prevalent at riparian edge sites. A similar pattern of plant functional group composition was observed by Blank et al. (2006) in a Sierra Nevada montane riparian meadow. Dwire et al. (2004) also found that narrow zonation of dominant vegetation occurs along a landscape gradient from the stream to the floodplain terrace of a montane riparian meadows in northeastern Oregon. Differences in species composition were also reflected in biomass distribution. Total biomass was highest in sedge-dominated stream edges, intermediate biomass occurred in grass-sedge moist meadow communities in transitions of the riparian meadows, and biomass was lowest in dry meadows (near floodplain terrace) dominated by grasses and forbs.

Belowground nutrient pools in the Sheep Creek riparian zone exhibited a pattern opposite of aboveground dynamics: streambank sites had smaller total soil C and N pools, smaller WSOC and WSTN pools, and less soil organic matter than sites at the edge of the riparian zone. These patterns indicate that turnover rates of C and N might be faster at streambank sites compared with sites farther away from the stream. Faster nutrient supply rates at streambank sites were supported by higher soil microbial biomass C and N and higher mineralization (ammonification or NH_4^+ production) measured with ion-exchange resin (IER) bags (see Chapter IV) in streambank soils compared with riparian edge soils. Denitrification also occurred near the stream bank throughout the growing season because the groundwater level remained elevated at the streambank while it declined at the edge of the riparian zone by early fall.

However, I did not detect significant differences in potential net N mineralization or litter decomposition among the three riparian locations. Because it is difficult to duplicate in situ soil moisture during soil incubations (Robertson et al. 1999), I used a constant moisture of 55% water-filled pore space for all samples which might have contributed to no relative differences between soils from different riparian locations under similar laboratory conditions. After one year, litter decomposed to 46-49% AFDM across the three riparian locations. However, one year might not have been long enough for decomposition of recalcitrant litter fractions. Aerts and de Caluwe (1997) estimated percent of initial mass remaining of 4 different *Carex* spp. to range from 5 to 43% after 3 years of decomposition depending on litter chemistry and soil fertility of the plants' native growing sites. Vitousek et al. (1994) also found that site characteristics explained most variation in decomposition rates across an environmental gradient and different substrates. Thus, it is possible that decomposition of *Carex* litter in my study could have differed across riparian sites after a longer litter bag incubation period, especially since I observed larger microbial biomass pools at the streambank compared with the riparian edge.

Merrill and Benning (2006) also found landscape variation in N dynamics in a montane riparian zone along Ward Creek, a tributary to Lake Tahoe. They found significant differences in denitrification potential, net mineralization, net nitrification, and groundwater nutrient flux among five different ecosystem types. They also compared direct and indirect control factors (e.g., soil redox, soil temperature, groundwater elevation, valley form, flood frequency) on denitrification dynamics and found differences in these controls among ecosystem types. The ecosystem types spanned a longitudinal gradient from upper alluvial valleys to steep mid-reaches and lower wide alluvial valleys. Their results suggest that riparian zones should be stratified or classified by ecosystem types when evaluating landscape differences in riparian N processes or water quality effects.

Conclusions

Cattle grazing did not accelerate ecosystem-level N cycling (i.e., increase N pools or fluxes) in the Sheep Creek montane riparian zone. Evidence of accelerated N cycling was found only at cattle-grazed streambank sites where potential net N mineralization measured in laboratory soil incubations was greater compared with cattle excluded streambank sites. The higher net N mineralization rates, however, were not reflected by significantly higher aboveground or belowground N pools that were measured *in situ*. The results of this study suggest that the Sheep Creek riparian zone is resistant to cattle grazing and that season-long, light-to-moderate grazing does not significantly alter plant production, species composition, litter decomposition, or N dynamics. The riparian ecosystem appears to have recovered from severe degradation from heavy livestock grazing in the early to mid-20th century, and current livestock management is a viable use within the Sheep Creek allotment.

Furthermore, the results of my study confirm that spatial variation occurs in montane-riparian nutrient dynamics even across relatively narrow riparian zones such as Sheep Creek. Streambank sites were more productive but had smaller soil C and N pools than upland edges of the riparian zone. Denitrification was also higher near the stream bank than the edge of the riparian zone, but N mineralization did not differ along the landscape gradient. Consequently, montane riparian corridors should not be viewed as a uniform swath of land adjacent to a stream but rather should be stratified by zones or ecosystem types when considered in the context of larger spatial scales such as watersheds.

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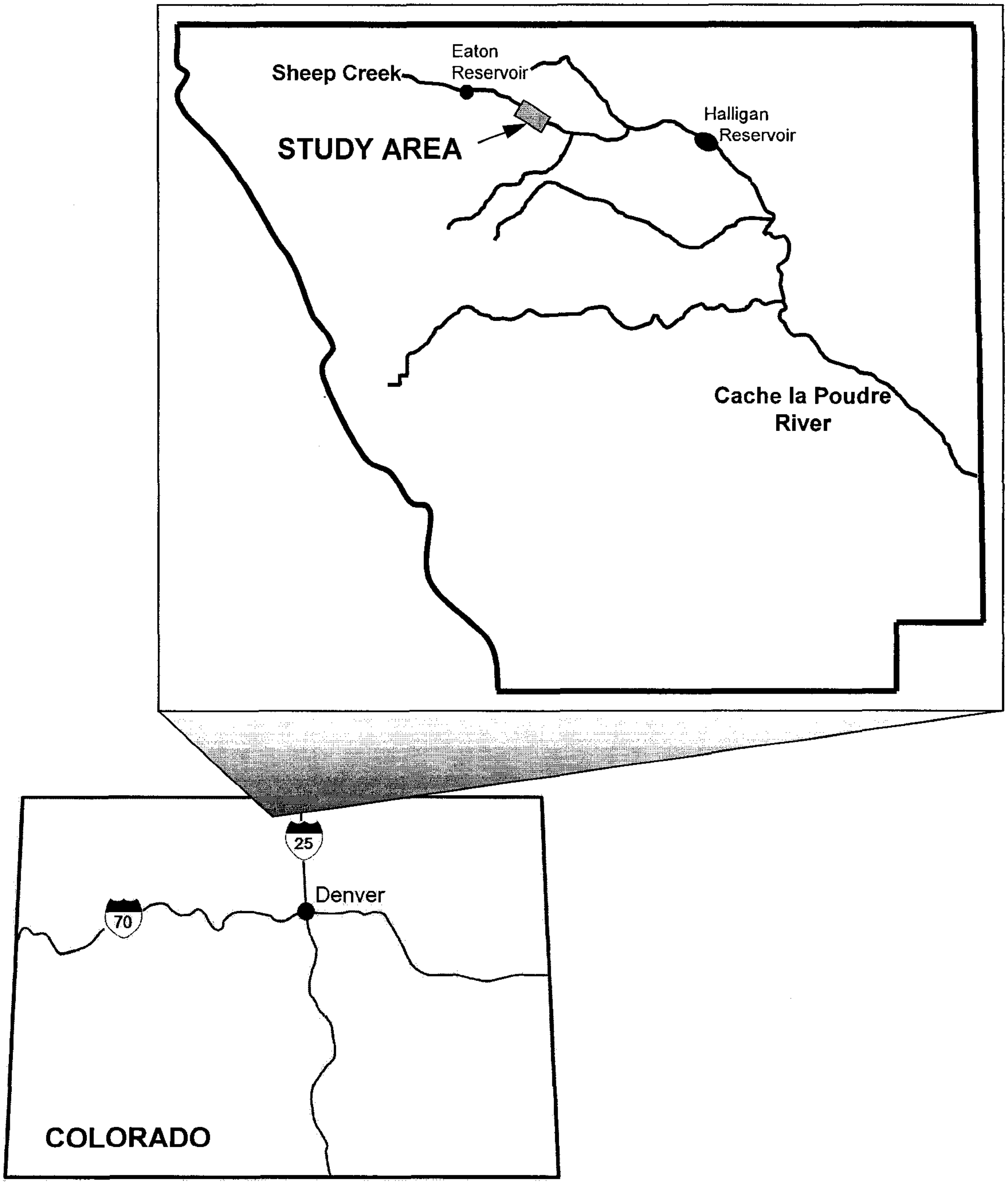


Figure 3.1. Location of the Sheep Creek study site in north-central Colorado, Roosevelt National Forest.

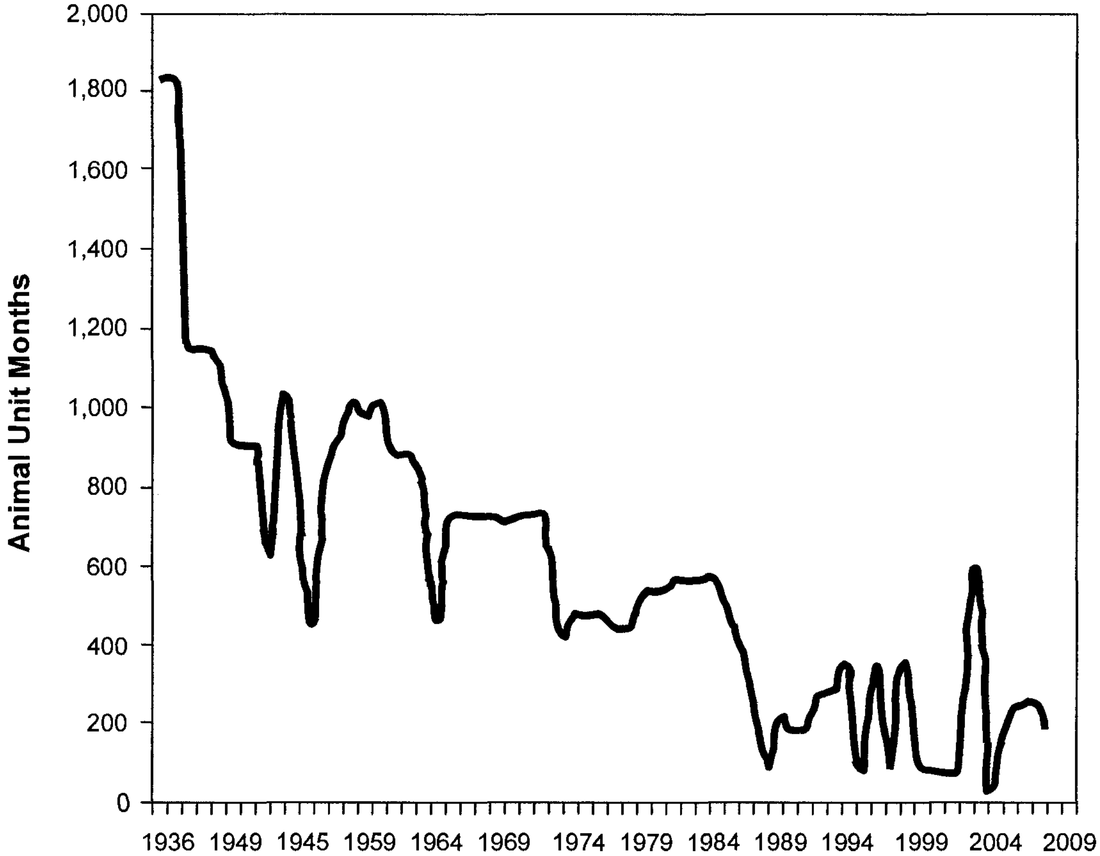


Figure 3.2. Animal unit months on the Sheep Creek Grazing Allotment since 1936. Source: USFS Sheep Creek C & H Allotment Management Plan, Red Feather Ranger District, Roosevelt National Forest (Holland et al. 2005, USDA-USFS 2008).

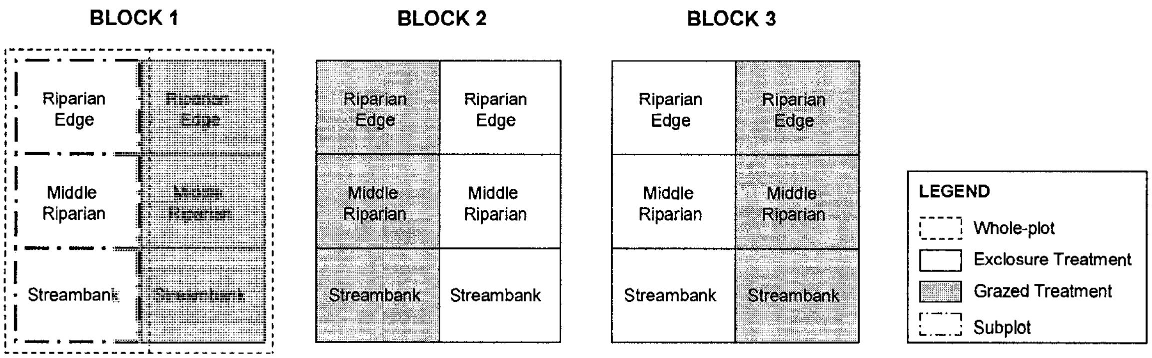


Figure 3.3. Split-plot design with 3 blocks as replicates. The whole-plot factor was cattle grazing treatment with 2 levels (exclosure and grazed) while the subplot factor was landscape location with 3 levels (streambank, middle riparian, riparian edge).

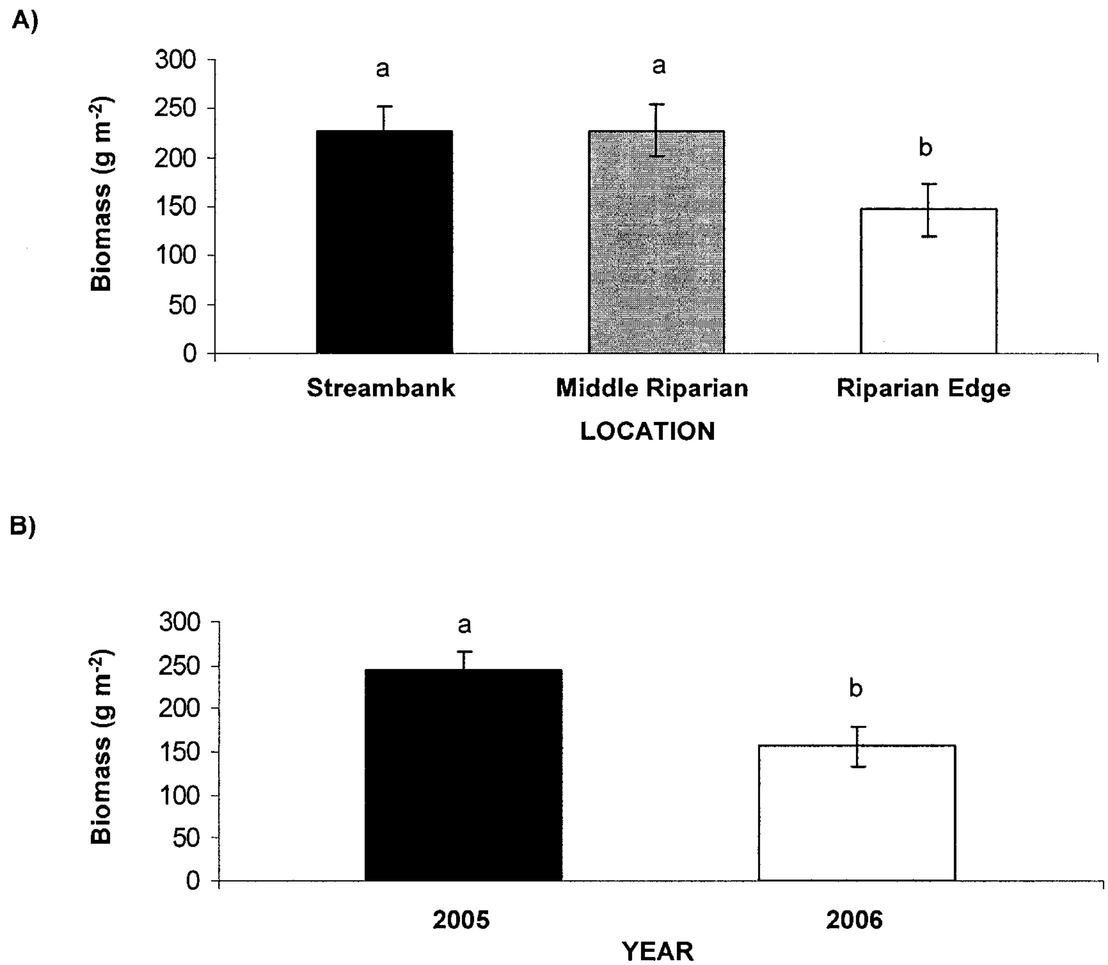
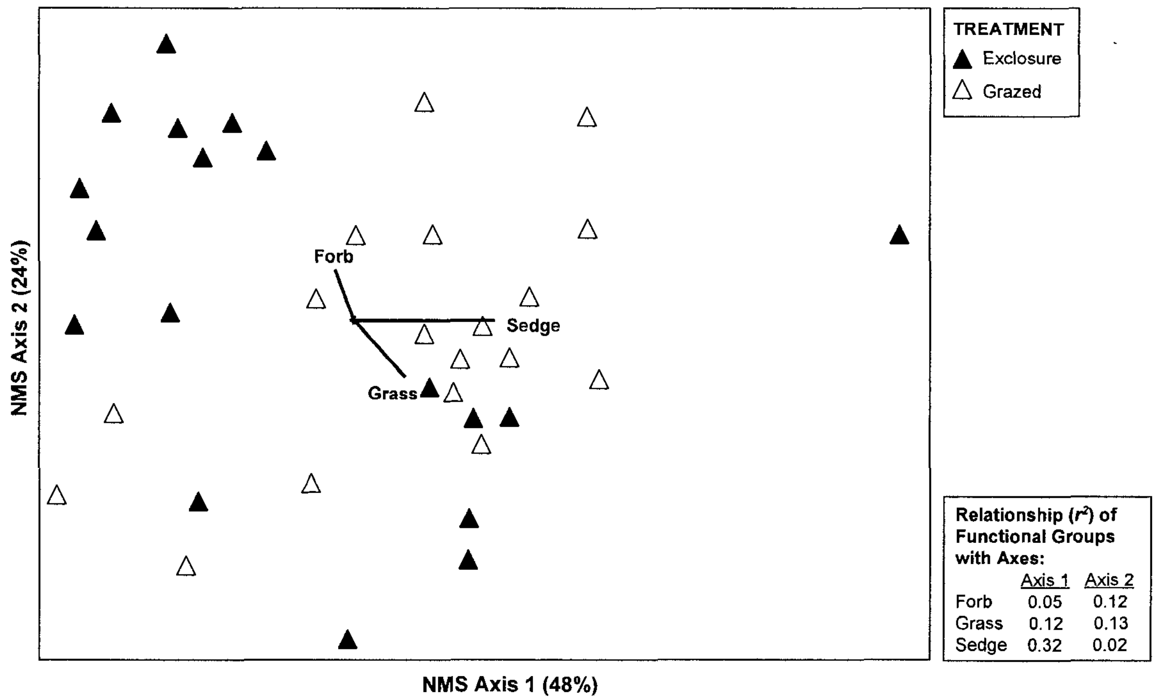


Figure 3.4. Comparison of aboveground primary production estimated by given year's peak standing biomass (g m^{-2}) between **A)** locations and **B)** years. Letters above standard error bars (± 1 SE) indicate significant differences from an ANOVA at $P < 0.10$, n = 18.

A)



B)

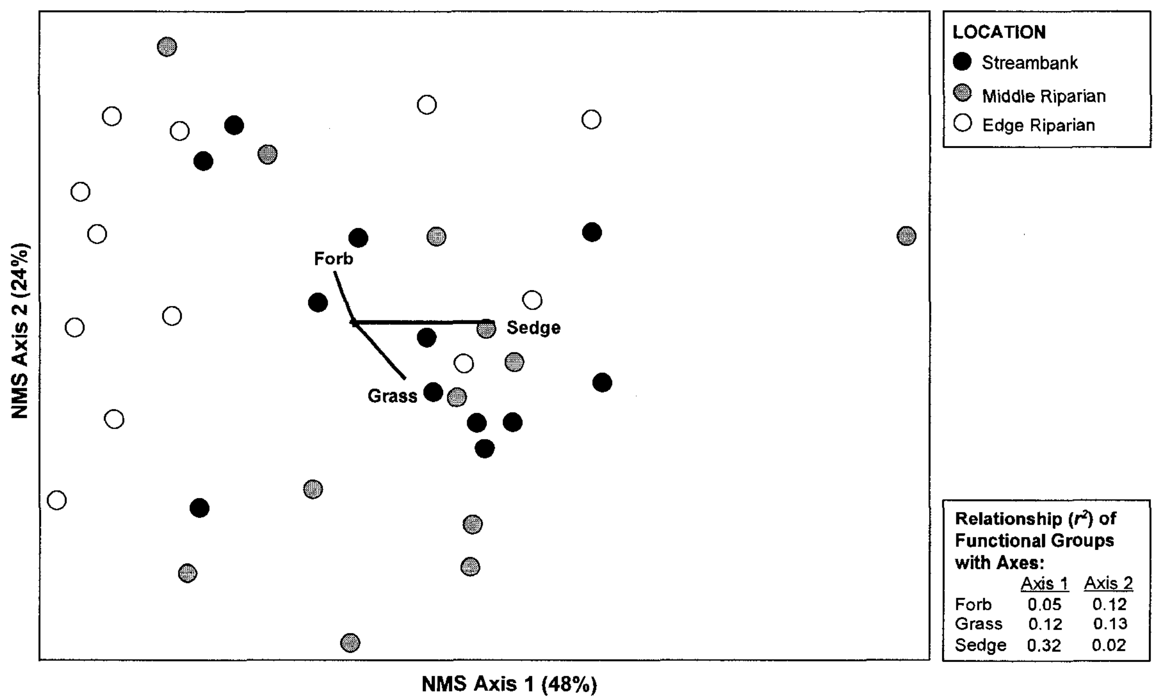


Figure 3.5. Ordination of sampling units in plant species space with Nonmetric Multidimensional Scaling (NMS) using Sorensen (Bray-Curtis) distance measure. **A)** Graphical representation of sampling units by treatment and **B)** by location.

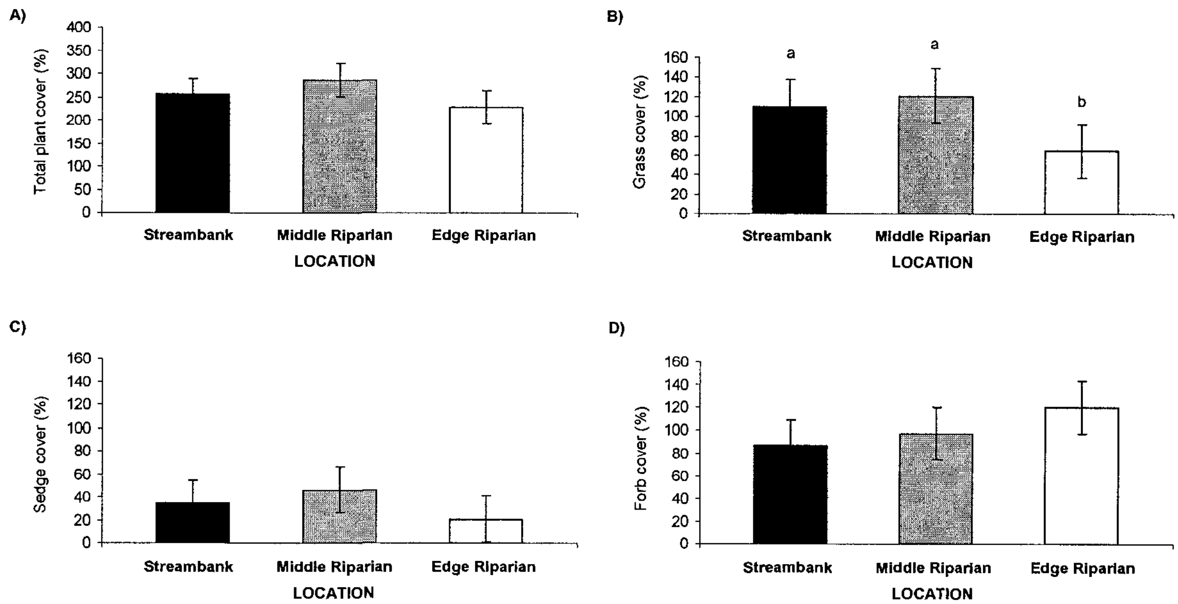


Figure 3.6. A) Total plant cover (%), **B)** grass cover (%), **C)** sedge cover, and D) forb cover (%) at three locations across the riparian zone. Different letters above standard error bars (± 1 SE) indicate significant differences from an ANOVA at $P < 0.10$, n = 18.

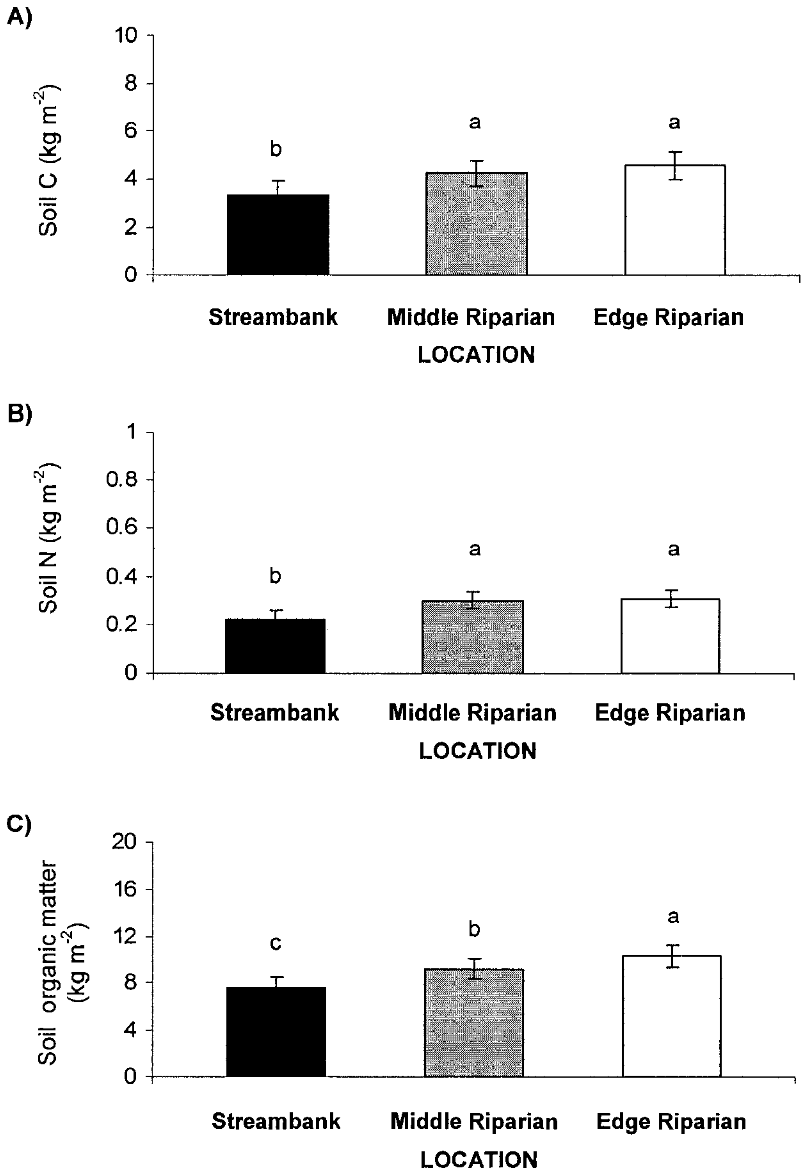


Figure 3.7. **A)** Soil C pool (kg m^{-2}), **B)** soil N pool (kg m^{-2}), and **C)** soil organic matter pool (kg m^{-2}) at three locations across the riparian zone. Different letters above standard error bars (± 1 SE) indicate significant differences from an ANOVA at $P < 0.10$, n = 108. Soil C and N data were log transformed for analysis but original means are presented for ease of interpretation.

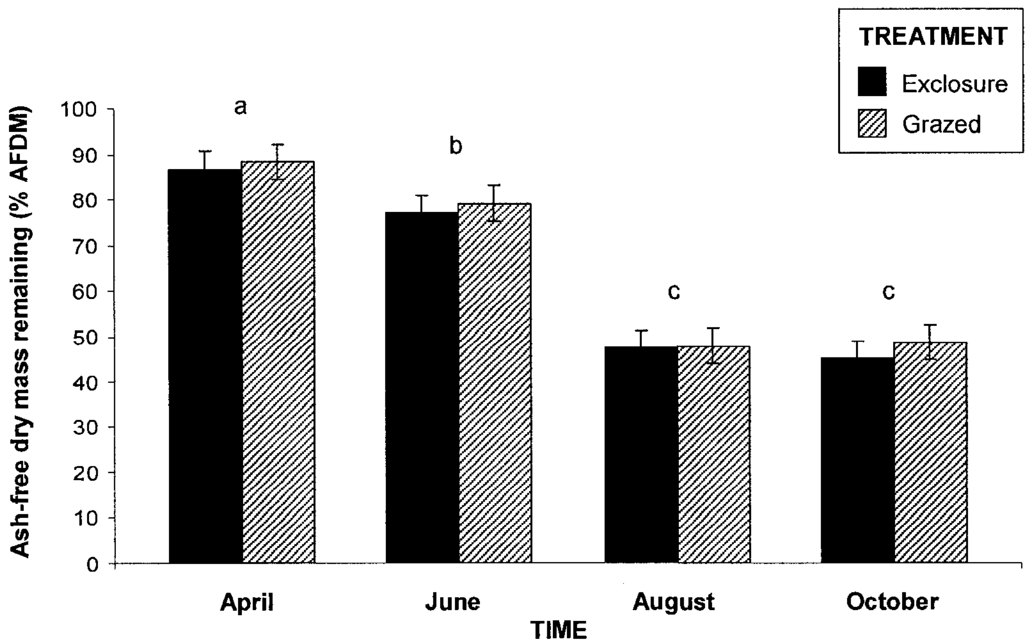


Figure 3.8. Ash-free dry mass remaining (% AFDM) at different times during the 2005 season. Litter bags were buried in October 2004. Different letters above paired bars (mean ± 1 SE) indicate significant differences from an ANOVA at $P < 0.10$, n = 72 in % AFDM among months, averaged over grazing treatments.

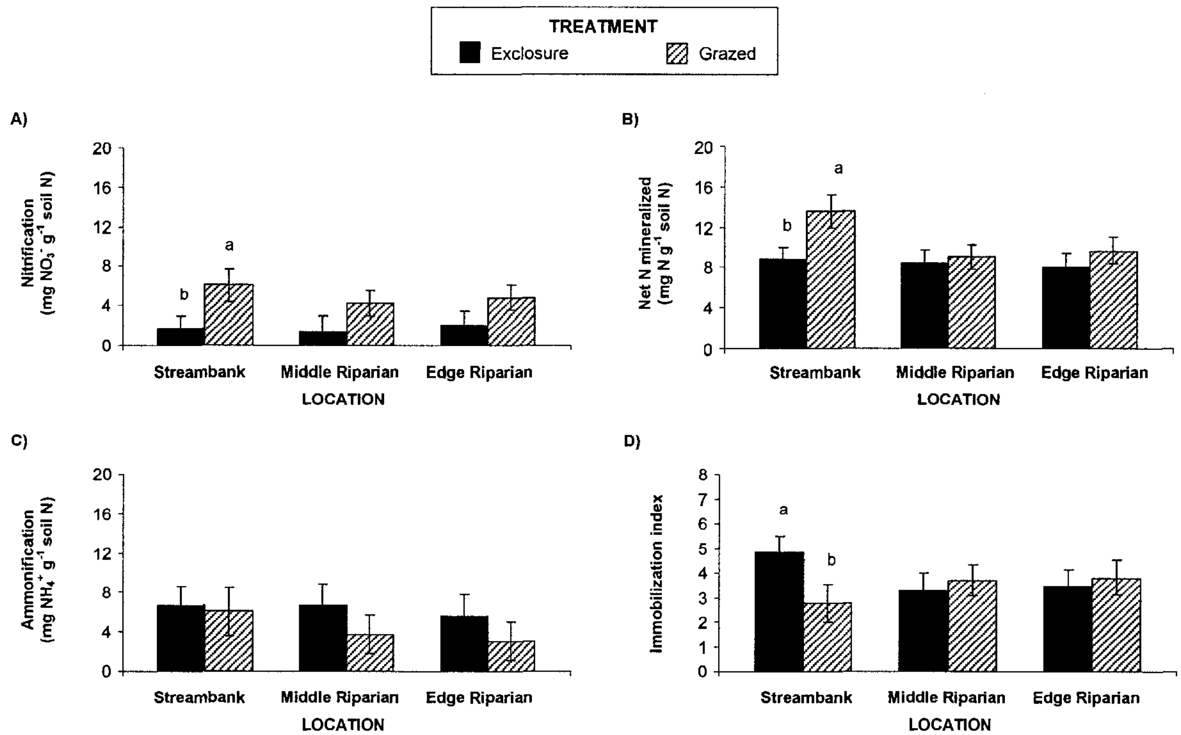
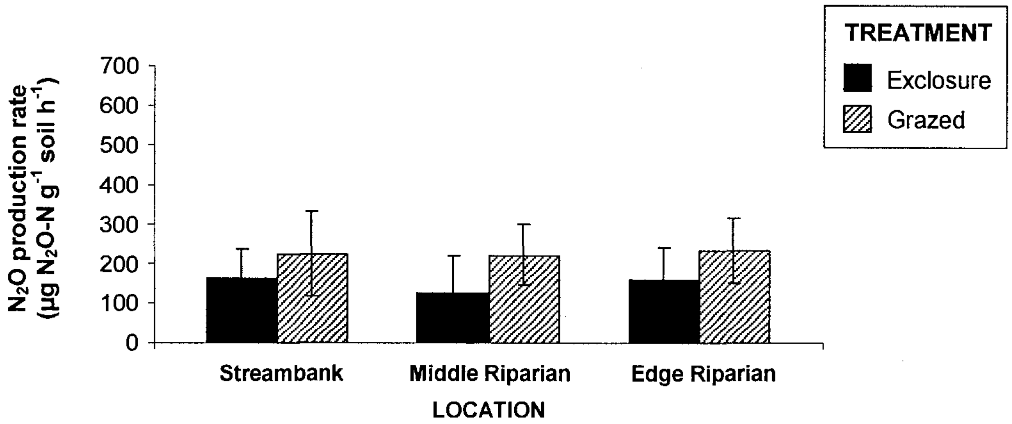


Figure 3.9. **A)** Nitrification (mg NO_3^- g soil N^{-1}), **B)** ammonification (mg NH_4^+ g soil N^{-1}), **C)** net N mineralization (mg total inorganic N g soil N^{-1}), and **D)** immobilization index (soil CO_2 respiration : net N mineralization) measured at the end of a 21-day incubation period and compared by grazing treatment within three locations: streambank, middle riparian, and edge of riparian. Different letters above standard error bars (± 1 SE) indicate significant differences at $P < 0.10$, n = 108 from an ANCOVA with clay content, soil C, N, and SOM pools as covariates.

A)



B)

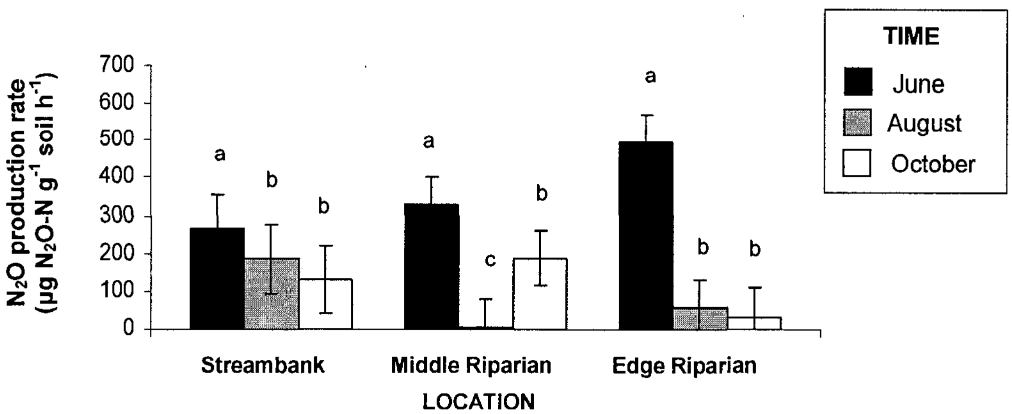


Figure 3.10. A) Denitrification potential measured as N_2O production rate (μg N_2O-N g^{-1}soil h^{-1}) by treatment within each location and **B)** by time of growing season within each location. Different letters above standard error bars (± 1 SE) indicate significant differences of log transformed data, $P < 0.10$, n = 54, within each location that occurred over the growing season (June, August, October). Results are from an ANCOVA with clay content, soil C, N, and SOM pools as covariates.

Table 3.1. Summary of data collected at Sheep Creek, north-central Colorado.

Data Collected	Year	Month
Aboveground Plant Dynamics		
Peak standing biomass	2005, 2006	Oct.
Plant C and N pools	2005, 2006	Oct.
Root C and N pools	2006	Jun., Aug. Oct.
Species composition	2005	Oct.
Species richness	2005	Oct.
Plant cover	2005	Oct.
Belowground Soil Dynamics		
Soil texture, bulk density	2005	Aug.
Soil pH	2005	Jun., Aug. Oct.
Soil moisture, organic matter, C and N	2005, 2006	Jun., Aug. Oct.
Soil water soluble organic C and total N	2006	Jun., Aug. Oct.
Soil inorganic N (NH_4^+, NO_3^-, total inorganic N)	2005, 2006	Jun., Aug. Oct.
Soil CO_2 respiration and N mineralization	2005, 2006	Jun., Aug. Oct.
Litter decomposition	2005	Apr. - Oct.
Denitrification	2006	Jun., Aug. Oct.
Soil Microbial Biomass	2006	Jun., Aug. Oct.

Table 3.2. Comparisons of plant C and N pools and C:N ratios across grazing treatments, locations, and years. Different letters next to means indicate significant differences from an ANOVA at $P < 0.10$ between treatments, locations, or years for each respective plant variable, n = 36.

	Plant C ($g\ m^{-2}$)		**Plant N ($g\ m^{-2}$)**		**Plant C:N**	
Effect	**Mean**	**1 SE**	**Mean**	**1 SE**	**Mean**	**1 SE**
Treatment						
Exclosure	76a	14	1.3a	0.3	63a	2
Grazed	91a	14	1.6a	0.3	60a	2
Location						
Streambank	90**a**	12	1.5**a**	0.2	61a	3
Middle Riparian	100**a**	12	1.7**a**	0.2	59a	3
Edge Riparian	59**b**	12	1.0**b**	0.2	63a	3
Year						
2005	105**a**	10	1.6**a**	0.2	69**a**	2
2006	62**b**	10	1.2**b**	0.2	53**b**	2

Table 3.3. Comparisons of root C and N pools and C:N ratios across grazing treatments and locations. Same letters next to means indicate no significant differences from an ANOVA at $P < 0.10$ between locations or grazing treatments for each respective root variable, n = 54.

	Root C (g m^{-2})		Root N (g m^{-2})		Root C:N	
Effect	**Mean**	**1 SE**	**Mean**	**1 SE**	**Mean**	**1 SE**
Treatment						
Exclosure	245a	60	4.3a	1.0	57a	4
Grazed	237a	60	4.6a	1.0	54a	4
Location						
Streambank	294a	68	5.3a	1.2	57a	3
Middle Riparian	225a	68	4.0a	1.2	55a	3
Edge Riparian	205a	68	4.1a	1.2	55a	3

Table 3.4. Species cover and richness of most abundant species (%) by grazing treatment (exclosure and grazed) and location (streambank, middle riparian, edge of riparian). Comparisons were made respectively within grazing treatments and landscape locations. Different letters next to means indicate significant differences at $P < 0.1$, n = 18 from an ANOVA. Cover data were transformed into square-root scale but original means are presented.

	Exclosure Treatment		vs.	Grazed Treatment		Streambank		vs.	Middle Riparian		vs.	Edge Riparian	
	Mean	1 SE		Mean	1 SE	Mean	1 SE		Mean	1 SE		Mean	1 SE
Grass Cover													
Agrostis stolonifera	16.6a	6.7		22.0a	6.7	27.8a	7.1		17.3a	7.1		12.7a	7.1
Phleum pratense	11.7a	4.0		2.9a	4.0	8.7a	4.4		3.7a	4.4		9.5a	4.4
Poa pratensis	8.9a	3.3		7.9a	3.3	6.0**b**	3.9		17.8**a**	3.9		1.3**b**	3.9
Sedge Cover													
Carex aquatilis	6.8a	5.7		11.1a	5.7	8.8a	6.6		15.2a	6.6		2.8a	6.6
Carex utriculata	4.6a	4.1		6.4a	4.1	4.5a	4.6		1.7a	4.6		10.3a	4.6
Rush Cover													
Juncus arcticus	0.8a	2.7		5.1a	2.7	1.3a	2.8		4.2a	2.8		3.3a	2.8
Juncus balticus	5.8a	2.3		3.8a	2.3	6.7a	2.8		2.7a	2.8		5.0a	2.8
Forb Cover													
Achillea millefolium	2.9a	2.3		5.9a	2.3	5.5a	2.2		4.5a	2.2		3.2a	2.2
Erigeron formosissimus	7.3a	2.4		2.0a	2.4	2.5**b**	2.1		1.3**b**	2.1		10.2**a**	2.1
Fragaria spp.	6.2**a**	1.9		1.9**b**	1.9	3.5a	2.2		4.8a	2.2		3.8a	2.2
Potentilla spp.	4.7a	2.6		3.4a	2.6	1.5a	2.8		4.0a	2.8		6.7a	2.8
Taraxacum officinale	4.8a	2.0		7.2a	2.0	3.3a	2.3		5.3a	2.3		9.3a	2.3
Trifolium repens	3.4a	2.1		5.2a	2.1	4.0a	2.0		4.8a	2.0		4.2a	2.0
Species Richness	12a	1.5		12a	1.5	13a	1.6		11a	1.6		12a	1.6

Table 3.5. **A)** Comparisons of soil physiochemical properties between grazing treatments and locations, and **B)** comparisons of soil properties which resulted in treatment by year and treatment by location interactions. Different letters in a row indicate significant differences from an ANOVA at $P < 0.10$, n = sample size. Comparisons were made respectively within A) grazing treatments and landscape locations and B) by grazing treatments within each year, and within landscape locations averaged over year. Soil moisture, water-soluble total N, C, N, and C:N data were log transformed but original means are presented for

A.

Soil Property	Exclosure Treatment Mean	Exclosure Treatment 1 SE	vs. Grazed Treatment Mean	Grazed Treatment 1 SE	n	Streambank Mean	Streambank 1 SE	vs. Middle Riparian Mean	Middle Riparian 1 SE	vs. Edge Riparian Mean	Edge Riparian 1 SE	n
Clay (%)	10.6a	0.72	8.2a	0.72	18	7.4**b**	0.71	10.1**a**	0.71	10.7**a**	0.71	18
Silt (%)	24.6a	1.34	21.9a	1.34	18	21.2**b**	1.45	24.5**a**	1.45	24.1**a**	1.45	18
Sand (%)	64.8a	1.40	69.8a	1.40	18	71.4**a**	1.62	65.4**b**	1.62	65.2**b**	1.62	18
Bulk density (g cm^{-3})	0.78a	0.04	0.91a	0.04	18	0.83a	0.05	0.82a	0.05	0.89a	0.05	18
pH	5.6a	0.17	5.6a	0.17	54	5.4a	0.18	5.6a	0.18	5.7a	0.18	54
Soil moisture (%)	40a	4.94	35a	4.91	108	42a	5.66	39a	5.70	31a	5.66	108
Water-soluble organic C (g m^{-2})	3.2a	0.65	3.4a	0.65	54	3.0**b**	0.60	2.9**b**	0.60	4.0**a**	0.60	54
Water-soluble total N (g m^{-2})	0.04a	0.009	0.05a	0.009	54	0.03**b**	0.009	0.05**a**	0.009	0.05**a**	0.009	54

B.

Soil Property	2005 Exclosure	vs. Grazed	2006 Exclosure	vs. Grazed	n	Streambank Exclosure	vs. Grazed	Middle Riparian Exclosure	vs. Grazed	Edge Riparian Exclosure	vs. Grazed	n
Soil organic matter pool (kg m^{-2})	9.8 (1.04)a	8.6 (1.04)a	9.1 (1.04)a	8.7 (1.04)a	108	8.4 (1.12)a	6.7 (1.12)a	10.4 (1.12)a	8.1 (1.12)a	9.4 (1.12)a	11.2 (1.12)a	108
Soil C (kg m^{-2})	5.1 (0.69)**a**	3.7 (0.69)**b**	3.9 (0.69)a	3.6 (0.69)a	108	4.1 (0.76)**a**	2.7 (0.76)**b**	5.2 (0.76)a	3.3 (0.76)**b**	4.2 (0.76)a	4.9 (0.76)a	108
Soil N (kg m^{-2})	0.31 (0.04)**a**	0.25 (0.04)**b**	0.28 (0.04)a	0.26 (0.04)a	108	0.25 (0.04)**a**	0.19 (0.04)**b**	0.33 (0.04)a	0.27 (0.04)a	0.30 (0.04)a	0.31 (0.04)a	108
Soil C:N	16.5 (1.01)a	14.9 (1.01)a	14.0 (1.01)a	13.6 (1.01)a	108	16.0 (1.40)a	14.7 (1.40)a	15.3 (1.40)a	12.4 (1.40)a	14.4 (1.40)a	15.7 (1.40)a	108

Table 3.6. Comparisons of inorganic N pools among grazing treatments and locations. Different letters next to means within grazing treatments or locations indicate significant differences at $P < 0.10$, n = 108 from an ANOVA. Data were log transformed but original means are presented for ease of interpretation.

	Exclosure Treatment		vs.	Grazed Treatment		Streambank		vs.	Middle Riparian		vs.	Edge Riparian	
Inorganic N	**Mean**	**1 SE**		**Mean**	**1 SE**	**Mean**	**1 SE**		**Mean**	**1 SE**		**Mean**	**1 SE**
Nitrate (g NO_3^--N m^{-2})	0.02a	0.01		0.03a	0.01	0.01**b**	0.01		0.04**a**	0.01		0.03**a**	0.01
Ammonium (g NH_4^+-N m^{-2})	0.66a	0.03		0.67a	0.03	0.64a	0.03		0.70a	0.03		0.66a	0.03
Total inorganic N (g N m^{-2})	0.68a	0.03		0.70a	0.03	0.65a	0.03		0.74a	0.03		0.69a	0.03

Table 3.7. Comparisons of treatment and year effects on N mineralization, soil CO_2 respiration, and immobilization. Different letters next to means in a row for grazing treatment or year indicate significant differences at $P < 0.10$, n = 108 from an ANCOVA with clay content, soil C, N, and SOM pools as covariates.

	Exclosure Treatment		vs.	Grazed Treatment		2005		vs.	2006	
Species	**Mean**	**1 SE**		**Mean**	**1 SE**	**Mean**	**1 SE**		**Mean**	**1 SE**
Nitrification (mg NO_3^- g soil N^{-1})	1.7a	1.0		5.0a	1.0	3.9a	0.6		2.9b	0.6
Ammonification (mg NH_4^+ g soil N^{-1})	6.3a	1.5		4.3a	1.5	5.0a	1.3		5.7a	1.3
Net N mineralization (mg N soil N^{-1})	8.5a	1.1		10.8a	1.1	10.7a	0.7		8.5a	0.7
Soil CO_2 respiration (mg CO_2-C g soil C^{-1})	30.8a	1.9		32.5a	1.9	31.6a	1.3		31.8a	1.3
Immobilization index	4a	0.6		3a	0.6	3b	0.4		4a	0.4

Table 3.8. Comparisons of soil microbial C and N pools and C:N ratios across grazing treatments and locations. There were no differences between grazing treatments, but location had a significant effect on microbial C and N at $P < 0.10$, n = 54 in an ANCOVA with clay content, soil C, N, and SOM pools as covariates.

	Microbial C (mg C m^{-2})		Microbial N (mg N m^{-2})		Microbial C:N	
Effect	**Mean**	**1 SE**	**Mean**	**1 SE**	**Mean**	**1 SE**
Treatment						
Exclosure	84a	5	6.1a	0.7	15a	3
Grazed	101a	5	6.2a	0.7	18a	3
Location						
Streambank	107**a**	7	7.6**a**	0.9	15a	3
Middle Riparian	86**b**	6	5.8**ab**	0.7	17a	2
Edge Riparian	84**b**	6	5.1**a**	0.7	19a	2

CHAPTER IV

CATTLE GRAZING EFFECTS ON STREAM AND GROUNDWATER NITROGEN IN A MONTANE RIPARIAN ECOSYSTEM

Abstract

Riparian zones are important aquatic-terrestrial interfaces because they have the potential to decrease nitrogen (N) inputs from upland ecosystems to surface water and act as a N sink. Cattle grazing is an important land-use in montane riparian ecosystems of the western U.S. that could alter site specific properties (e.g., soil properties, hydrology, oxidation-reduction potentials, N pools, vegetation) and hence affect N dynamics in riparian zones. In this study, I evaluated cattle grazing effects on stream and groundwater nitrate (NO_3^-) and ammonium (NH_4^+) concentrations in a montane riparian ecosystem of north-central Colorado. I determined gaining and losing streamflow conditions from stream stage and groundwater piezometric surface and used these conditions to characterize sink-source relationships for groundwater N in the riparian zone. I also measured nitrification and N mineralization in surface soils to compare soil and groundwater N dynamics in the riparian zone.

Annual streamflows in Sheep Creek are characterized by a spring snowmelt peak and a second mid-summer peak from an upstream storage reservoir water releases. These

flows create spring gaining and summer losing streamflow conditions. Season-long cattle grazing at light-to-moderate utilization levels did not affect stream or groundwater NO_3^- and NH_4^+ during gaining or losing streamflows. When averaged over grazing treatments, stream NO_3^- and NH_4^+ concentrations during gaining streamflows were 0.07 and 0.05 $mg \cdot L^{-1}$, respectively, while groundwater NO_3^- and NH_4^+ concentrations were 0.06 and 0.07 $mg \cdot L^{-1}$. Under losing streamflows, stream NO_3^- and NH_4^+ concentrations were 0.05 and 0.07 $mg \cdot L^{-1}$ and groundwater NO_3^- and NH_4^+ concentrations were 0.12 and 0.11 $mg \cdot L^{-1}$. Results suggest that the Sheep Creek riparian zone may be a potential sink for groundwater N during spring gaining streamflow conditions (i.e., lower N in riparian zone than stream) and a potential source of groundwater N to the stream during summer losing streamflow conditions (i.e., higher N in riparian zone than stream). In contrast to groundwater N, soil NO_3^- did not change over time and soil NH_4^+ decreased from spring to early fall. Different soil and groundwater N dynamics suggest that NO_3^- and NH_4^+ attenuation mechanisms change seasonally in montane riparian soils and groundwater.

Introduction

Riparian zones are important aquatic-terrestrial interfaces because they have the potential to reduce nitrogen (N) inputs from upland ecosystems to surface water and act as a N sink (Tilton and Kadlec 1979; Seitzinger 1994; Griffiths et al. 1997). Numerous studies have measured the ability of riparian zones to retain or lose N, especially nitrate (NO_3^-), to aquatic systems (Simmons et al. 1992; Irons et al. 1994; Seitzinger 1994; Groffman et al. 1996; Griffiths et al. 1997; Verchot et al. 1997; Spruill 2000). The main mechanisms that have been suggested to explain NO_3^- removal in riparian zones include denitrification, plant uptake, microbial immobilization, and dissimilatory NO_3^- reduction to ammonium NH_4^+ (Groffman et al. 1992; Simmons et al. 1992; Verchot et al. 1997; Dhondt et al. 2006). Denitrification is the prominent agent of NO_3^- attenuation during the dormant season (winter) when groundwater levels are high and soils are anaerobic (Lowrance 1992; Haycock and Pinay 1993; Jacks et al. 1994). Plant uptake is usually the dominant groundwater NO_3^- sink during the growing season (summer) when the water table is generally low and soils are aerobic (Groffman et al. 1992; Verchot et al. 1997; Van der Putten et al. 2001). Since the end product of denitrification are nitrogenous gases (N_2O, N_2), denitrification removes NO_3^- from an ecosystem and should not cause this sink to become saturated by long-term inputs of N to the system (Groffman et al. 1991; Dhondt et al. 2006). Nitrogen species taken up by plants, however, can eventually be recycled back to an ecosystem through decomposition and mineralization of plant litter (Groffman et al. 1991; Groffman et al. 1992; Hanson et al. 1994; Dhondt et al. 2006).

Nitrogen attenuation mechanisms in riparian zones are temporally and spatially variable and have been attributed to site-specific soil properties (i.e., texture, drainage, soil carbon (C) content, hydrology (i.e., groundwater levels, lateral flow), dilution effects, oxygen levels, vegetation type and land-use activities (Lowrance et al. 1984; Cooper 1990; Seitzinger 1994; Hill 1996; Flite et al. 2001). Spatially, groundwater NO_3^- concentrations attenuate in riparian zones via denitrification, plant and microbial uptake within the first few meters of the input source of NO_3^- such as upslope environments (Dhondt et al. 2006). Soil properties are spatially heterogeneous across riparian zone width because riparian systems are subject to disturbances such as flooding, erosion, and sediment deposition which result in variable microtopography and hydrogeomorphic settings. Different vegetation types also have different N removal efficiencies. In general, trees or shrubs are better at removing N from groundwater than herbaceous plants such as grasses because they have deeper roots that can remove more N and supply C at depth for denitrification (Haycock and Pinay 1993; Lowrance et al. 1995). Furthermore, plant phenology of different riparian species can affect temporal variability of plant uptake of N from riparian soils and groundwater (Haycock and Pinay 1993).

Numerous studies have been conducted to determine nutrient retention of riparian strips in maintaining stream water quality in areas of intensive agriculture (Lowrance et al. 1984; Peterjohn and Correll 1984; Jordan et al. 1993; Cey et al. 1999). Less attention has been given to the effects of cattle grazing on N in stream and groundwater of small headwater streams (Stednick and Fernald 1999). Cattle grazing is an important land-use in montane riparian ecosystems of the western U.S. Large ungulates can alter ecosystem N pools as well as N inputs and outputs (losses) to an ecosystem (Ritchie et al. 1998; Wardle et al. 2004). Removal of aboveground plant tissue by ungulates and inputs of labile fecal material could accelerate N cycling in fertile and productive systems such as riparian zones by increasing N pools (i.e., plant N, total soil N, inorganic N) and N fluxes (i.e., mineralization, nitrification, denitrification) (Singer and Schoenecker 2003). In the short-term, aboveground herbivory and N inputs can result in release of root exudates, stimulation of microbial decomposition and mineralization, and increased N availability in the soil (Hamilton and Frank 2001). Long-term transport and inputs of N through urine and feces to riparian zones could enrich soil organic matter and microbial communities and lead to increased N mineralization and nitrification. If plant and microbial pools become enriched over time and lose their capacity to retain N, excess NO_3^- and NH_4^+ could be exported from the riparian zone to the stream (Aber et al. 1989; Hill and Shackleton 1989; Groffman et al. 1992). The goal of my study was to determine if light-to-moderate cattle grazing at Sheep Creek, Colorado has altered stream and groundwater N in a montane riparian zone.

Stednick and Fernald (1999) concluded that the montane Sheep Creek riparian corridor may serve as a sink for NO_3^- in both gaining (spring snowmelt) and losing (summer) streamflow conditions, and as a source of NH_4^+ during gaining conditions. These analyses were conducted on soil water samples collected from tension lysimeters at 30-cm soil depth. In my study, I collected groundwater samples from piezometers to determine NO_3^- and NH_4^+ dynamics deeper in the soil profile. Specific objectives of my study were to 1) measure stream stage and groundwater piezometric potentials to determine gaining and losing streamflow conditions, 2) measure NO_3^- and NH_4^+ in stream water and groundwater in streambank, middle riparian, and riparian edge locations in both cattle grazed and excluded areas, 3) relate NO_3^- and NH_4^+ concentrations to streamflow stage to determine sink-source relationships in the Sheep Creek riparian zone with and without cattle grazing, and 4) measure N mineralization and nitrification in surface soils to better explain groundwater NO_3^- and NH_4^+ dynamics.

Methods

Study Site

Sheep Creek is located in north-central Colorado, approximately 80 km northwest of Fort Collins, CO, within the Arapaho-Roosevelt National Forest (Fig. 1). Sheep Creek is a first-order stream that flows southeasterly into the North Fork of the Cache la Poudre River. Eaton Reservoir is located in the headwaters of the stream, 5 km upstream of the study sites which were located at 2,500 m elevation. The annual hydrograph is characterized by a snowmelt peak in early spring and a second peak in late July or August when about 1.5 m^3 s^{-1} are released from an upstream reservoir for three to four weeks (Stednick and Fernald 1999). Limited weather data exist for this site, but available data indicate mean annual precipitation of 400 mm with 240 mm average precipitation during the growing season from May to September. Average daily temperatures range from 0° to 25°C during the growing season (Holland et al. 2005).

Soils in the Sheep Creek riparian zone are Naz sandy loams (Pachic cryoboroll) that occur to depths of 76-154 cm. These soils are well-drained, have moderately rapid permeability and medium water-holding capacity (Stednick and Fernald 1999; USDA-NRCS 2008). The overstory vegetation along Sheep Creek is dominated by several species of willow (*Salix planifolia* Pursch var. *planifolia, S. geyeriana* Andersson, *S. amygdaloides* Andersson, S. *exigua* Nuttall ssp. *exigua,* and *S. monticola* Bebb) (Holland et al. 2005). The herbaceous understory is comprised of several sedge species (*Carex* *aquatilis* Whalenb., *C. utriculata* Boott, *C. praticola* Rydb.), rushes (*Juncus arcticus* Willd., *J. balticus* Willd.), numerous forbs (*Erigeron formossisimus* Greene, *Taraxacum officionale* Weber, and *Trifolium repens* L.) and grasses (*Agrostis stolonifera* L., *Deschampsia caespitosa* L., *Phleum alpinum* L., *Phleum pratense* L., *Poa pratensis* L., *Poa palustris* L.) (Schulz and Leininger 1990, Popolizio et al. 1994). My study transects were in riparian meadows dominated by herbaceous cover with very few willows.

Current livestock grazing in the Sheep Creek allotment is season long from 21 June until 25 September and fluctuates between 100-300 animal unit months (AUMs). Utilization has been estimated at 40-60% since the mid -1980s. Cattle are restricted to only certain riparian pastures along Sheep Creek and are excluded from three long-term riparian exclosures that were established in the late 1950s (Schulz and Leininger 1990; Holland et al. 2005).

Experimental Design

I established three pairs of transects (14-25 m long) perpendicular to the stream to measure NO_3^- and NH_4^+ in Sheep Creek stream water and groundwater. One transect from each pair was located in a control treatment (50-y exclosure) and the second transect was located in a grazed treatment (areas that have been grazed heavily until mid-1980 and moderately since then). At the end of each transect I installed a stream staff gage in the thalweg of the stream channel to measure stream stage. To measure groundwater piezometric potential or head across the riparian zone, I installed piezometers at three locations along each transect: streambank, middle riparian and riparian edge in fall 2004. After each piezometer was placed in the ground, the hole was backfilled with soil collected from excavation to prevent water piping. Streambank piezometers were 1.5 – 2 m from the bank of the stream channel, piezometers near edges of the riparian zone were at 14, 20, or 25 m from the bank of the stream channel depending on the width of the riparian zone. And, middle riparian piezometers were half-way between the streambank and riparian edge piezometers. The study design was a split-plot with grazing treatment (2 levels: exclosure and grazed) as the whole-plot factor and landscape location (3 levels: streambank, middle riparian, and riparian edge) as the subplot factor.

Sample Collection

Stream stage was measured by recording stream water level at each transect from May to mid-July 2005 and thereafter mostly bi-weekly until October 2005 (Appendix W). Piezometric potential (cm) was determined by measuring the distance from the top of the piezometer to the water level in the piezometer and then adjusted by the distance between the top of the piezometer and soil surface. Lastly, I referenced all head (cm) measurements for each piezometer and channel thalweg to a common transect datum by surveying each transect with an auto-leveler (Appendix X).

Stream water and groundwater samples were collected on the same dates as stream stage and piezometric potential measurements from early May to late September 2005 (Appendix Z). I collected grab samples of stream water at each transect for analysis of NO_3^- and NH_4^+. Piezometers were completely evacuated by a hand pump only at the beginning of May, one week prior to the first sampling date to remove groundwater from the winter season. Thereafter, I collected groundwater samples by pumping water out of the piezometers into a flask and filtering 20 mL of the sample through a Whatman® GF/A glass microfiber filter into polypropylene scintillation vials. All samples were transported on ice to the laboratory and frozen until analysis. The stream and groundwater samples were analyzed colorimetrically for NO_3^- and NH_4^+ on an Alpkem® segmented flow autoanalyzer (OI Analytical, College Station, TX).

I used the ion-exchangeable resin (IER) method to measure NO_3^- and NH_4^+ in the top 10 cm of soil at each sampling location and use nitrification and N mineralization as an index of microbial activity (Binkley and Matson 1983) (Appendix AA). I made IER bags by placing 10 g of cation and 10 g of anion resin in a nylon bag. Four IER bags were buried 10 cm below the soil surface at each riparian location within each transect for one month starting in early June 2005; the bags were replaced with fresh IER bags at the beginning of each month. Thus, the bags captured NO_3^- and NH_4^+ available in the surface soil solution during June, July, August, and September 2005. Upon removal from soil, the IER bags were stored in individual plastic bags and iced until extraction with 2M KCl on the same day. The extracts were then frozen until colorimetric NO_3^- and NH_4^+ analysis on an Alpkem® segmented flow autoanalyzer (OI Analytical).

Data Analysis

I determined gaining and losing streamflow conditions by calculating slopes (change in head elevation divided by change in distance) between 1) the stream thalweg and streambank piezometer, 2) the streambank and middle riparian piezometers, and 3) the middle and riparian edge piezometers (Appendix Y). Positive slopes between the piezometers indicated gaining streamflow conditions while negative slopes indicated losing streamflow conditions. I also used an analysis of variance (ANOVA) with repeated measures (by month) to test significant differences in water levels between the stream and the three piezometer locations to verify the characterization of gaining vs. losing streamflow conditions.

I used repeated measures ANOVA to test the effect of cattle grazing treatments on stream NO_3^- and NH_4^+. This analysis was also used to test differences in stream NO_3^- and NH_4^+ between months and if cattle grazing had an effect on stream N during different months of the growing season. I used an analysis of covariance (ANCOVA) with piezometric potential as the covariate for groundwater N to test whether cattle grazing had altered groundwater NO_3^- and NH_4^+ concentrations during gaining or losing streamflow conditions. I also conducted another ANCOVA with water elevation as the covariate for all locations (stream stage for stream locations and piezometric potential for riparian locations) and month as repeated measures to a) make multiple comparisons of stream N with groundwater N at different times of the growing season and b) to determine N sink-source relationships in the Sheep Creek riparian zone. Stream and groundwater N data were log transformed to normalize data distribution for the ANCOVAs but untransformed means and confidence intervals are presented.

Lastly, I used an ANOVA with repeated measures to test cattle grazing effects, riparian locations, and time of season on surface soil nitrification and N mineralization measured with IER bags. I used the results of this analysis to explain NO_3^- and NH_4^+ dynamics in the Sheep Creek riparian zone. I conducted all statistical analyses in SAS 9.1 software (SAS Institute 2003) and accepted significant differences at $P < 0.05$. Summary statistics of all analyses are presented in Appendix AB.

Results

Stream Stage and Groundwater Dynamics

The 2005 Sheep Creek hydrograph had two peaks (Figure 4.1). The highest peak occurred as snowmelt between mid-May and early June. Stream flows were lower between mid-June and early July and then increased again from late July to late August when Eaton Reservoir releases occurred, with a second reservoir release in early September.

The groundwater potential or head in the piezometers decreased over the course of the field season (Table 4.1). Gaining streamflow conditions occurred in May and June, and losing streamflow conditions existed from July to September. Significant differences in stream stage and riparian piezometric potentials occurred only at the beginning of the growing season (Appendix AB, Table AB-1b). In May, stream stage was higher than piezometric potential at streambank sites ($P < 0.01$) because streamflow was above bankfull. At this time, head at the riparian edge was also higher than head at the streambank ($P < 0.02$) and indicated gaining streamflow conditions. Gaining streamflow conditions persisted from May through June when head at the riparian edge remained higher than head in streambank piezometers ($P < 0.04$). There were no significant differences in stream stage and riparian piezometric potentials ($P > 0.11$) as head decreased from July to September (Table 4.1). These results indicated losing streamflow conditions during summer months (July and August) and into early fall (September). These results are consistent with Stednick and Fernald (1999) who observed gaining streamflow conditions during spring snowmelt runoff and losing streamflow conditions during summer reservoir releases.

Stream and Groundwater Nitrogen

Cattle grazing had no significant effect on stream NO_3^- or NH_4^+ concentrations ($P > 0.19$; Appendix AB, Table AB-2a). Stream NO_3^- ranged from 0.02 – 0.09 mg·L^{-1} and NH_4^+ from 0.03 – 0.09 mg·L^{-1} (Fig. 4.2). Concentrations of NO_3^- or NH_4^+ changed over time in stream water ($P < 0.001$; Appendix AB, Table AB-2b). Stream NO_3^- decreased by 29% between May and June. It then increased in July and August to similar levels as in May before declining to lowest concentrations of 0.02 mg L^{-1}. Ammonium, however, increased on average by 46% from May to September (Fig. 4.2). Average stream NO_3^- during gaining conditions was 0.07 mg L^{-1} and 0.05 mg L^{-1} during losing streamflow conditions. Average stream NH_4^+ during gaining conditions was 0.05 mg L^{-1} and 0.07 mg L^{-1} during losing streamflow conditions. The NO_3^- concentrations were below the EPA water quality standard of 45 mg L^{-1}. Water quality standard for NH_4^+ is not available but for unionized ammonia NH_3 it is 0.02 mg L^{-1} (US-EPA 2006).

Season-long, light-to-moderate grazing also did not have a significant effect on groundwater NO_3^- or NH_4^+ concentrations during gaining or losing streamflow conditions ($P > 0.75$; Appendix AB, Table AB-3a). Groundwater NO_3^- ranged from below detection, or measured 0, to 0.64 mg L^{-1} and NH_4^+ from 0.03 to 0.79 mg L^{-1}. The upper bounds of these ranges were caused by infrequent but high spikes in both N species. Piezometric potential explained 34% of variation in groundwater NO_3^- and 56% of variation in groundwater NH_4^+. The piezometric potential or head covariate adjusted monthly groundwater NO_3^- concentration means to 0.05 – 0.17 mg L^{-1} and monthly groundwater NH_4^+ concentration means to 0.06 – 0.13 mg L^{-1} (Fig. 4.3). Groundwater NO_3^- and NH_4^+ concentrations increased from May to September as piezometric potential decreased. Average groundwater NO_3^- was 0.06 mg L^{-1} during gaining streamflow conditions and 0.12 mg L^{-1} during losing streamflow conditions. Average groundwater NH_4^+ was 0.07 mg L^{-1} during gaining streamflow conditions and 0.11 mg L^{-1} during losing streamflow conditions.

Although cattle grazing did not affect N sink-source relationships under different streamflow stages, N sink-source relationships differed during gaining and losing streamflow conditions when averaged over grazing treatments. Nitrate concentrations in the stream did not differ from groundwater NO_3^- concentrations during gaining streamflow conditions in May and June ($P > 0.46$; Appendix AB, Table AB-4b) which suggests that the riparian zone may serve as a potential sink for NO_3^- during spring, gaining streamflows (Fig. 4.4B). Stream and groundwater NO_3^- concentrations did not differ during losing streamflow conditions in July and August ($P > 0.10$; Appendix AB, Table AB-4b). However, in September when piezometric potential was lowest in riparian piezometers, NO_3^- concentrations were significantly higher in groundwater than in stream water ($P < 0.04$; Appendix AB, Table AB-4b). Groundwater NO_3^- was higher in the riparian edge piezometers than elsewhere. Although NO_3^- concentrations were significantly different only during losing streamflow conditions in September, median NO_3^- concentrations suggest that the riparian zone may also be a potential source of NO_3^- to the stream during losing streamflow conditions in July and August.

Ammonium concentrations in the stream were not significantly different from groundwater NH_4^+ concentrations during gaining streamflow conditions ($P > 0.08$; Fig. 4.5B, Appendix AB, Table AB-4b). Thus, the riparian zone may be a potential sink for NH_4^+ during spring, gaining streamflow stage. During losing streamflow conditions, however, groundwater NH_4^+ concentrations were higher in most riparian piezometers than in the stream ($P < 0.04$; Appendix AB, Table AB-4b). The riparian zone may serve as a potential source of NH_4^+ to the stream during losing streamflow conditions.

Soil Nitrogen Mineralization and Nitrification

Cattle grazing did not significantly alter nitrification or N mineralization in surface soils ($P > 0.82$; Appendix AB, Table AB-5a). Nitrification in surface soils of the riparian zone was very low (0.0003 to 0.01 mg NO_3^- g^{-1} resin $month^{-1}$) and did not change significantly during the growing season ($P = 0.57$; Fig. 4.4A) or between riparian sampling locations ($P = 0.80$; Appendix AB, Table AB-5a). These patterns were different from groundwater NO_3^- which increased in the riparian zone from May to September (Fig. 4.3 and 4.4). Nitrogen mineralization declined from June to September from 0.03 to 0.007 mg NH_4^+ g^{-1} resin $month^{-1}$ ($P < 0.001$; Fig. 4.5A, Appendix AB, Table AB-5b). The seasonal decline in soil NH_4^+ contrasted with an increase in groundwater NH_4^+ from May to September (Fig. 4.3 and 4.5). Also, N mineralization differed between riparian locations ($P = 0.02$; Appendix AB, Table AB-5b). It declined from the streambank to the middle and edge of the riparian zone, and it was higher in streambank soils compared with the edge of the riparian zone.

Discussion

Light-to-moderate cattle grazing did not affect stream or groundwater NO_3^- and NH_4^+ concentrations. High cattle inputs of N via urine and feces to riparian zones could lead to higher N concentrations via enhanced nitrification and mineralization (Groffman et al. 1992). Consequently, N export from the riparian zone to surface waters could be increased if denitrification, plant, and microbial pools become enriched with N and lose their capacity to retain it (Aber et al. 1989; Hill and Shackleton 1989; Groffman et al. 1992). Trlica et al. (2003) showed a high filtration capacity for N and phosphorus (P) in the Sheep Creek riparian zone. Runoff from simulated rainfall under a heavy grazing treatment increased nutrient runoff by 70% in grazed compared with control plots, but concentrations of NO_3^- and NH_4^+ did not exceed EPA criteria. Furthermore, current light grazing intensity by cattle does not appear to lead to high inputs of fecal material to the riparian zone. Thus, season-long cattle grazing at light to moderate utilization levels does not seem to alter stream and groundwater NO_3^- and NH_4^+ dynamics in the Sheep Creek allotment.

Although cattle grazing did not affect stream or groundwater NO_3^- and NH_4^+ concentrations, I detected seasonal changes in NO_3^- and NH_4^+ sink-source relationships. The riparian zone may serve as a potential sink for groundwater NO_3^- and NH_4^+ during gaining streamflows (spring) and as a potential source of NO_3^- and NH_4^+ during losing streamflows (summer). Soil nitrification and N mineralization also were not affected by cattle grazing, but seasonal patterns in these processes may help to explain seasonal groundwater N dynamics.

Nitrification (NO_3^-) was low in the riparian soils during both gaining (spring) and losing (summer) streamflow conditions while N mineralization (NH_4^+) was high in the spring and low in the summer. Similarly, Stednick and Fernald (1999) did not find seasonal differences in soil NO_3^- concentrations, but found higher NH_4^+ concentrations in soil water during the spring compared with the summer. In contrast to no seasonal change in soil NO_3^- and a decline in soil NH_4^+, groundwater NO_3^- and NH_4^+ increased from spring to summer. The seasonal differences in soil and groundwater N dynamics, suggest that NO_3^- and NH_4^+ attenuation mechanisms are different in upper riparian soils than in groundwater.

In a companion study (Chapter III), I observed that denitrification potential in surface soils was highest in early spring and lowest in late summer, while microbial biomass C and N was low in early spring and high in late summer. Thus, denitrification may be the main mechanism for NO_3^- removal from upper Sheep Creek soils and groundwater during spring gaining streamflow conditions when the groundwater level is high, anaerobic conditions exist, and groundwater interacts with soil organic matter near the soil surface (Lowrance 1992; Haycock and Pinay 1993; Jacks et al. 1994). Under anaerobic conditions, NO_3^- could also be removed through dissimilatory NO_3^- reduction to ammonium NH_4^+ (DNRA) (Yin et al. 2002; Dhondt et al. 2006). DNRA could also explain high NH_4^+ in riparian soils during spring gaining streamflow conditions. Ammonium in groundwater, however, might be low at this time if N mineralization is low at depth.

As the groundwater level declines and streamflow conditions become losing in summer to early fall, plant uptake and microbial immobilization likely attenuate NO_3^- and NH_4^+ in upper riparian soils (i.e., net soil nitrification and N mineralization are low). Plant uptake often becomes the dominant sink for groundwater N during losing streamflow conditions (Groffman et al. 1992; Verchot et al. 1997; van der Peijl and Verhoeven 1999). However, it is possible that during summer and early fall the groundwater level at my study sites declined below the major rooting zone of herbaceous vegetation which was more abundant than deeper-rooted woody plants. Low attenuation of groundwater NO_3^- and NH_4^+ by plants deeper in the soil profile might have resulted in elevated groundwater concentrations of NO_3^- and NH_4^+ during the summer and early fall. Thus, the riparian zone may serve as a source of NO_3^- and NH_4^+ to the stream during losing streamflow conditions.

Detailed analyses of NO_3^- and NH_4^+ attenuation mechanisms discussed above were outside the scope of this study but should be considered in the future to better understand the functioning of this montane riparian zone. Characterization of spatial and temporal variation of oxidation-reduction potentials could help to explain fluctuations and spikes in groundwater N concentrations. Oxidation-reduction potential (ORP) measurements taken at two different sampling dates in 2005 indicated large fluctuations in ORP within and between piezometers and could indicate heterogeneity in subsurface groundwater pathways and parent material. A tracer study (Br^- or Cl^-) with a larger network of piezometers and wells could be utilized to trace N flows in subsurface and groundwater to better understand lateral flows and potential dilution effects of N concentrations (Simmons et al. 1992). In addition to groundwater tracers, ^{15}N tracers could be used to estimate spatial and temporal variation in plant uptake and microbial immobilization of N species (Ostrom et al. 2002; Yin et al. 2002).

Conclusions

Annual streamflows in Sheep Creek are characterized by a spring snowmelt peak and a second mid-summer peak from an upstream storage reservoir release. These flows create spring gaining and summer losing streamflow conditions. Season long, light-to-moderate cattle grazing had no significant effect on stream or graoundwater NO_3^- and NH_4^+ concentrations. Although seasonal changes in NO_3^- and NH_4^+ concentrations were statistically significant, they might not be biologically important because average concentrations were very low and below EPA water quality standards. Average stream NO_3^- and NH_4^+ concentrations were respectively 0.07 and 0.05 mg L^{-1} during gaining streamflows and 0.05 and 0.07 mg L^{-1} during losing streamflows. Average groundwater NO_3^- was 0.06 mg L^{-1} during gaining streamflow conditions and 0.12 mg L^{-1} during losing streamflow conditions. Average groundwater NH_4^+ was 0.07 mg L^{-1} during gaining streamflow conditions and 0.11 mg L^{-1} during losing streamflow conditions.

The stream and groundwater N concentrations suggest that the Sheep Creek riparian zone acts as a potential sink for groundwater NO_3^- and NH_4^+ during spring gaining streamflow conditions and a potential source of NO_3^- and NH_4^+ during summer losing streamflow conditions. These sink-source relationships however were different in upper riparian soils: soil NO_3^- did not change over time but soil NH_4^+ decreased from spring to early fall. The differences in soil and groundwater N dynamics suggest that NO_3^- and NH_4^+ attenuation mechanisms change seasonally in riparian soils and groundwater, but these patterns are not affected by current cattle grazing practices.

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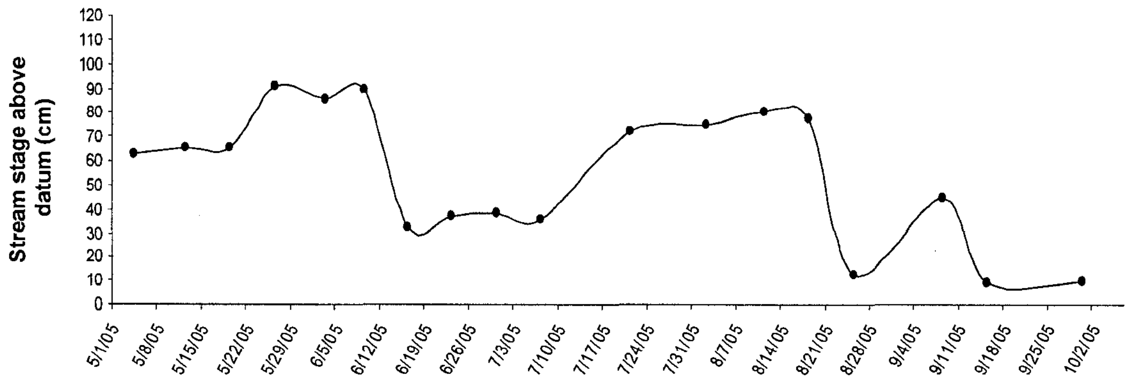


Figure 4.1. Stream stage of Sheep Creek measured from May to October 2005. Stream and groundwater samples were collected on dates marked by solid circles.

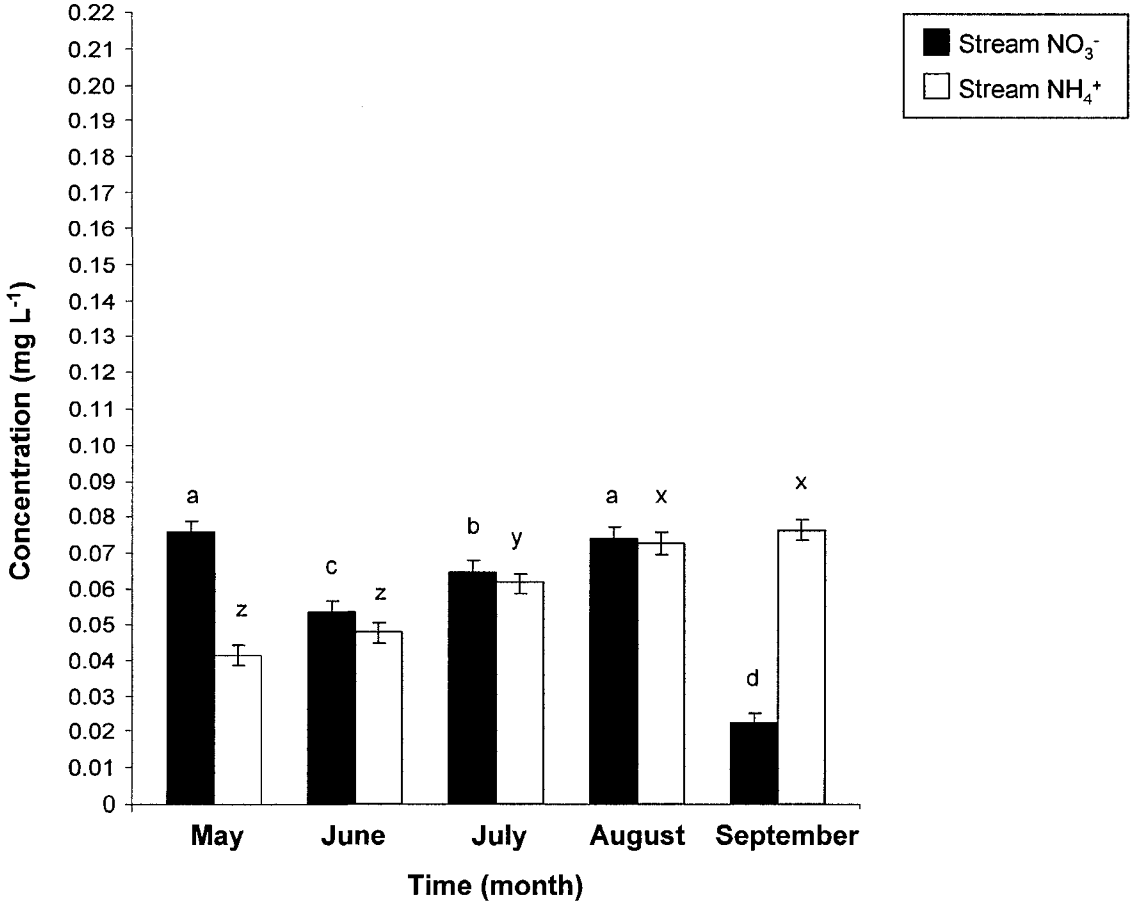


Figure 4.2. Stream NO_3^- and NH_4^+ (mg L^{-1}) measured from May to September 2005. Letters above means indicate significant differences, from an ANOVA, between months for NO_3^- (a, b, c, d) and NH_4^+ (x, y, z) at $P < 0.05$, n = 6 for each mean. Bars are standard errors of the mean (± 1 SEM).

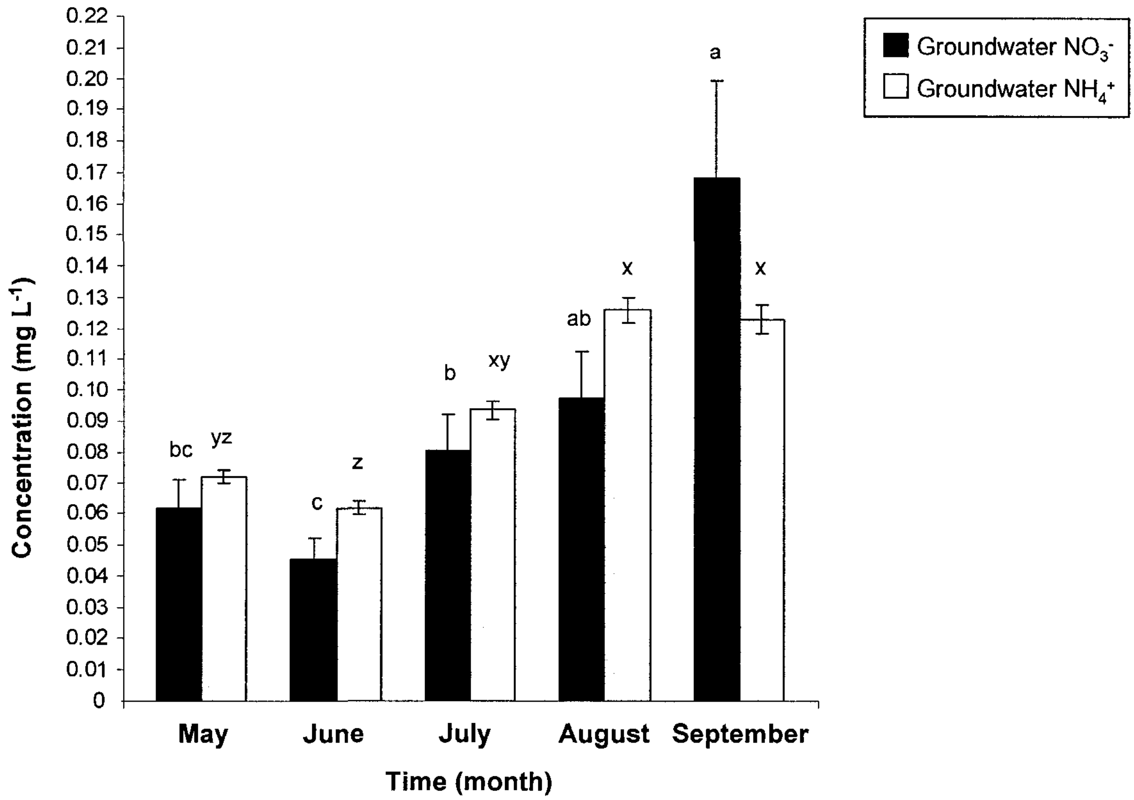


Figure 4.3. Groundwater NO_3^- and NH_4^+ (mg L^{-1}) measured from May to September 2005. Letters above means indicate significant differences, from an ANCOVA, between months for NO_3^- (a, b, c) and NH_4^+ (x, y, z) at $P < 0.05$, n = 6 for each mean. Means were adjusted by piezometric potential and untransformed from log transformation. Bars are confidence intervals for untransformed means.

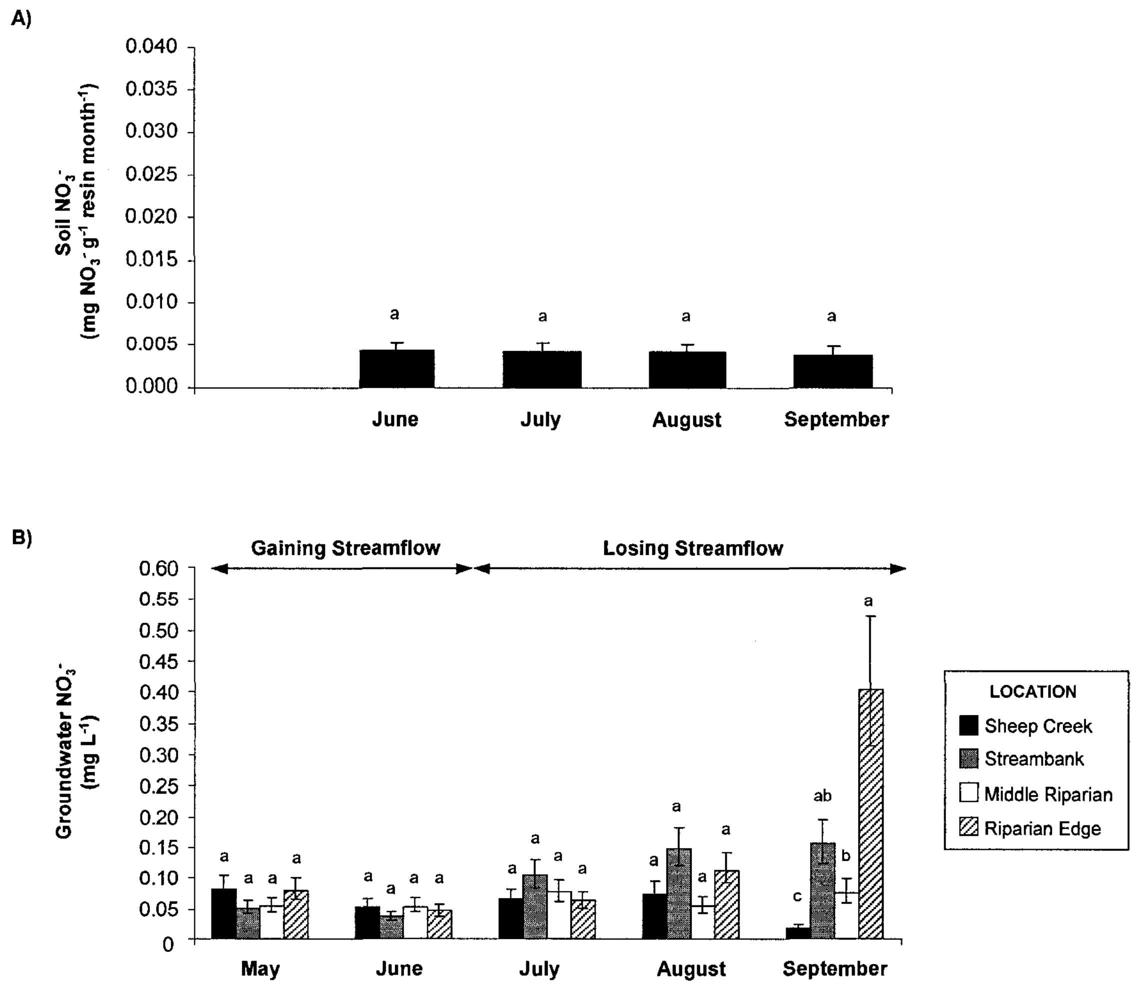
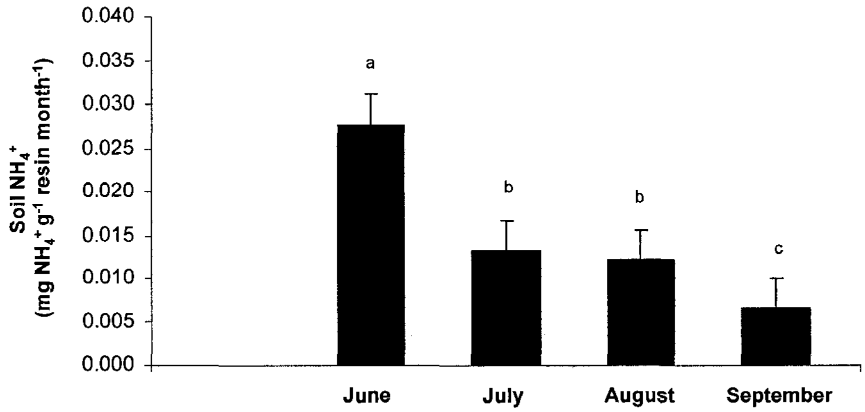


Figure 4.4. **A)** Nitrification (mg NO_3^- g^{-1} resin $month^{-1}$) in riparian soils measured from June to September 2005. Letters above means and standard error bars (± 1 SEM) indicate significant differences from an ANOVA at $P < 0.05$. **B)** NO_3^- concentration (mg L^{-1}) measured in the stream and riparian piezometers from May to September 2005. Gaining streamflow conditions occurred in May and June and losing streamflow conditions existed from July to September. Letters above untransformed least square means from the log transformation indicate significant differences between sampling locations within a given month at $P < 0.05$. Bars are confidence intervals calculated for untransformed means.

A)



B)

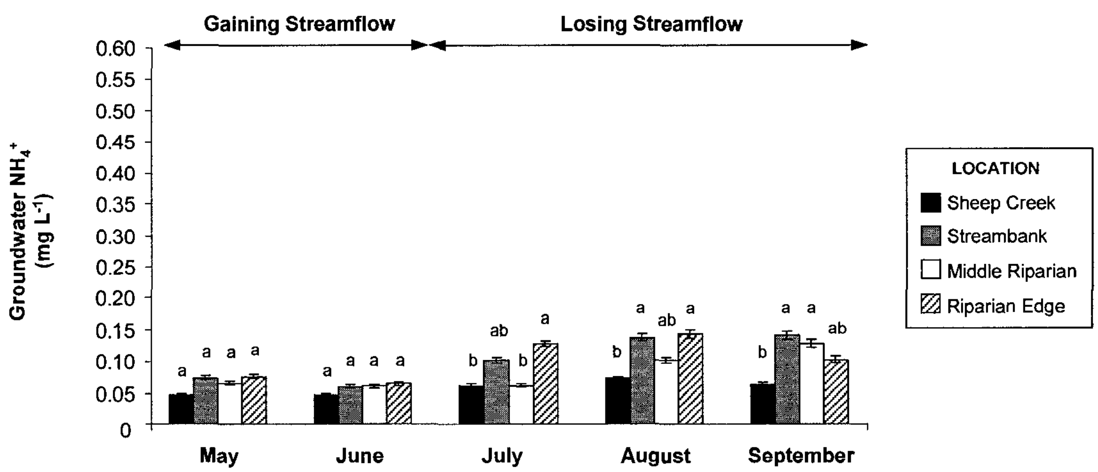


Figure 4.5. A) N mineralization (mg NH_4^+ g^{-1} resin $month^{-1}$) in riparian soils measured from June to September 2005. Letters above means and standard error bars (± 1 SEM) indicate significant differences from an ANOVA at $P < 0.05$. **B)** NH_4^+ concentration (mg L^{-1}) measured in the stream and riparian piezometers from May to September 2005. Gaining streamflow conditions occurred in May and June and losing streamflow conditions existed from July to September. Letters above untransformed least square means from the log transformation indicate significant differences between sampling locations within a given month at $P < 0.05$. Bars are confidence intervals calculated for untransformed means.

Table 4.1. Means of stream stage and riparian piezometric potential (head) measured between May and September 2005. Letters next to means indicate significant differences, from an ANOVA, between locations for a given month at $P < 0.05$, SEM = 1 standard error of the mean, n = number of observations for each mean.

	Sheep Creek			Streambank			Middle Riparian			Riparian Edge		
	Stage (cm)	SEM	n	Head (cm)	SEM	n	Head (cm)	SEM	n	Head (cm)	SEM	n
May	88a	17.2	5	58b	16.8	6	72ab	16.8	6	82a	16.8	6
June	66b	17.2	5	67b	16.8	6	80ab	16.8	6	88a	16.8	6
July	74a	17.2	5	60a	16.8	6	62a	16.8	6	71a	16.8	6
August	71a	17.2	5	54a	16.8	6	61a	16.9	5	67a	16.9	5
September	46a	17.2	5	39a	16.9	5	50a	16.9	5	45a	17.3	4

CHAPTER V

SUMMARY AND FUTURE CONSIDERATIONS

Summary

I investigated the effects of large ungulates on nitrogen (N) dynamics in riparian ecosystems of Colorado. Large ungulates can alter N inputs and outputs in aboveground and belowground N pools, and thus affect nutrient mineralization rates, soil food webs, and turnover rates of these pools at different temporal and spatial scales (Hobbs 1996; Bardgett and Wardle 2003; Singer and Schoenecker 2003). Studies have shown both positive and negative effects of ungulates on ecosystem N cycling (McNaughton 1985; De Mazancourt et al. 1998; Frank and Groffman 1998; Ritchie et al. 1998; Tracy and Frank 1998; Bardgett and Wardle 2003; Le Roux et al. 2003; Singer and Schoenecker 2003). Most of these studies have focused on the effects of wild ungulates or livestock on upland ecosystems such as grasslands, shrublands, or pasturelands. Little is known about the effects of large ungulates on N cycling in riparian ecosystems, especially their effects on belowground N pools and processes (but see: Kauffman et al. 2004; Blank et al. 2006).

The effects of large ungulates on nutrient cycling have been generalized into an accelerating – decelerating nutrient scenarios framework. The accelerating effect usually occurs in fertile, productive ecosystems; where selective consumption of plants by herbivores is low, herbivores may promote compensatory aboveground plant growth and return some organic matter as labile fecal material to the soil. This in turn enhances nutrient concentration in living plant tissue and the resulting high quality litter stimulates microbial activity which has a positive feedback of high nutrient supply rates to plants (Ritchie et al. 1998; Wardle et al. 2004). In contrast, the decelerating nutrient scenario is more prevalent in ecosystems with low fertility and composed of plant species less resilient to grazing. Additionally selective feeding on palatable plants results in dominance of unpalatable species and poor litter quality, which leads to slow decomposition and low nutrient supply rates to plants; a negative feedback (Ritchie et al. 1998; Wardle et al. 2004).

I evaluated the effects of large ungulates on N dynamics in two different riparian ecosystems of Colorado. In the first study, I tested whether bison and cattle accelerate or decelerate soil N mineralization in riparian and wet meadow communities of the Great Sand Dunes region in south-central Colorado. In the second study, I evaluated the effects of long-term cattle grazing on N dynamics in soils, groundwater, and stream water of the Sheep Creek montane riparian ecosystem in north-central Colorado. Cattle grazing treatment effects across a landscape gradient were evaluated at Sheep Creek sites located adjacent to the stream bank, in the middle of the riparian zone and at the edge of the riparian zone to capture spatial variation in aboveground and belowground ecosystem components. Based on Ritchie et al. (1998) and Wardle et al. (2004), I expected to find evidence of accelerated nutrient cycling associated with ungulate herbivory in both studies because riparian ecosystems are fertile and productive.

In the Great Sand Dunes study, I rejected my hypothesis that in addition to elk herbivory, bison and cattle accelerate N cycling in riparian or wet meadow soils. I expected increased potential soil N mineralization in riparian and wet meadow sites utilized by bison or cattle because these communities are more productive and provide more palatable forage for herbivores than the surrounding xeric uplands. Although data did not support the accelerating nutrient effect scenario (Ritchie et al. 1998), I observed highest estimates of potentially mineralizable N pools and measured highest net N mineralization in soils from cattle grazed wet meadows. Potentially mineralizable N and net N mineralization were also considerably higher (130% and 28%, respectively) in cattle grazed wet meadows than bison grazed meadows. This might be a result of long contemporary presence of cattle grazing in the Great Sand Dunes region compared with only 15 years of bison grazing (and 3 years of bison exclosure treatments) at the time of this study. The cattle grazing effect, however, was not statistically significant because of high variation in the mean value of mineralization parameters (high SE).

I attributed the high variance to difficulty in maintaining constant soil moisture in samples during the long-term incubation, potential differences in fine root or litter content among laboratory replicates, and variable leaching efficiencies of the vacuum manifold I used. The high variance in N mineralization estimates might have also been a result of differences in riparian and wet meadow site characteristics that were not measured in this study. For example, the magnitude of grazer effects on N mineralization have been attributed to plant community structure, aboveground plant production, litter quality, water availability, presence of mineral licks, and differences in soil microbial communities (Tracy and McNaughton 1995; Brussaard et al. 1997; Frank and Groffman 1998; Frank et al. 2000; Bardgett et al. 2001; Augustine et al. 2003; Singer and Schoenecker 2003). Some of these variables as well as estimates of elk populations, bison movements, and forage offtake in the Great Sand Dunes region are currently being investigated in a collaborative effort between the US Geological Survey, The Nature Conservancy, and the Great Sand Dunes National Park. The results of these studies will be complementary to my study; although I did not find strong evidence for ungulate alteration of soil N dynamics, ecosystem level N processes might be significantly altered if the carrying capacity of all ungulates (bison, cattle, and elk) is exceeded in the Great Sand Dunes region.

I also rejected the hypothesis that long-term cattle grazing in the Sheep Creek montane riparian zone has accelerated N cycling. I expected to find elevated aboveground plant N pools and belowground N pools (root N, soil microbial N, available soil N) as well as increased N processes (mineralization, denitrification) in the long-term grazed sites. Instead, cattle grazing did not significantly increase aboveground production, aboveground or belowground plant N pools, soil N pools, soil microbial biomass, litter decomposition, potential net N mineralization or denitrification in the riparian zone as a whole. There were no apparent differences in plant species composition between cattle grazed and excluded treatments. Also, there was no evidence of high forage utilization and transport of N via feces to surrounding uplands. Thus, cattle did not appear to increase system N at the Sheep Creek riparian zone.

The potential for accelerated N cycling was detected only at streambank sites where net N mineralization in incubated soils was 13.6 ± 1.6 mg N g^{-1} soil N in cattle grazed sites compared with 8.8 ± 1.3 mg N g^{-1} soil N in excluded sites, while the immobilization index was lower in grazed than excluded sites. Increased net N mineralization in the streambank grazed sites was a result of high nitrification. High potential nitrification could indicate a higher likelihood of N loss because NO_3^- is more readily lost from most ecosystems than NH_4^+ (Robertson 1999). Thus, cattle grazed streambank sites could potentially be a source of NO_3^- to the stream. In the stream and groundwater N study, I found that streambank sites are a source of NO_3^- only during losing streamflow conditions in late-summer. However, there was no difference in this response between cattle grazed and excluded sites.

Data suggest that higher nitrification in grazed streambank sites could have been specifically associated with high nitrification (89% higher) for one of the three grazed streambank sites I sampled. This particular site also had higher aboveground production, plant N pools and soil N pools than the other two grazed streambank sites and was utilized the most by cattle compared with all other study locations in 2005 and 2006. Areas repeatedly and frequently grazed by large herbivores such as cattle have been shown to enhance N cycling by increasing available N through urine and fecal inputs, lowering carbon C:N ratios of plant litter and soil organic matter, increasing mineralization rates and reducing microbial immobilization of N (Risser and Parton 1982; Ritchie et al. 1998; Singer and Schoenecker 2003). Since cattle tend to concentrate near the stream where forage and water are abundant (Kauffman and Krueger 1984), it is likely that they move N from surrounding areas to the streambank. It is possible that Sheep Creek streambank sites repeatedly grazed by cattle exhibit enhanced N cycling compared with other riparian locations, but I was unable to fully capture this in my study because my site replicates might have unequal histories of cattle use. When I set up the study, there were no records or data available on cattle site preferences at Sheep Creek since the change in livestock management in the late 1950s.

Aboveground and belowground ecosystem components associated with N dynamics varied across the Sheep Creek riparian zone from the streambank to sites near the edge of the riparian zone. In general, streambank sites were more productive and had greater aboveground plant C and N pools than sites at the edge of the riparian zone. Herbaceous vegetation near the streambank was dominated by grasses and sedges whereas forbs were more prevalent at the upland edge of the riparian zone. Similar patterns in plant composition have been observed along riparian landscape gradients from the stream to the floodplain terrace in montane riparian meadows of northeastern Oregon and the Sierra Nevada (Dwire et al. 2004; Blank et al. 2006). Belowground nutrient pools in the Sheep Creek riparian zone exhibited a pattern opposite of aboveground dynamics: streambank sites had smaller total soil C and N pools, smaller water-soluble organic C (WSOC) and water-soluble total N (WSTN) pools, and less soil organic matter than sites at the edge of the riparian zone. These patterns indicate that turnover rates of C and N might be faster at streambank sites compared with sites farther away from the stream. Faster nutrient supply rates at streambank sites were supported by higher soil microbial biomass C and N and higher mineralization (ammonification or NH_4^+ production) measured with ion-exchange resin (IER) bags in streambank soils compared with riparian edge soils.

Lastly, season-long, light to moderate cattle grazing does not appear to have significant effects on stream or groundwater N dynamics at Sheep Creek. Higher grazing intensity, however, might increase N loading into the stream and groundwater because high cattle inputs of N to riparian zones could lead to higher N production via enhanced nitrification and mineralization (Groffman et al. 1992). Consequently, N export from the riparian zone to surface waters could be increased if denitrification, plant, and microbial pools become enriched with N and lose their capacity to retain N (Aber et al. 1989; Hill and Shackleton 1989; Groffman et al. 1992).

Annual streamflows in Sheep Creek were characterized by a spring snowmelt peak and a second flat top peak in mid-summer from a storage reservoir release. These flows created spring gaining and summer losing streamflow conditions. Stream and groundwater NO_3^- and NH_4^+ were generally low and met U.S. EPA water quality standards for surface waters (US-EPA 2008). During gaining streamflows, stream NO_3^- and NH_4^+ concentrations were 0.07 and 0.05 $mg \cdot L^{-1}$, respectively, while groundwater NO_3^- and NH_4^+ concentrations were 0.06 and 0.07 $mg \cdot L^{-1}$. Under losing streamflows, stream NO_3^- and NH_4^+ concentrations were 0.05 and 0.07 $mg \cdot L^{-1}$ and groundwater NO_3^- and NH_4^+ concentrations were 0.12 and 0.11 $mg \cdot L^{-1}$. Results suggest that the Sheep Creek riparian zone may be a potential sink for groundwater N during spring gaining streamflow conditions (i.e., lower N in riparian zone than stream) and a potential source of groundwater N to the stream during summer losing streamflow conditions (i.e., higher N in riparian zone than stream).

These results differed from N dynamics found by Stednick and Fernald (1999) in soil water at a 30-cm soil depth. They concluded that the Sheep Creek riparian corridor may be a NO_3^- sink during both gaining and losing streamflow conditions but, a source of NH_4^+ during gaining streamflow conditions and a sink of NH_4^+ during losing streamflow conditions. The results of my study and Stednick and Fernald's (1999) study suggest that different N attenuation mechanisms may be responsible for N sink-source relationships in upper riparian soils and groundwater. Under gaining streamflow conditions NO_3^- is most likely removed from surface soils and groundwater by denitrification (Lowrance 1992; Haycock and Pinay 1993; Jacks et al. 1994). Under losing streamflow conditions NO_3^- could be attenuated in surface soils by plant uptake and microbial immobilization but it could increase in the groundwater if the water table declines below the rooting zone (Groffman et al. 1992; Verchot et al. 1997; van der Peijl and Verhoeven 1999). Groundwater NO_3^- might have been elevated at the end of the 2005 growing season if the groundwater table dropped below the rooting zone of herbaceous vegetation (which was more abundant than woody plants) at my study transects.

Sheep Creek surface soils are a source of NH_4^+ during gaining streamflow conditions because plant uptake and microbial immobilization should be low and the high water table and anaerobic conditions are conducive to dissimilatory NO_3^- reduction to ammonium NH_4^+ (DNRA) (Yin et al. 2002; Dhondt et al. 2006). Ammonium in groundwater, however, was low during spring gaining streamflows and might be attributed to low N mineralization at deeper depths in the soil profile. Under losing streamflow conditions NH_4^+ in surface soils could decrease if DNRA decreases and plant uptake and microbial immobilization increase and remove soil NH_4^+. Thus, surface soils might be a sink of NH_4^+ during summer losing streamflows. Groundwater, however, can be a source of NH_4^+ during losing streamflow conditions if the water table declines below the rooting zone of riparian vegetation and microbial immobilization is low at deeper depths in the soil profile.

In summary, I did not find strong evidence for accelerated N cycling in riparian zones grazed by large ungulates. The overall conclusion, however, should be qualified with several observations from both the Great Sand Dunes and Sheep Creek studies. Although not statistically significant because of high variance, net N mineralization was highest in the cattle grazed Great Sand Dunes wet meadows with the longest history of ungulate grazing. At Sheep Creek, net N mineralization was significantly higher in cattle grazed compared with excluded sites near the stream bank. These results were especially apparent at one particular streambank site that had been utilized repeatedly by cattle. These observations suggest increased N mineralization, and thus potential acceleration of N cycling, is more likely in riparian systems that have a long history of grazing, are grazed frequently at moderate intensity, and do not lose N via ungulate movements to other habitats. Although little support for this inference exists in the literature, studies of ungulate effects on N dynamics and primary production in upland ecosystems have suggested that the direction of the response depends on the evolutionary history of the ecosystem, intensity of grazing or browsing, and the opportunity for plant re-growth (McNaughton 1984; Holland and Detling 1990; Shariff et al. 1994; Hobbs 1996; Bardgett et al. 2001; Augustine et al. 2003; Le Roux et al. 2003; Singer and Schoenecker 2003).

Future Considerations

My work and other studies have shown that there is a great deal of spatial heterogeneity in plant communities, groundwater dynamics, soil properties and processes in riparian zones along landscape gradients (i.e., across riparian zone width) and along longitudinal gradients (i.e., along riparian corridor length) (Groffman et al. 1992; Dwire et al. 2004; Blank et al. 2006; Dhondt et al. 2006; Merrill and Benning 2006; Merrill et al. 2006). Studies of riparian ecosystems should account for this heterogeneity by stratifying riparian zones into appropriate ecosystem types or process domains, especially when considering riparian functioning and disturbances on a watershed scale (Montgomery 1999; Merrill and Benning 2006).

I attempted to account for spatial and temporal variation in my Sheep Creek studies by stratifying sampling sites into streambank, middle riparian, and edge of riparian landscape locations and collecting repeated measures data over the course of two growing seasons. However, one limitation of my study was its design because the sampling locations were set up by pairing equal length grazed and excluded study transects so that I could establish groundwater piezometers at equal intervals in the three landscape locations. This approach minimized variance within blocks for piezometer locations but it did not necessarily minimize within block variation in plant and soil characteristics between each paired grazed and excluded landscape location. For example, within a given block, a middle riparian site in a grazed treatment might have had different plant species composition or microtopography characteristics than its paired excluded treatment middle riparian site. Blocking is most effective when experimental units within each block are as similar as possible (Gotelli and Ellison 2004).

Future studies should attempt to minimize within block variance of experimental units to better test treatment effects. They should also have more replicates for each treatment combination. I had only three field replicates of each grazing treatment level per landscape position. Although the total number of samples collected during each sampling event was barely manageable for completion of a series of different soil analyses, more replicates could have better normalized variances of response variables for a given treatment effect. However, more time and greater expense would be involved.

Many grazing studies are limited by pseudoreplication of grazing treatments, unequal histories of grazing treatments for comparisons between different herbivores or ecosystems, or limited data on historical intensity or frequency of grazing. In my Great Sand Dunes study, cattle had a longer contemporary history of grazing in the area than did bison. Furthermore, at the time of the study cattle had been excluded from control sites for 15 years while bison had been excluded from control sites for only three years. Thus, the regulatory influence of bison on soil N dynamics in riparian and wet meadow sites might be underestimated in my study.

My Sheep Creek study was limited by unequal utilization of grazed study sites by cattle. Patterns of cattle use at Sheep Creek have not been quantified, but based on my field observations, cattle do not equally utilize all parts of the riparian pastures they are allotted to. For example, cattle utilized one of the three streambank sites more frequently and repeatedly during my two field seasons. Cattle generally concentrate near the stream where forage and water are abundant (Kauffman and Krueger 1984). Based on my study, it also appears that they prefer some streambank locations over others. Since my study sites likely had unequal utilization levels and frequencies since the change in livestock management in the late 1950s, it is possible that I underestimated long-term effects of cattle grazing on N dynamics in areas of the montane riparian zone used more repeatedly by cattle. Future studies of N dynamics in riparian ecosystems should better account for potential differences in historical livestock or wildlife management, herbivore movements, frequency of use, and utilization of different landscape habitats or patches.

The methods I used in both of my studies for analyzing soil properties and processes were developed for upland mineral soils. Riparian soils, however, are quite different from most upland soils because they contain very high soil organic matter and are frequently saturated with water for extended periods of time. Thus, collection of soil core samples in riparian zones is difficult because soil cores can be easily compressed or soils are too saturated and waterlogged for a soil core to be pulled. In the laboratory, preparation of riparian soil samples is incredibly time intensive because fine roots and pieces of organic matter (i.e. particulate organic matter, POM) have to be separated from mineral soil before analysis. In the end, soil samples are often laden with indistinguishable fine organic matter which can affect the results of many soil analyses (i.e., N mineralization, denitrification, water-soluble fractions, microbial biomass, etc.). Fine roots and organic matter can be especially problematic for laboratory soil incubations because they can contribute to large variation in soil microbial activity which mediates soil processes such as N mineralization and C respiration. High organic matter and fine particle sizes of riparian soils are also problematic for maintaining constant soil moisture in incubated soils, especially if the samples are leached periodically as was the case in my Great Sand Dunes study. Thus, extra care should be taken when collecting, preparing, and analyzing riparian soils. Furthermore, there is a need for improved methods of soil analysis for riparian soils. These methods could potentially be developed from existing protocols for mineral soils by including correction factors such as soil organic matter, POM, bulk density, or extraction efficiency coefficients.

Lastly, future studies of N groundwater dynamics, especially at Sheep Creek, should utilize groundwater tracers (e.g., Br^- or Cl^-) and a larger network of piezometers and wells to better understand lateral flows and potential dilution effect on NO_3^- and NH_4^+ concentrations (Simmons et al. 1992; Verchot et al. 1997). Furthermore, although numerous studies have demonstrated the ability of riparian zones to remove N, especially NO_3^-, from upland waters before they enter streams, there is still uncertainty about the specific mechanisms of N attenuation (Lowrance et al. 1984; Cooper 1990; Groffman et al. 1996). Novel approaches with N isotopes ($\delta^{15}N$ techniques) should be evaluated further to elucidate spatial and temporal variation of N attenuation by denitrification, plant uptake, and microbial immobilization. Non-conservative behavior of N isotopes allows for a fine spatial resolution of different microbial processes (e.g. denitrification, nitrification, uptake) that are variable over short distances in riparian environments (Cey et al. 1999; Ostrom et al. 2002; Dhondt et al. 2003). A better understanding of N attenuation mechanisms in different riparian ecosystems would be useful for predicting changes in potential for nutrient retention of riparian zones under different disturbance regimes.

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APPENDIX

CHAPTER II

Appendix A. Gravimetric water content (%) of incubated soils from Great Sand Dunes riparian corridors and wet meadows. Moisture content was measured after each leaching (L) of samples with a micronutrient solution.

Site	Wetland type	Graing treatment	Replicate	L-1 day 0	L-2 week 1	L-3 week 2	L-4 week 3	L-5 week 5	L-6 week 7	L-7 week 10	L-8 week 13	L-9 week 17	L-10 week 21	L-11 week 24
Big Spring Creek	riparian	control	1	25	30	30	25	25	25	25	25	25	25	25
Big Spring Creek	riparian	control	2	22	24	24	27	22	22	22	22	22	22	23
Big Spring Creek	riparian	control	3	24	24	25	25	24	24	24	25	24	24	27
Big Spring Creek	riparian	control	4	24	24	29	28	24	25	30	24	25	28	30
Big Spring Creek	riparian	bison	1	19	23	31	21	21	20	19	19	19	19	23
Big Spring Creek	riparian	bison	2	29	33	31	30	29	29	29	29	29	29	31
Big Spring Creek	riparian	bison	3	17	18	21	21	18	17	17	17	17	17	20
Big Spring Creek	riparian	bison	4	42	42	42	42	42	42	42	42	42	42	42
Little Spring Creek	riparian	control	1	37	37	37	37	37	37	37	37	37	37	37
Little Spring Creek	riparian	control	2	42	42	42	42	42	42	42	42	42	42	42
Little Spring Creek	riparian	control	3	40	45	43	41	40	40	40	40	40	40	40
Little Spring Creek	riparian	control	4	41	41	41	41	41	41	41	41	41	41	41
Little Spring Creek	riparian	bison	1	31	31	31	32	31	31	31	31	31	31	31
Little Spring Creek	riparian	bison	2	32	34	33	32	32	32	32	32	32	32	32
Little Spring Creek	riparian	bison	3	40	40	40	40	40	40	40	40	40	40	40
Little Spring Creek	riparian	bison	4	31	36	31	33	31	31	31	31	31	31	32
Elk Springs	wet meadow	bison	1	11	19	26	11	20	17	22	16	13	13	20
Elk Springs	wet meadow	bison	2	27	29	27	27	27	27	27	27	27	27	27
Elk Springs	wet meadow	bison	3	24	26	30	27	24	25	24	24	24	24	24
Elk Springs	wet meadow	bison	4	19	21	30	19	19	19	20	19	19	19	22
Elk Springs	wet meadow	control	1	14	14	14	14	14	14	15	14	18	14	20
Elk Springs	wet meadow	control	2	16	16	16	16	16	16	16	16	16	16	16
Elk Springs	wet meadow	control	3	15	18	15	16	15	15	15	15	15	18	21
Elk Springs	wet meadow	control	4	17	22	25	17	17	18	17	17	20	17	25
Twin Lakes	wet meadow	bison	1	30	30	30	30	30	30	30	30	30	30	32
Twin Lakes	wet meadow	bison	2	27	29	27	27	27	28	27	27	27	27	32
Twin Lakes	wet meadow	bison	3	49	49	49	49	49	49	49	49	49	49	49
Twin Lakes	wet meadow	bison	4	50	50	50	50	50	50	50	50	50	50	50

Appendix A. Continued.

Site	Wetland type	Graing treatment	Replicate	L-1 day 0	L-2 week 1	L-3 week 2	L-4 week 3	L-5 week 5	L-6 week 7	L-7 week 10	L-8 week 13	L-9 week 17	L-10 week 21	L-11 week 24
Twin Lakes	wet meadow	control	1	36	36	36	36	36	36	36	36	36	36	36
Twin Lakes	wet meadow	control	2	27	35	31	29	27	27	27	27	27	27	32
Twin Lakes	wet meadow	control	3	30	32	30	30	30	30	30	30	30	30	31
Twin Lakes	wet meadow	control	4	31	31	31	31	31	31	31	31	31	31	31
West MZ Ranch	wet meadow	cattle	1	22	23	24	24	22	22	24	22	22	22	25
West MZ Ranch	wet meadow	cattle	2	21	21	22	23	22	21	21	22	21	21	21
West MZ Ranch	wet meadow	cattle	3	29	29	29	29	29	29	29	29	29	29	29
West MZ Ranch	wet meadow	cattle	4	28	29	28	28	28	28	28	28	29	28	28
West MZ Ranch	wet meadow	control	1	28	28	28	28	28	28	28	28	28	28	28
West MZ Ranch	wet meadow	control	2	23	24	24	23	23	23	24	23	23	23	23
West MZ Ranch	wet meadow	control	3	21	21	27	25	21	22	22	21	21	21	24
West MZ Ranch	wet meadow	control	4	23	27	24	23	23	24	23	23	23	24	24
South MZ Ranch	wet meadow	cattle	1	29	29	31	29	29	29	29	29	29	29	29
South MZ Ranch	wet meadow	cattle	2	35	35	35	35	35	35	35	35	35	35	35
South MZ Ranch	wet meadow	cattle	3	29	29	33	32	29	31	29	29	29	29	29
South MZ Ranch	wet meadow	cattle	4	46	46	46	46	46	46	47	46	46	46	46
South MZ Ranch	wet meadow	control	1	35	35	35	35	35	35	35	35	35	35	35
South MZ Ranch	wet meadow	control	2	28	28	33	31	29	28	29	29	28	28	32
South MZ Ranch	wet meadow	control	3	36	36	36	36	36	36	36	36	36	36	36
South MZ Ranch	wet meadow	control	4	31	31	32	32	31	31	31	31	31	31	31

Appendix B. Soil microbial CO2 respiration rates of incubated soils from Great Sand Dunes wetlands. Respiration rates were measured periodically during a 6- month incubation period.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Microbial CO_2 respiration rate ($mg\ C\ g^{-1}\ soil\ C\ d^{-1}$)
Big Spring Creek	riparian	control	1	3	1.80
Big Spring Creek	riparian	control	1	6	1.27
Big Spring Creek	riparian	control	1	10	1.09
Big Spring Creek	riparian	control	1	13	1.03
Big Spring Creek	riparian	control	1	20	0.77
Big Spring Creek	riparian	control	1	34	0.91
Big Spring Creek	riparian	control	1	48	1.29
Big Spring Creek	riparian	control	1	69	0.92
Big Spring Creek	riparian	control	1	89	---
Big Spring Creek	riparian	control	1	116	0.77
Big Spring Creek	riparian	control	1	140	0.54
Big Spring Creek	riparian	control	1	164	0.51
Big Spring Creek	riparian	control	2	3	1.52
Big Spring Creek	riparian	control	2	6	1.83
Big Spring Creek	riparian	control	2	10	1.13
Big Spring Creek	riparian	control	2	13	1.09
Big Spring Creek	riparian	control	2	20	0.92
Big Spring Creek	riparian	control	2	34	0.48
Big Spring Creek	riparian	control	2	48	0.60
Big Spring Creek	riparian	control	2	69	0.93
Big Spring Creek	riparian	control	2	89	0.92
Big Spring Creek	riparian	control	2	116	0.98
Big Spring Creek	riparian	control	2	140	0.58
Big Spring Creek	riparian	control	2	164	0.62
Big Spring Creek	riparian	control	3	3	3.68
Big Spring Creek	riparian	control	3	6	2.61
Big Spring Creek	riparian	control	3	10	2.20
Big Spring Creek	riparian	control	3	13	2.06
Big Spring Creek	riparian	control	3	20	1.70
Big Spring Creek	riparian	control	3	34	1.66
Big Spring Creek	riparian	control	3	48	1.96
Big Spring Creek	riparian	control	3	69	1.46
Big Spring Creek	riparian	control	3	89	1.75
Big Spring Creek	riparian	control	3	116	1.50
Big Spring Creek	riparian	control	3	140	1.01
Big Spring Creek	riparian	control	3	164	1.12
Big Spring Creek	riparian	control	4	3	1.97
Big Spring Creek	riparian	control	4	6	2.64
Big Spring Creek	riparian	control	4	10	1.37
Big Spring Creek	riparian	control	4	13	1.06
Big Spring Creek	riparian	control	4	20	1.01
Big Spring Creek	riparian	control	4	34	0.80
Big Spring Creek	riparian	control	4	48	0.84
Big Spring Creek	riparian	control	4	69	1.08
Big Spring Creek	riparian	control	4	89	0.74
Big Spring Creek	riparian	control	4	116	0.91
Big Spring Creek	riparian	control	4	140	0.68
Big Spring Creek	riparian	control	4	164	0.75
Big Spring Creek	riparian	bison	1	3	3.89
Big Spring Creek	riparian	bison	1	6	2.46
Big Spring Creek	riparian	bison	1	10	1.69

Appendix B. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Microbial CO_2 respiration rate (mg C g^{-1} soil C d^{-1})
Big Spring Creek	riparian	bison	1	13	1.59
Big Spring Creek	riparian	bison	1	20	1.35
Big Spring Creek	riparian	bison	1	34	1.02
Big Spring Creek	riparian	bison	1	48	1.14
Big Spring Creek	riparian	bison	1	69	1.51
Big Spring Creek	riparian	bison	1	89	1.58
Big Spring Creek	riparian	bison	1	116	1.28
Big Spring Creek	riparian	bison	1	140	0.57
Big Spring Creek	riparian	bison	1	164	0.74
Big Spring Creek	riparian	bison	2	3	2.88
Big Spring Creek	riparian	bison	2	6	1.74
Big Spring Creek	riparian	bison	2	10	1.36
Big Spring Creek	riparian	bison	2	13	1.20
Big Spring Creek	riparian	bison	2	20	1.05
Big Spring Creek	riparian	bison	2	34	0.89
Big Spring Creek	riparian	bison	2	48	1.16
Big Spring Creek	riparian	bison	2	69	0.94
Big Spring Creek	riparian	bison	2	89	0.89
Big Spring Creek	riparian	bison	2	116	0.91
Big Spring Creek	riparian	bison	2	140	0.60
Big Spring Creek	riparian	bison	2	164	0.67
Big Spring Creek	riparian	bison	3	3	3.07
Big Spring Creek	riparian	bison	3	6	2.01
Big Spring Creek	riparian	bison	3	10	2.02
Big Spring Creek	riparian	bison	3	13	1.96
Big Spring Creek	riparian	bison	3	20	1.42
Big Spring Creek	riparian	bison	3	34	1.19
Big Spring Creek	riparian	bison	3	48	1.08
Big Spring Creek	riparian	bison	3	69	0.95
Big Spring Creek	riparian	bison	3	89	1.08
Big Spring Creek	riparian	bison	3	116	0.90
Big Spring Creek	riparian	bison	3	140	0.61
Big Spring Creek	riparian	bison	3	164	0.79
Big Spring Creek	riparian	bison	4	3	2.48
Big Spring Creek	riparian	bison	4	6	1.80
Big Spring Creek	riparian	bison	4	10	1.20
Big Spring Creek	riparian	bison	4	13	1.09
Big Spring Creek	riparian	bison	4	20	0.94
Big Spring Creek	riparian	bison	4	34	1.14
Big Spring Creek	riparian	bison	4	48	1.13
Big Spring Creek	riparian	bison	4	69	1.93
Big Spring Creek	riparian	bison	4	89	1.67
Big Spring Creek	riparian	bison	4	116	1.28
Big Spring Creek	riparian	bison	4	140	1.03
Big Spring Creek	riparian	bison	4	164	1.13
Little Spring Creek	riparian	control	1	3	2.66
Little Spring Creek	riparian	control	1	6	2.06
Little Spring Creek	riparian	control	1	10	1.70
Little Spring Creek	riparian	control	1	13	1.49
Little Spring Creek	riparian	control	1	20	1.28
Little Spring Creek	riparian	control	1	34	1.53
Little Spring Creek	riparian	control	1	48	1.35
Little Spring Creek	riparian	control	1	69	1.19

Appendix B. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Microbial CO_2 respiration rate ($mg\ C\ g^{-1}\ soil\ C\ d^{-1}$)
Little Spring Creek	riparian	control	1	89	1.71
Little Spring Creek	riparian	control	1	116	1.83
Little Spring Creek	riparian	control	1	140	0.95
Little Spring Creek	riparian	control	1	164	0.83
Little Spring Creek	riparian	control	2	3	2.52
Little Spring Creek	riparian	control	2	6	1.88
Little Spring Creek	riparian	control	2	10	1.48
Little Spring Creek	riparian	control	2	13	1.32
Little Spring Creek	riparian	control	2	20	0.91
Little Spring Creek	riparian	control	2	34	1.43
Little Spring Creek	riparian	control	2	48	1.57
Little Spring Creek	riparian	control	2	69	2.08
Little Spring Creek	riparian	control	2	89	2.11
Little Spring Creek	riparian	control	2	116	2.40
Little Spring Creek	riparian	control	2	140	1.50
Little Spring Creek	riparian	control	2	164	1.32
Little Spring Creek	riparian	control	3	3	3.49
Little Spring Creek	riparian	control	3	6	2.37
Little Spring Creek	riparian	control	3	10	2.23
Little Spring Creek	riparian	control	3	13	1.63
Little Spring Creek	riparian	control	3	20	1.41
Little Spring Creek	riparian	control	3	34	1.61
Little Spring Creek	riparian	control	3	48	1.62
Little Spring Creek	riparian	control	3	69	1.24
Little Spring Creek	riparian	control	3	89	2.90
Little Spring Creek	riparian	control	3	116	3.31
Little Spring Creek	riparian	control	3	140	2.35
Little Spring Creek	riparian	control	3	164	1.88
Little Spring Creek	riparian	control	4	3	2.41
Little Spring Creek	riparian	control	4	6	1.69
Little Spring Creek	riparian	control	4	10	1.23
Little Spring Creek	riparian	control	4	13	1.23
Little Spring Creek	riparian	control	4	20	1.12
Little Spring Creek	riparian	control	4	34	1.21
Little Spring Creek	riparian	control	4	48	1.13
Little Spring Creek	riparian	control	4	69	1.97
Little Spring Creek	riparian	control	4	89	2.38
Little Spring Creek	riparian	control	4	116	2.56
Little Spring Creek	riparian	control	4	140	1.92
Little Spring Creek	riparian	control	4	164	1.44
Little Spring Creek	riparian	bison	1	3	4.09
Little Spring Creek	riparian	bison	1	6	2.38
Little Spring Creek	riparian	bison	1	10	1.96
Little Spring Creek	riparian	bison	1	13	1.89
Little Spring Creek	riparian	bison	1	20	1.56
Little Spring Creek	riparian	bison	1	34	1.36
Little Spring Creek	riparian	bison	1	48	0.55
Little Spring Creek	riparian	bison	1	69	1.37
Little Spring Creek	riparian	bison	1	89	1.74
Little Spring Creek	riparian	bison	1	116	1.38
Little Spring Creek	riparian	bison	1	140	1.07
Little Spring Creek	riparian	bison	1	164	1.05
Little Spring Creek	riparian	bison	2	3	3.98

Appendix B. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Microbial CO_2 respiration rate (mg C g^{-1} soil C d^{-1})
Little Spring Creek	riparian	bison	2	6	3.11
Little Spring Creek	riparian	bison	2	10	2.72
Little Spring Creek	riparian	bison	2	13	2.24
Little Spring Creek	riparian	bison	2	20	2.02
Little Spring Creek	riparian	bison	2	34	2.21
Little Spring Creek	riparian	bison	2	48	2.06
Little Spring Creek	riparian	bison	2	69	2.42
Little Spring Creek	riparian	bison	2	89	2.89
Little Spring Creek	riparian	bison	2	116	2.84
Little Spring Creek	riparian	bison	2	140	1.95
Little Spring Creek	riparian	bison	2	164	1.96
Little Spring Creek	riparian	bison	3	3	2.88
Little Spring Creek	riparian	bison	3	6	2.15
Little Spring Creek	riparian	bison	3	10	1.62
Little Spring Creek	riparian	bison	3	13	1.54
Little Spring Creek	riparian	bison	3	20	1.39
Little Spring Creek	riparian	bison	3	34	1.49
Little Spring Creek	riparian	bison	3	48	1.23
Little Spring Creek	riparian	bison	3	69	2.58
Little Spring Creek	riparian	bison	3	89	2.68
Little Spring Creek	riparian	bison	3	116	3.08
Little Spring Creek	riparian	bison	3	140	---
Little Spring Creek	riparian	bison	3	164	2.33
Little Spring Creek	riparian	bison	4	3	2.84
Little Spring Creek	riparian	bison	4	6	1.90
Little Spring Creek	riparian	bison	4	10	1.45
Little Spring Creek	riparian	bison	4	13	1.33
Little Spring Creek	riparian	bison	4	20	0.92
Little Spring Creek	riparian	bison	4	34	1.20
Little Spring Creek	riparian	bison	4	48	1.21
Little Spring Creek	riparian	bison	4	69	1.02
Little Spring Creek	riparian	bison	4	89	1.03
Little Spring Creek	riparian	bison	4	116	1.00
Little Spring Creek	riparian	bison	4	140	0.79
Little Spring Creek	riparian	bison	4	164	0.55
Elk Springs	wet meadow	control	1	3	4.47
Elk Springs	wet meadow	control	1	6	3.55
Elk Springs	wet meadow	control	1	10	2.70
Elk Springs	wet meadow	control	1	13	1.79
Elk Springs	wet meadow	control	1	20	1.73
Elk Springs	wet meadow	control	1	34	1.73
Elk Springs	wet meadow	control	1	48	1.15
Elk Springs	wet meadow	control	1	69	2.15
Elk Springs	wet meadow	control	1	89	1.87
Elk Springs	wet meadow	control	1	116	2.07
Elk Springs	wet meadow	control	1	140	1.13
Elk Springs	wet meadow	control	1	164	1.12
Elk Springs	wet meadow	control	2	3	5.84
Elk Springs	wet meadow	control	2	6	4.16
Elk Springs	wet meadow	control	2	10	3.74
Elk Springs	wet meadow	control	2	13	2.72
Elk Springs	wet meadow	control	2	20	2.46
Elk Springs	wet meadow	control	2	34	2.28

Appendix B. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Microbial CO_2 respiration rate ($mg\ C\ g^{-1}\ soil\ C\ d^{-1}$)
Elk Springs	wet meadow	control	2	48	1.75
Elk Springs	wet meadow	control	2	69	1.73
Elk Springs	wet meadow	control	2	89	2.31
Elk Springs	wet meadow	control	2	116	2.05
Elk Springs	wet meadow	control	2	140	1.71
Elk Springs	wet meadow	control	2	164	1.59
Elk Springs	wet meadow	control	3	3	3.50
Elk Springs	wet meadow	control	3	6	2.48
Elk Springs	wet meadow	control	3	10	1.83
Elk Springs	wet meadow	control	3	13	1.66
Elk Springs	wet meadow	control	3	20	1.18
Elk Springs	wet meadow	control	3	34	1.53
Elk Springs	wet meadow	control	3	48	1.45
Elk Springs	wet meadow	control	3	69	1.61
Elk Springs	wet meadow	control	3	89	1.89
Elk Springs	wet meadow	control	3	116	1.78
Elk Springs	wet meadow	control	3	140	1.59
Elk Springs	wet meadow	control	3	164	1.07
Elk Springs	wet meadow	control	4	3	4.59
Elk Springs	wet meadow	control	4	6	2.79
Elk Springs	wet meadow	control	4	10	2.81
Elk Springs	wet meadow	control	4	13	1.59
Elk Springs	wet meadow	control	4	20	1.36
Elk Springs	wet meadow	control	4	34	1.36
Elk Springs	wet meadow	control	4	48	1.38
Elk Springs	wet meadow	control	4	69	1.72
Elk Springs	wet meadow	control	4	89	2.06
Elk Springs	wet meadow	control	4	116	1.98
Elk Springs	wet meadow	control	4	140	1.19
Elk Springs	wet meadow	control	4	164	0.93
Elk Springs	wet meadow	bison	1	3	4.16
Elk Springs	wet meadow	bison	1	6	3.25
Elk Springs	wet meadow	bison	1	10	2.97
Elk Springs	wet meadow	bison	1	13	2.41
Elk Springs	wet meadow	bison	1	20	1.95
Elk Springs	wet meadow	bison	1	34	1.30
Elk Springs	wet meadow	bison	1	48	1.82
Elk Springs	wet meadow	bison	1	69	2.02
Elk Springs	wet meadow	bison	1	89	2.24
Elk Springs	wet meadow	bison	1	116	1.56
Elk Springs	wet meadow	bison	1	140	1.72
Elk Springs	wet meadow	bison	1	164	1.35
Elk Springs	wet meadow	bison	2	3	5.39
Elk Springs	wet meadow	bison	2	6	3.99
Elk Springs	wet meadow	bison	2	10	3.62
Elk Springs	wet meadow	bison	2	13	2.66
Elk Springs	wet meadow	bison	2	20	1.89
Elk Springs	wet meadow	bison	2	34	2.30
Elk Springs	wet meadow	bison	2	48	2.48
Elk Springs	wet meadow	bison	2	69	3.54
Elk Springs	wet meadow	bison	2	89	3.73
Elk Springs	wet meadow	bison	2	116	2.76
Elk Springs	wet meadow	bison	2	140	2.94

Appendix B. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Microbial CO_2 respiration rate (mg C g^{-1} soil C d^{-1})
Elk Springs	wet meadow	bison	2	164	2.19
Elk Springs	wet meadow	bison	3	3	4.55
Elk Springs	wet meadow	bison	3	6	3.30
Elk Springs	wet meadow	bison	3	10	2.64
Elk Springs	wet meadow	bison	3	13	2.18
Elk Springs	wet meadow	bison	3	20	1.61
Elk Springs	wet meadow	bison	3	34	1.82
Elk Springs	wet meadow	bison	3	48	1.85
Elk Springs	wet meadow	bison	3	69	2.21
Elk Springs	wet meadow	bison	3	89	2.23
Elk Springs	wet meadow	bison	3	116	1.48
Elk Springs	wet meadow	bison	3	140	1.23
Elk Springs	wet meadow	bison	3	164	1.19
Elk Springs	wet meadow	bison	4	3	4.65
Elk Springs	wet meadow	bison	4	6	3.59
Elk Springs	wet meadow	bison	4	10	2.95
Elk Springs	wet meadow	bison	4	13	2.25
Elk Springs	wet meadow	bison	4	20	1.83
Elk Springs	wet meadow	bison	4	34	1.76
Elk Springs	wet meadow	bison	4	48	1.80
Elk Springs	wet meadow	bison	4	69	2.08
Elk Springs	wet meadow	bison	4	89	2.09
Elk Springs	wet meadow	bison	4	116	1.92
Elk Springs	wet meadow	bison	4	140	2.25
Elk Springs	wet meadow	bison	4	164	1.45
Twin Lakes	wet meadow	control	1	3	2.92
Twin Lakes	wet meadow	control	1	6	1.34
Twin Lakes	wet meadow	control	1	10	1.10
Twin Lakes	wet meadow	control	1	13	1.04
Twin Lakes	wet meadow	control	1	20	1.13
Twin Lakes	wet meadow	control	1	34	1.12
Twin Lakes	wet meadow	control	1	48	1.29
Twin Lakes	wet meadow	control	1	69	2.47
Twin Lakes	wet meadow	control	1	89	---
Twin Lakes	wet meadow	control	1	116	---
Twin Lakes	wet meadow	control	1	140	---
Twin Lakes	wet meadow	control	1	164	---
Twin Lakes	wet meadow	control	2	3	1.52
Twin Lakes	wet meadow	control	2	6	0.99
Twin Lakes	wet meadow	control	2	10	0.96
Twin Lakes	wet meadow	control	2	13	0.92
Twin Lakes	wet meadow	control	2	20	0.76
Twin Lakes	wet meadow	control	2	34	0.90
Twin Lakes	wet meadow	control	2	48	0.94
Twin Lakes	wet meadow	control	2	69	2.69
Twin Lakes	wet meadow	control	2	89	1.70
Twin Lakes	wet meadow	control	2	116	1.95
Twin Lakes	wet meadow	control	2	140	1.69
Twin Lakes	wet meadow	control	2	164	1.46
Twin Lakes	wet meadow	control	3	3	2.23
Twin Lakes	wet meadow	control	3	6	1.38
Twin Lakes	wet meadow	control	3	10	1.20
Twin Lakes	wet meadow	control	3	13	1.08

Appendix B. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Microbial CO_2 respiration rate (mg C g^{-1} soil C d^{-1})
Twin Lakes	wet meadow	control	3	20	0.94
Twin Lakes	wet meadow	control	3	34	1.16
Twin Lakes	wet meadow	control	3	48	1.09
Twin Lakes	wet meadow	control	3	69	1.71
Twin Lakes	wet meadow	control	3	89	1.83
Twin Lakes	wet meadow	control	3	116	1.74
Twin Lakes	wet meadow	control	3	140	1.44
Twin Lakes	wet meadow	control	3	164	1.35
Twin Lakes	wet meadow	control	4	3	2.40
Twin Lakes	wet meadow	control	4	6	1.46
Twin Lakes	wet meadow	control	4	10	1.16
Twin Lakes	wet meadow	control	4	13	0.98
Twin Lakes	wet meadow	control	4	20	0.92
Twin Lakes	wet meadow	control	4	34	1.11
Twin Lakes	wet meadow	control	4	48	1.27
Twin Lakes	wet meadow	control	4	69	1.87
Twin Lakes	wet meadow	control	4	89	2.01
Twin Lakes	wet meadow	control	4	116	1.96
Twin Lakes	wet meadow	control	4	140	1.63
Twin Lakes	wet meadow	control	4	164	1.53
Twin Lakes	wet meadow	bison	1	3	2.01
Twin Lakes	wet meadow	bison	1	6	1.16
Twin Lakes	wet meadow	bison	1	10	0.77
Twin Lakes	wet meadow	bison	1	13	0.84
Twin Lakes	wet meadow	bison	1	20	0.72
Twin Lakes	wet meadow	bison	1	34	0.96
Twin Lakes	wet meadow	bison	1	48	1.02
Twin Lakes	wet meadow	bison	1	69	1.58
Twin Lakes	wet meadow	bison	1	89	1.84
Twin Lakes	wet meadow	bison	1	116	2.24
Twin Lakes	wet meadow	bison	1	140	1.55
Twin Lakes	wet meadow	bison	1	164	1.31
Twin Lakes	wet meadow	bison	2	3	1.72
Twin Lakes	wet meadow	bison	2	6	1.03
Twin Lakes	wet meadow	bison	2	10	0.77
Twin Lakes	wet meadow	bison	2	13	0.83
Twin Lakes	wet meadow	bison	2	20	0.93
Twin Lakes	wet meadow	bison	2	34	0.92
Twin Lakes	wet meadow	bison	2	48	0.83
Twin Lakes	wet meadow	bison	2	69	1.61
Twin Lakes	wet meadow	bison	2	89	1.76
Twin Lakes	wet meadow	bison	2	116	2.03
Twin Lakes	wet meadow	bison	2	140	1.58
Twin Lakes	wet meadow	bison	2	164	1.42
Twin Lakes	wet meadow	bison	3	3	2.33
Twin Lakes	wet meadow	bison	3	6	1.50
Twin Lakes	wet meadow	bison	3	10	1.06
Twin Lakes	wet meadow	bison	3	13	1.05
Twin Lakes	wet meadow	bison	3	20	1.02
Twin Lakes	wet meadow	bison	3	34	1.21
Twin Lakes	wet meadow	bison	3	48	1.60
Twin Lakes	wet meadow	bison	3	69	---
Twin Lakes	wet meadow	bison	3	89	3.44

Appendix B. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Microbial CO_2 respiration rate ($mg\ C\ g^{-1}$ soil $C\ d^{-1}$)
Twin Lakes	wet meadow	bison	3	116	3.35
Twin Lakes	wet meadow	bison	3	140	3.17
Twin Lakes	wet meadow	bison	3	164	2.73
Twin Lakes	wet meadow	bison	4	3	2.20
Twin Lakes	wet meadow	bison	4	6	1.34
Twin Lakes	wet meadow	bison	4	10	1.06
Twin Lakes	wet meadow	bison	4	13	1.04
Twin Lakes	wet meadow	bison	4	20	0.92
Twin Lakes	wet meadow	bison	4	34	1.14
Twin Lakes	wet meadow	bison	4	48	1.27
Twin Lakes	wet meadow	bison	4	69	2.99
Twin Lakes	wet meadow	bison	4	89	3.14
Twin Lakes	wet meadow	bison	4	116	4.03
Twin Lakes	wet meadow	bison	4	140	3.97
Twin Lakes	wet meadow	bison	4	164	3.50
South MZ Ranch	wet meadow	control	1	3	2.07
South MZ Ranch	wet meadow	control	1	6	1.70
South MZ Ranch	wet meadow	control	1	10	1.58
South MZ Ranch	wet meadow	control	1	13	1.71
South MZ Ranch	wet meadow	control	1	20	2.76
South MZ Ranch	wet meadow	control	1	34	1.59
South MZ Ranch	wet meadow	control	1	48	1.77
South MZ Ranch	wet meadow	control	1	69	2.01
South MZ Ranch	wet meadow	control	1	89	2.20
South MZ Ranch	wet meadow	control	1	116	1.86
South MZ Ranch	wet meadow	control	1	140	1.67
South MZ Ranch	wet meadow	control	1	164	1.59
South MZ Ranch	wet meadow	control	2	3	2.76
South MZ Ranch	wet meadow	control	2	6	2.47
South MZ Ranch	wet meadow	control	2	10	2.55
South MZ Ranch	wet meadow	control	2	13	2.71
South MZ Ranch	wet meadow	control	2	20	2.29
South MZ Ranch	wet meadow	control	2	34	2.29
South MZ Ranch	wet meadow	control	2	48	1.80
South MZ Ranch	wet meadow	control	2	69	2.15
South MZ Ranch	wet meadow	control	2	89	1.68
South MZ Ranch	wet meadow	control	2	116	1.56
South MZ Ranch	wet meadow	control	2	140	1.44
South MZ Ranch	wet meadow	control	2	164	1.50
South MZ Ranch	wet meadow	control	3	3	2.44
South MZ Ranch	wet meadow	control	3	6	1.38
South MZ Ranch	wet meadow	control	3	10	1.76
South MZ Ranch	wet meadow	control	3	13	1.65
South MZ Ranch	wet meadow	control	3	20	1.80
South MZ Ranch	wet meadow	control	3	34	2.30
South MZ Ranch	wet meadow	control	3	48	2.10
South MZ Ranch	wet meadow	control	3	69	---
South MZ Ranch	wet meadow	control	3	89	---
South MZ Ranch	wet meadow	control	3	116	2.68
South MZ Ranch	wet meadow	control	3	140	2.41
South MZ Ranch	wet meadow	control	3	164	2.43
South MZ Ranch	wet meadow	control	4	3	1.72
South MZ Ranch	wet meadow	control	4	6	1.32

Appendix B. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Microbial CO_2 respiration rate (mg C g^{-1} soil C d^{-1})
South MZ Ranch	wet meadow	control	4	10	1.32
South MZ Ranch	wet meadow	control	4	13	1.19
South MZ Ranch	wet meadow	control	4	20	2.00
South MZ Ranch	wet meadow	control	4	34	1.60
South MZ Ranch	wet meadow	control	4	48	1.53
South MZ Ranch	wet meadow	control	4	69	1.83
South MZ Ranch	wet meadow	control	4	89	2.45
South MZ Ranch	wet meadow	control	4	116	1.93
South MZ Ranch	wet meadow	control	4	140	1.43
South MZ Ranch	wet meadow	control	4	164	1.24
South MZ Ranch	wet meadow	cattle	1	3	3.87
South MZ Ranch	wet meadow	cattle	1	6	2.35
South MZ Ranch	wet meadow	cattle	1	10	2.87
South MZ Ranch	wet meadow	cattle	1	13	2.85
South MZ Ranch	wet meadow	cattle	1	20	2.19
South MZ Ranch	wet meadow	cattle	1	34	2.46
South MZ Ranch	wet meadow	cattle	1	48	3.41
South MZ Ranch	wet meadow	cattle	1	69	4.12
South MZ Ranch	wet meadow	cattle	1	89	2.62
South MZ Ranch	wet meadow	cattle	1	116	3.03
South MZ Ranch	wet meadow	cattle	1	140	1.78
South MZ Ranch	wet meadow	cattle	1	164	1.48
South MZ Ranch	wet meadow	cattle	2	3	4.59
South MZ Ranch	wet meadow	cattle	2	6	3.15
South MZ Ranch	wet meadow	cattle	2	10	3.02
South MZ Ranch	wet meadow	cattle	2	13	2.86
South MZ Ranch	wet meadow	cattle	2	20	2.87
South MZ Ranch	wet meadow	cattle	2	34	3.06
South MZ Ranch	wet meadow	cattle	2	48	3.17
South MZ Ranch	wet meadow	cattle	2	69	3.94
South MZ Ranch	wet meadow	cattle	2	89	4.25
South MZ Ranch	wet meadow	cattle	2	116	6.12
South MZ Ranch	wet meadow	cattle	2	140	3.49
South MZ Ranch	wet meadow	cattle	2	164	2.48
South MZ Ranch	wet meadow	cattle	3	3	3.50
South MZ Ranch	wet meadow	cattle	3	6	2.69
South MZ Ranch	wet meadow	cattle	3	10	2.92
South MZ Ranch	wet meadow	cattle	3	13	3.21
South MZ Ranch	wet meadow	cattle	3	20	3.37
South MZ Ranch	wet meadow	cattle	3	34	2.89
South MZ Ranch	wet meadow	cattle	3	48	2.61
South MZ Ranch	wet meadow	cattle	3	69	3.29
South MZ Ranch	wet meadow	cattle	3	89	2.45
South MZ Ranch	wet meadow	cattle	3	116	3.85
South MZ Ranch	wet meadow	cattle	3	140	2.32
South MZ Ranch	wet meadow	cattle	3	164	1.91
South MZ Ranch	wet meadow	cattle	4	3	2.11
South MZ Ranch	wet meadow	cattle	4	6	---
South MZ Ranch	wet meadow	cattle	4	10	---
South MZ Ranch	wet meadow	cattle	4	13	---
South MZ Ranch	wet meadow	cattle	4	20	---
South MZ Ranch	wet meadow	cattle	4	34	---
South MZ Ranch	wet meadow	cattle	4	48	---

Appendix B. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Microbial CO_2 respiration rate ($mg\ C\ g^{-1}$ soil C d^{-1})
South MZ Ranch	wet meadow	cattle	4	69	---
South MZ Ranch	wet meadow	cattle	4	89	---
South MZ Ranch	wet meadow	cattle	4	116	---
South MZ Ranch	wet meadow	cattle	4	140	2.00
South MZ Ranch	wet meadow	cattle	4	164	1.88
West MZ Ranch	wet meadow	control	1	3	2.96
West MZ Ranch	wet meadow	control	1	6	1.14
West MZ Ranch	wet meadow	control	1	10	0.91
West MZ Ranch	wet meadow	control	1	13	0.86
West MZ Ranch	wet meadow	control	1	20	0.74
West MZ Ranch	wet meadow	control	1	34	0.84
West MZ Ranch	wet meadow	control	1	48	0.80
West MZ Ranch	wet meadow	control	1	69	1.14
West MZ Ranch	wet meadow	control	1	89	1.10
West MZ Ranch	wet meadow	control	1	116	1.10
West MZ Ranch	wet meadow	control	1	140	1.19
West MZ Ranch	wet meadow	control	1	164	0.91
West MZ Ranch	wet meadow	control	2	3	3.96
West MZ Ranch	wet meadow	control	2	6	2.16
West MZ Ranch	wet meadow	control	2	10	1.99
West MZ Ranch	wet meadow	control	2	13	1.60
West MZ Ranch	wet meadow	control	2	20	1.25
West MZ Ranch	wet meadow	control	2	34	0.97
West MZ Ranch	wet meadow	control	2	48	1.27
West MZ Ranch	wet meadow	control	2	69	1.43
West MZ Ranch	wet meadow	control	2	89	1.50
West MZ Ranch	wet meadow	control	2	116	1.54
West MZ Ranch	wet meadow	control	2	140	1.37
West MZ Ranch	wet meadow	control	2	164	1.08
West MZ Ranch	wet meadow	control	3	3	4.61
West MZ Ranch	wet meadow	control	3	6	1.71
West MZ Ranch	wet meadow	control	3	10	1.10
West MZ Ranch	wet meadow	control	3	13	1.31
West MZ Ranch	wet meadow	control	3	20	1.13
West MZ Ranch	wet meadow	control	3	34	1.12
West MZ Ranch	wet meadow	control	3	48	0.97
West MZ Ranch	wet meadow	control	3	69	1.44
West MZ Ranch	wet meadow	control	3	89	1.48
West MZ Ranch	wet meadow	control	3	116	1.22
West MZ Ranch	wet meadow	control	3	140	1.16
West MZ Ranch	wet meadow	control	3	164	1.08
West MZ Ranch	wet meadow	control	4	3	2.92
West MZ Ranch	wet meadow	control	4	6	1.60
West MZ Ranch	wet meadow	control	4	10	1.40
West MZ Ranch	wet meadow	control	4	13	1.36
West MZ Ranch	wet meadow	control	4	20	1.07
West MZ Ranch	wet meadow	control	4	34	1.07
West MZ Ranch	wet meadow	control	4	48	1.14
West MZ Ranch	wet meadow	control	4	69	2.88
West MZ Ranch	wet meadow	control	4	89	2.64
West MZ Ranch	wet meadow	control	4	116	2.54
West MZ Ranch	wet meadow	control	4	140	2.28
West MZ Ranch	wet meadow	control	4	164	2.02

Appendix B. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Microbial CO_2 respiration rate (mg C g^{-1} soil C d^{-1})
West MZ Ranch	wet meadow	cattle	1	3	2.64
West MZ Ranch	wet meadow	cattle	1	6	1.66
West MZ Ranch	wet meadow	cattle	1	10	1.63
West MZ Ranch	wet meadow	cattle	1	13	1.60
West MZ Ranch	wet meadow	cattle	1	20	1.26
West MZ Ranch	wet meadow	cattle	1	34	1.36
West MZ Ranch	wet meadow	cattle	1	48	1.58
West MZ Ranch	wet meadow	cattle	1	69	1.92
West MZ Ranch	wet meadow	cattle	1	89	1.42
West MZ Ranch	wet meadow	cattle	1	116	1.31
West MZ Ranch	wet meadow	cattle	1	140	0.88
West MZ Ranch	wet meadow	cattle	1	164	0.81
West MZ Ranch	wet meadow	cattle	2	3	3.64
West MZ Ranch	wet meadow	cattle	2	6	2.22
West MZ Ranch	wet meadow	cattle	2	10	2.11
West MZ Ranch	wet meadow	cattle	2	13	1.59
West MZ Ranch	wet meadow	cattle	2	20	1.71
West MZ Ranch	wet meadow	cattle	2	34	1.94
West MZ Ranch	wet meadow	cattle	2	48	1.90
West MZ Ranch	wet meadow	cattle	2	69	1.59
West MZ Ranch	wet meadow	cattle	2	89	1.84
West MZ Ranch	wet meadow	cattle	2	140	1.29
West MZ Ranch	wet meadow	cattle	2	164	1.29
West MZ Ranch	wet meadow	cattle	2	116	1.58
West MZ Ranch	wet meadow	cattle	3	3	2.20
West MZ Ranch	wet meadow	cattle	3	6	1.75
West MZ Ranch	wet meadow	cattle	3	10	1.68
West MZ Ranch	wet meadow	cattle	3	13	1.62
West MZ Ranch	wet meadow	cattle	3	20	1.37
West MZ Ranch	wet meadow	cattle	3	34	1.26
West MZ Ranch	wet meadow	cattle	3	48	1.12
West MZ Ranch	wet meadow	cattle	3	69	1.57
West MZ Ranch	wet meadow	cattle	3	89	1.58
West MZ Ranch	wet meadow	cattle	3	116	1.12
West MZ Ranch	wet meadow	cattle	3	140	0.71
West MZ Ranch	wet meadow	cattle	3	164	0.86
West MZ Ranch	wet meadow	cattle	4	3	2.98
West MZ Ranch	wet meadow	cattle	4	6	1.51
West MZ Ranch	wet meadow	cattle	4	10	1.49
West MZ Ranch	wet meadow	cattle	4	13	1.70
West MZ Ranch	wet meadow	cattle	4	20	1.22
West MZ Ranch	wet meadow	cattle	4	34	1.42
West MZ Ranch	wet meadow	cattle	4	48	1.27
West MZ Ranch	wet meadow	cattle	4	69	2.21
West MZ Ranch	wet meadow	cattle	4	89	2.33
West MZ Ranch	wet meadow	cattle	4	116	2.66
West MZ Ranch	wet meadow	cattle	4	140	1.96
West MZ Ranch	wet meadow	cattle	4	164	2.04

Appendix C. Net N mineralization and N mineralization rates of soil samples from Great Sand Dunes riparian corridors and wet meadowss. N was measured by repeatedly leaching soil samples during a 6-month incubation period.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Net N mineralized (mg N g^{-1} soil N)	N mineralization rate (mg N g^{-1} soil N wk^{-1})
Big Spring Creek	riparian	control	1	7	3.84	3.84
Big Spring Creek	riparian	control	1	14	6.59	2.76
Big Spring Creek	riparian	control	1	21	8.41	1.81
Big Spring Creek	riparian	control	1	35	10.20	0.89
Big Spring Creek	riparian	control	1	49	16.45	3.13
Big Spring Creek	riparian	control	1	70	28.41	3.99
Big Spring Creek	riparian	control	1	90	34.53	2.04
Big Spring Creek	riparian	control	1	117	41.60	1.83
Big Spring Creek	riparian	control	1	143	45.42	1.03
Big Spring Creek	riparian	control	1	165	48.97	1.13
Big Spring Creek	riparian	control	2	7	5.05	5.05
Big Spring Creek	riparian	control	2	14	8.78	3.73
Big Spring Creek	riparian	control	2	21	10.76	1.98
Big Spring Creek	riparian	control	2	35	13.40	1.32
Big Spring Creek	riparian	control	2	49	15.04	0.82
Big Spring Creek	riparian	control	2	70	17.58	0.85
Big Spring Creek	riparian	control	2	90	20.47	0.96
Big Spring Creek	riparian	control	2	117	24.19	0.96
Big Spring Creek	riparian	control	2	143	27.16	0.80
Big Spring Creek	riparian	control	2	165	29.97	0.89
Big Spring Creek	riparian	control	3	7	5.56	5.56
Big Spring Creek	riparian	control	3	14	9.23	3.67
Big Spring Creek	riparian	control	3	21	11.32	2.09
Big Spring Creek	riparian	control	3	35	14.56	1.62
Big Spring Creek	riparian	control	3	49	18.70	2.07
Big Spring Creek	riparian	control	3	70	30.65	3.98
Big Spring Creek	riparian	control	3	90	37.88	2.41
Big Spring Creek	riparian	control	3	117	47.37	2.46
Big Spring Creek	riparian	control	3	143	52.00	1.25
Big Spring Creek	riparian	control	3	165	58.01	1.91
Big Spring Creek	riparian	control	4	7	3.98	3.98
Big Spring Creek	riparian	control	4	14	9.04	5.06

Appendix C. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Net N mineralized ($mg\ N\ g^{-1}$ soil N)	N mineralization rate ($mg\ N\ g^{-1}$ soil N wk^{-1})
Big Spring Creek	riparian	control	4	21	11.48	2.44
Big Spring Creek	riparian	control	4	35	14.76	1.64
Big Spring Creek	riparian	control	4	49	17.95	1.59
Big Spring Creek	riparian	control	4	70	23.60	1.89
Big Spring Creek	riparian	control	4	90	28.24	1.55
Big Spring Creek	riparian	control	4	117	31.28	0.79
Big Spring Creek	riparian	control	4	143	34.69	0.92
Big Spring Creek	riparian	control	4	165	39.28	1.46
Big Spring Creek	riparian	bison	1	7	10.12	10.12
Big Spring Creek	riparian	bison	1	14	16.75	6.63
Big Spring Creek	riparian	bison	1	21	23.39	6.64
Big Spring Creek	riparian	bison	1	35	29.65	3.13
Big Spring Creek	riparian	bison	1	49	32.90	1.62
Big Spring Creek	riparian	bison	1	70	37.07	1.39
Big Spring Creek	riparian	bison	1	90	40.80	1.24
Big Spring Creek	riparian	bison	1	117	50.63	2.55
Big Spring Creek	riparian	bison	1	143	59.42	2.37
Big Spring Creek	riparian	bison	1	165	64.07	1.48
Big Spring Creek	riparian	bison	2	7	18.87	8.87
Big Spring Creek	riparian	bison	2	14	26.36	7.48
Big Spring Creek	riparian	bison	2	21	31.47	5.12
Big Spring Creek	riparian	bison	2	35	34.78	2.68
Big Spring Creek	riparian	bison	2	49	40.17	2.69
Big Spring Creek	riparian	bison	2	70	52.05	3.96
Big Spring Creek	riparian	bison	2	90	58.24	2.06
Big Spring Creek	riparian	bison	2	117	62.76	1.17
Big Spring Creek	riparian	bison	2	143	66.56	1.03
Big Spring Creek	riparian	bison	2	165	70.51	1.26
Big Spring Creek	riparian	bison	3	7	6.70	6.70
Big Spring Creek	riparian	bison	3	14	9.33	2.63
Big Spring Creek	riparian	bison	3	21	11.27	1.94
Big Spring Creek	riparian	bison	3	35	15.69	2.21
Big Spring Creek	riparian	bison	3	49	20.01	2.16
Big Spring Creek	riparian	bison	3	70	28.06	2.68

Appendix C. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Net N mineralized (mg N g^{-1} soil N)	N mineralization rate (mg N g^{-1} soil N wk^{-1})
Big Spring Creek	riparian	bison	3	90	36.96	2.97
Big Spring Creek	riparian	bison	3	117	43.62	1.73
Big Spring Creek	riparian	bison	3	143	45.87	0.61
Big Spring Creek	riparian	bison	3	165	48.08	0.70
Big Spring Creek	riparian	bison	4	7	4.92	4.92
Big Spring Creek	riparian	bison	4	14	8.58	3.65
Big Spring Creek	riparian	bison	4	21	10.52	1.94
Big Spring Creek	riparian	bison	4	35	13.00	1.24
Big Spring Creek	riparian	bison	4	49	15.95	1.47
Big Spring Creek	riparian	bison	4	70	22.52	2.19
Big Spring Creek	riparian	bison	4	90	28.65	2.04
Big Spring Creek	riparian	bison	4	117	33.97	1.38
Big Spring Creek	riparian	bison	4	143	36.23	0.61
Big Spring Creek	riparian	bison	4	165	38.21	0.63
Little Spring Creek	riparian	control	1	7	5.45	5.45
Little Spring Creek	riparian	control	1	14	10.10	4.66
Little Spring Creek	riparian	control	1	21	11.79	1.68
Little Spring Creek	riparian	control	1	35	12.93	0.57
Little Spring Creek	riparian	control	1	49	14.75	0.91
Little Spring Creek	riparian	control	1	70	18.71	1.32
Little Spring Creek	riparian	control	1	90	23.99	1.76
Little Spring Creek	riparian	control	1	117	33.23	2.39
Little Spring Creek	riparian	control	1	143	37.46	1.14
Little Spring Creek	riparian	control	1	165	43.32	1.87
Little Spring Creek	riparian	control	2	7	4.46	4.46
Little Spring Creek	riparian	control	2	14	9.44	4.98
Little Spring Creek	riparian	control	2	21	11.97	2.53
Little Spring Creek	riparian	control	2	35	14.24	1.13
Little Spring Creek	riparian	control	2	49	17.31	1.54
Little Spring Creek	riparian	control	2	70	23.23	1.97
Little Spring Creek	riparian	control	2	90	31.42	2.73
Little Spring Creek	riparian	control	2	117	41.13	2.52
Little Spring Creek	riparian	control	2	143	45.32	1.13

Appendix C. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Net N mineralized (mg N g^{-1} soil N)	N mineralization rate (mg N g^{-1} soil N wk^{-1})
Little Spring Creek	riparian	control	2	165	52.12	2.17
Little Spring Creek	riparian	control	3	7	4.57	4.57
Little Spring Creek	riparian	control	3	14	10.23	5.66
Little Spring Creek	riparian	control	3	21	13.07	2.84
Little Spring Creek	riparian	control	3	35	16.11	1.52
Little Spring Creek	riparian	control	3	49	19.05	1.47
Little Spring Creek	riparian	control	3	70	23.32	1.42
Little Spring Creek	riparian	control	3	90	28.79	1.82
Little Spring Creek	riparian	control	3	117	37.35	2.22
Little Spring Creek	riparian	control	3	143	42.22	1.32
Little Spring Creek	riparian	control	3	165	48.61	2.03
Little Spring Creek	riparian	control	4	7	11.18	11.18
Little Spring Creek	riparian	control	4	14	23.46	12.28
Little Spring Creek	riparian	control	4	21	26.36	2.90
Little Spring Creek	riparian	control	4	35	30.79	2.21
Little Spring Creek	riparian	control	4	49	34.02	1.62
Little Spring Creek	riparian	control	4	70	37.57	1.18
Little Spring Creek	riparian	control	4	90	44.20	2.21
Little Spring Creek	riparian	control	4	117	54.54	2.68
Little Spring Creek	riparian	control	4	143	59.37	1.30
Little Spring Creek	riparian	control	4	165	65.70	2.02
Little Spring Creek	riparian	bison	1	7	6.99	6.99
Little Spring Creek	riparian	bison	1	14	11.99	5.00
Little Spring Creek	riparian	bison	1	21	14.44	2.45
Little Spring Creek	riparian	bison	1	35	18.01	1.79
Little Spring Creek	riparian	bison	1	49	21.93	1.96
Little Spring Creek	riparian	bison	1	70	32.08	3.38
Little Spring Creek	riparian	bison	1	90	37.04	1.65
Little Spring Creek	riparian	bison	1	117	42.46	1.40
Little Spring Creek	riparian	bison	1	143	45.82	0.91
Little Spring Creek	riparian	bison	1	165	49.61	1.21
Little Spring Creek	riparian	bison	2	7	3.91	3.91
Little Spring Creek	riparian	bison	2	14	7.66	3.76
Little Spring Creek	riparian	bison	2	21	11.66	4.00

Appendix C. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Net N mineralized (mg N g^{-1} soil N)	N mineralization rate (mg N g^{-1} soil N wk^{-1})
Little Spring Creek	riparian	bison	2	35	14.72	1.53
Little Spring Creek	riparian	bison	2	49	20.00	2.64
Little Spring Creek	riparian	bison	2	70	26.77	2.26
Little Spring Creek	riparian	bison	2	90	33.87	2.37
Little Spring Creek	riparian	bison	2	117	43.48	2.49
Little Spring Creek	riparian	bison	2	143	52.08	2.32
Little Spring Creek	riparian	bison	2	165	59.09	2.23
Little Spring Creek	riparian	bison	3	7	6.90	6.90
Little Spring Creek	riparian	bison	3	14	14.44	7.54
Little Spring Creek	riparian	bison	3	21	18.47	4.03
Little Spring Creek	riparian	bison	3	35	25.23	3.38
Little Spring Creek	riparian	bison	3	49	31.48	3.13
Little Spring Creek	riparian	bison	3	70	37.42	1.98
Little Spring Creek	riparian	bison	3	90	43.47	2.01
Little Spring Creek	riparian	bison	3	117	50.88	1.92
Little Spring Creek	riparian	bison	3	143	56.01	1.38
Little Spring Creek	riparian	bison	3	165	62.22	1.98
Little Spring Creek	riparian	bison	4	7	9.27	9.27
Little Spring Creek	riparian	bison	4	14	15.82	6.55
Little Spring Creek	riparian	bison	4	21	20.14	4.32
Little Spring Creek	riparian	bison	4	35	24.98	2.42
Little Spring Creek	riparian	bison	4	49	30.65	2.84
Little Spring Creek	riparian	bison	4	70	37.17	2.18
Little Spring Creek	riparian	bison	4	90	41.41	1.41
Little Spring Creek	riparian	bison	4	117	46.16	1.23
Little Spring Creek	riparian	bison	4	143	50.40	1.15
Little Spring Creek	riparian	bison	4	165	52.88	0.79
Elk Springs	wet meadow	conrol	1	7	9.90	9.90
Elk Springs	wet meadow	conrol	1	14	14.68	4.77
Elk Springs	wet meadow	conrol	1	21	19.10	4.42
Elk Springs	wet meadow	conrol	1	35	32.09	6.50
Elk Springs	wet meadow	conrol	1	49	38.21	3.06
Elk Springs	wet meadow	conrol	1	70	43.94	1.91

Appendix C. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Net N mineralized (mg N g^{-1} soil N)	N mineralization rate (mg N g^{-1} soil N wk^{-1})
Elk Springs	wet meadow	conrol	1	90	51.47	2.51
Elk Springs	wet meadow	conrol	1	117	61.95	2.71
Elk Springs	wet meadow	conrol	1	143	65.93	1.08
Elk Springs	wet meadow	conrol	1	165	72.07	1.96
Elk Springs	wet meadow	conrol	2	7	5.59	5.59
Elk Springs	wet meadow	conrol	2	14	8.24	2.65
Elk Springs	wet meadow	conrol	2	21	11.57	3.33
Elk Springs	wet meadow	conrol	2	35	21.31	4.87
Elk Springs	wet meadow	conrol	2	49	33.36	6.03
Elk Springs	wet meadow	conrol	2	70	42.76	3.13
Elk Springs	wet meadow	conrol	2	90	48.06	1.77
Elk Springs	wet meadow	conrol	2	117	52.46	1.14
Elk Springs	wet meadow	conrol	2	143	59.75	1.97
Elk Springs	wet meadow	conrol	2	165	66.08	2.01
Elk Springs	wet meadow	conrol	3	7	20.27	20.27
Elk Springs	wet meadow	conrol	3	14	26.97	6.70
Elk Springs	wet meadow	conrol	3	21	29.63	2.66
Elk Springs	wet meadow	conrol	3	35	36.69	3.53
Elk Springs	wet meadow	conrol	3	49	43.34	3.33
Elk Springs	wet meadow	conrol	3	70	52.10	2.92
Elk Springs	wet meadow	conrol	3	90	58.78	2.23
Elk Springs	wet meadow	conrol	3	117	66.27	1.94
Elk Springs	wet meadow	conrol	3	143	71.88	1.52
Elk Springs	wet meadow	conrol	3	165	78.89	2.23
Elk Springs	wet meadow	conrol	4	7	6.12	6.12
Elk Springs	wet meadow	conrol	4	14	9.35	3.23
Elk Springs	wet meadow	conrol	4	21	12.88	3.53
Elk Springs	wet meadow	conrol	4	35	22.14	4.63
Elk Springs	wet meadow	conrol	4	49	27.17	2.52
Elk Springs	wet meadow	conrol	4	70	33.56	2.13
Elk Springs	wet meadow	conrol	4	90	41.31	2.58
Elk Springs	wet meadow	conrol	4	117	50.55	2.39
Elk Springs	wet meadow	conrol	4	143	61.24	2.89
Elk Springs	wet meadow	conrol	4	165	67.96	2.14

Appendix C. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Net N mineralized ($mg\ N\ g^{-1}$ soil N)	N mineralization rate ($mg\ N\ g^{-1}$ soil N wk^{-1})
Elk Springs	wet meadow	bison	1	7	9.19	9.19
Elk Springs	wet meadow	bison	1	14	11.58	2.39
Elk Springs	wet meadow	bison	1	21	14.00	2.42
Elk Springs	wet meadow	bison	1	35	28.47	7.24
Elk Springs	wet meadow	bison	1	49	34.51	3.02
Elk Springs	wet meadow	bison	1	70	41.80	2.43
Elk Springs	wet meadow	bison	1	90	53.22	3.80
Elk Springs	wet meadow	bison	1	117	62.70	2.46
Elk Springs	wet meadow	bison	1	143	74.44	3.17
Elk Springs	wet meadow	bison	1	165	81.82	2.35
Elk Springs	wet meadow	bison	2	7	12.11	12.11
Elk Springs	wet meadow	bison	2	14	16.34	4.23
Elk Springs	wet meadow	bison	2	21	20.18	3.84
Elk Springs	wet meadow	bison	2	35	29.19	4.50
Elk Springs	wet meadow	bison	2	49	38.01	4.41
Elk Springs	wet meadow	bison	2	70	54.31	5.44
Elk Springs	wet meadow	bison	2	90	63.65	3.11
Elk Springs	wet meadow	bison	2	117	73.61	2.58
Elk Springs	wet meadow	bison	2	143	87.56	3.77
Elk Springs	wet meadow	bison	2	165	97.55	3.18
Elk Springs	wet meadow	bison	3	7	13.07	13.07
Elk Springs	wet meadow	bison	3	14	14.86	1.79
Elk Springs	wet meadow	bison	3	21	17.76	2.91
Elk Springs	wet meadow	bison	3	35	27.00	4.62
Elk Springs	wet meadow	bison	3	49	35.07	4.03
Elk Springs	wet meadow	bison	3	70	51.75	5.56
Elk Springs	wet meadow	bison	3	90	60.85	3.03
Elk Springs	wet meadow	bison	3	117	67.88	1.82
Elk Springs	wet meadow	bison	3	143	75.04	1.94
Elk Springs	wet meadow	bison	3	165	83.36	2.65
Elk Springs	wet meadow	bison	4	7	10.89	10.89
Elk Springs	wet meadow	bison	4	14	14.52	3.63
Elk Springs	wet meadow	bison	4	21	17.58	3.06

Appendix C. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Net N mineralized ($mg N g^{-1}$ soil N)	N mineralization rate ($mg N g^{-1}$ soil N wk^{-1})
Elk Springs	wet meadow	bison	4	35	24.95	3.68
Elk Springs	wet meadow	bison	4	49	33.27	4.16
Elk Springs	wet meadow	bison	4	70	44.35	3.69
Elk Springs	wet meadow	bison	4	90	52.58	2.74
Elk Springs	wet meadow	bison	4	117	57.90	1.38
Elk Springs	wet meadow	bison	4	143	78.32	5.52
Elk Springs	wet meadow	bison	4	165	97.06	5.97
Twin Lakes	wet meadow	control	1	7	7.16	7.16
Twin Lakes	wet meadow	control	1	14	10.31	3.14
Twin Lakes	wet meadow	control	1	21	12.86	2.56
Twin Lakes	wet meadow	control	1	35	20.24	3.69
Twin Lakes	wet meadow	control	1	49	28.02	3.89
Twin Lakes	wet meadow	control	1	70	36.15	2.71
Twin Lakes	wet meadow	control	1	90	44.72	2.86
Twin Lakes	wet meadow	control	1	117	55.84	2.88
Twin Lakes	wet meadow	control	1	143	---	4.38
Twin Lakes	wet meadow	control	1	165	---	5.16
Twin Lakes	wet meadow	control	2	7	4.60	4.60
Twin Lakes	wet meadow	control	2	14	8.07	3.48
Twin Lakes	wet meadow	control	2	21	11.16	3.09
Twin Lakes	wet meadow	control	2	35	18.59	3.72
Twin Lakes	wet meadow	control	2	49	25.67	3.54
Twin Lakes	wet meadow	control	2	70	31.24	1.86
Twin Lakes	wet meadow	control	2	90	37.98	2.25
Twin Lakes	wet meadow	control	2	117	45.62	1.98
Twin Lakes	wet meadow	control	2	143	52.84	1.95
Twin Lakes	wet meadow	control	2	165	65.30	3.97
Twin Lakes	wet meadow	control	3	7	9.11	9.11
Twin Lakes	wet meadow	control	3	14	11.84	2.73
Twin Lakes	wet meadow	control	3	21	13.88	2.04
Twin Lakes	wet meadow	control	3	35	19.33	2.72
Twin Lakes	wet meadow	control	3	49	26.72	3.70
Twin Lakes	wet meadow	control	3	70	34.50	2.60
Twin Lakes	wet meadow	control	3	90	44.29	3.26

Appendix C. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Net N mineralized (mg N g^{-1} soil N)	N mineralization rate (mg N g^{-1} soil N wk^{-1})
Twin Lakes	wet meadow	control	3	117	51.16	1.78
Twin Lakes	wet meadow	control	3	143	59.38	2.22
Twin Lakes	wet meadow	control	3	165	71.07	3.72
Twin Lakes	wet meadow	control	4	7	6.61	6.61
Twin Lakes	wet meadow	control	4	14	9.25	2.64
Twin Lakes	wet meadow	control	4	21	10.98	1.73
Twin Lakes	wet meadow	control	4	35	16.19	2.60
Twin Lakes	wet meadow	control	4	49	21.22	2.51
Twin Lakes	wet meadow	control	4	70	29.89	2.89
Twin Lakes	wet meadow	control	4	90	37.51	2.54
Twin Lakes	wet meadow	control	4	117	49.97	3.23
Twin Lakes	wet meadow	control	4	143	56.98	1.89
Twin Lakes	wet meadow	control	4	165	68.42	3.64
Twin Lakes	wet meadow	bison	1	7	6.97	6.97
Twin Lakes	wet meadow	bison	1	14	9.22	2.25
Twin Lakes	wet meadow	bison	1	21	11.00	1.78
Twin Lakes	wet meadow	bison	1	35	15.44	2.22
Twin Lakes	wet meadow	bison	1	49	20.12	2.34
Twin Lakes	wet meadow	bison	1	70	23.84	1.24
Twin Lakes	wet meadow	bison	1	90	30.26	2.14
Twin Lakes	wet meadow	bison	1	117	35.61	1.39
Twin Lakes	wet meadow	bison	1	143	46.49	2.94
Twin Lakes	wet meadow	bison	1	165	56.00	3.03
Twin Lakes	wet meadow	bison	2	7	7.23	7.23
Twin Lakes	wet meadow	bison	2	14	9.42	2.19
Twin Lakes	wet meadow	bison	2	21	11.25	1.82
Twin Lakes	wet meadow	bison	2	35	16.78	2.77
Twin Lakes	wet meadow	bison	2	49	22.72	2.97
Twin Lakes	wet meadow	bison	2	70	27.28	1.52
Twin Lakes	wet meadow	bison	2	90	35.02	2.58
Twin Lakes	wet meadow	bison	2	117	41.70	1.73
Twin Lakes	wet meadow	bison	2	143	52.17	2.83
Twin Lakes	wet meadow	bison	2	165	61.77	3.06

Appendix C. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Net N mineralized ($mg\ N\ g^{-1}$ soil N)	N mineralization rate ($mg\ N\ g^{-1}$ soil N wk^{-1})
Twin Lakes	wet meadow	bison	3	7	7.32	7.32
Twin Lakes	wet meadow	bison	3	14	9.81	2.49
Twin Lakes	wet meadow	bison	3	21	11.72	1.91
Twin Lakes	wet meadow	bison	3	35	17.10	2.69
Twin Lakes	wet meadow	bison	3	49	24.06	3.48
Twin Lakes	wet meadow	bison	3	70	34.56	3.50
Twin Lakes	wet meadow	bison	3	90	43.06	2.83
Twin Lakes	wet meadow	bison	3	117	48.41	1.39
Twin Lakes	wet meadow	bison	3	143	57.01	2.32
Twin Lakes	wet meadow	bison	3	165	66.55	3.04
Twin Lakes	wet meadow	bison	4	7	3.58	3.58
Twin Lakes	wet meadow	bison	4	14	5.75	2.17
Twin Lakes	wet meadow	bison	4	21	7.24	1.49
Twin Lakes	wet meadow	bison	4	35	11.94	2.35
Twin Lakes	wet meadow	bison	4	49	17.24	2.65
Twin Lakes	wet meadow	bison	4	70	22.88	1.88
Twin Lakes	wet meadow	bison	4	90	30.88	2.67
Twin Lakes	wet meadow	bison	4	117	42.38	2.98
Twin Lakes	wet meadow	bison	4	143	47.99	1.51
Twin Lakes	wet meadow	bison	4	165	57.49	3.03
South MZ Ranch	wet meadow	control	1	7	5.70	5.70
South MZ Ranch	wet meadow	control	1	14	10.51	4.81
South MZ Ranch	wet meadow	control	1	21	16.39	5.88
South MZ Ranch	wet meadow	control	1	35	30.02	6.81
South MZ Ranch	wet meadow	control	1	49	40.26	5.12
South MZ Ranch	wet meadow	control	1	70	51.67	3.80
South MZ Ranch	wet meadow	control	1	90	61.67	3.33
South MZ Ranch	wet meadow	control	1	117	67.01	1.38
South MZ Ranch	wet meadow	control	1	143	75.45	2.28
South MZ Ranch	wet meadow	control	1	165	83.86	2.68
South MZ Ranch	wet meadow	control	2	7	5.16	5.16
South MZ Ranch	wet meadow	control	2	14	10.51	5.35
South MZ Ranch	wet meadow	control	2	21	18.65	8.14
South MZ Ranch	wet meadow	control	2	35	36.57	8.96

Appendix C. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Net N mineralized (mg N g^{-1} soil N)	N mineralization rate (mg N g^{-1} soil N wk^{-1})
South MZ Ranch	wet meadow	control	2	49	48.39	5.91
South MZ Ranch	wet meadow	control	2	70	63.58	5.06
South MZ Ranch	wet meadow	control	2	90	74.33	3.58
South MZ Ranch	wet meadow	control	2	117	86.67	3.20
South MZ Ranch	wet meadow	control	2	143	94.95	2.24
South MZ Ranch	wet meadow	control	2	165	100.20	1.67
South MZ Ranch	wet meadow	control	3	7	8.47	8.47
South MZ Ranch	wet meadow	control	3	14	10.42	1.95
South MZ Ranch	wet meadow	control	3	21	13.26	2.84
South MZ Ranch	wet meadow	control	3	35	22.74	4.74
South MZ Ranch	wet meadow	control	3	49	32.40	4.83
South MZ Ranch	wet meadow	control	3	70	44.23	3.95
South MZ Ranch	wet meadow	control	3	90	54.27	3.34
South MZ Ranch	wet meadow	control	3	117	62.58	2.15
South MZ Ranch	wet meadow	control	3	143	70.61	2.17
South MZ Ranch	wet meadow	control	3	165	83.21	4.01
South MZ Ranch	wet meadow	control	4	7	6.44	6.44
South MZ Ranch	wet meadow	control	4	14	9.51	3.07
South MZ Ranch	wet meadow	control	4	21	14.61	5.10
South MZ Ranch	wet meadow	control	4	35	24.59	4.99
South MZ Ranch	wet meadow	control	4	49	29.93	2.67
South MZ Ranch	wet meadow	control	4	70	35.97	2.02
South MZ Ranch	wet meadow	control	4	90	41.73	1.92
South MZ Ranch	wet meadow	control	4	117	54.64	3.34
South MZ Ranch	wet meadow	control	4	143	62.91	2.24
South MZ Ranch	wet meadow	control	4	165	66.86	1.26
South MZ Ranch	wet meadow	cattle	1	7	4.85	4.85
South MZ Ranch	wet meadow	cattle	1	14	10.31	5.46
South MZ Ranch	wet meadow	cattle	1	21	14.41	4.10
South MZ Ranch	wet meadow	cattle	1	35	23.04	4.32
South MZ Ranch	wet meadow	cattle	1	49	34.35	5.66
South MZ Ranch	wet meadow	cattle	1	70	47.96	4.53
South MZ Ranch	wet meadow	cattle	1	90	63.69	5.24
South MZ Ranch	wet meadow	cattle	1	117	86.40	5.88

Appendix C. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Net N mineralized (mg N g^{-1} soil N)	N mineralization rate (mg N g^{-1} soil N wk^{-1})
South MZ Ranch	wet meadow	cattle	1	143	109.61	6.27
South MZ Ranch	wet meadow	cattle	1	165	126.77	5.46
South MZ Ranch	wet meadow	cattle	2	7	5.45	5.45
South MZ Ranch	wet meadow	cattle	2	14	8.99	3.54
South MZ Ranch	wet meadow	cattle	2	21	13.85	4.86
South MZ Ranch	wet meadow	cattle	2	35	24.97	5.56
South MZ Ranch	wet meadow	cattle	2	49	37.30	6.17
South MZ Ranch	wet meadow	cattle	2	70	53.01	5.24
South MZ Ranch	wet meadow	cattle	2	90	79.65	8.88
South MZ Ranch	wet meadow	cattle	2	117	115.83	9.37
South MZ Ranch	wet meadow	cattle	2	143	134.64	5.08
South MZ Ranch	wet meadow	cattle	2	165	160.52	8.24
South MZ Ranch	wet meadow	cattle	3	7	5.14	3.33
South MZ Ranch	wet meadow	cattle	3	14	7.98	2.84
South MZ Ranch	wet meadow	cattle	3	21	16.27	8.29
South MZ Ranch	wet meadow	cattle	3	35	27.39	5.56
South MZ Ranch	wet meadow	cattle	3	49	42.00	7.31
South MZ Ranch	wet meadow	cattle	3	70	56.66	4.89
South MZ Ranch	wet meadow	cattle	3	90	70.07	4.47
South MZ Ranch	wet meadow	cattle	3	117	95.97	6.71
South MZ Ranch	wet meadow	cattle	3	143	107.07	3.00
South MZ Ranch	wet meadow	cattle	3	165	124.67	5.61
South MZ Ranch	wet meadow	cattle	4	7	5.27	2.42
South MZ Ranch	wet meadow	cattle	4	14	10.05	2.20
South MZ Ranch	wet meadow	cattle	4	21	22.25	5.61
South MZ Ranch	wet meadow	cattle	4	35	41.84	4.50
South MZ Ranch	wet meadow	cattle	4	49	54.48	2.90
South MZ Ranch	wet meadow	cattle	4	70	74.37	3.04
South MZ Ranch	wet meadow	cattle	4	90	92.28	2.74
South MZ Ranch	wet meadow	cattle	4	117	---	4.82
South MZ Ranch	wet meadow	cattle	4	143	---	5.09
South MZ Ranch	wet meadow	cattle	4	165	---	2.89
West MZ Ranch	wet meadow	control	1	7	5.57	5.57
West MZ Ranch	wet meadow	control	1	14	10.66	5.09

Appendix C. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Net N mineralized (mg N g^{-1} soil N)	N mineralization rate (mg N g^{-1} soil N wk^{-1})
West MZ Ranch	wet meadow	control	1	21	14.00	3.34
West MZ Ranch	wet meadow	control	1	35	21.36	3.68
West MZ Ranch	wet meadow	control	1	49	27.10	2.87
West MZ Ranch	wet meadow	control	1	70	31.03	1.31
West MZ Ranch	wet meadow	control	1	90	36.84	1.94
West MZ Ranch	wet meadow	control	1	117	45.14	2.15
West MZ Ranch	wet meadow	control	1	143	49.78	1.25
West MZ Ranch	wet meadow	control	1	165	56.92	2.27
West MZ Ranch	wet meadow	control	2	7	4.05	4.05
West MZ Ranch	wet meadow	control	2	14	8.37	4.33
West MZ Ranch	wet meadow	control	2	21	12.26	3.88
West MZ Ranch	wet meadow	control	2	35	15.68	3.66
West MZ Ranch	wet meadow	control	2	49	21.63	2.97
West MZ Ranch	wet meadow	control	2	70	25.34	1.24
West MZ Ranch	wet meadow	control	2	90	31.31	1.99
West MZ Ranch	wet meadow	control	2	117	40.76	2.45
West MZ Ranch	wet meadow	control	2	143	46.01	1.42
West MZ Ranch	wet meadow	control	2	165	52.72	2.14
West MZ Ranch	wet meadow	control	3	7	3.17	3.17
West MZ Ranch	wet meadow	control	3	14	7.05	3.88
West MZ Ranch	wet meadow	control	3	21	9.76	2.71
West MZ Ranch	wet meadow	control	3	35	15.49	2.86
West MZ Ranch	wet meadow	control	3	49	20.05	2.28
West MZ Ranch	wet meadow	control	3	70	23.29	1.08
West MZ Ranch	wet meadow	control	3	90	26.96	1.22
West MZ Ranch	wet meadow	control	3	117	31.16	1.09
West MZ Ranch	wet meadow	control	3	143	39.70	2.31
West MZ Ranch	wet meadow	control	3	165	47.23	2.40
West MZ Ranch	wet meadow	control	4	7	4.81	4.81
West MZ Ranch	wet meadow	control	4	14	7.24	2.43
West MZ Ranch	wet meadow	control	4	21	9.70	2.45
West MZ Ranch	wet meadow	control	4	35	12.13	2.44
West MZ Ranch	wet meadow	control	4	49	16.23	2.05
West MZ Ranch	wet meadow	control	4	70	20.04	1.27

Appendix C. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Net N mineralized (mg N g^{-1} soil N)	N mineralization rate (mg N g^{-1} soil N wk^{-1})
West MZ Ranch	wet meadow	control	4	90	25.84	1.93
West MZ Ranch	wet meadow	control	4	117	34.87	2.34
West MZ Ranch	wet meadow	control	4	143	40.71	1.58
West MZ Ranch	wet meadow	control	4	165	48.31	2.42
West MZ Ranch	wet meadow	cattle	1	7	4.27	4.27
West MZ Ranch	wet meadow	cattle	1	14	8.05	3.78
West MZ Ranch	wet meadow	cattle	1	21	10.10	2.05
West MZ Ranch	wet meadow	cattle	1	35	15.89	2.89
West MZ Ranch	wet meadow	cattle	1	49	21.53	2.82
West MZ Ranch	wet meadow	cattle	1	70	30.21	2.89
West MZ Ranch	wet meadow	cattle	1	90	40.35	3.38
West MZ Ranch	wet meadow	cattle	1	117	50.92	2.74
West MZ Ranch	wet meadow	cattle	1	143	56.73	1.57
West MZ Ranch	wet meadow	cattle	1	165	57.18	1.99
West MZ Ranch	wet meadow	cattle	2	7	6.98	6.98
West MZ Ranch	wet meadow	cattle	2	14	8.50	1.52
West MZ Ranch	wet meadow	cattle	2	21	12.20	3.70
West MZ Ranch	wet meadow	cattle	2	35	---	2.73
West MZ Ranch	wet meadow	cattle	2	49	22.91	4.48
West MZ Ranch	wet meadow	cattle	2	70	31.78	2.96
West MZ Ranch	wet meadow	cattle	2	90	41.32	3.18
West MZ Ranch	wet meadow	cattle	2	117	53.12	3.06
West MZ Ranch	wet meadow	cattle	2	143	---	3.10
West MZ Ranch	wet meadow	cattle	2	165	---	3.57
West MZ Ranch	wet meadow	cattle	3	7	5.21	5.21
West MZ Ranch	wet meadow	cattle	3	14	9.71	4.50
West MZ Ranch	wet meadow	cattle	3	21	13.55	3.83
West MZ Ranch	wet meadow	cattle	3	35	22.52	4.48
West MZ Ranch	wet meadow	cattle	3	49	30.45	3.97
West MZ Ranch	wet meadow	cattle	3	70	39.73	3.09
West MZ Ranch	wet meadow	cattle	3	90	47.12	2.46
West MZ Ranch	wet meadow	cattle	3	117	54.17	1.83
West MZ Ranch	wet meadow	cattle	3	143	56.20	0.55
West MZ Ranch	wet meadow	cattle	3	165	59.64	1.10

Appendix C. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Net N mineralized (mg N g^{-1} soil N)	N mineralization rate (mg N g^{-1} soil N wk^{-1})
West MZ Ranch	wet meadow	cattle	4	7	5.04	5.04
West MZ Ranch	wet meadow	cattle	4	14	7.78	2.75
West MZ Ranch	wet meadow	cattle	4	21	11.18	3.40
West MZ Ranch	wet meadow	cattle	4	35	12.83	2.52
West MZ Ranch	wet meadow	cattle	4	49	18.33	2.75
West MZ Ranch	wet meadow	cattle	4	70	23.92	1.87
West MZ Ranch	wet meadow	cattle	4	90	30.60	2.22
West MZ Ranch	wet meadow	cattle	4	117	40.14	2.47
West MZ Ranch	wet meadow	cattle	4	143	44.07	1.06
West MZ Ranch	wet meadow	cattle	4	165	50.38	2.01

Appendix D. N mineralization parameters for soils from Great Sand Dunes riparian corridors and wet meadows estimated with the first-order model.

Table D-1. N_o = potentially mineralizable N (mg N g^{-1} soil N) and k = mineralization rate constant ($week^{-1}$) estimated with the first-order model. Models which did not converge did not produce parameter estimates.

Site	Wetland type	Grazing treatment	Replicate	N_o	k
Big Spring Creek	riparian	control	1	93.03	0.005
Big Spring Creek	riparian	control	2	30.17	0.015
Big Spring Creek	riparian	control	3	111.11	0.005
Big Spring Creek	riparian	control	4	43.84	0.012
Big Spring Creek	riparian	bison	1	65.03	0.015
Big Spring Creek	riparian	bison	2	67.75	0.024
Big Spring Creek	riparian	bison	3	64.74	0.009
Big Spring Creek	riparian	bison	4	48.78	0.009
Little Spring Creek	riparian	control	1	80.00	0.004
Little Spring Creek	riparian	control	2	108.82	0.004
Little Spring Creek	riparian	control	3	70.45	0.007
Little Spring Creek	riparian	control	4	63.14	0.018
Little Spring Creek	riparian	bison	1	57.14	0.012
Little Spring Creek	riparian	bison	2	171.25	0.003
Little Spring Creek	riparian	bison	3	67.51	0.013
Little Spring Creek	riparian	bison	4	53.02	0.019
Elk Springs	wet meadow	control	1	78.68	0.013
Elk Springs	wet meadow	control	2	81.86	0.010
Elk Springs	wet meadow	control	3	75.47	0.020
Elk Springs	wet meadow	control	4	115.33	0.005
Elk Springs	wet meadow	bison	1	123.54	0.006
Elk Springs	wet meadow	bison	2	143.65	0.007
Elk Springs	wet meadow	bison	3	104.92	0.009
Elk Springs	wet meadow	bison	4	260.30	0.003
Twin Lakes	wet meadow	control	1	109.71	0.006
Twin Lakes	wet meadow	control	2	118.66	0.004
Twin Lakes	wet meadow	control	3	118.48	0.005
Twin Lakes	wet meadow	control	4	281.32	0.002
Twin Lakes	wet meadow	bison	1	140.68	0.003
Twin Lakes	wet meadow	bison	2	141.74	0.003
Twin Lakes	wet meadow	bison	3	116.53	0.005
Twin Lakes	wet meadow	bison	4	---	---
South MZ Ranch	wet meadow	cattle	1	---	---
South MZ Ranch	wet meadow	cattle	2	---	---
South MZ Ranch	wet meadow	cattle	3	609.04	0.001
South MZ Ranch	wet meadow	cattle	4	513.67	0.002
South MZ Ranch	wet meadow	control	1	103.69	0.010
South MZ Ranch	wet meadow	control	2	131.00	0.009
South MZ Ranch	wet meadow	control	3	135.28	0.005
South MZ Ranch	wet meadow	control	4	94.86	0.007
West MZ Ranch	wet meadow	cattle	1	106.70	0.005
West MZ Ranch	wet meadow	cattle	2	199.40	0.003
West MZ Ranch	wet meadow	cattle	3	71.39	0.011
West MZ Ranch	wet meadow	cattle	4	97.75	0.004
West MZ Ranch	wet meadow	control	1	68.13	0.010
West MZ Ranch	wet meadow	control	2	85.80	0.005
West MZ Ranch	wet meadow	control	3	71.14	0.006
West MZ Ranch	wet meadow	control	4	164.40	0.002

Appendix D. Continued.

Table D-2. N_t = cumulative N mineralized at time t (mg N g^{-1} soil N) estimated with the first-order model during the incubation period. Models which did not converge did not produce parameter estimates.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	N_t
Big Spring Creek	riparian	control	1	7	3.04
Big Spring Creek	riparian	control	1	14	5.98
Big Spring Creek	riparian	control	1	21	8.82
Big Spring Creek	riparian	control	1	35	14.23
Big Spring Creek	riparian	control	1	49	19.30
Big Spring Creek	riparian	control	1	70	26.29
Big Spring Creek	riparian	control	1	90	32.33
Big Spring Creek	riparian	control	1	117	39.63
Big Spring Creek	riparian	control	1	143	45.82
Big Spring Creek	riparian	control	1	165	50.50
Big Spring Creek	riparian	control	2	7	3.06
Big Spring Creek	riparian	control	2	14	5.81
Big Spring Creek	riparian	control	2	21	8.28
Big Spring Creek	riparian	control	2	35	12.49
Big Spring Creek	riparian	control	2	49	15.89
Big Spring Creek	riparian	control	2	70	19.81
Big Spring Creek	riparian	control	2	90	22.54
Big Spring Creek	riparian	control	2	117	25.12
Big Spring Creek	riparian	control	2	143	26.77
Big Spring Creek	riparian	control	2	165	27.74
Big Spring Creek	riparian	control	3	7	3.46
Big Spring Creek	riparian	control	3	14	6.80
Big Spring Creek	riparian	control	3	21	10.05
Big Spring Creek	riparian	control	3	35	16.23
Big Spring Creek	riparian	control	3	49	22.04
Big Spring Creek	riparian	control	3	70	30.10
Big Spring Creek	riparian	control	3	90	37.09
Big Spring Creek	riparian	control	3	117	45.58
Big Spring Creek	riparian	control	3	143	52.83
Big Spring Creek	riparian	control	3	165	58.34
Big Spring Creek	riparian	control	4	7	3.41
Big Spring Creek	riparian	control	4	14	6.56
Big Spring Creek	riparian	control	4	21	9.47
Big Spring Creek	riparian	control	4	35	14.61
Big Spring Creek	riparian	control	4	49	18.99
Big Spring Creek	riparian	control	4	70	24.36
Big Spring Creek	riparian	control	4	90	28.39
Big Spring Creek	riparian	control	4	117	32.54
Big Spring Creek	riparian	control	4	143	35.48
Big Spring Creek	riparian	control	4	165	37.36
Big Spring Creek	riparian	bison	1	7	6.36
Big Spring Creek	riparian	bison	1	14	12.10
Big Spring Creek	riparian	bison	1	21	17.28
Big Spring Creek	riparian	bison	1	35	26.17
Big Spring Creek	riparian	bison	1	49	33.40
Big Spring Creek	riparian	bison	1	70	41.81
Big Spring Creek	riparian	bison	1	90	47.73
Big Spring Creek	riparian	bison	1	117	53.40
Big Spring Creek	riparian	bison	1	143	57.10

Appendix D. Table D-2. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	N_t
Big Spring Creek	riparian	bison	1	165	59.29
Big Spring Creek	riparian	bison	2	7	10.34
Big Spring Creek	riparian	bison	2	14	19.10
Big Spring Creek	riparian	bison	2	21	26.52
Big Spring Creek	riparian	bison	2	35	38.14
Big Spring Creek	riparian	bison	2	49	46.49
Big Spring Creek	riparian	bison	2	70	54.81
Big Spring Creek	riparian	bison	2	90	59.68
Big Spring Creek	riparian	bison	2	117	63.49
Big Spring Creek	riparian	bison	2	143	65.45
Big Spring Creek	riparian	bison	2	165	66.38
Big Spring Creek	riparian	bison	3	7	3.82
Big Spring Creek	riparian	bison	3	14	7.42
Big Spring Creek	riparian	bison	3	21	10.80
Big Spring Creek	riparian	bison	3	35	16.98
Big Spring Creek	riparian	bison	3	49	22.46
Big Spring Creek	riparian	bison	3	70	29.51
Big Spring Creek	riparian	bison	3	90	35.13
Big Spring Creek	riparian	bison	3	117	41.33
Big Spring Creek	riparian	bison	3	143	46.06
Big Spring Creek	riparian	bison	3	165	49.31
Big Spring Creek	riparian	bison	4	7	3.14
Big Spring Creek	riparian	bison	4	14	6.07
Big Spring Creek	riparian	bison	4	21	8.82
Big Spring Creek	riparian	bison	4	35	13.79
Big Spring Creek	riparian	bison	4	49	18.15
Big Spring Creek	riparian	bison	4	70	23.69
Big Spring Creek	riparian	bison	4	90	28.03
Big Spring Creek	riparian	bison	4	117	32.72
Big Spring Creek	riparian	bison	4	143	36.24
Big Spring Creek	riparian	bison	4	165	38.60
Little Spring Creek	riparian	control	1	7	2.47
Little Spring Creek	riparian	control	1	14	4.87
Little Spring Creek	riparian	control	1	21	7.19
Little Spring Creek	riparian	control	1	35	11.62
Little Spring Creek	riparian	control	1	49	15.78
Little Spring Creek	riparian	control	1	70	21.56
Little Spring Creek	riparian	control	1	90	26.57
Little Spring Creek	riparian	control	1	117	32.67
Little Spring Creek	riparian	control	1	143	37.88
Little Spring Creek	riparian	control	1	165	41.83
Little Spring Creek	riparian	control	2	7	2.91
Little Spring Creek	riparian	control	2	14	5.74
Little Spring Creek	riparian	control	2	21	8.50
Little Spring Creek	riparian	control	2	35	13.79
Little Spring Creek	riparian	control	2	49	18.81
Little Spring Creek	riparian	control	2	70	25.84
Little Spring Creek	riparian	control	2	90	32.02
Little Spring Creek	riparian	control	2	117	39.64
Little Spring Creek	riparian	control	2	143	46.27
Little Spring Creek	riparian	control	2	165	51.38
Little Spring Creek	riparian	control	3	7	3.15
Little Spring Creek	riparian	control	3	14	6.16
Little Spring Creek	riparian	control	3	21	9.04

Appendix D. Table D-2. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	N_t
Little Spring Creek	riparian	control	3	35	14.41
Little Spring Creek	riparian	control	3	49	19.32
Little Spring Creek	riparian	control	3	70	25.88
Little Spring Creek	riparian	control	3	90	31.34
Little Spring Creek	riparian	control	3	117	37.67
Little Spring Creek	riparian	control	3	143	42.80
Little Spring Creek	riparian	control	3	165	46.51
Little Spring Creek	riparian	control	4	7	7.36
Little Spring Creek	riparian	control	4	14	13.87
Little Spring Creek	riparian	control	4	21	19.61
Little Spring Creek	riparian	control	4	35	29.18
Little Spring Creek	riparian	control	4	49	36.64
Little Spring Creek	riparian	control	4	70	44.87
Little Spring Creek	riparian	control	4	90	50.32
Little Spring Creek	riparian	control	4	117	55.20
Little Spring Creek	riparian	control	4	143	58.13
Little Spring Creek	riparian	control	4	165	59.75
Little Spring Creek	riparian	bison	1	7	4.47
Little Spring Creek	riparian	bison	1	14	8.58
Little Spring Creek	riparian	bison	1	21	12.38
Little Spring Creek	riparian	bison	1	35	19.10
Little Spring Creek	riparian	bison	1	49	24.81
Little Spring Creek	riparian	bison	1	70	31.82
Little Spring Creek	riparian	bison	1	90	37.07
Little Spring Creek	riparian	bison	1	117	42.48
Little Spring Creek	riparian	bison	1	143	46.30
Little Spring Creek	riparian	bison	1	165	48.75
Little Spring Creek	riparian	bison	2	7	3.01
Little Spring Creek	riparian	bison	2	14	5.96
Little Spring Creek	riparian	bison	2	21	8.86
Little Spring Creek	riparian	bison	2	35	14.52
Little Spring Creek	riparian	bison	2	49	19.97
Little Spring Creek	riparian	bison	2	70	27.80
Little Spring Creek	riparian	bison	2	90	34.88
Little Spring Creek	riparian	bison	2	117	43.89
Little Spring Creek	riparian	bison	2	143	52.00
Little Spring Creek	riparian	bison	2	165	58.46
Little Spring Creek	riparian	bison	3	7	5.73
Little Spring Creek	riparian	bison	3	14	10.98
Little Spring Creek	riparian	bison	3	21	15.78
Little Spring Creek	riparian	bison	3	35	24.19
Little Spring Creek	riparian	bison	3	49	31.23
Little Spring Creek	riparian	bison	3	70	39.71
Little Spring Creek	riparian	bison	3	90	45.94
Little Spring Creek	riparian	bison	3	117	52.19
Little Spring Creek	riparian	bison	3	143	56.49
Little Spring Creek	riparian	bison	3	165	59.17
Little Spring Creek	riparian	bison	4	7	6.58
Little Spring Creek	riparian	bison	4	14	12.34
Little Spring Creek	riparian	bison	4	21	17.38
Little Spring Creek	riparian	bison	4	35	25.67
Little Spring Creek	riparian	bison	4	49	32.04
Little Spring Creek	riparian	bison	4	70	38.92
Little Spring Creek	riparian	bison	4	90	43.36

Appendix D. Table D-2. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	N_t
Little Spring Creek	riparian	bison	4	117	47.22
Little Spring Creek	riparian	bison	4	143	49.48
Little Spring Creek	riparian	bison	4	165	50.68
Elk Springs	wet meadow	control	1	7	6.89
Elk Springs	wet meadow	control	1	14	13.18
Elk Springs	wet meadow	control	1	21	18.91
Elk Springs	wet meadow	control	1	35	28.92
Elk Springs	wet meadow	control	1	49	37.25
Elk Springs	wet meadow	control	1	70	47.21
Elk Springs	wet meadow	control	1	90	54.46
Elk Springs	wet meadow	control	1	117	61.67
Elk Springs	wet meadow	control	1	143	66.58
Elk Springs	wet meadow	control	1	165	69.61
Elk Springs	wet meadow	control	2	7	5.28
Elk Springs	wet meadow	control	2	14	10.23
Elk Springs	wet meadow	control	2	21	14.85
Elk Springs	wet meadow	control	2	35	23.22
Elk Springs	wet meadow	control	2	49	30.54
Elk Springs	wet meadow	control	2	70	39.85
Elk Springs	wet meadow	control	2	90	47.14
Elk Springs	wet meadow	control	2	117	55.02
Elk Springs	wet meadow	control	2	143	60.91
Elk Springs	wet meadow	control	2	165	64.87
Elk Springs	wet meadow	control	3	7	9.82
Elk Springs	wet meadow	control	3	14	18.37
Elk Springs	wet meadow	control	3	21	25.80
Elk Springs	wet meadow	control	3	35	37.89
Elk Springs	wet meadow	control	3	49	47.03
Elk Springs	wet meadow	control	3	70	56.75
Elk Springs	wet meadow	control	3	90	62.90
Elk Springs	wet meadow	control	3	117	68.13
Elk Springs	wet meadow	control	3	143	71.10
Elk Springs	wet meadow	control	3	165	72.65
Elk Springs	wet meadow	control	4	7	4.13
Elk Springs	wet meadow	control	4	14	8.12
Elk Springs	wet meadow	control	4	21	11.96
Elk Springs	wet meadow	control	4	35	19.23
Elk Springs	wet meadow	control	4	49	25.99
Elk Springs	wet meadow	control	4	70	35.25
Elk Springs	wet meadow	control	4	90	43.18
Elk Springs	wet meadow	control	4	117	52.65
Elk Springs	wet meadow	control	4	143	60.59
Elk Springs	wet meadow	control	4	165	66.52
Elk Springs	wet meadow	bison	1	7	5.39
Elk Springs	wet meadow	bison	1	14	10.55
Elk Springs	wet meadow	bison	1	21	15.48
Elk Springs	wet meadow	bison	1	35	24.70
Elk Springs	wet meadow	bison	1	49	33.14
Elk Springs	wet meadow	bison	1	70	44.47
Elk Springs	wet meadow	bison	1	90	53.93
Elk Springs	wet meadow	bison	1	117	64.94
Elk Springs	wet meadow	bison	1	143	73.89
Elk Springs	wet meadow	bison	1	165	80.38
Elk Springs	wet meadow	bison	2	7	6.47

Appendix D. Table D-2. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	N_t
Elk Springs	wet meadow	bison	2	14	12.66
Elk Springs	wet meadow	bison	2	21	18.56
Elk Springs	wet meadow	bison	2	35	29.58
Elk Springs	wet meadow	bison	2	49	39.64
Elk Springs	wet meadow	bison	2	70	53.08
Elk Springs	wet meadow	bison	2	90	64.26
Elk Springs	wet meadow	bison	2	117	77.20
Elk Springs	wet meadow	bison	2	143	87.66
Elk Springs	wet meadow	bison	2	165	95.21
Elk Springs	wet meadow	bison	3	7	6.54
Elk Springs	wet meadow	bison	3	14	12.67
Elk Springs	wet meadow	bison	3	21	18.42
Elk Springs	wet meadow	bison	3	35	28.86
Elk Springs	wet meadow	bison	3	49	38.04
Elk Springs	wet meadow	bison	3	70	49.78
Elk Springs	wet meadow	bison	3	90	59.04
Elk Springs	wet meadow	bison	3	117	69.12
Elk Springs	wet meadow	bison	3	143	76.73
Elk Springs	wet meadow	bison	3	165	81.89
Elk Springs	wet meadow	bison	4	7	4.66
Elk Springs	wet meadow	bison	4	14	9.24
Elk Springs	wet meadow	bison	4	21	13.74
Elk Springs	wet meadow	bison	4	35	22.50
Elk Springs	wet meadow	bison	4	49	30.95
Elk Springs	wet meadow	bison	4	70	43.06
Elk Springs	wet meadow	bison	4	90	53.99
Elk Springs	wet meadow	bison	4	117	67.89
Elk Springs	wet meadow	bison	4	143	80.39
Elk Springs	wet meadow	bison	4	165	90.33
Twin Lakes	wet meadow	control	1	7	4.47
Twin Lakes	wet meadow	control	1	14	8.75
Twin Lakes	wet meadow	control	1	21	12.87
Twin Lakes	wet meadow	control	1	35	20.59
Twin Lakes	wet meadow	control	1	49	27.70
Twin Lakes	wet meadow	control	1	70	37.32
Twin Lakes	wet meadow	control	1	90	45.43
Twin Lakes	wet meadow	control	1	117	54.95
Twin Lakes	wet meadow	control	1	143	62.79
Twin Lakes	wet meadow	control	1	165	68.54
Twin Lakes	wet meadow	control	2	7	3.63
Twin Lakes	wet meadow	control	2	14	7.14
Twin Lakes	wet meadow	control	2	21	10.55
Twin Lakes	wet meadow	control	2	35	17.06
Twin Lakes	wet meadow	control	2	49	23.17
Twin Lakes	wet meadow	control	2	70	31.66
Twin Lakes	wet meadow	control	2	90	39.04
Twin Lakes	wet meadow	control	2	117	48.03
Twin Lakes	wet meadow	control	2	143	55.72
Twin Lakes	wet meadow	control	2	165	61.57
Twin Lakes	wet meadow	control	3	7	4.19
Twin Lakes	wet meadow	control	3	14	8.23
Twin Lakes	wet meadow	control	3	21	12.13
Twin Lakes	wet meadow	control	3	35	19.51
Twin Lakes	wet meadow	control	3	49	26.39

Appendix D. **Table D-2.** Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	N_t
Twin Lakes	wet meadow	control	3	70	35.81
Twin Lakes	wet meadow	control	3	90	43.89
Twin Lakes	wet meadow	control	3	117	53.56
Twin Lakes	wet meadow	control	3	143	61.68
Twin Lakes	wet meadow	control	3	165	67.76
Twin Lakes	wet meadow	control	4	7	3.22
Twin Lakes	wet meadow	control	4	14	6.40
Twin Lakes	wet meadow	control	4	21	9.55
Twin Lakes	wet meadow	control	4	35	15.73
Twin Lakes	wet meadow	control	4	49	21.77
Twin Lakes	wet meadow	control	4	70	30.58
Twin Lakes	wet meadow	control	4	90	38.69
Twin Lakes	wet meadow	control	4	117	49.22
Twin Lakes	wet meadow	control	4	143	58.93
Twin Lakes	wet meadow	control	4	165	66.83
Twin Lakes	wet meadow	bison	1	7	2.78
Twin Lakes	wet meadow	bison	1	14	5.50
Twin Lakes	wet meadow	bison	1	21	8.17
Twin Lakes	wet meadow	bison	1	35	13.35
Twin Lakes	wet meadow	bison	1	49	18.33
Twin Lakes	wet meadow	bison	1	70	25.43
Twin Lakes	wet meadow	bison	1	90	31.81
Twin Lakes	wet meadow	bison	1	117	39.87
Twin Lakes	wet meadow	bison	1	143	47.07
Twin Lakes	wet meadow	bison	1	165	52.76
Twin Lakes	wet meadow	bison	2	7	3.20
Twin Lakes	wet meadow	bison	2	14	6.33
Twin Lakes	wet meadow	bison	2	21	9.39
Twin Lakes	wet meadow	bison	2	35	15.30
Twin Lakes	wet meadow	bison	2	49	20.95
Twin Lakes	wet meadow	bison	2	70	28.95
Twin Lakes	wet meadow	bison	2	90	36.08
Twin Lakes	wet meadow	bison	2	117	45.00
Twin Lakes	wet meadow	bison	2	143	52.87
Twin Lakes	wet meadow	bison	2	165	59.03
Twin Lakes	wet meadow	bison	3	7	3.92
Twin Lakes	wet meadow	bison	3	14	7.71
Twin Lakes	wet meadow	bison	3	21	11.37
Twin Lakes	wet meadow	bison	3	35	18.33
Twin Lakes	wet meadow	bison	3	49	24.83
Twin Lakes	wet meadow	bison	3	70	33.78
Twin Lakes	wet meadow	bison	3	90	41.49
Twin Lakes	wet meadow	bison	3	117	50.77
Twin Lakes	wet meadow	bison	3	143	58.62
Twin Lakes	wet meadow	bison	3	165	64.53
Twin Lakes	wet meadow	bison	4	7	---
Twin Lakes	wet meadow	bison	4	14	---
Twin Lakes	wet meadow	bison	4	21	---
Twin Lakes	wet meadow	bison	4	35	---
Twin Lakes	wet meadow	bison	4	49	---
Twin Lakes	wet meadow	bison	4	70	---
Twin Lakes	wet meadow	bison	4	90	---
Twin Lakes	wet meadow	bison	4	117	---
Twin Lakes	wet meadow	bison	4	143	---

Appendix B. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Microbial CO_2 respiration rate ($mg\ C\ g^{-1}\ soil\ C\ d^{-1}$)
Little Spring Creek	riparian	control	1	89	1.71
Little Spring Creek	riparian	control	1	116	1.83
Little Spring Creek	riparian	control	1	140	0.95
Little Spring Creek	riparian	control	1	164	0.83
Little Spring Creek	riparian	control	2	3	2.52
Little Spring Creek	riparian	control	2	6	1.88
Little Spring Creek	riparian	control	2	10	1.48
Little Spring Creek	riparian	control	2	13	1.32
Little Spring Creek	riparian	control	2	20	0.91
Little Spring Creek	riparian	control	2	34	1.43
Little Spring Creek	riparian	control	2	48	1.57
Little Spring Creek	riparian	control	2	69	2.08
Little Spring Creek	riparian	control	2	89	2.11
Little Spring Creek	riparian	control	2	116	2.40
Little Spring Creek	riparian	control	2	140	1.50
Little Spring Creek	riparian	control	2	164	1.32
Little Spring Creek	riparian	control	3	3	3.49
Little Spring Creek	riparian	control	3	6	2.37
Little Spring Creek	riparian	control	3	10	2.23
Little Spring Creek	riparian	control	3	13	1.63
Little Spring Creek	riparian	control	3	20	1.41
Little Spring Creek	riparian	control	3	34	1.61
Little Spring Creek	riparian	control	3	48	1.62
Little Spring Creek	riparian	control	3	69	1.24
Little Spring Creek	riparian	control	3	89	2.90
Little Spring Creek	riparian	control	3	116	3.31
Little Spring Creek	riparian	control	3	140	2.35
Little Spring Creek	riparian	control	3	164	1.88
Little Spring Creek	riparian	control	4	3	2.41
Little Spring Creek	riparian	control	4	6	1.69
Little Spring Creek	riparian	control	4	10	1.23
Little Spring Creek	riparian	control	4	13	1.23
Little Spring Creek	riparian	control	4	20	1.12
Little Spring Creek	riparian	control	4	34	1.21
Little Spring Creek	riparian	control	4	48	1.13
Little Spring Creek	riparian	control	4	69	1.97
Little Spring Creek	riparian	control	4	89	2.38
Little Spring Creek	riparian	control	4	116	2.56
Little Spring Creek	riparian	control	4	140	1.92
Little Spring Creek	riparian	control	4	164	1.44
Little Spring Creek	riparian	bison	1	3	4.09
Little Spring Creek	riparian	bison	1	6	2.38
Little Spring Creek	riparian	bison	1	10	1.96
Little Spring Creek	riparian	bison	1	13	1.89
Little Spring Creek	riparian	bison	1	20	1.56
Little Spring Creek	riparian	bison	1	34	1.36
Little Spring Creek	riparian	bison	1	48	0.55
Little Spring Creek	riparian	bison	1	69	1.37
Little Spring Creek	riparian	bison	1	89	1.74
Little Spring Creek	riparian	bison	1	116	1.38
Little Spring Creek	riparian	bison	1	140	1.07
Little Spring Creek	riparian	bison	1	164	1.05
Little Spring Creek	riparian	bison	2	3	3.98

Appendix B. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Microbial CO_2 respiration rate ($mg\ C\ g^{-1}$ soil $C\ d^{-1}$)
Elk Springs	wet meadow	control	2	48	1.75
Elk Springs	wet meadow	control	2	69	1.73
Elk Springs	wet meadow	control	2	89	2.31
Elk Springs	wet meadow	control	2	116	2.05
Elk Springs	wet meadow	control	2	140	1.71
Elk Springs	wet meadow	control	2	164	1.59
Elk Springs	wet meadow	control	3	3	3.50
Elk Springs	wet meadow	control	3	6	2.48
Elk Springs	wet meadow	control	3	10	1.83
Elk Springs	wet meadow	control	3	13	1.66
Elk Springs	wet meadow	control	3	20	1.18
Elk Springs	wet meadow	control	3	34	1.53
Elk Springs	wet meadow	control	3	48	1.45
Elk Springs	wet meadow	control	3	69	1.61
Elk Springs	wet meadow	control	3	89	1.89
Elk Springs	wet meadow	control	3	116	1.78
Elk Springs	wet meadow	control	3	140	1.59
Elk Springs	wet meadow	control	3	164	1.07
Elk Springs	wet meadow	control	4	3	4.59
Elk Springs	wet meadow	control	4	6	2.79
Elk Springs	wet meadow	control	4	10	2.81
Elk Springs	wet meadow	control	4	13	1.59
Elk Springs	wet meadow	control	4	20	1.36
Elk Springs	wet meadow	control	4	34	1.36
Elk Springs	wet meadow	control	4	48	1.38
Elk Springs	wet meadow	control	4	69	1.72
Elk Springs	wet meadow	control	4	89	2.06
Elk Springs	wet meadow	control	4	116	1.98
Elk Springs	wet meadow	control	4	140	1.19
Elk Springs	wet meadow	control	4	164	0.93
Elk Springs	wet meadow	bison	1	3	4.16
Elk Springs	wet meadow	bison	1	6	3.25
Elk Springs	wet meadow	bison	1	10	2.97
Elk Springs	wet meadow	bison	1	13	2.41
Elk Springs	wet meadow	bison	1	20	1.95
Elk Springs	wet meadow	bison	1	34	1.30
Elk Springs	wet meadow	bison	1	48	1.82
Elk Springs	wet meadow	bison	1	69	2.02
Elk Springs	wet meadow	bison	1	89	2.24
Elk Springs	wet meadow	bison	1	116	1.56
Elk Springs	wet meadow	bison	1	140	1.72
Elk Springs	wet meadow	bison	1	164	1.35
Elk Springs	wet meadow	bison	2	3	5.39
Elk Springs	wet meadow	bison	2	6	3.99
Elk Springs	wet meadow	bison	2	10	3.62
Elk Springs	wet meadow	bison	2	13	2.66
Elk Springs	wet meadow	bison	2	20	1.89
Elk Springs	wet meadow	bison	2	34	2.30
Elk Springs	wet meadow	bison	2	48	2.48
Elk Springs	wet meadow	bison	2	69	3.54
Elk Springs	wet meadow	bison	2	89	3.73
Elk Springs	wet meadow	bison	2	116	2.76
Elk Springs	wet meadow	bison	2	140	2.94

Appendix B. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Microbial CO_2 respiration rate (mg C g^{-1} soil C d^{-1})
South MZ Ranch	wet meadow	cattle	4	69	---
South MZ Ranch	wet meadow	cattle	4	89	---
South MZ Ranch	wet meadow	cattle	4	116	---
South MZ Ranch	wet meadow	cattle	4	140	2.00
South MZ Ranch	wet meadow	cattle	4	164	1.88
West MZ Ranch	wet meadow	control	1	3	2.96
West MZ Ranch	wet meadow	control	1	6	1.14
West MZ Ranch	wet meadow	control	1	10	0.91
West MZ Ranch	wet meadow	control	1	13	0.86
West MZ Ranch	wet meadow	control	1	20	0.74
West MZ Ranch	wet meadow	control	1	34	0.84
West MZ Ranch	wet meadow	control	1	48	0.80
West MZ Ranch	wet meadow	control	1	69	1.14
West MZ Ranch	wet meadow	control	1	89	1.10
West MZ Ranch	wet meadow	control	1	116	1.10
West MZ Ranch	wet meadow	control	1	140	1.19
West MZ Ranch	wet meadow	control	1	164	0.91
West MZ Ranch	wet meadow	control	2	3	3.96
West MZ Ranch	wet meadow	control	2	6	2.16
West MZ Ranch	wet meadow	control	2	10	1.99
West MZ Ranch	wet meadow	control	2	13	1.60
West MZ Ranch	wet meadow	control	2	20	1.25
West MZ Ranch	wet meadow	control	2	34	0.97
West MZ Ranch	wet meadow	control	2	48	1.27
West MZ Ranch	wet meadow	control	2	69	1.43
West MZ Ranch	wet meadow	control	2	89	1.50
West MZ Ranch	wet meadow	control	2	116	1.54
West MZ Ranch	wet meadow	control	2	140	1.37
West MZ Ranch	wet meadow	control	2	164	1.08
West MZ Ranch	wet meadow	control	3	3	4.61
West MZ Ranch	wet meadow	control	3	6	1.71
West MZ Ranch	wet meadow	control	3	10	1.10
West MZ Ranch	wet meadow	control	3	13	1.31
West MZ Ranch	wet meadow	control	3	20	1.13
West MZ Ranch	wet meadow	control	3	34	1.12
West MZ Ranch	wet meadow	control	3	48	0.97
West MZ Ranch	wet meadow	control	3	69	1.44
West MZ Ranch	wet meadow	control	3	89	1.48
West MZ Ranch	wet meadow	control	3	116	1.22
West MZ Ranch	wet meadow	control	3	140	1.16
West MZ Ranch	wet meadow	control	3	164	1.08
West MZ Ranch	wet meadow	control	4	3	2.92
West MZ Ranch	wet meadow	control	4	6	1.60
West MZ Ranch	wet meadow	control	4	10	1.40
West MZ Ranch	wet meadow	control	4	13	1.36
West MZ Ranch	wet meadow	control	4	20	1.07
West MZ Ranch	wet meadow	control	4	34	1.07
West MZ Ranch	wet meadow	control	4	48	1.14
West MZ Ranch	wet meadow	control	4	69	2.88
West MZ Ranch	wet meadow	control	4	89	2.64
West MZ Ranch	wet meadow	control	4	116	2.54
West MZ Ranch	wet meadow	control	4	140	2.28
West MZ Ranch	wet meadow	control	4	164	2.02

Appendix C. Net N mineralization and N mineralization rates of soil samples from Great Sand Dunes riparian corridors and wet meadowss. N was measured by repeatedly leaching soil samples during a 6-month incubation period.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Net N mineralized (mg N g^{-1} soil N)	N mineralization rate (mg N g^{-1} soil N wk^{-1})
Big Spring Creek	riparian	control	1	7	3.84	3.84
Big Spring Creek	riparian	control	1	14	6.59	2.76
Big Spring Creek	riparian	control	1	21	8.41	1.81
Big Spring Creek	riparian	control	1	35	10.20	0.89
Big Spring Creek	riparian	control	1	49	16.45	3.13
Big Spring Creek	riparian	control	1	70	28.41	3.99
Big Spring Creek	riparian	control	1	90	34.53	2.04
Big Spring Creek	riparian	control	1	117	41.60	1.83
Big Spring Creek	riparian	control	1	143	45.42	1.03
Big Spring Creek	riparian	control	1	165	48.97	1.13
Big Spring Creek	riparian	control	2	7	5.05	5.05
Big Spring Creek	riparian	control	2	14	8.78	3.73
Big Spring Creek	riparian	control	2	21	10.76	1.98
Big Spring Creek	riparian	control	2	35	13.40	1.32
Big Spring Creek	riparian	control	2	49	15.04	0.82
Big Spring Creek	riparian	control	2	70	17.58	0.85
Big Spring Creek	riparian	control	2	90	20.47	0.96
Big Spring Creek	riparian	control	2	117	24.19	0.96
Big Spring Creek	riparian	control	2	143	27.16	0.80
Big Spring Creek	riparian	control	2	165	29.97	0.89
Big Spring Creek	riparian	control	3	7	5.56	5.56
Big Spring Creek	riparian	control	3	14	9.23	3.67
Big Spring Creek	riparian	control	3	21	11.32	2.09
Big Spring Creek	riparian	control	3	35	14.56	1.62
Big Spring Creek	riparian	control	3	49	18.70	2.07
Big Spring Creek	riparian	control	3	70	30.65	3.98
Big Spring Creek	riparian	control	3	90	37.88	2.41
Big Spring Creek	riparian	control	3	117	47.37	2.46
Big Spring Creek	riparian	control	3	143	52.00	1.25
Big Spring Creek	riparian	control	3	165	58.01	1.91
Big Spring Creek	riparian	control	4	7	3.98	3.98
Big Spring Creek	riparian	control	4	14	9.04	5.06

Appendix C. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	Net N mineralized (mg N g^{-1} soil N)	N mineralization rate (mg N g^{-1} soil N wk^{-1})
West MZ Ranch	wet meadow	cattle	4	7	5.04	5.04
West MZ Ranch	wet meadow	cattle	4	14	7.78	2.75
West MZ Ranch	wet meadow	cattle	4	21	11.18	3.40
West MZ Ranch	wet meadow	cattle	4	35	12.83	2.52
West MZ Ranch	wet meadow	cattle	4	49	18.33	2.75
West MZ Ranch	wet meadow	cattle	4	70	23.92	1.87
West MZ Ranch	wet meadow	cattle	4	90	30.60	2.22
West MZ Ranch	wet meadow	cattle	4	117	40.14	2.47
West MZ Ranch	wet meadow	cattle	4	143	44.07	1.06
West MZ Ranch	wet meadow	cattle	4	165	50.38	2.01

Appendix D. Continued.

Table D-2. N_t = cumulative N mineralized at time t (mg N g^{-1} soil N) estimated with the first-order model during the incubation period. Models which did not converge did not produce parameter estimates.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	N_t
Big Spring Creek	riparian	control	1	7	3.04
Big Spring Creek	riparian	control	1	14	5.98
Big Spring Creek	riparian	control	1	21	8.82
Big Spring Creek	riparian	control	1	35	14.23
Big Spring Creek	riparian	control	1	49	19.30
Big Spring Creek	riparian	control	1	70	26.29
Big Spring Creek	riparian	control	1	90	32.33
Big Spring Creek	riparian	control	1	117	39.63
Big Spring Creek	riparian	control	1	143	45.82
Big Spring Creek	riparian	control	1	165	50.50
Big Spring Creek	riparian	control	2	7	3.06
Big Spring Creek	riparian	control	2	14	5.81
Big Spring Creek	riparian	control	2	21	8.28
Big Spring Creek	riparian	control	2	35	12.49
Big Spring Creek	riparian	control	2	49	15.89
Big Spring Creek	riparian	control	2	70	19.81
Big Spring Creek	riparian	control	2	90	22.54
Big Spring Creek	riparian	control	2	117	25.12
Big Spring Creek	riparian	control	2	143	26.77
Big Spring Creek	riparian	control	2	165	27.74
Big Spring Creek	riparian	control	3	7	3.46
Big Spring Creek	riparian	control	3	14	6.80
Big Spring Creek	riparian	control	3	21	10.05
Big Spring Creek	riparian	control	3	35	16.23
Big Spring Creek	riparian	control	3	49	22.04
Big Spring Creek	riparian	control	3	70	30.10
Big Spring Creek	riparian	control	3	90	37.09
Big Spring Creek	riparian	control	3	117	45.58
Big Spring Creek	riparian	control	3	143	52.83
Big Spring Creek	riparian	control	3	165	58.34
Big Spring Creek	riparian	control	4	7	3.41
Big Spring Creek	riparian	control	4	14	6.56
Big Spring Creek	riparian	control	4	21	9.47
Big Spring Creek	riparian	control	4	35	14.61
Big Spring Creek	riparian	control	4	49	18.99
Big Spring Creek	riparian	control	4	70	24.36
Big Spring Creek	riparian	control	4	90	28.39
Big Spring Creek	riparian	control	4	117	32.54
Big Spring Creek	riparian	control	4	143	35.48
Big Spring Creek	riparian	control	4	165	37.36
Big Spring Creek	riparian	bison	1	7	6.36
Big Spring Creek	riparian	bison	1	14	12.10
Big Spring Creek	riparian	bison	1	21	17.28
Big Spring Creek	riparian	bison	1	35	26.17
Big Spring Creek	riparian	bison	1	49	33.40
Big Spring Creek	riparian	bison	1	70	41.81
Big Spring Creek	riparian	bison	1	90	47.73
Big Spring Creek	riparian	bison	1	117	53.40
Big Spring Creek	riparian	bison	1	143	57.10

Appendix D. Table D-2. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	N_t
Big Spring Creek	riparian	bison	1	165	59.29
Big Spring Creek	riparian	bison	2	7	10.34
Big Spring Creek	riparian	bison	2	14	19.10
Big Spring Creek	riparian	bison	2	21	26.52
Big Spring Creek	riparian	bison	2	35	38.14
Big Spring Creek	riparian	bison	2	49	46.49
Big Spring Creek	riparian	bison	2	70	54.81
Big Spring Creek	riparian	bison	2	90	59.68
Big Spring Creek	riparian	bison	2	117	63.49
Big Spring Creek	riparian	bison	2	143	65.45
Big Spring Creek	riparian	bison	2	165	66.38
Big Spring Creek	riparian	bison	3	7	3.82
Big Spring Creek	riparian	bison	3	14	7.42
Big Spring Creek	riparian	bison	3	21	10.80
Big Spring Creek	riparian	bison	3	35	16.98
Big Spring Creek	riparian	bison	3	49	22.46
Big Spring Creek	riparian	bison	3	70	29.51
Big Spring Creek	riparian	bison	3	90	35.13
Big Spring Creek	riparian	bison	3	117	41.33
Big Spring Creek	riparian	bison	3	143	46.06
Big Spring Creek	riparian	bison	3	165	49.31
Big Spring Creek	riparian	bison	4	7	3.14
Big Spring Creek	riparian	bison	4	14	6.07
Big Spring Creek	riparian	bison	4	21	8.82
Big Spring Creek	riparian	bison	4	35	13.79
Big Spring Creek	riparian	bison	4	49	18.15
Big Spring Creek	riparian	bison	4	70	23.69
Big Spring Creek	riparian	bison	4	90	28.03
Big Spring Creek	riparian	bison	4	117	32.72
Big Spring Creek	riparian	bison	4	143	36.24
Big Spring Creek	riparian	bison	4	165	38.60
Little Spring Creek	riparian	control	1	7	2.47
Little Spring Creek	riparian	control	1	14	4.87
Little Spring Creek	riparian	control	1	21	7.19
Little Spring Creek	riparian	control	1	35	11.62
Little Spring Creek	riparian	control	1	49	15.78
Little Spring Creek	riparian	control	1	70	21.56
Little Spring Creek	riparian	control	1	90	26.57
Little Spring Creek	riparian	control	1	117	32.67
Little Spring Creek	riparian	control	1	143	37.88
Little Spring Creek	riparian	control	1	165	41.83
Little Spring Creek	riparian	control	2	7	2.91
Little Spring Creek	riparian	control	2	14	5.74
Little Spring Creek	riparian	control	2	21	8.50
Little Spring Creek	riparian	control	2	35	13.79
Little Spring Creek	riparian	control	2	49	18.81
Little Spring Creek	riparian	control	2	70	25.84
Little Spring Creek	riparian	control	2	90	32.02
Little Spring Creek	riparian	control	2	117	39.64
Little Spring Creek	riparian	control	2	143	46.27
Little Spring Creek	riparian	control	2	165	51.38
Little Spring Creek	riparian	control	3	7	3.15
Little Spring Creek	riparian	control	3	14	6.16
Little Spring Creek	riparian	control	3	21	9.04

Appendix D. Table D-2. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	N_t
Little Spring Creek	riparian	bison	4	117	47.22
Little Spring Creek	riparian	bison	4	143	49.48
Little Spring Creek	riparian	bison	4	165	50.68
Elk Springs	wet meadow	control	1	7	6.89
Elk Springs	wet meadow	control	1	14	13.18
Elk Springs	wet meadow	control	1	21	18.91
Elk Springs	wet meadow	control	1	35	28.92
Elk Springs	wet meadow	control	1	49	37.25
Elk Springs	wet meadow	control	1	70	47.21
Elk Springs	wet meadow	control	1	90	54.46
Elk Springs	wet meadow	control	1	117	61.67
Elk Springs	wet meadow	control	1	143	66.58
Elk Springs	wet meadow	control	1	165	69.61
Elk Springs	wet meadow	control	2	7	5.28
Elk Springs	wet meadow	control	2	14	10.23
Elk Springs	wet meadow	control	2	21	14.85
Elk Springs	wet meadow	control	2	35	23.22
Elk Springs	wet meadow	control	2	49	30.54
Elk Springs	wet meadow	control	2	70	39.85
Elk Springs	wet meadow	control	2	90	47.14
Elk Springs	wet meadow	control	2	117	55.02
Elk Springs	wet meadow	control	2	143	60.91
Elk Springs	wet meadow	control	2	165	64.87
Elk Springs	wet meadow	control	3	7	9.82
Elk Springs	wet meadow	control	3	14	18.37
Elk Springs	wet meadow	control	3	21	25.80
Elk Springs	wet meadow	control	3	35	37.89
Elk Springs	wet meadow	control	3	49	47.03
Elk Springs	wet meadow	control	3	70	56.75
Elk Springs	wet meadow	control	3	90	62.90
Elk Springs	wet meadow	control	3	117	68.13
Elk Springs	wet meadow	control	3	143	71.10
Elk Springs	wet meadow	control	3	165	72.65
Elk Springs	wet meadow	control	4	7	4.13
Elk Springs	wet meadow	control	4	14	8.12
Elk Springs	wet meadow	control	4	21	11.96
Elk Springs	wet meadow	control	4	35	19.23
Elk Springs	wet meadow	control	4	49	25.99
Elk Springs	wet meadow	control	4	70	35.25
Elk Springs	wet meadow	control	4	90	43.18
Elk Springs	wet meadow	control	4	117	52.65
Elk Springs	wet meadow	control	4	143	60.59
Elk Springs	wet meadow	control	4	165	66.52
Elk Springs	wet meadow	bison	1	7	5.39
Elk Springs	wet meadow	bison	1	14	10.55
Elk Springs	wet meadow	bison	1	21	15.48
Elk Springs	wet meadow	bison	1	35	24.70
Elk Springs	wet meadow	bison	1	49	33.14
Elk Springs	wet meadow	bison	1	70	44.47
Elk Springs	wet meadow	bison	1	90	53.93
Elk Springs	wet meadow	bison	1	117	64.94
Elk Springs	wet meadow	bison	1	143	73.89
Elk Springs	wet meadow	bison	1	165	80.38
Elk Springs	wet meadow	bison	2	7	6.47

Appendix D. Table D-2. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	N_t
Elk Springs	wet meadow	bison	2	14	12.66
Elk Springs	wet meadow	bison	2	21	18.56
Elk Springs	wet meadow	bison	2	35	29.58
Elk Springs	wet meadow	bison	2	49	39.64
Elk Springs	wet meadow	bison	2	70	53.08
Elk Springs	wet meadow	bison	2	90	64.26
Elk Springs	wet meadow	bison	2	117	77.20
Elk Springs	wet meadow	bison	2	143	87.66
Elk Springs	wet meadow	bison	2	165	95.21
Elk Springs	wet meadow	bison	3	7	6.54
Elk Springs	wet meadow	bison	3	14	12.67
Elk Springs	wet meadow	bison	3	21	18.42
Elk Springs	wet meadow	bison	3	35	28.86
Elk Springs	wet meadow	bison	3	49	38.04
Elk Springs	wet meadow	bison	3	70	49.78
Elk Springs	wet meadow	bison	3	90	59.04
Elk Springs	wet meadow	bison	3	117	69.12
Elk Springs	wet meadow	bison	3	143	76.73
Elk Springs	wet meadow	bison	3	165	81.89
Elk Springs	wet meadow	bison	4	7	4.66
Elk Springs	wet meadow	bison	4	14	9.24
Elk Springs	wet meadow	bison	4	21	13.74
Elk Springs	wet meadow	bison	4	35	22.50
Elk Springs	wet meadow	bison	4	49	30.95
Elk Springs	wet meadow	bison	4	70	43.06
Elk Springs	wet meadow	bison	4	90	53.99
Elk Springs	wet meadow	bison	4	117	67.89
Elk Springs	wet meadow	bison	4	143	80.39
Elk Springs	wet meadow	bison	4	165	90.33
Twin Lakes	wet meadow	control	1	7	4.47
Twin Lakes	wet meadow	control	1	14	8.75
Twin Lakes	wet meadow	control	1	21	12.87
Twin Lakes	wet meadow	control	1	35	20.59
Twin Lakes	wet meadow	control	1	49	27.70
Twin Lakes	wet meadow	control	1	70	37.32
Twin Lakes	wet meadow	control	1	90	45.43
Twin Lakes	wet meadow	control	1	117	54.95
Twin Lakes	wet meadow	control	1	143	62.79
Twin Lakes	wet meadow	control	1	165	68.54
Twin Lakes	wet meadow	control	2	7	3.63
Twin Lakes	wet meadow	control	2	14	7.14
Twin Lakes	wet meadow	control	2	21	10.55
Twin Lakes	wet meadow	control	2	35	17.06
Twin Lakes	wet meadow	control	2	49	23.17
Twin Lakes	wet meadow	control	2	70	31.66
Twin Lakes	wet meadow	control	2	90	39.04
Twin Lakes	wet meadow	control	2	117	48.03
Twin Lakes	wet meadow	control	2	143	55.72
Twin Lakes	wet meadow	control	2	165	61.57
Twin Lakes	wet meadow	control	3	7	4.19
Twin Lakes	wet meadow	control	3	14	8.23
Twin Lakes	wet meadow	control	3	21	12.13
Twin Lakes	wet meadow	control	3	35	19.51
Twin Lakes	wet meadow	control	3	49	26.39

Appendix D. Table D-2. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	N_t
Twin Lakes	wet meadow	control	3	70	35.81
Twin Lakes	wet meadow	control	3	90	43.89
Twin Lakes	wet meadow	control	3	117	53.56
Twin Lakes	wet meadow	control	3	143	61.68
Twin Lakes	wet meadow	control	3	165	67.76
Twin Lakes	wet meadow	control	4	7	3.22
Twin Lakes	wet meadow	control	4	14	6.40
Twin Lakes	wet meadow	control	4	21	9.55
Twin Lakes	wet meadow	control	4	35	15.73
Twin Lakes	wet meadow	control	4	49	21.77
Twin Lakes	wet meadow	control	4	70	30.58
Twin Lakes	wet meadow	control	4	90	38.69
Twin Lakes	wet meadow	control	4	117	49.22
Twin Lakes	wet meadow	control	4	143	58.93
Twin Lakes	wet meadow	control	4	165	66.83
Twin Lakes	wet meadow	bison	1	7	2.78
Twin Lakes	wet meadow	bison	1	14	5.50
Twin Lakes	wet meadow	bison	1	21	8.17
Twin Lakes	wet meadow	bison	1	35	13.35
Twin Lakes	wet meadow	bison	1	49	18.33
Twin Lakes	wet meadow	bison	1	70	25.43
Twin Lakes	wet meadow	bison	1	90	31.81
Twin Lakes	wet meadow	bison	1	117	39.87
Twin Lakes	wet meadow	bison	1	143	47.07
Twin Lakes	wet meadow	bison	1	165	52.76
Twin Lakes	wet meadow	bison	2	7	3.20
Twin Lakes	wet meadow	bison	2	14	6.33
Twin Lakes	wet meadow	bison	2	21	9.39
Twin Lakes	wet meadow	bison	2	35	15.30
Twin Lakes	wet meadow	bison	2	49	20.95
Twin Lakes	wet meadow	bison	2	70	28.95
Twin Lakes	wet meadow	bison	2	90	36.08
Twin Lakes	wet meadow	bison	2	117	45.00
Twin Lakes	wet meadow	bison	2	143	52.87
Twin Lakes	wet meadow	bison	2	165	59.03
Twin Lakes	wet meadow	bison	3	7	3.92
Twin Lakes	wet meadow	bison	3	14	7.71
Twin Lakes	wet meadow	bison	3	21	11.37
Twin Lakes	wet meadow	bison	3	35	18.33
Twin Lakes	wet meadow	bison	3	49	24.83
Twin Lakes	wet meadow	bison	3	70	33.78
Twin Lakes	wet meadow	bison	3	90	41.49
Twin Lakes	wet meadow	bison	3	117	50.77
Twin Lakes	wet meadow	bison	3	143	58.62
Twin Lakes	wet meadow	bison	3	165	64.53
Twin Lakes	wet meadow	bison	4	7	---
Twin Lakes	wet meadow	bison	4	14	---
Twin Lakes	wet meadow	bison	4	21	---
Twin Lakes	wet meadow	bison	4	35	---
Twin Lakes	wet meadow	bison	4	49	---
Twin Lakes	wet meadow	bison	4	70	---
Twin Lakes	wet meadow	bison	4	90	---
Twin Lakes	wet meadow	bison	4	117	---
Twin Lakes	wet meadow	bison	4	143	---

Appendix D. Table D-2. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	N_t
Twin Lakes	wet meadow	bison	4	165	---
South MZ Ranch	wet meadow	control	1	7	6.69
South MZ Ranch	wet meadow	control	1	14	12.95
South MZ Ranch	wet meadow	control	1	21	18.80
South MZ Ranch	wet meadow	control	1	35	29.40
South MZ Ranch	wet meadow	control	1	49	38.67
South MZ Ranch	wet meadow	control	1	70	50.46
South MZ Ranch	wet meadow	control	1	90	59.69
South MZ Ranch	wet meadow	control	1	117	69.67
South MZ Ranch	wet meadow	control	1	143	77.13
South MZ Ranch	wet meadow	control	1	165	82.15
South MZ Ranch	wet meadow	control	2	7	8.07
South MZ Ranch	wet meadow	control	2	14	15.64
South MZ Ranch	wet meadow	control	2	21	22.75
South MZ Ranch	wet meadow	control	2	35	35.67
South MZ Ranch	wet meadow	control	2	49	47.05
South MZ Ranch	wet meadow	control	2	70	61.63
South MZ Ranch	wet meadow	control	2	90	73.15
South MZ Ranch	wet meadow	control	2	117	85.73
South MZ Ranch	wet meadow	control	2	143	95.25
South MZ Ranch	wet meadow	control	2	165	101.73
South MZ Ranch	wet meadow	control	3	7	5.10
South MZ Ranch	wet meadow	control	3	14	10.02
South MZ Ranch	wet meadow	control	3	21	14.74
South MZ Ranch	wet meadow	control	3	35	23.67
South MZ Ranch	wet meadow	control	3	49	31.93
South MZ Ranch	wet meadow	control	3	70	43.19
South MZ Ranch	wet meadow	control	3	90	52.78
South MZ Ranch	wet meadow	control	3	117	64.15
South MZ Ranch	wet meadow	control	3	143	73.62
South MZ Ranch	wet meadow	control	3	165	80.64
South MZ Ranch	wet meadow	control	4	7	4.73
South MZ Ranch	wet meadow	control	4	14	9.22
South MZ Ranch	wet meadow	control	4	21	13.49
South MZ Ranch	wet meadow	control	4	35	21.40
South MZ Ranch	wet meadow	control	4	49	28.54
South MZ Ranch	wet meadow	control	4	70	37.97
South MZ Ranch	wet meadow	control	4	90	45.70
South MZ Ranch	wet meadow	control	4	117	54.50
South MZ Ranch	wet meadow	control	4	143	61.48
South MZ Ranch	wet meadow	control	4	165	66.43
South MZ Ranch	wet meadow	cattle	1	7	---
South MZ Ranch	wet meadow	cattle	1	14	---
South MZ Ranch	wet meadow	cattle	1	21	---
South MZ Ranch	wet meadow	cattle	1	35	---
South MZ Ranch	wet meadow	cattle	1	49	---
South MZ Ranch	wet meadow	cattle	1	70	---
South MZ Ranch	wet meadow	cattle	1	90	---
South MZ Ranch	wet meadow	cattle	1	117	---
South MZ Ranch	wet meadow	cattle	1	143	---
South MZ Ranch	wet meadow	cattle	1	165	---
South MZ Ranch	wet meadow	cattle	2	7	---
South MZ Ranch	wet meadow	cattle	2	14	---
South MZ Ranch	wet meadow	cattle	2	21	---

Appendix D. Table D-2. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	N_t
Twin Lakes	wet meadow	bison	4	165	---
South MZ Ranch	wet meadow	control	1	7	6.69
South MZ Ranch	wet meadow	control	1	14	12.95
South MZ Ranch	wet meadow	control	1	21	18.80
South MZ Ranch	wet meadow	control	1	35	29.40
South MZ Ranch	wet meadow	control	1	49	38.67
South MZ Ranch	wet meadow	control	1	70	50.46
South MZ Ranch	wet meadow	control	1	90	59.69
South MZ Ranch	wet meadow	control	1	117	69.67
South MZ Ranch	wet meadow	control	1	143	77.13
South MZ Ranch	wet meadow	control	1	165	82.15
South MZ Ranch	wet meadow	control	2	7	8.07
South MZ Ranch	wet meadow	control	2	14	15.64
South MZ Ranch	wet meadow	control	2	21	22.75
South MZ Ranch	wet meadow	control	2	35	35.67
South MZ Ranch	wet meadow	control	2	49	47.05
South MZ Ranch	wet meadow	control	2	70	61.63
South MZ Ranch	wet meadow	control	2	90	73.15
South MZ Ranch	wet meadow	control	2	117	85.73
South MZ Ranch	wet meadow	control	2	143	95.25
South MZ Ranch	wet meadow	control	2	165	101.73
South MZ Ranch	wet meadow	control	3	7	5.10
South MZ Ranch	wet meadow	control	3	14	10.02
South MZ Ranch	wet meadow	control	3	21	14.74
South MZ Ranch	wet meadow	control	3	35	23.67
South MZ Ranch	wet meadow	control	3	49	31.93
South MZ Ranch	wet meadow	control	3	70	43.19
South MZ Ranch	wet meadow	control	3	90	52.78
South MZ Ranch	wet meadow	control	3	117	64.15
South MZ Ranch	wet meadow	control	3	143	73.62
South MZ Ranch	wet meadow	control	3	165	80.64
South MZ Ranch	wet meadow	control	4	7	4.73
South MZ Ranch	wet meadow	control	4	14	9.22
South MZ Ranch	wet meadow	control	4	21	13.49
South MZ Ranch	wet meadow	control	4	35	21.40
South MZ Ranch	wet meadow	control	4	49	28.54
South MZ Ranch	wet meadow	control	4	70	37.97
South MZ Ranch	wet meadow	control	4	90	45.70
South MZ Ranch	wet meadow	control	4	117	54.50
South MZ Ranch	wet meadow	control	4	143	61.48
South MZ Ranch	wet meadow	control	4	165	66.43
South MZ Ranch	wet meadow	cattle	1	7	---
South MZ Ranch	wet meadow	cattle	1	14	---
South MZ Ranch	wet meadow	cattle	1	21	---
South MZ Ranch	wet meadow	cattle	1	35	---
South MZ Ranch	wet meadow	cattle	1	49	---
South MZ Ranch	wet meadow	cattle	1	70	---
South MZ Ranch	wet meadow	cattle	1	90	---
South MZ Ranch	wet meadow	cattle	1	117	---
South MZ Ranch	wet meadow	cattle	1	143	---
South MZ Ranch	wet meadow	cattle	1	165	---
South MZ Ranch	wet meadow	cattle	2	7	---
South MZ Ranch	wet meadow	cattle	2	14	---
South MZ Ranch	wet meadow	cattle	2	21	---

Appendix D. Table D-2. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	N_t
South MZ Ranch	wet meadow	cattle	2	35	---
South MZ Ranch	wet meadow	cattle	2	49	---
South MZ Ranch	wet meadow	cattle	2	70	---
South MZ Ranch	wet meadow	cattle	2	90	---
South MZ Ranch	wet meadow	cattle	2	117	---
South MZ Ranch	wet meadow	cattle	2	143	---
South MZ Ranch	wet meadow	cattle	2	165	---
South MZ Ranch	wet meadow	cattle	3	7	5.89
South MZ Ranch	wet meadow	cattle	3	14	11.73
South MZ Ranch	wet meadow	cattle	3	21	17.51
South MZ Ranch	wet meadow	cattle	3	35	28.90
South MZ Ranch	wet meadow	cattle	3	49	40.07
South MZ Ranch	wet meadow	cattle	3	70	56.42
South MZ Ranch	wet meadow	cattle	3	90	71.56
South MZ Ranch	wet meadow	cattle	3	117	91.34
South MZ Ranch	wet meadow	cattle	3	143	109.70
South MZ Ranch	wet meadow	cattle	3	165	124.72
South MZ Ranch	wet meadow	cattle	4	7	7.94
South MZ Ranch	wet meadow	cattle	4	14	15.75
South MZ Ranch	wet meadow	cattle	4	21	23.45
South MZ Ranch	wet meadow	cattle	4	35	38.48
South MZ Ranch	wet meadow	cattle	4	49	53.06
South MZ Ranch	wet meadow	cattle	4	70	74.08
South MZ Ranch	wet meadow	cattle	4	90	93.22
South MZ Ranch	wet meadow	cattle	4	117	117.73
South MZ Ranch	wet meadow	cattle	4	143	139.99
South MZ Ranch	wet meadow	cattle	4	165	157.84
West MZ Ranch	wet meadow	control	1	7	4.43
West MZ Ranch	wet meadow	control	1	14	8.56
West MZ Ranch	wet meadow	control	1	21	12.43
West MZ Ranch	wet meadow	control	1	35	19.44
West MZ Ranch	wet meadow	control	1	49	25.56
West MZ Ranch	wet meadow	control	1	70	33.33
West MZ Ranch	wet meadow	control	1	90	39.40
West MZ Ranch	wet meadow	control	1	117	45.96
West MZ Ranch	wet meadow	control	1	143	50.86
West MZ Ranch	wet meadow	control	1	165	54.14
West MZ Ranch	wet meadow	control	2	7	3.24
West MZ Ranch	wet meadow	control	2	14	6.36
West MZ Ranch	wet meadow	control	2	21	9.36
West MZ Ranch	wet meadow	control	2	35	15.02
West MZ Ranch	wet meadow	control	2	49	20.26
West MZ Ranch	wet meadow	control	2	70	27.41
West MZ Ranch	wet meadow	control	2	90	33.49
West MZ Ranch	wet meadow	control	2	117	40.70
West MZ Ranch	wet meadow	control	2	143	46.71
West MZ Ranch	wet meadow	control	2	165	51.16
West MZ Ranch	wet meadow	control	3	7	2.85
West MZ Ranch	wet meadow	control	3	14	5.58
West MZ Ranch	wet meadow	control	3	21	8.20
West MZ Ranch	wet meadow	control	3	35	13.14
West MZ Ranch	wet meadow	control	3	49	17.69
West MZ Ranch	wet meadow	control	3	70	23.85
West MZ Ranch	wet meadow	control	3	90	29.06

Appendix D. Table D-2. Continued.

Site	Wetland type	Grazing treatment	Replicate	Day of incubation	N_t
West MZ Ranch	wet meadow	control	3	117	35.19
West MZ Ranch	wet meadow	control	3	143	40.25
West MZ Ranch	wet meadow	control	3	165	43.97
West MZ Ranch	wet meadow	control	4	7	2.33
West MZ Ranch	wet meadow	control	4	14	4.62
West MZ Ranch	wet meadow	control	4	21	6.88
West MZ Ranch	wet meadow	control	4	35	11.31
West MZ Ranch	wet meadow	control	4	49	15.62
West MZ Ranch	wet meadow	control	4	70	21.85
West MZ Ranch	wet meadow	control	4	90	27.54
West MZ Ranch	wet meadow	control	4	117	34.86
West MZ Ranch	wet meadow	control	4	143	41.55
West MZ Ranch	wet meadow	control	4	165	46.93
West MZ Ranch	wet meadow	cattle	1	7	3.71
West MZ Ranch	wet meadow	cattle	1	14	7.29
West MZ Ranch	wet meadow	cattle	1	21	10.74
West MZ Ranch	wet meadow	cattle	1	35	17.30
West MZ Ranch	wet meadow	cattle	1	49	23.41
West MZ Ranch	wet meadow	cattle	1	70	31.79
West MZ Ranch	wet meadow	cattle	1	90	38.99
West MZ Ranch	wet meadow	cattle	1	117	47.63
West MZ Ranch	wet meadow	cattle	1	143	54.90
West MZ Ranch	wet meadow	cattle	1	165	60.35
West MZ Ranch	wet meadow	cattle	2	7	3.60
West MZ Ranch	wet meadow	cattle	2	14	7.13
West MZ Ranch	wet meadow	cattle	2	21	10.60
West MZ Ranch	wet meadow	cattle	2	35	17.35
West MZ Ranch	wet meadow	cattle	2	49	23.86
West MZ Ranch	wet meadow	cattle	2	70	33.19
West MZ Ranch	wet meadow	cattle	2	90	41.61
West MZ Ranch	wet meadow	cattle	2	117	52.31
West MZ Ranch	wet meadow	cattle	2	143	61.93
West MZ Ranch	wet meadow	cattle	2	165	69.57
West MZ Ranch	wet meadow	cattle	3	7	5.46
West MZ Ranch	wet meadow	cattle	3	14	10.51
West MZ Ranch	wet meadow	cattle	3	21	15.16
West MZ Ranch	wet meadow	cattle	3	35	23.44
West MZ Ranch	wet meadow	cattle	3	49	30.49
West MZ Ranch	wet meadow	cattle	3	70	39.18
West MZ Ranch	wet meadow	cattle	3	90	45.73
West MZ Ranch	wet meadow	cattle	3	117	52.52
West MZ Ranch	wet meadow	cattle	3	143	57.35
West MZ Ranch	wet meadow	cattle	3	165	60.45
West MZ Ranch	wet meadow	cattle	4	7	2.91
West MZ Ranch	wet meadow	cattle	4	14	5.73
West MZ Ranch	wet meadow	cattle	4	21	8.47
West MZ Ranch	wet meadow	cattle	4	35	13.70
West MZ Ranch	wet meadow	cattle	4	49	18.62
West MZ Ranch	wet meadow	cattle	4	70	25.48
West MZ Ranch	wet meadow	cattle	4	90	31.45
West MZ Ranch	wet meadow	cattle	4	117	38.74
West MZ Ranch	wet meadow	cattle	4	143	45.00
West MZ Ranch	wet meadow	cattle	4	165	49.77

Appendix E. N mineralization parameters for soils from Great Sand Dunes riparian corridors and wet meadows estimated with the mixed-order model. Nt = cumulative N mineralized at time t (mg N g^{-1} soil N), t = 24 weeks, for N mineralized during the incubation period, Nl = potentially mineralizable labile N (mg N g^{-1} soil N), h = mineralization rate constant of the labile N pool ($week^{-1}$), c = mineralization rate constant for recalcitrant N pool (mg N g^{-1} soil N $week^{-1}$). Models which did not converge, did not produce parameter estimates.

Site	Wetland type	Grazing treatment	Replicate	N_t	N_l	h	c
Big Spring Creek	riparian	control	1	---	---	---	---
Big Spring Creek	riparian	control	2	30.00	9.05	0.099	0.127
Big Spring Creek	riparian	control	3	60.54	4.66	0.163	0.339
Big Spring Creek	riparian	control	4	39.00	12.97	0.042	0.158
Big Spring Creek	riparian	bison	1	63.85	19.24	0.091	0.270
Big Spring Creek	riparian	bison	2	73.24	30.56	0.098	0.259
Big Spring Creek	riparian	bison	3	---	---	---	---
Big Spring Creek	riparian	bison	4	38.87	30.36	0.014	0.071
Little Spring Creek	riparian	control	1	42.48	5.20	0.283	0.226
Little Spring Creek	riparian	control	2	52.54	4.58	0.185	0.291
Little Spring Creek	riparian	control	3	48.15	7.23	0.123	0.248
Little Spring Creek	riparian	control	4	65.47	21.24	0.120	0.268
Little Spring Creek	riparian	bison	1	50.17	22.07	0.029	0.172
Little Spring Creek	riparian	bison	2	59.30	3.56	0.126	0.338
Little Spring Creek	riparian	bison	3	62.09	21.48	0.046	0.246
Little Spring Creek	riparian	bison	4	53.82	25.55	0.048	0.171
Elk Springs	wet meadow	control	1	72.25	31.25	0.034	0.249
Elk Springs	wet meadow	control	2	64.58	118.32	0.007	---
Elk Springs	wet meadow	control	3	80.29	27.56	0.126	0.320
Elk Springs	wet meadow	control	4	68.12	10.01	0.051	0.352
Elk Springs	wet meadow	bison	1	82.19	18.54	0.032	0.386
Elk Springs	wet meadow	bison	2	97.81	19.89	0.040	0.472
Elk Springs	wet meadow	bison	3	82.49	63.45	0.013	0.158
Elk Springs	wet meadow	bison	4	90.90	6.98	1.033	0.509
Twin Lakes	wet meadow	control	1	77.70	4.89	0.190	0.441
Twin Lakes	wet meadow	control	2	62.66	8.62	0.045	0.328
Twin Lakes	wet meadow	control	3	70.28	6.84	0.376	0.385
Twin Lakes	wet meadow	control	4	67.21	3.06	2.444	0.389
Twin Lakes	wet meadow	bison	1	53.06	4.63	1.176	0.294
Twin Lakes	wet meadow	bison	2	60.00	4.71	1.105	0.335
Twin Lakes	wet meadow	bison	3	65.54	13.05	0.027	0.319
Twin Lakes	wet meadow	bison	4	56.86	0.42	1.038	0.342
South MZ Ranch	wet meadow	control	1	82.15	104.28	0.010	---
South MZ Ranch	wet meadow	control	2	---	---	---	---
South MZ Ranch	wet meadow	control	3	81.31	35.49	0.014	0.300
South MZ Ranch	wet meadow	control	4	68.25	16.27	0.036	0.315
South MZ Ranch	wet meadow	cattle	1	---	---	---	---
South MZ Ranch	wet meadow	cattle	2	---	---	---	---
South MZ Ranch	wet meadow	cattle	3	127.29	0.83	0.964	0.766
South MZ Ranch	wet meadow	cattle	4	---	---	---	---
West MZ Ranch	wet meadow	control	1	56.30	15.23	0.046	0.249
West MZ Ranch	wet meadow	control	2	52.63	7.23	0.072	0.275
West MZ Ranch	wet meadow	control	3	45.07	7.31	0.061	0.229
West MZ Ranch	wet meadow	control	4	47.12	2.96	0.994	0.268
West MZ Ranch	wet meadow	cattle	1	---	---	---	---
West MZ Ranch	wet meadow	cattle	2	72.80	3.03	3.050	0.423
West MZ Ranch	wet meadow	cattle	3	---	---	---	---
West MZ Ranch	wet meadow	cattle	4	51.27	4.43	0.171	0.284

Appendix F. Properties of soils from Great Sand Dunes riparian corridors and wet meadows

Site	Wetland type	Grazing treatment	Replicate	Soil C (%)	Soil N (%)	Soil C:N ratio	Soil organic matter (%)	Sand (%)	Clay (%)	Silt (%)
Big Spring Creek	riparian	control	1	2.33	0.14	16.85	4.56	84	6	9
Big Spring Creek	riparian	control	2	1.40	0.11	13.22	3.89	84	6	9
Big Spring Creek	riparian	control	3	1.04	0.09	11.14	3.01	84	6	9
Big Spring Creek	riparian	control	4	1.71	0.13	12.74	4.56	84	6	9
Big Spring Creek	riparian	bison	1	1.70	0.12	14.32	3.88	84	10	6
Big Spring Creek	riparian	bison	2	1.75	0.13	13.29	4.63	84	10	6
Big Spring Creek	riparian	bison	3	1.30	0.11	12.12	3.69	84	10	6
Big Spring Creek	riparian	bison	4	3.86	0.30	12.87	9.65	84	10	6
Little Spring Creek	riparian	control	1	3.36	0.25	13.64	8.19	78	13	10
Little Spring Creek	riparian	control	2	3.67	0.27	13.45	9.33	78	13	10
Little Spring Creek	riparian	control	3	3.42	0.27	12.82	9.28	78	13	10
Little Spring Creek	riparian	control	4	4.04	0.31	13.05	8.98	78	13	10
Little Spring Creek	riparian	bison	1	1.40	0.11	12.93	3.66	84	6	9
Little Spring Creek	riparian	bison	2	1.79	0.15	12.36	4.78	84	6	9
Little Spring Creek	riparian	bison	3	3.48	0.29	12.00	8.07	84	6	9
Little Spring Creek	riparian	bison	4	2.72	0.21	12.78	6.52	84	6	9
Elk Springs	wet meadow	control	1	0.91	0.08	10.90	2.77	89	6	5
Elk Springs	wet meadow	control	2	0.63	0.07	9.01	2.22	89	6	5
Elk Springs	wet meadow	control	3	1.14	0.11	10.23	3.27	89	6	5
Elk Springs	wet meadow	control	4	0.64	0.07	9.86	1.97	89	6	5
Elk Springs	wet meadow	bison	1	1.16	0.11	10.44	4.08	84	6	10
Elk Springs	wet meadow	bison	2	1.01	0.09	11.14	3.56	84	6	10
Elk Springs	wet meadow	bison	3	1.75	0.17	10.26	4.87	84	6	10
Elk Springs	wet meadow	bison	4	1.34	0.12	11.33	3.96	84	6	10
Twin Lakes	wet meadow	control	1	4.56	0.32	14.21	8.91	58	16	26
Twin Lakes	wet meadow	control	2	5.68	0.42	13.43	10.69	58	16	26
Twin Lakes	wet meadow	control	3	4.22	0.43	9.87	10.75	58	16	26
Twin Lakes	wet meadow	control	4	3.36	0.35	9.72	8.74	58	16	26
Twin Lakes	wet meadow	bison	1	5.10	0.52	9.87	12.54	46	19	35
Twin Lakes	wet meadow	bison	2	4.38	0.39	11.37	9.80	46	19	35
Twin Lakes	wet meadow	bison	3	6.63	0.61	10.89	14.30	46	19	35
Twin Lakes	wet meadow	bison	4	5.79	0.58	9.92	13.23	46	19	35

Appendix F. Properties of soils from Great Sand Dunes riparian corridors and wet meadows.

Appendix F. Continued.

Site	Wetland type	Grazing treatment	Replicate	Soil C (%)	Soil N (%)	Soil C:N ratio	Soil organic matter (%)	Sand (%)	Clay (%)	Silt (%)
South MZ Ranch	wet meadow	control	1	2.53	0.24	10.46	6.75	48	19	32
South MZ Ranch	wet meadow	control	2	2.19	0.21	10.53	5.69	48	19	32
South MZ Ranch	wet meadow	control	3	4.00	0.34	11.77	9.97	48	19	32
South MZ Ranch	wet meadow	control	4	2.64	0.26	10.31	7.09	48	19	32
South MZ Ranch	wet meadow	cattle	1	2.79	0.25	10.96	6.50	53	16	32
South MZ Ranch	wet meadow	cattle	2	3.18	0.28	11.35	8.03	53	16	32
South MZ Ranch	wet meadow	cattle	3	2.92	0.27	10.80	7.00	53	16	32
South MZ Ranch	wet meadow	cattle	4	6.82	0.58	11.68	15.19	53	16	32
West MZ Ranch	wet meadow	control	1	1.72	0.15	11.25	4.95	65	13	22
West MZ Ranch	wet meadow	control	2	1.07	0.11	9.61	3.51	65	13	22
West MZ Ranch	wet meadow	control	3	1.05	0.11	10.03	3.17	65	13	22
West MZ Ranch	wet meadow	control	4	1.88	0.15	12.96	4.50	65	13	22
West MZ Ranch	wet meadow	cattle	1	2.64	0.27	9.80	6.70	59	16	25
West MZ Ranch	wet meadow	cattle	2	2.11	0.20	10.82	5.87	59	16	25
West MZ Ranch	wet meadow	cattle	3	2.79	0.26	10.56	7.78	59	16	25
West MZ Ranch	wet meadow	cattle	4	2.34	0.22	10.49	5.93	59	16	25

Appendix G. Statistical analyses of Great Sand Dunes riparian corridors and wet meadows soil N mineralization parameters and soil properties.

Table G-1a. Analysis of variance (ANOVA) of community type, grazing treatment (Trt), and day of incubation (Day) effects on cumulative N mineralization (N_t) estimated with the first-order model. Community types were bison-riparian, bison-wet meadow, and cattle-wet meadow. Sites were 2 study locations in each community type. Treatments were grazed and control. Rep were 2 analytical replicates for each incubated soil sample. Data were log-transformed and significant differences were accepted at $P < 0.05$.

Covariance Parameter Estimates

Covariance Parameter	Subject	Estimate
Site(Community Type)		0.08
Site*Trt(Community Type)		0
Rep(Site*Community Type*Trt)		0
Site*Day(Community Type)		0
Site*Trt*Day(Community Type)		0
SP(POW)[1]	Rep(Site*Community Type*Trt)	0.9996
Residual		0.06

[1]SP(POW) is power function correction for repeated measures (Day) with subject = Rep(Site*Community Type*Trt)

Type III Tests of Fixed Effects

Effect	Numerator DF	Denominator DF	*F*-value	*P*-value
Community Type	2	3	0.43	0.68
Trt	1	3	4.71	0.12
Community Type*Trt	2	3	1.73	0.32
Day	9	27	10248.2	<.0001
Community Type*Day	18	27	4.81	0.0001
Trt*Day	9	27	0.18	1.00
Community Type*Trt*Day	18	27	2.77	0.008

Appendix G. Continued.

Table G-1b. Differences of least square means in cumulative N mineralization (N_t) for Community Type*Treatment*Day interaction in Table G-1a. Differences were compared between grazing treatments at each community type over the course of the incubation period at $P < 0.05$, P-diff = difference between log-transformed least square means.

Day	Grazing treatment		*P*-diff	DF	*t*-value	*P*-value
Bison effects in riparian zones						
7	control	grazed	-0.39	27	-3.10	0.01
14	control	grazed	-0.37	27	-2.98	0.01
21	control	grazed	-0.36	27	-2.87	0.01
35	control	grazed	-0.33	27	-2.66	0.01
49	control	grazed	-0.31	27	-2.47	0.02
70	control	grazed	-0.27	27	-2.19	0.04
90	control	grazed	-0.24	27	-1.96	0.06
117	control	grazed	-0.21	27	-1.68	0.11
143	control	grazed	-0.18	27	-1.44	0.16
165	control	grazed	-0.16	27	-1.26	0.22
Bison effects in wet meadows						
7	control	grazed	0.11	27	0.84	0.41
14	control	grazed	0.10	27	0.74	0.47
21	control	grazed	0.09	27	0.66	0.51
35	control	grazed	0.07	27	0.52	0.61
49	control	grazed	0.05	27	0.38	0.71
70	control	grazed	0.02	27	0.18	0.86
90	control	grazed	0.00	27	0.02	0.99
117	control	grazed	-0.02	27	-0.19	0.85
143	control	grazed	-0.05	27	-0.36	0.72
165	control	grazed	-0.06	27	-0.49	0.63
Cattle effects in wet meadows						
7	control	grazed	-0.16	27	-1.20	0.24
14	control	grazed	-0.17	27	-1.26	0.22
21	control	grazed	-0.18	27	-1.32	0.20
35	control	grazed	-0.19	27	-1.43	0.16
49	control	grazed	-0.21	27	-1.54	0.13
70	control	grazed	-0.23	27	-1.70	0.10
90	control	grazed	-0.25	27	-1.85	0.07
117	control	grazed	-0.28	27	-2.05	0.05
143	control	grazed	-0.30	27	-2.22	0.03
165	control	grazed	-0.32	27	-2.37	0.03
Bison vs. cattle effects in wet meadows						
7	grazed	grazed	-0.15	27	-0.47	0.64
14	grazed	grazed	-0.15	27	-0.48	0.64
21	grazed	grazed	-0.15	27	-0.49	0.63
35	grazed	grazed	-0.16	27	-0.50	0.62
49	grazed	grazed	-0.16	27	-0.51	0.61
70	grazed	grazed	-0.17	27	-0.53	0.60
90	grazed	grazed	-0.17	27	-0.55	0.58
117	grazed	grazed	-0.18	27	-0.58	0.57
143	grazed	grazed	-0.19	27	-0.60	0.55
165	grazed	grazed	-0.20	27	-0.62	0.54

Appendix G. Continued.

Table G-2a. Analysis of variance (ANOVA) of community type, and grazing treatment (Trt) effects on potentially mineralizable (N_o) estimated with the first-order model. Community types were bison-riparian, bison-wet meadow, and cattle-wet meadow. Sites were 2 study locations in each community type. Treatments were grazed and control. Significant differences were accepted at P-value < 0.05.

Covariance Parameter Estimates

Covariance Parameter	Estimate
Site(Community Type)	1127
Site*Trt(Community Type)	14699
Residual	2231

Type III Tests of Fixed Effects

Effect	Numerator DF	Denominator DF	F-value	P-value
Community Type	2	3	1.24	0.40
Trt	1	3	1.38	0.32
Community Type*Trt	2	3	1.04	0.45

Table G-2b. Differences of least square means in potentially mineralizable (N_o) for Community Type*Trt interactionin Table G-2a. Comparisons were made between grazing treatments at each community type over the course of the incubation period at $P < 0.05$, P-diff = difference between least square means.

Effect	Grazing treatment		P-diff	DF	t-value	P-value
Bison effects in riparian zones	control	grazed	0.67	3	0.01	1.00
Bison effects in wet meadows	control	grazed	-23.19	3	-0.19	0.86
Cattle effects in wet meadows	control	grazed	-229.59	3	-1.85	0.16
Bison vs. cattle effects in wet meadows	grazed	grazed	-190.75	3	-1.48	0.23

Appendix G. Continued.

Table G-3a. Analysis of variance (ANOVA) of community wetland type and grazing treatment (Trt) effects on mineralization constant (k) estimated with the first-order model. Community types were bison-riparian, bison-wet meadow, and cattle-wet meadow. Sites were 2 study locations in each community type. Treatments were grazed and control. Significant differences were accepted at P-value < 0.05.

Covariance Parameter Estimates

Covariance Parameter	Estimate
Site(Community Type)	0.0000024
Site*Trt(Community Type)	0
Residual	0.000022

Type III Tests of Fixed Effects

Effect	Numerator DF	Denominator DF	F-value	P-value
Community Type	2	3	2.80	0.21
Trt	1	3	0.10	0.78
Community Type*Trt	2	3	2.90	0.20

Table G-3b. Differences of least square means in mineralization rate constat (k) for Community Type*Trt interaction in Table G-3a. Comparisons were made between grazing treatments at each community type over the course of the incubation period at P < 0.05, P-diff = difference between least square means.

Effect	Grazing treatment		P-diff	DF	t-value	P-value
Bison effects in riparian zones	control	grazed	-0.004	3	-1.80	0.17
Bison effects in wet meadows	control	grazed	0.003	3	1.32	0.28
Cattle effects in wet meadows	control	grazed	0.002	3	0.92	0.43
Bison vs. cattle effects in wet meadows	grazed	grazed	0.0005	3	0.16	0.89

Appendix G. Continued.

Table G-4a. Analysis of variance (ANOVA) of community type and grazing treatment (Trt) effects on net N mineralized by the end of the 24 week incubation period. Community types were bison-riparian, bison-wet meadow, and cattle-wet meadow. Sites were 2 study locations in each community type. Treatments were grazed and control. Significant differences were accepted at P-value < 0.05.

Covariance Parameter Estimates

Covariance Parameter	**Estimate**
Site(Community Type)	448
Site*Trt(Community Type)	233
Residual	101

Type III Tests of Fixed Effects

Effect	**Numerator DF**	**Denominator DF**	***F*-value**	***P*-value**
Community Type	2	3	0.82	0.52
Trt	1	3	2.26	0.23
Community Type*Trt	2	3	0.66	0.58

Table G-4b. Differences of least square means in net N mineralized at the end of the incubation period (Wetland Type*Trt interaction in Table G-4a). Comparisons were made between grazing treatments at each wetland type over the course of the incubation period at $P < 0.05$, P-diff = difference between least square means.

Effect	**Graziug treatment**		***P*-diff**	**DF**	***t*-value**	***P*-value**
Bison effects in riparian zones	control	grazed	-7.34	3	-0.46	0.68
Bison effects in wet meadows	control	grazed	-5.52	3	-0.34	0.75
Cattle effects in wet meadows	control	grazed	-33.94	3	-2.19	0.12
Bison vs. cattle effects in wet meadows	grazed	grazed	-26.84	3	-1.01	0.39

Appendix G. Continued.

Table G-5a. Analysis of variance (ANOVA) of community type and grazing treatment (Trt) effects on soil properties. Community types were bison-riparian, bison-wet meadow, and cattle-wet meadow. Sites were 2 study locations in each community type. Treatments were grazed and control. Soil C, N, and organic matter data were log-transformed and significant differences were accepted at *P*-value < 0.05.

Covariance Parameter Estimates		Type III Tests of Fixed Effects				
Covariance Parameter	**Estimate**	**Effect**	**Numerator DF**	**Denominator DF**	***F*-value**	***P*-value**
Soil Carbon (%)						
Site(Community Type)	0.47	Community Type	2	3	0.01	0.99
Site*Trt(Community Type)	0.03	Trt	1	3	2.37	0.22
Residual	0.09	Community Type*Trt	2	3	1.55	0.34
Soil Nitrogen (%)						
Site(Community Type)	0.44	Community Type	2	3	0.09	0.92
Site*Trt(Community Type)	0.03	Trt	1	3	3.01	0.18
Residual	0.07	Community Type*Trt	2	3	1.50	0.35
Soil C:N ratio						
Site(Community Type)	0	Community Type	2	3	18.88	0.02
Site*Trt(Community Type)	0.02	Trt	1	3	0.63	0.48
Residual	1.41	Community Type*Trt	2	3	0.15	0.87
Soil Organic Matter (%)						
Site(Community Type)	0.29	Community Type	2	3	0.02	0.98
Site*Trt(Community Type)	0.04	Trt	1	3	1.96	0.26
Residual	0.06	Community Type*Trt	2	3	1.29	0.39
Sand (%)						
Site(Community Type)	225	Community Type	2	3	1.41	0.37
Site*Trt(Community Type)	13.52	Trt	1	3	0.72	0.46
Residual	1	Community Type*Trt	2	3	2.57	0.22
Clay (%)						
Site(Community Type)	18.37	Community Type	2	3	1.13	0.43
Site*Trt(Community Type)	8.09	Trt	1	3	0.01	0.92
Residual	1	Community Type*Trt	2	3	0.76	0.54
Silt (%)						
Site(Community Type)	106	Community Type	2	3	1.56	0.34
Site*Trt(Community Type)	5.73	Trt	1	3	1.90	0.26
Residual	1	Community Type*Trt	2	3	2.04	0.28

Appendix G. Continued.

Table G-5b. Differences in least square means of soil properties in Great Sand Dunes riparian corridors and wet meadows. Comparisons were made between community types averaged over grazing treatment (i.e., significant Community Type effect in Table G-5b) at $P < 0.05$, P-diff = difference between least square means. Soil C, N, and organic matter data were. Bison-wet meadows were Elk Springs and Twin Lakes sites, bison-riparian were Big and Little Spring Creek sites, cattle-wet meadows were South and West MZ Ranch sites.

Soil property	Wetland type			P-diff	DF	t-value	P-value
Soil Carbon (%)							
	bison-wet meadow	vs.	bison-riparian	0.002	3	0.003	1.00
	bison-wet meadow	vs.	cattle-wet meadow	-0.08	3	-0.12	0.91
	bison-riparian	vs.	cattle-wet meadow	-0.09	3	-0.12	0.91
Soil Nitrogen (%)							
	bison-wet meadow	vs.	bison-riparian	0.20	3	0.29	0.79
	bison-wet meadow	vs.	cattle-wet meadow	-0.07	3	-0.11	0.92
	bison-riparian	vs.	cattle-wet meadow	-0.27	3	-0.40	0.72
Soil C:N ratio							
	bison-wet meadow	vs.	bison-riparian	-2.32	3	-5.39	0.01
	bison-wet meadow	vs.	cattle-wet meadow	-0.06	3	-0.13	0.90
	bison-riparian	vs.	cattle-wet meadow	2.26	3	5.25	0.01
Soil Organic Matter (%)							
	bison-wet meadow	vs.	bison-riparian	0.06	3	0.10	0.92
	bison-wet meadow	vs.	cattle-wet meadow	-0.07	3	-0.12	0.91
	bison-riparian	vs.	cattle-wet meadow	-0.13	3	-0.22	0.84
Sand (%)							
	bison-wet meadow	vs.	bison-riparian	-14.14	3	-0.93	0.42
	bison-wet meadow	vs.	cattle-wet meadow	11.41	3	0.75	0.51
	bison-riparian	vs.	cattle-wet meadow	25.54	3	1.68	0.19
Clay (%)							
	bison-wet meadow	vs.	bison-riparian	3.27	3	0.68	0.54
	bison-wet meadow	vs.	cattle-wet meadow	-3.91	3	-0.82	0.47
	bison-riparian	vs.	cattle-wet meadow	-7.19	3	-1.50	0.23
Silt (%)							
	bison-wet meadow	vs.	bison-riparian	10.86	3	1.04	0.37
	bison-wet meadow	vs.	cattle-wet meadow	-7.49	3	-0.72	0.53
	bison-riparian	vs.	cattle-wet meadow	-18.36	3	-1.76	0.18

Appendix G. Continued.

Table G-6. Linear regressions (analysis of variance with proc reg procedure) for estimation of N parameters: potentially mineralizable N (No), mineralization rate constant (k), and net N mineralized with soil properties (C, N, C:N, soil organic matter, sand, clay, silt).

Dependent variable: N_o

Source	DF	Sum of Squares	Mean Square Error	*F*-value	*P*-value	R^2
Model	1	46012	46012	4.23	0.05	0.09
Error	43	467935	10882			
Corrected Total	44	513946				

Independent variable: Soil C (%)

Variable	DF	Parameter Estimate	Standard Error	*t*-value	*P*-value
Intercept	1	71	31	2.29	0.03
Soil C	1	21	10	2.06	0.05

Dependent variable: N_o

Source	DF	Sum of Squares	Mean Square Error	*F*-value	*P*-value	R^2
Model	1	60186	60186	5.7	0.02	0.12
Error	43	453761	10553			
Corrected Total	44	513946				

Independent variable: Soil N (%)

Variable	DF	Parameter Estimate	Standard Error	*t*-value	*P*-value
Intercept	1	64	30	2.11	0.04
Soil N	1	274	115	2.39	0.02

Dependent variable: N_o

Source	DF	Sum of Squares	Mean Square Error	*F*-value	*P*-value	R^2
Model	1	16825	16825	1.46	0.23	0.03
Error	43	497121	11561			
Corrected Total	44	513946				

Independent variable: Soil C:N ratio

Variable	DF	Parameter Estimate	Standard Error	*t*-value	*P*-value
Intercept	1	267	118	2.26	0.03
C:N ratio	1	-12	10	-1.21	0.23

Appendix G. Table G-6. Continued.

Dependent variable: N_o

Source	DF	Sum of Squares	Mean Square Error	*F*-value	*P*-value	R^2
Model	1	48333	48333	4.46	0.04	0.09
Error	43	465614	10828			
Corrected Total	44	513946				

Independent variable: Soil Organic Matter (SOM %)

Variable	DF	Parameter Estimate	Standard Error	*t*-value	*P*-value
Intercept	1	58	35	1.65	0.11
SOM	1	1034	489	2.11	0.04

Dependent variable: N_o

Source	DF	Sum of Squares	Mean Square Error	*F*-value	*P*-value	R^2
Model	1	70603	70603	6.85	0.01	0.14
Error	43	443344	10310			
Corrected Total	44	513946				

Independent variable: Sand (%)

Variable	DF	Parameter Estimate	Standard Error	*t*-value	*P*-value
Intercept	1	312	73	4.29	0.0001
Sand	1	-3	1	-2.62	0.01

Dependent variable: N_o

Source	DF	Sum of Squares	Mean Square Error	*F*-value	*P*-value	R^2
Model	1	36879	36879	3.32	0.08	0.07
Error	43	477067	11095			
Corrected Total	44	513946				

Independent variable: Clay (%)

Variable	DF	Parameter Estimate	Standard Error	*t*-value	*P*-value
Intercept	1	55	42	1.33	0.19
Clay	1	6	3	1.82	0.08

Dependent variable: N_o

Source	DF	Sum of Squares	Mean Square Error	*F*-value	*P*-value	R^2
Model	1	85480	85480	8.58	0.01	0.17
Error	43	428466	9964			
Corrected Total	44	513946				

Independent variable: Silt (%)

Variable	DF	Parameter Estimate	Standard Error	*t*-value	*P*-value
Intercept	1	53	29	1.83	0.07
Silt	1	4	1	2.93	0.01

Appendix G. **Table G-6.** Continued.

Dependent variable: k

Source	DF	Sum of Squares	Mean Square Error	*F*-value	*P*-value	R^2
Model	1	0.0001	0.00010	3.65	0.06	0.08
Error	43	0.0011	0.00003			
Corrected Total	44	0.0012				

Independent variable: Soil C (%)

Variable	DF	Parameter Estimate	Standard Error	*t*-value	*P*-value
Intercept	1	0.0104	0.0015	6.81	<.0001
Soil C	1	-0.0010	0.0005	-1.91	0.06

Dependent variable: k

Source	DF	Sum of Squares	Mean Square Error	*F*-value	*P*-value	R^2
Model	1	0.0001	0.00013	5.05	0.03	0.11
Error	43	0.0011	0.00003			
Corrected Total	44	0.0012				

Independent variable: Soil N (%)

Variable	DF	Parameter Estimate	Standard Error	*t*-value	*P*-value
Intercept	1	0.0107	0.0015	7.23	<.0001
Soil N	1	-0.0127	0.0056	-2.25	0.03

Dependent variable: k

Source	DF	Sum of Squares	Mean Square Error	*F*-value	*P*-value	R^2
Model	1	0.00005	0.00005	1.71	0.20	0.04
Error	43	0.0012	0.00003			
Corrected Total	44	0.0012				

Independent variable: Soil C:N ratio

Variable	DF	Parameter Estimate	Standard Error	*t*-value	*P*-value
Intercept	1	0.0004	0.0058	0.07	0.95
C:N ratio	1	0.0006	0.0005	1.31	0.20

Appendix G. Table G-6. Continued.

Dependent variable: k

Source	DF	Sum of Squares	Mean Square Error	*F*-value	*P*-value	R^2
Model	1	0.0001	0.00011	4.15	0.05	0.09
Error	43	0.0011	0.00003			
Corrected Total	44	0.0012				

Independent variable: Soil Organic Matter (SOM %)

Variable	DF	Parameter Estimate	Standard Error	*t*-value	*P*-value
Intercept	1	0.0110	0.0017	6.34	<.0001
SOM	1	-0.0489	0.0240	-2.04	0.05

Dependent variable: k

Source	DF	Sum of Squares	Mean Square Error	*F*-value	*P*-value	R^2
Model	1	0.0003	0.00027	12.17	0.00	0.22
Error	43	0.0010	0.00002			
Corrected Total	44	0.0012				

Independent variable: Sand (%)

Variable	DF	Parameter Estimate	Standard Error	*t*-value	*P*-value
Intercept	1	-0.0037	0.0034	-1.09	0.28
Sand	1	0.0002	0.00005	3.49	0.001

Dependent variable: k

Source	DF	Sum of Squares	Mean Square Error	*F*-value	*P*-value	R^2
Model	1	0.0002	0.00019	8.03	0.01	0.16
Error	43	0.0010	0.00002			
Corrected Total	44	0.0012				

Independent variable: Clay (%)

Variable	DF	Parameter Estimate	Standard Error	*t*-value	*P*-value
Intercept	1	0.0129	0.0019	6.67	<.0001
Clay	1	-0.0004	0.0002	-2.83	0.007

Dependent variable: k

Source	DF	Sum of Squares	Mean Square Error	*F*-value	*P*-value	R^2
Model	1	0.0003	0.00029	13.61	0.00	0.24
Error	43	0.0009	0.00002			
Corrected Total	44	0.0012				

Independent variable: Silt (%)

Variable	DF	Parameter Estimate	Standard Error	*t*-value	*P*-value
Intercept	1	0.0121	0.0014	8.97	<.0001
Silt	1	-0.0002	0.0001	-3.69	0.001

Appendix G. Table G-6. Continued.

Dependent variable: net N mineralized

Source	DF	Sum of Squares	Mean Square Error	*F*-value	*P*-value	R^2
Model	1	0.04	0.04	0	0.99	0
Error	43	26968	627			
Corrected Total	44	26968				

Independent variable: Soil C (%)

Variable	DF	Parameter Estimate	Standard Error	*t*-value	*P*-value
Intercept	1	68	8	8.81	<.0001
Soil C	1	0	3	0.01	0.99

Dependent variable: net N mineralized

Source	DF	Sum of Squares	Mean Square Error	*F*-value	*P*-value	R^2
Model	1	76	76	0.12	0.73	0.003
Error	43	26892	625			
Corrected Total	44	26968				

Independent variable: Soil N (%)

Variable	DF	Parameter Estimate	Standard Error	*t*-value	*P*-value
Intercept	1	65	7	8.86	<.0001
Soil N	1	10	28	0.35	0.73

Dependent variable: net N mineralized

Source	DF	Sum of Squares	Mean Square Error	*F*-value	*P*-value	R^2
Model	1	2386	2386	4.17	0.05	0.09
Error	43	24582	572			
Corrected Total	44	26968				

Independent variable: Soil C:N ratio

Variable	DF	Parameter Estimate	Standard Error	*t*-value	*P*-value
Intercept	1	121	27	4.57	<.0001
C:N ratio	1	-5	2	-2.04	0.0472

Appendix G. Table G-6. Continued.

Dependent variable: net N mineralized

Source	DF	Sum of Squares	Mean Square Error	*F*-value	*P*-value	R^2
Model	1	4	4	0.01	0.94	0.001
Error	43	26964	627			
Corrected Total	44	26968				

Independent variable: Soil Organic Matter (SOM %)

Variable	DF	Parameter Estimate	Standard Error	*t*-value	*P*-value
Intercept	1	67	9	7.64	<.0001
SOM	1	10	122	0.08	0.94

Dependent variable: net N mineralized

Source	DF	Sum of Squares	Mean Square Error	*F*-value	*P*-value	R^2
Model	1	2563	2563	4.52	0.04	0.1
Error	43	24405	568			
Corrected Total	44	26968				

Independent variable: Sand (%)

Variable	DF	Parameter Estimate	Standard Error	*t*-value	*P*-value
Intercept	1	102	16	6.17	<.0001
Sand	1	-0.5	0.23	-2.12	0.04

Dependent variable: net N mineralized

Source	DF	Sum of Squares	Mean Square Error	*F*-value	*P*-value	R^2
Model	1	1272	1272	2.13	0.15	0.05
Error	43	25696	598			
Corrected Total	44	26968				

Independent variable: Clay (%)

Variable	DF	Parameter Estimate	Standard Error	*t*-value	*P*-value
Intercept	1	55	10	5.69	<.0001
Clay	1	1.1	0.74	1.46	0.15

Dependent variable: net N mineralized

Source	DF	Sum of Squares	Mean Square Error	*F*-value	*P*-value	R^2
Model	1	3139	3139	5.67	0.02	0.12
Error	43	23828	554			
Corrected Total	44	26968				

Independent variable: Silt (%)

Variable	DF	Parameter Estimate	Standard Error	*t*-value	*P*-value
Intercept	1	54	7	7.98	<.0001
Silt	1	0.8	0.32	2.38	0.02

APPENDIX

CHAPTER III

Appendix H. Aboveground Primary Production (APP) and cattle utilization measured at Sheep Creek in 2005 and 2006. Four plots were visually estimated for APP (biomass) and two of these plots were randomly selected and clipped to correct estimated weights in this double sampling procedure.

Block	Transect	Location	Plot	Grazing treatment	Year	Biomass ($g\ m^{-2}$)	Utilization (%)
1	1	Streambank	1*	grazed	2005	254	0
1	1	Streambank	2	grazed	2005	236	0
1	1	Streambank	3	grazed	2005	241	0
1	1	Streambank	4*	grazed	2005	261	0
1	1	Middle	1*	grazed	2005	118	0
1	1	Middle	2	grazed	2005	203	0
1	1	Middle	3*	grazed	2005	95	0
1	1	Middle	4	grazed	2005	186	0
1	1	Edge	1	grazed	2005	38	0
1	1	Edge	2	grazed	2005	48	0
1	1	Edge	3*	grazed	2005	87	0
1	1	Edge	4*	grazed	2005	76	0
1	2	Streambank	1*	excluded	2005	269	0
1	2	Streambank	2	excluded	2005	130	0
1	2	Streambank	3*	excluded	2005	322	0
1	2	Streambank	4	excluded	2005	288	0
1	2	Middle	1	excluded	2005	510	0
1	2	Middle	2	excluded	2005	380	0
1	2	Middle	3*	excluded	2005	457	0
1	2	Middle	4*	excluded	2005	100	0
1	2	Edge	1*	excluded	2005	155	0
1	2	Edge	2	excluded	2005	116	0
1	2	Edge	3*	excluded	2005	129	0
1	2	Edge	4	excluded	2005	111	0
2	3	Streambank	1	grazed	2005	292	50
2	3	Streambank	2*	grazed	2005	412	50
2	3	Streambank	3	grazed	2005	431	50
2	3	Streambank	4*	grazed	2005	303	50
2	3	Middle	1	grazed	2005	326	30
2	3	Middle	2	grazed	2005	339	30
2	3	Middle	3*	grazed	2005	303	30
2	3	Middle	4*	grazed	2005	355	30
2	3	Edge	1	grazed	2005	293	0
2	3	Edge	2*	grazed	2005	297	0
2	3	Edge	3*	grazed	2005	278	0
2	3	Edge	4	grazed	2005	374	0
2	4	Streambank	1	excluded	2005	141	0
2	4	Streambank	2	excluded	2005	191	0
2	4	Streambank	3*	excluded	2005	210	0
2	4	Streambank	4*	excluded	2005	115	0
2	4	Middle	1	excluded	2005	226	0
2	4	Middle	2	excluded	2005	123	0
2	4	Middle	3*	excluded	2005	202	0
2	4	Middle	4*	excluded	2005	172	0
2	4	Edge	1	excluded	2005	136	0
2	4	Edge	2*	excluded	2005	217	0
2	4	Edge	3	excluded	2005	191	0
2	4	Edge	4*	excluded	2005	129	0
3	5	Streambank	1*	grazed	2005	350	0

Appendix H. Continued.

Block	Transect	Location	Plot	Grazing treatment	Year	Biomass ($g\ m^{-2}$)	Utilization (%)
3	5	Streambank	2	grazed	2005	284	0
3	5	Streambank	3*	grazed	2005	276	0
3	5	Streambank	4	grazed	2005	311	0
3	5	Middle	1	grazed	2005	385	0
3	5	Middle	2*	grazed	2005	333	0
3	5	Middle	3*	grazed	2005	345	0
3	5	Middle	4	grazed	2005	406	0
3	5	Edge	1	grazed	2005	181	0
3	5	Edge	2	grazed	2005	313	0
3	5	Edge	3*	grazed	2005	164	0
3	5	Edge	4*	grazed	2005	302	0
3	6	Streambank	1*	excluded	2005	284	0
3	6	Streambank	2*	excluded	2005	283	0
3	6	Streambank	3	excluded	2005	268	0
3	6	Streambank	4	excluded	2005	282	0
3	6	Middle	1*	excluded	2005	269	0
3	6	Middle	2	excluded	2005	258	0
3	6	Middle	3	excluded	2005	235	0
3	6	Middle	4*	excluded	2005	265	0
3	6	Edge	1*	excluded	2005	180	0
3	6	Edge	2	excluded	2005	314	0
3	6	Edge	3	excluded	2005	211	0
3	6	Edge	4*	excluded	2005	216	0
1	1	Streambank	1*	grazed	2006	198	30
1	1	Streambank	2	grazed	2006	172	30
1	1	Streambank	3	grazed	2006	207	30
1	1	Streambank	4*	grazed	2006	172	30
1	1	Middle	1*	grazed	2006	133	0
1	1	Middle	2	grazed	2006	132	0
1	1	Middle	3	grazed	2006	46	0
1	1	Middle	4*	grazed	2006	54	0
1	1	Edge	1	grazed	2006	17	0
1	1	Edge	2	grazed	2006	30	0
1	1	Edge	3*	grazed	2006	112	0
1	1	Edge	4*	grazed	2006	35	0
1	2	Streambank	1*	excluded	2006	152	0
1	2	Streambank	2	excluded	2006	237	0
1	2	Streambank	3*	excluded	2006	183	0
1	2	Streambank	4	excluded	2006	221	0
1	2	Middle	1	excluded	2006	208	0
1	2	Middle	2	excluded	2006	250	0
1	2	Middle	3*	excluded	2006	262	0
1	2	Middle	4*	excluded	2006	178	0
1	2	Edge	1*	excluded	2006	7	0
1	2	Edge	2	excluded	2006	95	0
1	2	Edge	3*	excluded	2006	83	0
1	2	Edge	4	excluded	2006	55	0
2	3	Streambank	1	grazed	2006	127	65
2	3	Streambank	2	grazed	2006	226	65
2	3	Streambank	3*	grazed	2006	153	65
2	3	Streambank	4*	grazed	2006	211	65
2	3	Middle	1	grazed	2006	125	50
2	3	Middle	2	grazed	2006	95	50

Appendix H. Continued.

Block	Transect	Location	Plot	Grazing treatment	Year	Biomass ($g\ m^{-2}$)	Utilization (%)
2	3	Middle	3*	grazed	2006	139	50
2	3	Middle	4*	grazed	2006	159	50
2	3	Edge	1	grazed	2006	164	30
2	3	Edge	2*	grazed	2006	226	30
2	3	Edge	3*	grazed	2006	127	30
2	3	Edge	4	grazed	2006	215	30
2	4	Streambank	1	excluded	2006	142	0
2	4	Streambank	2	excluded	2006	198	0
2	4	Streambank	3*	excluded	2006	71	0
2	4	Streambank	4*	excluded	2006	209	0
2	4	Middle	1	excluded	2006	165	0
2	4	Middle	2	excluded	2006	211	0
2	4	Middle	3*	excluded	2006	159	0
2	4	Middle	4*	excluded	2006	72	0
2	4	Edge	1	excluded	2006	74	0
2	4	Edge	2*	excluded	2006	116	0
2	4	Edge	3	excluded	2006	97	0
2	4	Edge	4*	excluded	2006	116	0
3	5	Streambank	1*	grazed	2006	228	50
3	5	Streambank	2	grazed	2006	248	50
3	5	Streambank	3*	grazed	2006	260	50
3	5	Streambank	4	grazed	2006	225	50
3	5	Middle	1	grazed	2006	312	30
3	5	Middle	2*	grazed	2006	234	30
3	5	Middle	3*	grazed	2006	223	30
3	5	Middle	4	grazed	2006	181	30
3	5	Edge	1	grazed	2006	61	0
3	5	Edge	2	grazed	2006	202	0
3	5	Edge	3*	grazed	2006	163	0
3	5	Edge	4*	grazed	2006	72	0
3	6	Streambank	1*	excluded	2006	119	0
3	6	Streambank	2*	excluded	2006	199	0
3	6	Streambank	3	excluded	2006	107	0
3	6	Streambank	4	excluded	2006	159	0
3	6	Middle	1*	excluded	2006	251	0
3	6	Middle	2	excluded	2006	268	0
3	6	Middle	3*	excluded	2006	248	0
3	6	Middle	4	excluded	2006	257	0
3	6	Edge	1*	excluded	2006	56	0
3	6	Edge	2	excluded	2006	114	0
3	6	Edge	3	excluded	2006	55	0
3	6	Edge	4*	excluded	2006	211	0

Appendix I. Aboveground plant C and N pools measured at Sheep Creek in October 2005 and 2006. Aboveground plant C and N pools were calculated by multiplying plant %C and %N by APP of clipped plots.

Block	Transect	Location	Plot	Grazing treatment	Year	Plant C ($g\ C\ m^{-2}$)	Plant N ($g\ N\ m^{-2}$)
1	1	Streambank	1	grazed	2005	109	1.8
1	1	Streambank	4	grazed	2005	103	1.4
1	1	Middle	1	grazed	2005	50	0.7
1	1	Middle	3	grazed	2005	88	1.1
1	1	Edge	3	grazed	2005	20	0.3
1	1	Edge	4	grazed	2005	16	0.3
1	2	Streambank	1	excluded	2005	114	1.6
1	2	Streambank	3	excluded	2005	56	0.9
1	2	Middle	3	excluded	2005	215	3.4
1	2	Middle	4	excluded	2005	163	2.6
1	2	Edge	1	excluded	2005	67	0.8
1	2	Edge	3	excluded	2005	51	0.6
2	3	Streambank	2	grazed	2005	131	1.3
2	3	Streambank	4	grazed	2005	183	2.5
2	3	Middle	3	grazed	2005	149	2.5
2	3	Middle	4	grazed	2005	134	2.2
2	3	Edge	2	grazed	2005	157	2.3
2	3	Edge	3	grazed	2005	124	2.3
2	4	Streambank	3	excluded	2005	81	1.2
2	4	Streambank	4	excluded	2005	48	0.7
2	4	Middle	3	excluded	2005	100	1.4
2	4	Middle	4	excluded	2005	54	0.7
2	4	Edge	2	excluded	2005	85	1.2
2	4	Edge	4	excluded	2005	58	0.5
3	5	Streambank	1	grazed	2005	152	1.9
3	5	Streambank	3	grazed	2005	124	2.1
3	5	Middle	2	grazed	2005	178	2.5
3	5	Middle	3	grazed	2005	145	1.6
3	5	Edge	3	grazed	2005	129	1.8
3	5	Edge	4	grazed	2005	75	1.8
3	6	Streambank	1	excluded	2005	120	2.1
3	6	Streambank	2	excluded	2005	114	2.1
3	6	Middle	1	excluded	2005	102	1.9
3	6	Middle	4	excluded	2005	111	2.2
3	6	Edge	1	excluded	2005	80	1.4
3	6	Edge	4	excluded	2005	92	1.3
1	1	Streambank	1	grazed	2006	85	1.5
1	1	Streambank	4	grazed	2006	74	1.1
1	1	Middle	1	grazed	2006	56	1.0
1	1	Middle	4	grazed	2006	23	0.4
1	1	Edge	3	grazed	2006	48	0.8
1	1	Edge	4	grazed	2006	15	0.2
1	2	Streambank	1	excluded	2006	67	1.4
1	2	Streambank	3	excluded	2006	80	1.5
1	2	Middle	3	excluded	2006	114	2.3
1	2	Middle	4	excluded	2006	76	1.4
1	2	Edge	1	excluded	2006	3	0.1
1	2	Edge	3	excluded	2006	37	0.5

Appendix I. Continued.

Block	Transect	Location	Plot	Grazing treatment	Year	Plant C ($g\ C\ m^{-2}$)	Plant N ($g\ N\ m^{-2}$)
2	3	Streambank	3	grazed	2006	55	1.1
2	3	Streambank	4	grazed	2006	90	1.7
2	3	Middle	3	grazed	2006	54	1.3
2	3	Middle	4	grazed	2006	68	1.4
2	3	Edge	2	grazed	2006	53	1.1
2	3	Edge	3	grazed	2006	91	2.0
2	4	Streambank	3	excluded	2006	60	1.2
2	4	Streambank	4	excluded	2006	30	0.7
2	4	Middle	3	excluded	2006	68	1.5
2	4	Middle	4	excluded	2006	31	0.7
2	4	Edge	2	excluded	2006	33	0.5
2	4	Edge	4	excluded	2006	43	0.6
3	5	Streambank	1	grazed	2006	97	2.2
3	5	Streambank	3	grazed	2006	95	2.2
3	5	Middle	2	grazed	2006	135	3.3
3	5	Middle	3	grazed	2006	76	1.9
3	5	Edge	3	grazed	2006	68	1.4
3	5	Edge	4	grazed	2006	29	0.6
3	6	Streambank	1	excluded	2006	52	0.7
3	6	Streambank	2	excluded	2006	47	0.7
3	6	Middle	1	excluded	2006	110	1.9
3	6	Middle	3	excluded	2006	111	1.9
3	6	Edge	1	excluded	2006	24	0.5
3	6	Edge	4	excluded	2006	24	0.5

Appendix J. Root C and N pools measured at Sheep Creek during the 2006 growing season. Root C and N pools were calculated by multiplying %C and %N of roots from composite soil cores (from each location) by soil bulk densities of each location.

Block	Transect	Location	Grazing treatment	Month	Root C ($g\ C\ m^{-2}$)	Root N ($g\ N\ m^{-2}$)
1	1	Streambank	grazed	June	330	5.4
1	1	Middle	grazed	June	375	6.4
1	1	Edge	grazed	June	111	1.5
1	2	Streambank	excluded	June	210	4.1
1	2	Middle	excluded	June	84	1.7
1	2	Edge	excluded	June	15	0.3
2	3	Streambank	grazed	June	192	3.4
2	3	Middle	grazed	June	142	3.7
2	3	Edge	grazed	June	369	8.7
2	4	Streambank	excluded	June	214	3.3
2	4	Middle	excluded	June	513	8.7
2	4	Edge	excluded	June	355	6.8
3	5	Streambank	grazed	June	305	7.3
3	5	Middle	grazed	June	148	3.1
3	5	Edge	grazed	June	185	4.0
3	6	Streambank	excluded	June	522	9.8
3	6	Middle	excluded	June	91	1.7
3	6	Edge	excluded	June	199	3.3
1	1	Streambank	grazed	August	325	4.8
1	1	Middle	grazed	August	368	5.6
1	1	Edge	grazed	August	110	1.6
1	2	Streambank	excluded	August	210	3.5
1	2	Middle	excluded	August	85	1.4
1	2	Edge	excluded	August	15	0.2
2	3	Streambank	grazed	August	192	3.5
2	3	Middle	grazed	August	143	3.4
2	3	Edge	grazed	August	362	7.3
2	4	Streambank	excluded	August	212	3.1
2	4	Middle	excluded	August	511	9.0
2	4	Edge	excluded	August	357	8.0
3	5	Streambank	grazed	August	268	5.8
3	5	Middle	grazed	August	149	2.9
3	5	Edge	grazed	August	188	3.8
3	6	Streambank	excluded	August	528	8.2
3	6	Middle	excluded	August	90	1.4
3	6	Edge	excluded	August	197	2.9
1	1	Streambank	grazed	October	322	4.6
1	1	Middle	grazed	October	373	6.7
1	1	Edge	grazed	October	108	1.7
1	2	Streambank	excluded	October	212	3.8
1	2	Middle	excluded	October	85	1.4
1	2	Edge	excluded	October	16	0.3
2	3	Streambank	grazed	October	192	3.5
2	3	Middle	grazed	October	142	2.7
2	3	Edge	grazed	October	362	7.7
2	4	Streambank	excluded	October	210	4.4
2	4	Middle	excluded	October	512	7.4
2	4	Edge	excluded	October	358	6.8

Appendix J. Continued.

Block	Transect	Location	Grazing treatment	Month	Root C ($g\ C\ m^{-2}$)	Root N ($g\ N\ m^{-2}$)
3	5	Streambank	grazed	October	309	6.9
3	5	Middle	grazed	October	148	2.9
3	5	Edge	grazed	October	185	3.9
3	6	Streambank	excluded	October	531	10.0
3	6	Middle	excluded	October	84	1.6
3	6	Edge	excluded	October	206	4.3

Appendix K. Species composition collected with a laser point frame at Sheep Creek in August 2005. Data are laser point hits on species collected at two of four plots within each location. Rare species (*) that occurred in three plots or fewer were removed from data analyses.

Transect	1	1	1	1	1	1	2	2	2
Location	Streambank	Streambank	Middle	Middle	Edge	Edge	Streambank	Streambank	Middle
Plot	1	4	1	3	3	4	1	3	3
Species									
Achillea millefolium	0	0	7	0	0	1	0	2	0
Agrostis stolonifera	24	41	1	0	2	5	58	6	0
*Antennaria rosea**	0	0	0	0	0	0	0	0	0
Arnica chamissonis	0	0	0	0	0	0	0	0	0
Astragalus alpinus	0	0	0	0	0	0	0	0	0
*Campanula parryi**	0	0	0	0	0	0	0	0	0
Carex aquatilis	46	48	29	0	0	2	11	2	123
Carex praticola	0	0	0	0	0	0	0	0	0
Carex urticulata	0	25	0	1	31	8	10	18	0
Cerastium arvense	0	0	5	4	0	1	1	0	0
Cerastrium strictum	0	0	0	0	0	0	0	0	0
Cirsium arvens	0	0	0	0	0	0	0	0	0
Cirsium sarsa	0	0	0	0	0	0	0	4	0
Danthonia intermedia	0	0	0	0	0	0	0	0	0
Dasiphora floribunda	0	0	1	0	0	0	0	0	0
Deschampsia caespitosa	0	0	0	0	0	0	0	0	0
*Dodecatheon pulchellum**	0	0	0	0	0	0	0	0	0
Epibbium ciliatum	0	0	0	0	0	0	0	0	0
Equesitum arvense	8	3	0	1	6	1	0	0	0
Erigeron formosissimus	17	1	9	3	2	2	0	0	0
Fragaria vesca	0	0	0	0	0	0	0	3	0
Fragaria virginiana	0	0	16	22	0	0	2	20	0
Galium boreale	2	1	0	0	0	0	0	0	0
*Gentianella acuta**	0	0	0	0	0	0	0	0	0
Geum aleppicum	0	2	0	0	0	0	0	1	0
Juncus arcticus	0	0	0	0	0	0	0	1	0
Juncus balticus	8	1	15	0	2	0	25	19	0
Ligusticum porteri	0	0	0	0	0	0	0	0	0
Machaeranthea canescens	0	0	0	0	0	0	0	0	0
Mentha arvensis	1	18	0	0	0	0	0	0	0

Appendix K. Continued.

Transect	1	1	1	1	1	1	2	2	2
Location	Streambank	Streambank	Middle	Middle	Edge	Edge	Streambank	Streambank	Middle
Plot	1	4	1	3	3	4	1	3	3
Species									
Moss	0	0	0	0	0	0	0	0	0
*Pascopyrum smithii**	0	0	0	0	4	0	0	0	0
Pedicularis groenlandica	0	0	0	0	0	0	0	0	0
Phleum alpinum	0	0	0	0	0	0	0	0	0
Phleum pratense	0	0	5	1	2	2	0	0	0
Plantago major	0	0	0	0	0	0	0	0	0
Poa pratensis	0	0	49	26	1	0	0	9	0
Populus tremuloides	0	0	0	0	0	0	0	0	0
Potentilla diversifolia	0	0	5	1	6	1	0	7	0
Potentilla pulcherrima	0	0	0	22	0	1	1	5	0
*Pseudocymopterus montanus**	0	0	0	0	0	0	0	0	0
*Pseudostellaria cerastrium**	0	0	0	0	0	0	0	0	0
Rumex paucifolius	0	0	0	0	0	0	0	0	0
*Rumex triangulivalvis**	0	0	0	0	0	0	0	0	3
*Salix geyerana**	0	6	0	0	0	0	0	0	0
Salix planifolia	15	0	0	0	0	0	0	0	0
*Solidago canadensis**	0	8	0	0	0	0	0	0	0
Stellaria longefolia	0	0	0	0	0	0	0	0	0
Taraxacum officinale	0	2	8	9	3	4	2	1	0
Thalictrum fendleri	0	0	0	0	0	0	0	0	0
Trifolium repens	0	0	0	14	0	7	0	0	0
Veronica americana	0	0	0	0	0	0	0	0	0
*Viola scopulorum**	0	4	0	0	0	0	0	0	0
Ground Hits	7	0	2	7	21	28	9	9	2
Number of Laser Positions	50	50	50	50	50	50	50	50	50

Appendix K. Continued.

Transect	2	2	2	3	3	3	3	3	3
Location	Middle	Edge	Edge	Streambank	Streambank	Middle	Middle	Edge	Edge
Plot	4	1	3	2	4	3	4	2	3
Species									
Achillea millefolium	0	0	3	17	27	16	17	5	15
Agrostis stolonifera	7	6	8	15	16	36	20	0	68
*Antennaria rosea**	0	0	0	0	0	0	0	0	0
Arnica chamissonis	0	0	0	0	0	0	0	2	11
Astragalus alpinus	0	0	0	0	0	0	0	0	0
*Campanula parryi**	0	0	0	0	0	0	0	0	0
Carex aquatilis	11	0	0	10	18	8	30	12	3
Carex praticola	0	0	0	0	0	0	0	0	0
Carex urticulata	9	15	5	7	1	3	1	3	2
Cerastium arvense	0	0	0	5	11	0	6	1	2
Cerastrium strictum	0	0	0	0	0	0	0	0	0
Cirsium arvens	0	0	0	7	10	0	0	0	0
Cirsium sarsa	0	0	0	0	3	0	0	1	0
Danthonia intermedia	0	0	0	0	0	0	0	0	0
Dasiphora floribunda	8	0	0	0	0	0	0	0	0
Deschampsia caespitosa	0	0	0	0	0	0	0	0	0
*Dodecatheon pulchellum**	0	0	0	0	0	0	0	0	0
Epibbium ciliatum	0	0	0	0	0	0	0	2	0
Equesitum arvense	1	11	9	1	3	0	0	1	0
Erigeron formosissimus	0	6	9	1	0	0	0	1	1
Fragaria vesca	0	0	0	0	0	0	0	0	0
Fragaria virginiana	2	3	15	0	2	0	0	0	0
Galium boreale	0	0	0	0	0	0	0	0	0
*Gentianella acuta**	0	0	0	0	0	0	0	0	0
Geum aleppicum	0	0	0	2	4	1	0	0	1
Juncus arcticus	0	0	0	0	0	19	30	25	9
Juncus balticus	0	0	3	0	5	4	0	3	0
Ligusticum porteri	0	0	0	0	0	0	0	0	0
Machaeranthea canescens	0	0	0	0	0	0	0	0	0
Mentha arvensis	0	0	0	0	0	0	0	0	0
Moss	0	0	2	0	0	0	0	2	0
*Pascopyrum smithii**	0	0	0	0	0	0	0	0	0

Appendix K. Continued.

Transect	2	2	2	3	3	3	3	3	3
Location	Middle	Edge	Edge	Streambank	Streambank	Middle	Middle	Edge	Edge
Plot	4	1	3	2	4	3	4	2	3
Species									
Pedicularis groenlandica	0	0	0	0	0	0	0	0	0
Phleum alpinum	0	0	0	0	0	0	0	0	0
Phleum pratense	0	20	11	25	21	0	6	1	2
Plantago major	0	0	0	0	5	0	0	0	0
Poa pratensis	76	0	0	20	8	16	6	1	12
Populus tremuloides	0	0	0	0	0	0	0	0	0
Potentilla diversifolia	5	38	9	0	6	15	6	0	1
Potentilla pulcherrima	0	0	0	0	0	0	0	0	0
*Pseudocymopterus montanus**	0	0	0	0	0	0	0	0	0
*Pseudostellaria cerastrium**	0	0	0	0	0	0	0	0	0
Rumex paucifolius	0	0	0	1	4	0	0	0	0
*Rumex triangulivalvis**	0	0	0	0	0	0	0	0	0
*Salix geyerana**	0	0	0	0	0	0	0	0	0
Salix planifolia	0	0	0	0	0	0	0	0	0
*Solidago canadensis**	0	0	0	0	0	0	0	0	0
Stellaria longefolia	0	0	0	0	0	0	0	0	0
Taraxacum officinale	1	10	26	15	16	3	26	13	30
Thalictrum fendleri	0	0	0	0	0	0	0	0	0
Trifolium repens	0	0	4	4	27	0	6	3	0
Veronica americana	0	0	0	0	0	0	0	0	0
*Viola scopulorum**	0	0	0	0	0	0	0	0	0
Ground Hits	3	4	2	6	2	4	0	0	2
Number of Laser Positions	50	50	50	50	50	50	50	50	50

Appendix K. Continued.

Transect	4	4	4	4	4	4	5	5	5
Location	Streambank	Streambank	Middle	Middle	Edge	Edge	Streambank	Streambank	Middle
Plot	3	4	3	4	2	4	1	3	2
Species									
Achillea millefolium	12	8	13	5	4	2	0	1	9
Agrostis stolonifera	33	27	29	0	22	3	63	49	74
*Antennaria rosea**	0	0	0	0	0	0	0	0	0
Arnica chamissonis	0	0	0	0	0	0	0	4	0
Astragalus alpinus	1	0	0	18	7	1	0	0	0
*Campanula parryi**	0	0	0	0	0	0	0	6	0
Carex aquatilis	0	0	0	0	0	0	1	7	26
Carex praticola	3	9	3	1	7	13	0	0	0
Carex urticulata	0	0	0	0	0	0	0	1	3
Cerastium arvense	0	6	0	0	0	0	2	6	16
Cerastrium strictum	0	0	0	0	0	0	0	0	1
Cirsium arvens	0	0	0	0	0	0	0	0	0
Cirsium sarsa	0	0	0	0	0	0	0	0	0
Danthonia intermedia	0	0	37	51	0	1	0	0	0
Dasiphora floribunda	0	0	0	0	0	20	0	0	0
Deschampsia caespitosa	0	0	0	0	0	0	12	7	0
*Dodecatheon pulchellum**	0	0	0	0	0	0	0	4	0
Epibbium ciliatum	0	0	0	0	0	0	0	0	0
Equesitum arvense	0	0	0	0	0	0	0	0	0
Erigeron formosissimus	14	7	5	15	73	59	0	5	0
Fragaria vesca	9	3	23	40	25	16	0	0	0
Fragaria virginiana	0	0	0	0	0	0	0	0	0
Galium boreale	25	2	2	5	0	0	0	8	19
*Gentianella acuta**	0	0	0	0	0	0	0	0	0
Geum aleppicum	0	0	0	0	6	2	0	1	0
Juncus arcticus	0	0	22	12	0	0	8	12	2
Juncus balticus	0	1	15	0	49	52	17	10	23
Ligusticum porteri	0	0	0	0	0	0	0	0	0
Machaeranthea canescens	0	0	0	0	0	0	0	0	0
Mentha arvensis	0	0	0	0	0	0	0	0	0
Moss	0	0	0	0	0	0	0	8	3
*Pascopyrum smithii**	0	0	0	0	0	0	0	0	0

Appendix K. Continued.

Transect	4	4	4	4	4	4	5	5	5
Location	Streambank	Streambank	Middle	Middle	Edge	Edge	Streambank	Streambank	Middle
Plot	3	4	3	4	2	4	1	3	2
Species									
Pedicularis groenlandica	0	0	0	0	0	0	0	0	0
Phleum alpinum	0	0	0	0	0	0	0	0	0
Phleum pratense	46	52	56	44	32	42	2	2	1
Plantago major	1	0	0	0	0	0	0	0	0
Poa pratensis	0	0	0	0	0	0	21	13	6
Populus tremuloides	0	0	0	0	0	0	0	0	0
Potentilla diversifolia	0	0	0	0	0	0	0	1	1
Potentilla pulcherrima	0	0	4	2	2	0	0	0	0
*Pseudocymopterus montanus**	0	0	0	0	0	0	0	0	0
*Pseudostellaria cerastrium**	0	0	8	0	0	0	0	0	0
Rumex paucifolius	0	0	0	0	0	0	0	0	0
*Rumex triangulivalvis**	0	0	0	0	0	0	0	0	0
*Salix geyerana**	0	0	0	0	0	0	0	0	0
Salix planifolia	0	0	0	0	0	0	3	0	0
*Solidago canadensis**	0	0	0	0	0	0	0	0	0
Stellaria longefolia	0	0	0	0	0	0	0	5	0
Taraxacum officinale	2	2	26	30	3	4	3	10	10
Thalictrum fendleri	4	0	3	9	6	0	0	0	0
Trifolium repens	3	18	54	27	12	19	3	17	13
Veronica americana	0	0	0	0	0	0	0	0	0
*Viola scopulorum**	0	0	0	0	0	0	0	0	0
Ground Hits	12	21	4	6	5	10	4	3	1
Number of Laser Positions	100	100	100	100	100	100	50	50	50

Appendix K. Continued.

Transect	5	5	5	6	6	6	6	6	6
Location	Middle	Edge	Edge	Streambank	Streambank	Middle	Middle	Edge	Edge
Plot	3	3	4	1	2	1	4	1	4
Species									
Achillea millefolium	31	6	12	20	13	0	0	3	2
Agrostis stolonifera	91	106	26	54	79	52	40	0	0
*Antennaria rosea**	0	0	0	0	0	0	0	0	0
Arnica chamissonis	0	0	0	0	2	0	0	1	0
Astragalus alpinus	0	0	0	0	0	0	0	0	0
*Campanula parryi**	0	0	0	0	0	0	0	0	0
Carex aquatilis	26	14	5	1	0	0	1	0	0
Carex praticola	0	0	0	0	0	0	0	0	0
Carex urticulata	0	1	0	0	4	4	4	10	14
Cerastium arvense	6	18	3	2	1	1	0	0	0
Cerastrium strictum	0	19	4	0	0	0	0	0	0
Cirsium arvens	0	0	0	0	0	0	0	0	0
Cirsium sarsa	0	0	0	0	0	0	0	0	0
Danthonia intermedia	0	0	0	0	0	0	0	0	0
Dasiphora floribunda	0	0	0	0	0	0	0	0	0
Deschampsia caespitosa	0	0	0	0	0	0	0	0	0
*Dodecatheon pulchellum**	0	0	0	0	0	0	0	0	0
Epibbium ciliatum	0	2	0	0	0	2	4	0	0
Equesitum arvense	1	0	0	4	4	8	13	1	1
Erigeron formosissimus	0	0	0	0	0	0	0	31	16
Fragaria vesca	0	0	0	8	0	0	0	7	7
Fragaria virginiana	0	0	0	0	0	0	0	0	0
Galium boreale	0	0	0	17	1	6	6	0	0
*Gentianella acuta**	0	1	0	0	0	0	0	0	0
Geum aleppicum	0	9	0	2	3	2	0	0	0
Juncus arcticus	1	4	0	0	0	0	0	0	0
Juncus balticus	3	5	4	9	6	0	0	1	2
Ligusticum porteri	0	0	0	4	3	0	0	0	0
Machaeranthea canescens	0	0	0	5	8	3	10	6	8
Mentha arvensis	0	0	0	0	0	0	0	0	0
Moss	0	4	1	0	1	1	4	1	3
*Pascopyrum smithii**	0	0	0	0	0	0	0	0	0

Appendix K. Continued.

Transect	5	5	5	6	6	6	6	6	6
Location	Middle	Edge	Edge	Streambank	Streambank	Middle	Middle	Edge	Edge
Plot	3	3	4	1	2	1	4	1	4
Species									
Pedicularis groenlandica	0	0	0	1	0	4	9	0	0
Phleum alpinum	0	0	0	2	0	0	0	3	3
Phleum pratense	0	0	0	4	2	0	0	26	25
Plantago major	0	0	12	0	1	0	0	0	0
Poa pratensis	16	0	0	19	9	35	52	3	3
Populus tremuloides	0	0	1	0	0	0	0	6	0
Potentilla diversifolia	0	0	0	0	0	0	0	0	0
Potentilla pulcherrima	0	0	0	0	0	0	0	7	17
*Pseudocymopterus montanus**	0	0	0	0	0	0	1	0	0
*Pseudostellaria cerastrium**	0	0	0	0	0	0	0	0	0
Rumex paucifolius	0	0	0	0	0	0	0	0	0
*Rumex triangulivalvis**	0	0	0	0	0	0	0	0	0
*Salix geyerana**	0	0	0	0	0	0	0	0	0
Salix planifolia	0	0	0	0	0	0	0	0	0
*Solidago canadensis**	0	0	0	0	0	0	0	0	0
Stellaria longefolia	0	0	24	0	0	0	0	0	0
Taraxacum officinale	8	15	0	5	3	1	1	5	17
Thalictrum fendleri	0	0	45	0	0	0	0	0	0
Trifolium repens	12	23	0	1	1	0	0	1	0
Veronica americana	0	0	0	1	2	2	10	0	0
*Viola scopulorum**	0	0	0	0	0	0	0	0	0
Ground Hits	1	0	3	4	3	2	1	3	6
Number of Laser Positions	50	50	50	50	50	50	50	50	50

Appendix L. Species absolute cover (%), total plant cover (%) and species richness (number count) collected at Sheep Creek from two of four plots at each location in August 2005.

	Transect	1	1	1	1	1	1	2	2	2
	Location	Streambank	Streambank	Middle	Middle	Edge	Edge	Streambank	Streambank	Middle
	Plot	1	4	1	3	3	4	1	3	3
Species	**Functional Group**									
Achillea millefolium	Forb	0	0	14	0	0	2	0	4	0
Agrostis stolonifera	Grass	48	82	2	0	4	10	116	12	0
Arnica chamissonis	Forb	0	0	0	0	0	0	0	0	0
Astragalus alpinus	Forb	0	0	0	0	0	0	0	0	0
Carex aquatilis	Sedge	92	96	58	0	0	4	22	4	246
Carex praticola	Sedge	0	0	0	0	0	0	0	0	0
Carex urticulata	Sedge	0	50	0	2	62	16	20	36	0
Cerastium arvense	Forb	0	0	10	8	0	2	2	0	0
Cerastrium strictum	Forb	0	0	0	0	0	0	0	0	0
Cirsium arvens	Forb	0	0	0	0	0	0	0	0	0
Cirsium sarsa	Forb	0	0	0	0	0	0	0	8	0
Danthonia intermedia	Grass	0	0	0	0	0	0	0	0	0
Dasiphora floribunda	Shrub	0	0	2	0	0	0	0	0	0
Deschampsia caespitosa	Grass	0	0	0	0	0	0	0	0	0
Epibbium ciliatum	Forb	0	0	0	0	0	0	0	0	0
Equesitum arvense	Forb	16	6	0	2	12	2	0	0	0
Erigeron formosissimus	Forb	34	2	18	6	4	4	0	0	0
Fragaria vesca	Forb	0	0	0	0	0	0	0	6	0
Fragaria virginiana	Forb	0	0	32	44	0	0	4	40	0
Galium boreale	Forb	4	2	0	0	0	0	0	0	0
Geum aleppicum	Forb	0	4	0	0	0	0	0	2	0
Juncus arcticus	Rush	0	0	0	0	0	0	0	2	0
Juncus balticus	Rush	16	2	30	0	4	0	50	38	0
Ligusticum porteri	Forb	0	0	0	0	0	0	0	0	0
Machaeranthea canescens	Forb	0	0	0	0	0	0	0	0	0
Mentha arvensis	Forb	2	36	0	0	0	0	0	0	0
Moss	Moss	0	0	0	0	0	0	0	0	0
Pedicularis groenlandica	Forb	0	0	0	0	0	0	0	0	0
Phleum alpinum	Grass	0	0	0	0	0	0	0	0	0

Appendix L. Continued.

	Transect	1	1	1	1	1	1	2	2	2
	Location	Streambank	Streambank	Middle	Middle	Edge	Edge	Streambank	Streambank	Middle
	Plot	1	4	1	3	3	4	1	3	3
Species	**Functional Group**									
Phleum pratense	Grass	0	0	10	2	4	4	0	0	0
Plantago major	Forb	0	0	0	0	0	0	0	0	0
Poa pratensis	Grass	0	0	98	52	2	0	0	18	0
Populus tremuloides	Tree	0	0	0	0	0	0	0	0	0
Potentilla diversifolia	Forb	0	0	10	2	12	2	0	14	0
Potentilla pulcherrima	Forb	0	0	0	44	0	2	2	10	0
Rumex paucifolius	Forb	0	0	0	0	0	0	0	0	0
Salix planifolia	Shrub	30	0	0	0	0	0	0	0	0
Stellaria longefolia	Forb	0	0	0	0	0	0	0	0	0
Taraxacum officinale	Forb	0	4	16	18	6	8	4	2	0
Thalictrum fendleri	Forb	0	0	0	0	0	0	0	0	0
Trifolium repens	Forb	0	0	0	28	0	14	0	0	0
Veronica americana	Forb	0	0	0	0	0	0	0	0	0
Total Plant Cover		244	289	302	212	114	75	223	201	251
Species Richness		8	10	12	11	9	12	8	14	1

Appendix L. Continued.

	Transect	2	2	2	3	3	3	3	3	3
	Location	Middle	Edge	Edge	Streambank	Streambank	Middle	Middle	Edge	Edge
	Plot	4	1	3	2	4	3	4	2	3
Species	**Functional Group**									
Achillea millefolium	Forb	0	0	6	34	54	32	34	10	30
Agrostis stolonifera	Grass	14	12	16	30	32	72	40	0	136
Arnica chamissonis	Forb	0	0	0	0	0	0	0	4	22
Astragalus alpinus	Forb	0	0	0	0	0	0	0	0	0
Carex aquatilis	Sedge	22	0	0	20	36	16	60	24	6
Carex praticola	Sedge	0	0	0	0	0	0	0	0	0
Carex urticulata	Sedge	18	30	10	14	2	6	2	6	4
Cerastium arvense	Forb	0	0	0	10	22	0	12	2	4
Cerastrium strictum	Forb	0	0	0	0	0	0	0	0	0
Cirsium arvens	Forb	0	0	0	14	20	0	0	0	0
Cirsium sarsa	Forb	0	0	0	0	6	0	0	2	0
Danthonia intermedia	Grass	0	0	0	0	0	0	0	0	0
Dasiphora floribunda	Shrub	16	0	0	0	0	0	0	0	0
Deschampsia caespitosa	Grass	0	0	0	0	0	0	0	0	0
Epibbium ciliatum	Forb	0	0	0	0	0	0	0	4	0
Equesitum arvense	Forb	2	22	18	2	6	0	0	2	0
Erigeron formosissimus	Forb	0	12	18	2	0	0	0	2	2
Fragaria vesca	Forb	0	0	0	0	0	0	0	0	0
Fragaria virginiana	Forb	4	6	30	0	4	0	0	0	0
Galium boreale	Forb	0	0	0	0	0	0	0	0	0
Geum aleppicum	Forb	0	0	0	4	8	2	0	0	2
Juncus arcticus	Rush	0	0	0	0	0	38	60	50	18
Juncus balticus	Rush	0	0	6	0	10	8	0	6	0
Ligusticum porteri	Forb	0	0	0	0	0	0	0	0	0
Machaeranthea canescens	Forb	0	0	0	0	0	0	0	0	0
Mentha arvensis	Forb	0	0	0	0	0	0	0	0	0
Moss	Moss	0	0	4	0	0	0	0	4	0
Pedicularis groenlandica	Forb	0	0	0	0	0	0	0	0	0
Phleum alpinum	Grass	0	0	0	0	0	0	0	0	0
Phleum pratense	Grass	0	40	22	50	42	0	12	2	4
Plantago major	Forb	0	0	0	0	10	0	0	0	0

Appendix L. Continued.

	Transect	2	2	2	3	3	3	3	3	3
	Location	Middle	Edge	Edge	Streambank	Streambank	Middle	Middle	Edge	Edge
	Plot	4	1	3	2	4	3	4	2	3
Species	**Functional Group**									
Poa pratensis	Grass	152	0	0	40	16	32	12	2	24
Populus tremuloides	Tree	0	0	0	0	0	0	0	0	0
Potentilla diversifolia	Forb	10	76	18	0	12	30	12	0	2
Potentilla pulcherrima	Forb	0	0	0	0	0	0	0	0	0
Rumex paucifolius	Forb	0	0	0	2	8	0	0	0	0
Salix planifolia	Shrub	0	0	0	0	0	0	0	0	0
Stellaria longefolia	Forb	0	0	0	0	0	0	0	0	0
Taraxacum officinale	Forb	2	20	52	30	32	6	52	26	60
Thalictrum fendleri	Forb	0	0	0	0	0	0	0	0	0
Trifolium repens	Forb	0	0	8	8	54	0	12	6	0
Veronica americana	Forb	0	0	0	0	0	0	0	0	0
Total Plant Cover		246	221	213	265	381	248	315	157	320
Species Richness		9	8	12	14	18	10	11	16	13

Appendix L. Continued.

	Transect	4	4	4	4	4	4	5	5	5
	Location	Streambank	Streambank	Middle	Middle	Edge	Edge	Streambank	Streambank	Middle
	Plot	3	4	3	4	2	4	1	3	2
Species	**Functional Group**									
Achillea millefolium	Forb	12	8	13	5	4	2	0	2	18
Agrostis stolonifera	Grass	33	27	29	0	22	3	126	98	148
Arnica chamissonis	Forb	0	0	0	0	0	0	0	8	0
Astragalus alpinus	Forb	1	0	0	18	7	1	0	0	0
Carex aquatilis	Sedge	0	0	0	0	0	0	2	14	52
Carex praticola	Sedge	3	9	3	1	7	13	0	0	0
Carex urticulata	Sedge	0	0	0	0	0	0	0	2	6
Cerastium arvense	Forb	0	6	0	0	0	0	4	12	32
Cerastrium strictum	Forb	0	0	0	0	0	0	0	0	2
Cirsium arvens	Forb	0	0	0	0	0	0	0	0	0
Cirsium sarsa	Forb	0	0	0	0	0	0	0	0	0
Danthonia intermedia	Grass	0	0	37	51	0	1	0	0	0
Dasiphora floribunda	Shrub	0	0	0	0	0	20	0	0	0
Deschampsia caespitosa	Grass	0	0	0	0	0	0	24	14	0
Epibbium ciliatum	Forb	0	0	0	0	0	0	0	0	0
Equesitum arvense	Forb	0	0	0	0	0	0	0	0	0
Erigeron formosissimus	Forb	14	7	5	15	73	59	0	10	0
Fragaria vesca	Forb	9	3	23	40	25	16	0	0	0
Fragaria virginiana	Forb	0	0	0	0	0	0	0	0	0
Galium boreale	Forb	25	2	2	5	0	0	0	16	38
Geum aleppicum	Forb	0	0	0	0	6	2	0	2	0
Juncus arcticus	Rush	0	0	22	12	0	0	16	24	4
Juncus balticus	Rush	0	1	15	0	49	52	34	20	46
Ligusticum porteri	Forb	0	0	0	0	0	0	0	0	0
Machaeranthea canescens	Forb	0	0	0	0	0	0	0	0	0
Mentha arvensis	Forb	0	0	0	0	0	0	0	0	0
Moss	Moss	0	0	0	0	0	0	0	16	6
Pedicularis groenlandica	Forb	0	0	0	0	0	0	0	0	0
Phleum alpinum	Grass	0	0	0	0	0	0	0	0	0
Phleum pratense	Grass	46	52	56	44	32	42	4	4	2
Plantago major	Forb	1	0	0	0	0	0	0	0	0

Appendix L. Continued.

	Transect	4	4	4	4	4	4	5	5	5
	Location	Streambank	Streambank	Middle	Middle	Edge	Edge	Streambank	Streambank	Middle
	Plot	3	4	3	4	2	4	1	3	2
Species	**Functional Group**									
Poa pratensis	Grass	0	0	0	0	0	0	42	26	12
Populus tremuloides	Tree	0	0	0	0	0	0	0	0	0
Potentilla diversifolia	Forb	0	0	0	0	0	0	0	2	2
Potentilla pulcherrima	Forb	0	0	4	2	2	0	0	0	0
Rumex paucifolius	Forb	0	0	0	0	0	0	0	0	0
Salix planifolia	Shrub	0	0	0	0	0	0	6	0	0
Stellaria longefolia	Forb	0	0	0	0	0	0	0	10	0
Taraxacum officinale	Forb	2	2	26	30	3	4	6	20	20
Thalictrum fendleri	Forb	4	0	3	9	6	0	0	0	0
Trifolium repens	Forb	3	18	54	27	12	19	6	34	26
Veronica americana	Forb	0	0	0	0	0	0	0	0	0
Total Plant Cover		160	143	299	267	254	242	276	342	421
Species Richness		12	11	14	13	13	13	11	19	15

Appendix **L.** Continued.

	Transect	5	5	5	6	6	6	6	6	6
	Location	Middle	Edge	Edge	Streambank	Streambank	Middle	Middle	Edge	Edge
	Plot	3	3	4	1	2	1	4	1	4
Species	**Functional Group**									
Achillea millefolium	Forb	62	12	24	40	26	0	0	6	4
Agrostis stolonifera	Grass	182	212	52	108	158	104	80	0	0
Arnica chamissonis	Forb	0	0	0	0	4	0	0	2	0
Astragalus alpinus	Forb	0	0	0	0	0	0	0	0	0
Carex aquatilis	Sedge	52	28	10	2	0	0	2	0	0
Carex praticola	Sedge	0	0	0	0	0	0	0	0	0
Carex urticulata	Sedge	0	2	0	0	8	8	8	20	28
Cerastium arvense	Forb	12	36	6	4	2	2	0	0	0
Cerastrium strictum	Forb	0	38	8	0	0	0	0	0	0
Cirsium arvens	Forb	0	0	0	0	0	0	0	0	0
Cirsium sarsa	Forb	0	0	0	0	0	0	0	0	0
Danthonia intermedia	Grass	0	0	0	0	0	0	0	0	0
Dasiphora floribunda	Shrub	0	0	0	0	0	0	0	0	0
Deschampsia caespitosa	Grass	0	0	0	0	0	0	0	0	0
Epibbium ciliatum	Forb	0	4	0	0	0	4	8	0	0
Equesitum arvense	Forb	2	0	0	8	8	16	26	2	2
Erigeron formosissimus	Forb	0	0	0	0	0	0	0	62	32
Fragaria vesca	Forb	0	0	0	16	0	0	0	14	14
Fragaria virginiana	Forb	0	0	0	0	0	0	0	0	0
Galium boreale	Forb	0	0	0	34	2	12	12	0	0
Geum aleppicum	Forb	0	18	0	4	6	4	0	0	0
Juncus arcticus	Rush	2	8	0	0	0	0	0	0	0
Juncus balticus	Rush	6	10	8	18	12	0	0	2	4
Ligusticum porteri	Forb	0	0	0	8	6	0	0	0	0
Machaeranthea canescens	Forb	0	0	0	10	16	6	20	12	16
Mentha arvensis	Forb	0	0	0	0	0	0	0	0	0
Moss	Moss	0	8	2	0	2	2	8	2	6
Pedicularis groenlandica	Forb	0	0	0	2	0	8	18	0	0
Phleum alpinum	Grass	0	0	0	4	0	0	0	6	6
Phleum pratense	Grass	0	0	0	8	4	0	0	52	50
Plantago major	Forb	0	0	24	0	2	0	0	0	0

Appendix L. Continued.

	Transect	5	5	5	6	6	6	6	6	6
	Location	Middle	Edge	Edge	Streambank	Streambank	Middle	Middle	Edge	Edge
	Plot	3	3	4	1	2	1	4	1	4
Species	**Functional Group**									
Poa pratensis	Grass	32	0	0	38	18	70	104	6	6
Populus tremuloides	Tree	0	0	2	0	0	0	0	12	0
Potentilla diversifolia	Forb	0	0	0	0	0	0	0	0	0
Potentilla pulcherrima	Forb	0	0	0	0	0	0	0	14	34
Rumex paucifolius	Forb	0	0	0	0	0	0	0	0	0
Salix planifolia	Shrub	0	0	0	0	0	0	0	0	0
Stellaria longefolia	Forb	0	0	48	0	0	0	0	0	0
Taraxacum officinale	Forb	16	30	0	10	6	2	2	10	34
Thalictrum fendleri	Forb	0	0	90	0	0	0	0	0	0
Trifolium repens	Forb	24	46	0	2	2	0	0	2	0
Veronica americana	Forb	0	0	0	2	4	4	20	0	0
Total Plant Cover		398	460	283	325	294	249	318	231	246
Species Richness		10	13	11	18	18	13	12	16	13

Appendix M. Soil particle size distribution and bulk density measured at Sheep Creek in mid-August 2005.

Block	Transect	Location	Grazing treatment	Sand (%)	Clay (%)	Silt (%)	Bulk density (g cm^{-3})
1	1	Streambank	grazed	75	7	18	0.84
1	1	Middle	grazed	69	10	22	1.02
1	1	Edge	grazed	66	10	24	1.02
1	2	Streambank	excluded	68	8	23	0.81
1	2	Middle	excluded	59	13	28	0.74
1	2	Edge	excluded	59	15	26	0.84
2	3	Streambank	grazed	75	7	18	1.08
2	3	Middle	grazed	65	8	26	0.76
2	3	Edge	grazed	62	10	28	0.76
2	4	Streambank	excluded	68	7	25	0.80
2	4	Middle	excluded	63	10	28	0.89
2	4	Edge	excluded	64	10	26	0.85
3	5	Streambank	grazed	73	6	21	0.72
3	5	Middle	grazed	75	7	18	0.91
3	5	Edge	grazed	68	10	22	1.09
3	6	Streambank	excluded	69	10	21	0.71
3	6	Middle	excluded	61	13	26	0.62
3	6	Edge	excluded	72	10	18	0.78

Appendix N. Soil pH measured at Sheep Creek in 2005.

Block	Transect	Location	Grazing treatment	Month	pH
1	1	Streambank	grazed	June	5.5
1	1	Middle	grazed	June	5.3
1	1	Edge	grazed	June	5.1
1	2	Streambank	excluded	June	5.3
1	2	Middle	excluded	June	5.2
1	2	Edge	excluded	June	5.4
2	3	Streambank	grazed	June	6.1
2	3	Middle	grazed	June	5.8
2	3	Edge	grazed	June	6.0
2	4	Streambank	excluded	June	5.3
2	4	Middle	excluded	June	6.1
2	4	Edge	excluded	June	5.8
3	5	Streambank	grazed	June	4.9
3	5	Middle	grazed	June	5.5
3	5	Edge	grazed	June	5.7
3	6	Streambank	excluded	June	5.6
3	6	Middle	excluded	June	---
3	6	Edge	excluded	June	5.8
1	1	Streambank	grazed	August	5.5
1	1	Middle	grazed	August	5.3
1	1	Edge	grazed	August	5.2
1	2	Streambank	excluded	August	5.2
1	2	Middle	excluded	August	5.3
1	2	Edge	excluded	August	5.5
2	3	Streambank	grazed	August	6.0
2	3	Middle	grazed	August	5.8
2	3	Edge	grazed	August	6.0
2	4	Streambank	excluded	August	5.4
2	4	Middle	excluded	August	5.9
2	4	Edge	excluded	August	5.7
3	5	Streambank	grazed	August	4.9
3	5	Middle	grazed	August	5.5
3	5	Edge	grazed	August	5.8
3	6	Streambank	excluded	August	5.7
3	6	Middle	excluded	August	5.5
3	6	Edge	excluded	August	5.7
1	1	Streambank	grazed	October	5.4
1	1	Middle	grazed	October	5.3
1	1	Edge	grazed	October	5.1
1	2	Streambank	excluded	October	5.2
1	2	Middle	excluded	October	5.4
1	2	Edge	excluded	October	5.5
2	3	Streambank	grazed	October	6.0
2	3	Middle	grazed	October	6.0
2	3	Edge	grazed	October	5.9
2	4	Streambank	excluded	October	5.4
2	4	Middle	excluded	October	6.1
2	4	Edge	excluded	October	5.9
3	5	Streambank	grazed	October	5.1
3	5	Middle	grazed	October	5.6
3	5	Edge	grazed	October	5.9
3	6	Streambank	excluded	October	5.7
3	6	Middle	excluded	October	5.5
3	6	Edge	excluded	October	5.9

Appendix O. Soil moisture, soil C and N pools, soil C:N measured at Sheep Creek in 2005 and 2006.

Block	Transect	Location	Grazing treatment	Month	Year	Soil moisture (%)	Soil C (kg C m^{-2})	Soil N (kg N m^{-2})	C:N
1	1	Streambank	grazed	June	2005	60	1.99	0.11	18
1	1	Middle	grazed	June	2005	25	2.49	0.22	11
1	1	Edge	grazed	June	2005	24	3.63	0.21	17
1	2	Streambank	excluded	June	2005	34	3.00	0.20	15
1	2	Middle	excluded	June	2005	46	3.65	0.24	15
1	2	Edge	excluded	June	2005	25	3.43	0.22	16
2	3	Streambank	grazed	June	2005	33	2.81	0.25	11
2	3	Middle	grazed	June	2005	52	4.75	0.33	14
2	3	Edge	grazed	June	2005	75	7.72	0.43	18
2	4	Streambank	excluded	June	2005	57	4.28	0.25	17
2	4	Middle	excluded	June	2005	48	4.92	0.38	13
2	4	Edge	excluded	June	2005	34	4.55	0.35	13
3	5	Streambank	grazed	June	2005	66	2.42	0.14	18
3	5	Middle	grazed	June	2005	33	2.45	0.19	13
3	5	Edge	grazed	June	2005	43	3.02	0.26	12
3	6	Streambank	excluded	June	2005	89	6.10	0.29	21
3	6	Middle	excluded	June	2005	---	9.43	0.43	22
3	6	Edge	excluded	June	2005	45	5.13	0.32	16
1	1	Streambank	grazed	August	2005	55	2.05	0.12	18
1	1	Middle	grazed	August	2005	20	2.49	0.22	11
1	1	Edge	grazed	August	2005	15	3.47	0.18	19
1	2	Streambank	excluded	August	2005	24	3.23	0.22	14
1	2	Middle	excluded	August	2005	25	3.64	0.24	15
1	2	Edge	excluded	August	2005	18	3.60	0.23	16
2	3	Streambank	grazed	August	2005	20	2.71	0.23	12
2	3	Middle	grazed	August	2005	27	4.53	0.32	14
2	3	Edge	grazed	August	2005	70	8.21	0.45	18
2	4	Streambank	excluded	August	2005	29	4.70	0.27	17
2	4	Middle	excluded	August	2005	17	4.72	0.37	13
2	4	Edge	excluded	August	2005	15	4.74	0.37	13
3	5	Streambank	grazed	August	2005	45	3.13	0.17	18
3	5	Middle	grazed	August	2005	31	2.90	0.25	12
3	5	Edge	grazed	August	2005	20	3.52	0.31	11
3	6	Streambank	excluded	August	2005	81	5.54	0.27	21
3	6	Middle	excluded	August	2005	120	9.58	0.42	23
3	6	Edge	excluded	August	2005	31	5.50	0.33	17
1	1	Streambank	grazed	October	2005	108	3.01	0.14	21
1	1	Middle	grazed	October	2005	78	2.64	0.23	11
1	1	Edge	grazed	October	2005	87	4.25	0.24	18
1	2	Streambank	excluded	October	2005	79	3.43	0.23	15
1	2	Middle	excluded	October	2005	89	3.77	0.25	15
1	2	Edge	excluded	October	2005	82	3.66	0.23	16
2	3	Streambank	grazed	October	2005	21	3.00	0.26	11
2	3	Middle	grazed	October	2005	30	4.65	0.33	14
2	3	Edge	grazed	October	2005	46	7.57	0.42	18
2	4	Streambank	excluded	October	2005	28	5.32	0.29	18
2	4	Middle	excluded	October	2005	18	5.08	0.39	13
2	4	Edge	excluded	October	2005	17	4.98	0.38	13
3	5	Streambank	grazed	October	2005	29	3.77	0.20	19
3	5	Middle	grazed	October	2005	27	3.64	0.27	13
3	5	Edge	grazed	October	2005	19	3.66	0.31	12
3	6	Streambank	excluded	October	2005	36	7.04	0.34	21
3	6	Middle	excluded	October	2005	79	9.15	0.41	22
3	6	Edge	excluded	October	2005	29	5.77	0.34	17

Appendix O. Continued.

Block	Transect	Location	Grazing treatment	Month	Year	Soil moisture (%)	Soil C (kg C m^{-2})	Soil N (kg N m^{-2})	C:N
1	1	Streambank	grazed	June	2006	42	2.08	0.14	15
1	1	Middle	grazed	June	2006	17	2.95	0.25	12
1	1	Edge	grazed	June	2006	18	4.21	0.24	17
1	2	Streambank	excluded	June	2006	24	2.80	0.23	12
1	2	Middle	excluded	June	2006	28	2.83	0.24	12
1	2	Edge	excluded	June	2006	18	3.00	0.22	14
2	3	Streambank	grazed	June	2006	18	4.00	0.32	12
2	3	Middle	grazed	June	2006	27	3.54	0.30	12
2	3	Edge	grazed	June	2006	32	5.91	0.39	15
2	4	Streambank	excluded	June	2006	44	3.46	0.24	14
2	4	Middle	excluded	June	2006	32	4.72	0.37	13
2	4	Edge	excluded	June	2006	19	3.98	0.33	12
3	5	Streambank	grazed	June	2006	37	1.92	0.15	13
3	5	Middle	grazed	June	2006	34	3.04	0.25	12
3	5	Edge	grazed	June	2006	27	3.86	0.30	13
3	6	Streambank	excluded	June	2006	39	3.80	0.24	16
3	6	Middle	excluded	June	2006	74	5.14	0.32	16
3	6	Edge	excluded	June	2006	29	4.25	0.30	14
1	1	Streambank	grazed	August	2006	49	1.92	0.14	14
1	1	Middle	grazed	August	2006	17	2.92	0.24	12
1	1	Edge	grazed	August	2006	15	4.24	0.24	18
1	2	Streambank	excluded	August	2006	18	2.79	0.23	12
1	2	Middle	excluded	August	2006	21	2.81	0.24	12
1	2	Edge	excluded	August	2006	16	3.08	0.22	14
2	3	Streambank	grazed	August	2006	19	3.78	0.30	13
2	3	Middle	grazed	August	2006	12	3.47	0.29	12
2	3	Edge	grazed	August	2006	25	6.14	0.40	15
2	4	Streambank	excluded	August	2006	44	3.40	0.24	14
2	4	Middle	excluded	August	2006	35	4.50	0.34	13
2	4	Edge	excluded	August	2006	16	4.14	0.34	12
3	5	Streambank	grazed	August	2006	27	2.12	0.16	13
3	5	Middle	grazed	August	2006	17	2.98	0.25	12
3	5	Edge	grazed	August	2006	14	3.57	0.27	13
3	6	Streambank	excluded	August	2006	22	3.57	0.21	17
3	6	Middle	excluded	August	2006	46	6.03	0.36	17
3	6	Edge	excluded	August	2006	13	4.46	0.30	15
1	1	Streambank	grazed	October	2006	42	1.81	0.13	14
1	1	Middle	grazed	October	2006	28	3.33	0.26	13
1	1	Edge	grazed	October	2006	22	4.29	0.24	18
1	2	Streambank	excluded	October	2006	31	3.01	0.24	13
1	2	Middle	excluded	October	2006	33	2.86	0.23	12
1	2	Edge	excluded	October	2006	28	3.08	0.22	14
2	3	Streambank	grazed	October	2006	22	4.12	0.32	13
2	3	Middle	grazed	October	2006	33	3.86	0.32	12
2	3	Edge	grazed	October	2006	38	6.29	0.39	16
2	4	Streambank	excluded	October	2006	49	3.79	0.26	15
2	4	Middle	excluded	October	2006	36	4.96	0.37	14
2	4	Edge	excluded	October	2006	34	4.44	0.35	13
3	5	Streambank	grazed	October	2006	37	2.17	0.17	13
3	5	Middle	grazed	October	2006	25	3.35	0.27	12
3	5	Edge	grazed	October	2006	23	4.47	0.32	14
3	6	Streambank	excluded	October	2006	38	3.87	0.23	17
3	6	Middle	excluded	October	2006	63	5.78	0.36	16
3	6	Edge	excluded	October	2006	35	4.56	0.32	14

Appendix P. Soil organic matter and soil available inorganic N (2M KCl extractable N) measured at Sheep Creek in 2005 and 2006.

Block	Transect	Location	Analytical replicate	Grazing treatment	Month	Year	Soil organic matter ($g\ N\ m^{-2}$)	Nitrate ($g\ NO_3^-\ m^{-2}$)	Ammonium ($g\ NH_4^+\ m^{-2}$)	Total inorganic N ($g\ N\ m^{-2}$)
1	1	Streambank	1	grazed	June	2005	4.7	0.01	0.40	0.41
1	1	Streambank	2	grazed	June	2005	4.7	0.01	0.31	0.32
1	1	Middle	1	grazed	June	2005	7.5	0.03	0.65	0.68
1	1	Middle	2	grazed	June	2005	7.6	0.03	0.84	0.87
1	1	Edge	1	grazed	June	2005	10.3	0.01	0.67	0.68
1	1	Edge	2	grazed	June	2005	9.3	0.04	0.77	0.81
1	2	Streambank	1	excluded	June	2005	6.8	0.02	0.61	0.63
1	2	Streambank	2	excluded	June	2005	7.0	0.01	0.44	0.45
1	2	Middle	1	excluded	June	2005	7.5	0.08	0.90	0.98
1	2	Middle	2	excluded	June	2005	7.4	0.09	0.87	0.96
1	2	Edge	1	excluded	June	2005	8.7	0.02	0.41	0.43
1	2	Edge	2	excluded	June	2005	8.7	0.01	0.54	0.55
2	3	Streambank	1	grazed	June	2005	8.4	0.03	0.66	0.69
2	3	Streambank	2	grazed	June	2005	8.2	0.06	0.68	0.74
2	3	Middle	1	grazed	June	2005	9.5	0.07	0.63	0.70
2	3	Middle	2	grazed	June	2005	9.7	0.06	0.60	0.66
2	3	Edge	1	grazed	June	2005	14.0	0.04	0.74	0.78
2	3	Edge	2	grazed	June	2005	13.8	0.04	0.89	0.94
2	4	Streambank	1	excluded	June	2005	9.8	0.04	0.79	0.83
2	4	Streambank	2	excluded	June	2005	9.3	0.03	0.55	0.57
2	4	Middle	1	excluded	June	2005	11.5	0.04	0.53	0.57
2	4	Middle	2	excluded	June	2005	11.6	0.03	0.65	0.68
2	4	Edge	1	excluded	June	2005	10.8	0.02	0.53	0.55
2	4	Edge	2	excluded	June	2005	10.7	0.02	0.50	0.52
3	5	Streambank	1	grazed	June	2005	5.0	0.01	0.46	0.47
3	5	Streambank	2	grazed	June	2005	4.7	0.02	0.42	0.44
3	5	Middle	1	grazed	June	2005	6.1	0.04	0.27	0.31
3	5	Middle	2	grazed	June	2005	6.2	0.05	0.60	0.65
3	5	Edge	1	grazed	June	2005	10.0	0.04	0.78	0.83
3	5	Edge	2	grazed	June	2005	9.8	0.07	0.78	0.84
3	6	Streambank	1	excluded	June	2005	10.4	0.03	0.66	0.69
3	6	Streambank	2	excluded	June	2005	10.4	0.02	0.40	0.42
3	6	Middle	1	excluded	June	2005	14.7	0.02	0.71	0.73

Appendix P. Continued.

Block	Transect	Location	Analytical replicate	Grazing treatment	Month	Year	Soil organic matter (g N m^{-2})	Nitrate (g NO_3^- m^{-2})	Ammonium (g NH_4^+ m^{-2})	Total inorganic N (g N m^{-2})
3	6	Middle	2	excluded	June	2005	13.4	0.01	0.79	0.80
3	6	Edge	1	excluded	June	2005	10.1	0.03	0.60	0.63
3	6	Edge	2	excluded	June	2005	10.3	0.04	0.61	0.64
1	1	Streambank	1	grazed	August	2005	5.2	0.01	0.50	0.51
1	1	Streambank	2	grazed	August	2005	5.3	0.02	0.61	0.63
1	1	Middle	1	grazed	August	2005	7.4	0.02	0.69	0.71
1	1	Middle	2	grazed	August	2005	7.5	0.02	0.70	0.72
1	1	Edge	1	grazed	August	2005	9.5	0.02	0.66	0.68
1	1	Edge	2	grazed	August	2005	9.7	0.02	0.65	0.67
1	2	Streambank	1	excluded	August	2005	7.0	0.01	0.51	0.52
1	2	Streambank	2	excluded	August	2005	6.6	0.01	0.58	0.60
1	2	Middle	1	excluded	August	2005	7.2	0.05	0.72	0.76
1	2	Middle	2	excluded	August	2005	7.3	0.03	0.58	0.62
1	2	Edge	1	excluded	August	2005	8.0	0.01	0.46	0.47
1	2	Edge	2	excluded	August	2005	7.1	0.03	0.75	0.78
2	3	Streambank	1	grazed	August	2005	7.9	0.03	0.56	0.59
2	3	Streambank	2	grazed	August	2005	8.0	0.03	0.57	0.60
2	3	Middle	1	grazed	August	2005	8.4	0.07	0.54	0.61
2	3	Middle	2	grazed	August	2005	8.4	0.08	0.59	0.67
2	3	Edge	1	grazed	August	2005	14.5	0.06	0.93	0.99
2	3	Edge	2	grazed	August	2005	15.1	0.08	1.09	1.17
2	4	Streambank	1	excluded	August	2005	8.8	0.01	0.70	0.71
2	4	Streambank	2	excluded	August	2005	9.2	0.01	0.54	0.55
2	4	Middle	1	excluded	August	2005	10.8	0.02	0.48	0.50
2	4	Middle	2	excluded	August	2005	11.3	0.02	0.65	0.68
2	4	Edge	1	excluded	August	2005	10.4	0.02	0.46	0.48
2	4	Edge	2	excluded	August	2005	10.3	0.02	0.50	0.52
3	5	Streambank	1	grazed	August	2005	6.3	0.01	0.84	0.85
3	5	Streambank	2	grazed	August	2005	6.8	0.01	0.83	0.84
3	5	Middle	1	grazed	August	2005	7.1	0.03	0.57	0.60
3	5	Middle	2	grazed	August	2005	7.3	0.02	0.51	0.53
3	5	Edge	1	grazed	August	2005	10.1	0.04	0.71	0.76
3	5	Edge	2	grazed	August	2005	9.9	0.04	0.73	0.77
3	6	Streambank	1	excluded	August	2005	10.1	0.01	0.72	0.73

Appendix P. Continued.

Block	Transect	Location	Analytical replicate	Grazing treatment	Month	Year	Soil organic matter ($g\ N\ m^{-2}$)	Nitrate ($g\ NO_3^-\ m^{-2}$)	Ammonium ($g\ NH_4^+\ m^{-2}$)	Total inorganic N ($g\ N\ m^{-2}$)
3	6	Streambank	2	excluded	August	2005	10.2	0.01	0.69	0.70
3	6	Middle	1	excluded	August	2005	13.3	0.01	0.80	0.81
3	6	Middle	2	excluded	August	2005	13.4	0.01	0.70	0.71
3	6	Edge	1	excluded	August	2005	9.6	0.03	0.63	0.66
3	6	Edge	2	excluded	August	2005	10.3	0.03	0.60	0.63
1	1	Streambank	1	grazed	October	2005	5.8	0	0.53	0.53
1	1	Streambank	2	grazed	October	2005	5.7	0.01	0.40	0.41
1	1	Middle	1	grazed	October	2005	7.5	0	0.73	0.73
1	1	Middle	2	grazed	October	2005	7.6	0	0.63	0.63
1	1	Edge	1	grazed	October	2005	9.7	0	0.39	0.39
1	1	Edge	2	grazed	October	2005	9.1	0	0.48	0.48
1	2	Streambank	1	excluded	October	2005	7.3	0	0.57	0.57
1	2	Streambank	2	excluded	October	2005	7.2	0	0.55	0.56
1	2	Middle	1	excluded	October	2005	7.6	0.03	0.52	0.54
1	2	Middle	2	excluded	October	2005	7.2	0.07	0.66	0.74
1	2	Edge	1	excluded	October	2005	7.7	0	0.52	0.52
1	2	Edge	2	excluded	October	2005	7.6	0	0.54	0.55
2	3	Streambank	1	grazed	October	2005	8.9	0.03	0.90	0.93
2	3	Streambank	2	grazed	October	2005	8.6	0.02	0.69	0.71
2	3	Middle	1	grazed	October	2005	9.7	0.05	0.59	0.64
2	3	Middle	2	grazed	October	2005	9.6	0.09	0.72	0.81
2	3	Edge	1	grazed	October	2005	13.8	0.04	0.77	0.81
2	3	Edge	2	grazed	October	2005	13.8	0.05	1.03	1.08
2	4	Streambank	1	excluded	October	2005	9.6	0	0.33	0.33
2	4	Streambank	2	excluded	October	2005	9.7	0	0.51	0.51
2	4	Middle	1	excluded	October	2005	11.6	0	0.43	0.44
2	4	Middle	2	excluded	October	2005	11.3	0	0.39	0.39
2	4	Edge	1	excluded	October	2005	10.6	0.01	0.47	0.48
2	4	Edge	2	excluded	October	2005	10.7	0	0.45	0.45
3	5	Streambank	1	grazed	October	2005	6.9	0	0.41	0.41
3	5	Streambank	2	grazed	October	2005	6.6	0	0.46	0.46
3	5	Middle	1	grazed	October	2005	9.1	0.01	0.42	0.43
3	5	Middle	2	grazed	October	2005	8.4	0.01	0.40	0.41
3	5	Edge	1	grazed	October	2005	10.9	0.01	0.51	0.52

Appendix P. Continued.

Block	Transect	Location	Analytical replicate	Grazing treatment	Month	Year	Soil organic matter (g N m^{-2})	Nitrate (g NO_3^- m^{-2})	Ammonium (g NH_4^+ m^{-2})	Total inorganic N (g N m^{-2})
3	5	Edge	2	grazed	October	2005	11.0	0	0.40	0.40
3	6	Streambank	1	excluded	October	2005	10.9	0	0.47	0.48
3	6	Streambank	2	excluded	October	2005	10.7	0	0.37	0.37
3	6	Middle	1	excluded	October	2005	13.9	0.02	0.70	0.71
3	6	Middle	2	excluded	October	2005	13.3	0.06	0.76	0.81
3	6	Edge	1	excluded	October	2005	11.5	0	0.51	0.51
3	6	Edge	2	excluded	October	2005	11.4	0.01	0.49	0.50
1	1	Streambank	1	grazed	June	2006	4.6	0.02	0.79	0.81
1	1	Streambank	2	grazed	June	2006	4.8	0.02	0.79	0.81
1	1	Middle	1	grazed	June	2006	7.5	0.03	0.73	0.76
1	1	Middle	2	grazed	June	2006	7.4	0	0.63	0.64
1	1	Edge	1	grazed	June	2006	9.6	0.02	0.64	0.66
1	1	Edge	2	grazed	June	2006	9.5	0.02	0.54	0.56
1	2	Streambank	1	excluded	June	2006	6.7	0	0.76	0.76
1	2	Streambank	2	excluded	June	2006	6.5	0	0.73	0.74
1	2	Middle	1	excluded	June	2006	7.5	0.11	0.75	0.86
1	2	Middle	2	excluded	June	2006	7.1	0.09	0.70	0.79
1	2	Edge	1	excluded	June	2006	7.2	0	0.56	0.57
1	2	Edge	2	excluded	June	2006	7.6	0.01	0.59	0.60
2	3	Streambank	1	grazed	June	2006	9.6	0.07	0.70	0.77
2	3	Streambank	2	grazed	June	2006	8.8	0.07	0.76	0.82
2	3	Middle	1	grazed	June	2006	9.1	0.16	0.64	0.80
2	3	Middle	2	grazed	June	2006	9.0	0.14	0.57	0.71
2	3	Edge	1	grazed	June	2006	13.3	0.09	0.66	0.75
2	3	Edge	2	grazed	June	2006	13.9	0.11	0.76	0.87
2	4	Streambank	1	excluded	June	2006	8.9	0.01	0.80	0.80
2	4	Streambank	2	excluded	June	2006	9.1	0.01	0.78	0.79
2	4	Middle	1	excluded	June	2006	10.3	0.04	0.78	0.82
2	4	Middle	2	excluded	June	2006	10.8	0.04	0.85	0.89
2	4	Edge	1	excluded	June	2006	9.6	0.03	0.64	0.67
2	4	Edge	2	excluded	June	2006	10.1	0.03	0.58	0.61
3	5	Streambank	1	grazed	June	2006	5.2	0	1.04	1.04
3	5	Streambank	2	grazed	June	2006	5.9	0	1.03	1.04
3	5	Middle	1	grazed	June	2006	6.4	0.07	1.25	1.31

Appendix P. Continued.

Block	Transect	Location	Analytical replicate	Grazing treatment	Month	Year	Soil organic matter (g N m^{-2})	Nitrate (g NO_3^- m^{-2})	Ammonium (g NH_4^+ m^{-2})	Total inorganic N (g N m^{-2})
3	5	Middle	2	grazed	June	2006	7.3	0.04	1.02	1.05
3	5	Edge	1	grazed	June	2006	8.9	0.04	0.95	0.99
3	5	Edge	2	grazed	June	2006	10.8	0.06	1.02	1.08
3	6	Streambank	1	excluded	June	2006	7.8	0	0.77	0.77
3	6	Streambank	2	excluded	June	2006	8.7	0	0.72	0.72
3	6	Middle	1	excluded	June	2006	12.0	0.05	1.32	1.37
3	6	Middle	2	excluded	June	2006	11.3	0.04	1.21	1.25
3	6	Edge	1	excluded	June	2006	10.6	0.05	1.29	1.34
3	6	Edge	2	excluded	June	2006	9.7	0.03	1.15	1.18
1	1	Streambank	1	grazed	August	2006	5.8	0.01	0.65	0.65
1	1	Streambank	2	grazed	August	2006	4.8	0.01	0.69	0.70
1	1	Middle	1	grazed	August	2006	7.4	0.01	---	---
1	1	Middle	2	grazed	August	2006	7.4	0	0.86	0.87
1	1	Edge	1	grazed	August	2006	9.4	0	0.66	0.66
1	1	Edge	2	grazed	August	2006	8.6	0.01	0.54	0.54
1	2	Streambank	1	excluded	August	2006	7.3	0	0.64	0.64
1	2	Streambank	2	excluded	August	2006	7.6	0.01	0.62	0.63
1	2	Middle	1	excluded	August	2006	6.8	0.02	0.58	0.60
1	2	Middle	2	excluded	August	2006	7.3	0.02	0.57	0.59
1	2	Edge	1	excluded	August	2006	7.4	0.01	---	---
1	2	Edge	2	excluded	August	2006	7.2	0	0.61	0.61
2	3	Streambank	1	grazed	August	2006	9.4	0.04	0.72	0.76
2	3	Streambank	2	grazed	August	2006	9.0	0.04	0.73	0.77
2	3	Middle	1	grazed	August	2006	8.1	0.06	0.45	0.51
2	3	Middle	2	grazed	August	2006	8.4	0.06	0.46	0.52
2	3	Edge	1	grazed	August	2006	13.5	0.02	0.68	0.70
2	3	Edge	2	grazed	August	2006	13.6	0.02	0.68	0.70
2	4	Streambank	1	excluded	August	2006	7.9	0	1.33	1.33
2	4	Streambank	2	excluded	August	2006	7.8	0	1.22	1.22
2	4	Middle	1	excluded	August	2006	10.1	0.04	1.01	1.05
2	4	Middle	2	excluded	August	2006	10.4	0.04	1.02	1.06
2	4	Edge	1	excluded	August	2006	9.4	0.01	0.73	0.74
2	4	Edge	2	excluded	August	2006	9.2	0.01	0.62	0.63
3	5	Streambank	1	grazed	August	2006	5.0	0	0.45	0.45

Appendix P. Continued.

Block	Transect	Location	Analytical replicate	Grazing treatment	Month	Year	Soil organic matter (g N m^{-2})	Nitrate (g NO_3^- m^{-2})	Ammonium (g NH_4^+ m^{-2})	Total inorganic N (g N m^{-2})
3	5	Streambank	2	grazed	August	2006	4.8	0	0.47	0.47
3	5	Middle	1	grazed	August	2006	7.2	0.02	0.53	0.55
3	5	Middle	2	grazed	August	2006	6.8	0.02	0.58	0.60
3	5	Edge	1	grazed	August	2006	8.9	0.01	0.64	0.65
3	5	Edge	2	grazed	August	2006	8.7	0.01	0.61	0.61
3	6	Streambank	1	excluded	August	2006	8.1	0	0.44	0.44
3	6	Streambank	2	excluded	August	2006	8.3	0	0.48	0.48
3	6	Middle	1	excluded	August	2006	11.8	0	0.65	0.65
3	6	Middle	2	excluded	August	2006	12.0	0	0.75	0.75
3	6	Edge	1	excluded	August	2006	9.9	0	0.40	0.40
3	6	Edge	2	excluded	August	2006	9.3	0.01	0.43	0.44
1	1	Streambank	1	grazed	October	2006	6.0	0.01	0.52	0.53
1	1	Streambank	2	grazed	October	2006	5.6	0.01	0.54	0.54
1	1	Middle	1	grazed	October	2006	9.3	0.01	0.90	0.91
1	1	Middle	2	grazed	October	2006	9.4	0	0.88	0.88
1	1	Edge	1	grazed	October	2006	9.4	0.03	0.74	0.77
1	1	Edge	2	grazed	October	2006	9.6	0	0.75	0.75
1	2	Streambank	1	excluded	October	2006	7.2	0	0.69	0.69
1	2	Streambank	2	excluded	October	2006	7.1	0	0.57	0.57
1	2	Middle	1	excluded	October	2006	9.1	0.04	0.72	0.75
1	2	Middle	2	excluded	October	2006	7.1	0.05	0.77	0.82
1	2	Edge	1	excluded	October	2006	8.2	0.01	0.70	0.72
1	2	Edge	2	excluded	October	2006	7.9	0	0.59	0.59
2	3	Streambank	1	grazed	October	2006	11.6	0.04	0.82	0.87
2	3	Streambank	2	grazed	October	2006	10.6	0.05	0.89	0.94
2	3	Middle	1	grazed	October	2006	9.3	0.13	0.63	0.76
2	3	Middle	2	grazed	October	2006	9.7	0.10	0.52	0.62
2	3	Edge	1	grazed	October	2006	15.0	0.04	0.79	0.83
2	3	Edge	2	grazed	October	2006	14.6	0.04	0.80	0.83
2	4	Streambank	1	excluded	October	2006	7.6	0.01	0.62	0.63
2	4	Streambank	2	excluded	October	2006	9.2	0.01	0.59	0.60
2	4	Middle	1	excluded	October	2006	11.4	0.05	0.90	0.95
2	4	Middle	2	excluded	October	2006	12.3	0.02	0.67	0.69
2	4	Edge	1	excluded	October	2006	10.5	0.02	0.74	0.76

Appendix P. Continued.

Block	Transect	Location	Analytical replicate	Grazing treatment	Month	Year	Soil organic matter (g N m^{-2})	Nitrate (g NO_3^- m^{-2})	Ammonium (g NH_4^+ m^{-2})	Total inorganic N (g N m^{-2})
2	4	Edge	2	excluded	October	2006	10.6	0.02	0.72	0.74
3	5	Streambank	1	grazed	October	2006	5.8	0	0.62	0.62
3	5	Streambank	2	grazed	October	2006	5.9	0	0.62	0.62
3	5	Middle	1	grazed	October	2006	8.0	0.02	0.73	0.74
3	5	Middle	2	grazed	October	2006	7.9	0.03	0.80	0.83
3	5	Edge	1	grazed	October	2006	10.5	0.01	0.63	0.65
3	5	Edge	2	grazed	October	2006	10.8	0.02	0.79	0.81
3	6	Streambank	1	excluded	October	2006	8.6	0	0.56	0.56
3	6	Streambank	2	excluded	October	2006	8.7	0	0.55	0.55
3	6	Middle	1	excluded	October	2006	11.3	0.02	0.79	0.80
3	6	Middle	2	excluded	October	2006	12.2	0.01	0.67	0.68
3	6	Edge	1	excluded	October	2006	10.1	0.02	0.59	0.61
3	6	Edge	2	excluded	October	2006	10.6	0.02	0.61	0.63

Appendix Q. Water soluble organic C (WSOC) and water soluble total N (WSTN) measured at Sheep Creek in 2006.

Block	Transect	Location	Analytical replicate	Grazing treatment	Month	WSOC (g C m^{-2})	WSTN (g N m^{-2})
1	1	Streambank	1	grazed	June	0.72	0.02
1	1	Streambank	2	grazed	June	0.56	0.02
1	1	Middle	1	grazed	June	1.20	0.03
1	1	Middle	2	grazed	June	1.32	0.03
1	1	Edge	1	grazed	June	3.73	0.04
1	1	Edge	2	grazed	June	3.64	0.04
1	2	Streambank	1	excluded	June	0.67	0.02
1	2	Streambank	2	excluded	June	0.55	0.02
1	2	Middle	1	excluded	June	0.21	0.04
1	2	Middle	2	excluded	June	0.36	0.04
1	2	Edge	1	excluded	June	1.07	0.03
1	2	Edge	2	excluded	June	0.99	0.03
2	3	Streambank	1	grazed	June	3.79	0.08
2	3	Streambank	2	grazed	June	3.25	0.07
2	3	Middle	1	grazed	June	2.46	0.08
2	3	Middle	2	grazed	June	2.18	0.07
2	3	Edge	1	grazed	June	5.34	0.07
2	3	Edge	2	grazed	June	4.97	0.06
2	4	Streambank	1	excluded	June	3.21	0.03
2	4	Streambank	2	excluded	June	3.18	0.03
2	4	Middle	1	excluded	June	3.80	0.05
2	4	Middle	2	excluded	June	4.04	0.05
2	4	Edge	1	excluded	June	4.13	0.07
2	4	Edge	2	excluded	June	4.12	0.08
3	5	Streambank	1	grazed	June	1.83	0.01
3	5	Streambank	2	grazed	June	1.62	0.01
3	5	Middle	1	grazed	June	1.94	0.04
3	5	Middle	2	grazed	June	1.97	0.04
3	5	Edge	1	grazed	June	2.62	0.05
3	5	Edge	2	grazed	June	2.97	0.05
3	6	Streambank	1	excluded	June	4.70	0.03
3	6	Streambank	2	excluded	June	5.15	0.04
3	6	Middle	1	excluded	June	3.73	0.02
3	6	Middle	2	excluded	June	3.95	0.02
3	6	Edge	1	excluded	June	3.21	0.03
3	6	Edge	2	excluded	June	3.33	0.03
1	1	Streambank	1	grazed	August	1.57	0.02
1	1	Streambank	2	grazed	August	1.94	0.02
1	1	Middle	1	grazed	August	2.80	0.04
1	1	Middle	2	grazed	August	2.86	0.04
1	1	Edge	1	grazed	August	6.57	0.06
1	1	Edge	2	grazed	August	6.03	0.05
1	2	Streambank	1	excluded	August	3.26	0.04
1	2	Streambank	2	excluded	August	3.40	0.04
1	2	Middle	1	excluded	August	2.39	0.05

Appendix Q.

Block	Transect	Location	Analytical replicate	Grazing treatment	Month	WSOC ($g\ C\ m^{-2}$)	WSTN ($g\ N\ m^{-2}$)
1	2	Middle	2	excluded	August	2.34	0.05
1	2	Edge	1	excluded	August	2.82	0.04
1	2	Edge	2	excluded	August	2.76	0.04
2	3	Streambank	1	grazed	August	4.80	0.08
2	3	Streambank	2	grazed	August	4.34	0.08
2	3	Middle	1	grazed	August	5.48	0.10
2	3	Middle	2	grazed	August	5.37	0.10
2	3	Edge	1	grazed	August	4.74	0.05
2	3	Edge	2	grazed	August	5.38	0.06
2	4	Streambank	1	excluded	August	2.80	0.02
2	4	Streambank	2	excluded	August	2.85	0.02
2	4	Middle	1	excluded	August	4.05	0.05
2	4	Middle	2	excluded	August	6.52	0.06
2	4	Edge	1	excluded	August	5.48	0.07
2	4	Edge	2	excluded	August	5.11	0.07
3	5	Streambank	1	grazed	August	2.73	0.03
3	5	Streambank	2	grazed	August	2.70	0.03
3	5	Middle	1	grazed	August	3.32	0.06
3	5	Middle	2	grazed	August	3.16	0.06
3	5	Edge	1	grazed	August	5.38	0.10
3	5	Edge	2	grazed	August	5.10	0.09
3	6	Streambank	1	excluded	August	6.09	0.05
3	6	Streambank	2	excluded	August	5.83	0.06
3	6	Middle	1	excluded	August	3.07	0.03
3	6	Middle	2	excluded	August	3.39	0.03
3	6	Edge	1	excluded	August	3.83	0.05
3	6	Edge	2	excluded	August	3.43	0.05
1	1	Streambank	1	grazed	October	1.40	0.01
1	1	Streambank	2	grazed	October	1.60	0.01
1	1	Middle	1	grazed	October	2.28	0.02
1	1	Middle	2	grazed	October	2.41	0.02
1	1	Edge	1	grazed	October	4.06	0.02
1	1	Edge	2	grazed	October	4.08	0.02
1	2	Streambank	1	excluded	October	2.17	0.01
1	2	Streambank	2	excluded	October	2.01	0.02
1	2	Middle	1	excluded	October	1.66	0.02
1	2	Middle	2	excluded	October	1.58	0.02
1	2	Edge	1	excluded	October	1.74	0.01
1	2	Edge	2	excluded	October	1.69	0.01
2	3	Streambank	1	grazed	October	4.33	0.06
2	3	Streambank	2	grazed	October	4.29	0.06
2	3	Middle	1	grazed	October	2.86	0.08
2	3	Middle	2	grazed	October	2.99	0.08
2	3	Edge	1	grazed	October	6.32	0.05
2	3	Edge	2	grazed	October	7.24	0.06
2	4	Streambank	1	excluded	October	2.91	0.01
2	4	Streambank	2	excluded	October	3.28	0.02

Appendix Q.

Block	Transect	Location	Analytical replicate	Grazing treatment	Month	WSOC (g C m^{-2})	WSTN (g N m^{-2})
2	4	Middle	1	excluded	October	3.91	0.03
2	4	Middle	2	excluded	October	3.80	0.03
2	4	Edge	1	excluded	October	3.63	0.03
2	4	Edge	2	excluded	October	4.07	0.03
3	5	Streambank	1	grazed	October	2.63	0.02
3	5	Streambank	2	grazed	October	2.81	0.02
3	5	Middle	1	grazed	October	2.21	0.05
3	5	Middle	2	grazed	October	2.24	0.05
3	5	Edge	1	grazed	October	4.02	0.06
3	5	Edge	2	grazed	October	4.04	0.05
3	6	Streambank	1	excluded	October	4.53	0.03
3	6	Streambank	2	excluded	October	4.82	0.03
3	6	Middle	1	excluded	October	4.39	0.02
3	6	Middle	2	excluded	October	4.16	0.02
3	6	Edge	1	excluded	October	3.66	0.03
3	6	Edge	2	excluded	October	3.85	0.04

Appendix R. Ash-free dry mass remaining (% AFDM) in litter bags upon removal from soil. Bags were buried at Sheep Creek in October 2004 and one bag from each plot was removed from April to October 2005.

Block	Transect	Location	Plot	Grazing treatment	Month removed	%AFDM
1	1	Streambank	1	grazed	End of April	77
1	1	Streambank	2	grazed	End of April	67
1	1	Streambank	3	grazed	End of April	72
1	1	Streambank	4	grazed	End of April	71
1	1	Middle	1	grazed	End of April	76
1	1	Middle	2	grazed	End of April	78
1	1	Middle	3	grazed	End of April	78
1	1	Middle	4	grazed	End of April	80
1	1	Edge	1	grazed	End of April	75
1	1	Edge	2	grazed	End of April	83
1	1	Edge	3	grazed	End of April	74
1	1	Edge	4	grazed	End of April	77
1	2	Streambank	1	excluded	End of April	67
1	2	Streambank	2	excluded	End of April	72
1	2	Streambank	3	excluded	End of April	75
1	2	Streambank	4	excluded	End of April	80
1	2	Middle	1	excluded	End of April	74
1	2	Middle	2	excluded	End of April	80
1	2	Middle	3	excluded	End of April	70
1	2	Middle	4	excluded	End of April	79
1	2	Edge	1	excluded	End of April	75
1	2	Edge	2	excluded	End of April	78
1	2	Edge	3	excluded	End of April	79
1	2	Edge	4	excluded	End of April	71
2	3	Streambank	1	grazed	End of April	98
2	3	Streambank	2	grazed	End of April	102
2	3	Streambank	3	grazed	End of April	93
2	3	Streambank	4	grazed	End of April	96
2	3	Middle	1	grazed	End of April	102
2	3	Middle	2	grazed	End of April	109
2	3	Middle	3	grazed	End of April	104
2	3	Middle	4	grazed	End of April	116
2	3	Edge	1	grazed	End of April	88
2	3	Edge	2	grazed	End of April	117
2	3	Edge	3	grazed	End of April	98
2	3	Edge	4	grazed	End of April	98
2	4	Streambank	1	excluded	End of April	96
2	4	Streambank	2	excluded	End of April	88
2	4	Streambank	3	excluded	End of April	100
2	4	Streambank	4	excluded	End of April	93
2	4	Middle	1	excluded	End of April	103
2	4	Middle	2	excluded	End of April	99
2	4	Middle	3	excluded	End of April	104
2	4	Middle	4	excluded	End of April	106
2	4	Edge	1	excluded	End of April	97
2	4	Edge	2	excluded	End of April	102
2	4	Edge	3	excluded	End of April	97
2	4	Edge	4	excluded	End of April	99
3	5	Streambank	1	grazed	End of April	81
3	5	Streambank	2	grazed	End of April	97
3	5	Streambank	3	grazed	End of April	80

Appendix R. Continued.

Block	Transect	Location	Plot	Grazing treatment	Month removed	%AFDM
3	5	Streambank	4	grazed	End of April	98
3	5	Middle	1	grazed	End of April	85
3	5	Middle	2	grazed	End of April	83
3	5	Middle	3	grazed	End of April	86
3	5	Middle	4	grazed	End of April	93
3	5	Edge	1	grazed	End of April	92
3	5	Edge	2	grazed	End of April	97
3	5	Edge	3	grazed	End of April	84
3	5	Edge	4	grazed	End of April	94
3	6	Streambank	1	excluded	End of April	77
3	6	Streambank	2	excluded	End of April	90
3	6	Streambank	3	excluded	End of April	85
3	6	Streambank	4	excluded	End of April	84
3	6	Middle	1	excluded	End of April	82
3	6	Middle	2	excluded	End of April	86
3	6	Middle	3	excluded	End of April	92
3	6	Middle	4	excluded	End of April	93
3	6	Edge	1	excluded	End of April	83
3	6	Edge	2	excluded	End of April	94
3	6	Edge	3	excluded	End of April	88
3	6	Edge	4	excluded	End of April	82
1	1	Streambank	1	grazed	June	88
1	1	Streambank	2	grazed	June	78
1	1	Streambank	3	grazed	June	79
1	1	Streambank	4	grazed	June	73
1	1	Middle	1	grazed	June	77
1	1	Middle	2	grazed	June	79
1	1	Middle	3	grazed	June	81
1	1	Middle	4	grazed	June	72
1	1	Edge	1	grazed	June	86
1	1	Edge	2	grazed	June	94
1	1	Edge	3	grazed	June	86
1	1	Edge	4	grazed	June	86
1	2	Streambank	1	excluded	June	77
1	2	Streambank	2	excluded	June	73
1	2	Streambank	3	excluded	June	86
1	2	Streambank	4	excluded	June	84
1	2	Middle	1	excluded	June	75
1	2	Middle	2	excluded	June	80
1	2	Middle	3	excluded	June	76
1	2	Middle	4	excluded	June	76
1	2	Edge	1	excluded	June	75
1	2	Edge	2	excluded	June	75
1	2	Edge	3	excluded	June	78
1	2	Edge	4	excluded	June	80
2	3	Streambank	1	grazed	June	89
2	3	Streambank	2	grazed	June	70
2	3	Streambank	3	grazed	June	76
2	3	Streambank	4	grazed	June	78
2	3	Middle	1	grazed	June	88
2	3	Middle	2	grazed	June	92
2	3	Middle	3	grazed	June	85
2	3	Middle	4	grazed	June	91
2	3	Edge	1	grazed	June	87

Appendix R. Continued.

Block	Transect	Location	Plot	Grazing treatment	Month removed	%AFDM
2	3	Edge	2	grazed	June	82
2	3	Edge	3	grazed	June	92
2	3	Edge	4	grazed	June	93
2	4	Streambank	1	excluded	June	82
2	4	Streambank	2	excluded	June	84
2	4	Streambank	3	excluded	June	76
2	4	Streambank	4	excluded	June	82
2	4	Middle	1	excluded	June	85
2	4	Middle	2	excluded	June	79
2	4	Middle	3	excluded	June	77
2	4	Middle	4	excluded	June	77
2	4	Edge	1	excluded	June	92
2	4	Edge	2	excluded	June	87
2	4	Edge	3	excluded	June	84
2	4	Edge	4	excluded	June	80
3	5	Streambank	1	grazed	June	73
3	5	Streambank	2	grazed	June	75
3	5	Streambank	3	grazed	June	68
3	5	Streambank	4	grazed	June	77
3	5	Middle	1	grazed	June	76
3	5	Middle	2	grazed	June	71
3	5	Middle	3	grazed	June	70
3	5	Middle	4	grazed	June	55
3	5	Edge	1	grazed	June	85
3	5	Edge	2	grazed	June	69
3	5	Edge	3	grazed	June	68
3	5	Edge	4	grazed	June	74
3	6	Streambank	1	excluded	June	64
3	6	Streambank	2	excluded	June	66
3	6	Streambank	3	excluded	June	54
3	6	Streambank	4	excluded	June	83
3	6	Middle	1	excluded	June	80
3	6	Middle	2	excluded	June	76
3	6	Middle	3	excluded	June	76
3	6	Middle	4	excluded	June	73
3	6	Edge	1	excluded	June	78
3	6	Edge	2	excluded	June	71
3	6	Edge	3	excluded	June	77
3	6	Edge	4	excluded	June	69
1	1	Streambank	1	grazed	August	52
1	1	Streambank	2	grazed	August	44
1	1	Streambank	3	grazed	August	55
1	1	Streambank	4	grazed	August	0
1	1	Middle	1	grazed	August	42
1	1	Middle	2	grazed	August	65
1	1	Middle	3	grazed	August	55
1	1	Middle	4	grazed	August	38
1	1	Edge	1	grazed	August	66
1	1	Edge	2	grazed	August	64
1	1	Edge	3	grazed	August	58
1	1	Edge	4	grazed	August	56
1	2	Streambank	1	excluded	August	40
1	2	Streambank	2	excluded	August	44
1	2	Streambank	3	excluded	August	51

Appendix R. Continued.

Block	Transect	Location	Plot	Grazing treatment	Month removed	%AFDM
1	2	Streambank	4	excluded	August	40
1	2	Middle	1	excluded	August	44
1	2	Middle	2	excluded	August	44
1	2	Middle	3	excluded	August	49
1	2	Middle	4	excluded	August	55
1	2	Edge	1	excluded	August	48
1	2	Edge	2	excluded	August	55
1	2	Edge	3	excluded	August	57
1	2	Edge	4	excluded	August	58
2	3	Streambank	1	grazed	August	53
2	3	Streambank	2	grazed	August	47
2	3	Streambank	3	grazed	August	51
2	3	Streambank	4	grazed	August	44
2	3	Middle	1	grazed	August	55
2	3	Middle	2	grazed	August	51
2	3	Middle	3	grazed	August	53
2	3	Middle	4	grazed	August	56
2	3	Edge	1	grazed	August	52
2	3	Edge	2	grazed	August	30
2	3	Edge	3	grazed	August	45
2	3	Edge	4	grazed	August	53
2	4	Streambank	1	excluded	August	59
2	4	Streambank	2	excluded	August	54
2	4	Streambank	3	excluded	August	58
2	4	Streambank	4	excluded	August	50
2	4	Middle	1	excluded	August	65
2	4	Middle	2	excluded	August	61
2	4	Middle	3	excluded	August	57
2	4	Middle	4	excluded	August	58
2	4	Edge	1	excluded	August	54
2	4	Edge	2	excluded	August	48
2	4	Edge	3	excluded	August	58
2	4	Edge	4	excluded	August	26
3	5	Streambank	1	grazed	August	34
3	5	Streambank	2	grazed	August	26
3	5	Streambank	3	grazed	August	39
3	5	Streambank	4	grazed	August	55
3	5	Middle	1	grazed	August	35
3	5	Middle	2	grazed	August	35
3	5	Middle	3	grazed	August	47
3	5	Middle	4	grazed	August	46
3	5	Edge	1	grazed	August	42
3	5	Edge	2	grazed	August	43
3	5	Edge	3	grazed	August	20
3	5	Edge	4	grazed	August	27
3	6	Streambank	1	excluded	August	16
3	6	Streambank	2	excluded	August	33
3	6	Streambank	3	excluded	August	22
3	6	Streambank	4	excluded	August	35
3	6	Middle	1	excluded	August	43
3	6	Middle	2	excluded	August	50
3	6	Middle	3	excluded	August	38
3	6	Middle	4	excluded	August	30
3	6	Edge	1	excluded	August	40

Appendix R. Continued.

Block	Transect	Location	Plot	Grazing treatment	Month removed	%AFDM
3	6	Edge	2	excluded	August	48
3	6	Edge	3	excluded	August	42
3	6	Edge	4	excluded	August	23
1	1	Streambank	1	grazed	October	53
1	1	Streambank	2	grazed	October	51
1	1	Streambank	3	grazed	October	53
1	1	Streambank	4	grazed	October	0
1	1	Middle	1	grazed	October	36
1	1	Middle	2	grazed	October	51
1	1	Middle	3	grazed	October	45
1	1	Middle	4	grazed	October	0
1	1	Edge	1	grazed	October	54
1	1	Edge	2	grazed	October	62
1	1	Edge	3	grazed	October	54
1	1	Edge	4	grazed	October	38
1	2	Streambank	1	excluded	October	37
1	2	Streambank	2	excluded	October	50
1	2	Streambank	3	excluded	October	41
1	2	Streambank	4	excluded	October	54
1	2	Middle	1	excluded	October	43
1	2	Middle	2	excluded	October	55
1	2	Middle	3	excluded	October	34
1	2	Middle	4	excluded	October	26
1	2	Edge	1	excluded	October	50
1	2	Edge	2	excluded	October	61
1	2	Edge	3	excluded	October	64
1	2	Edge	4	excluded	October	48
2	3	Streambank	1	grazed	October	43
2	3	Streambank	2	grazed	October	37
2	3	Streambank	3	grazed	October	43
2	3	Streambank	4	grazed	October	49
2	3	Middle	1	grazed	October	65
2	3	Middle	2	grazed	October	62
2	3	Middle	3	grazed	October	60
2	3	Middle	4	grazed	October	44
2	3	Edge	1	grazed	October	52
2	3	Edge	2	grazed	October	39
2	3	Edge	3	grazed	October	57
2	3	Edge	4	grazed	October	71
2	4	Streambank	1	excluded	October	45
2	4	Streambank	2	excluded	October	59
2	4	Streambank	3	excluded	October	47
2	4	Streambank	4	excluded	October	56
2	4	Middle	1	excluded	October	52
2	4	Middle	2	excluded	October	56
2	4	Middle	3	excluded	October	66
2	4	Middle	4	excluded	October	0
2	4	Edge	1	excluded	October	37
2	4	Edge	2	excluded	October	37
2	4	Edge	3	excluded	October	36
2	4	Edge	4	excluded	October	34
3	5	Streambank	1	grazed	October	40
3	5	Streambank	2	grazed	October	68
3	5	Streambank	3	grazed	October	51

Appendix R. Continued.

Block	Transect	Location	Plot	Grazing treatment	Month removed	%AFDM
3	5	Streambank	4	grazed	October	61
3	5	Middle	1	grazed	October	44
3	5	Middle	2	grazed	October	31
3	5	Middle	3	grazed	October	41
3	5	Middle	4	grazed	October	41
3	5	Edge	1	grazed	October	61
3	5	Edge	2	grazed	October	71
3	5	Edge	3	grazed	October	35
3	5	Edge	4	grazed	October	54
3	6	Streambank	1	excluded	October	36
3	6	Streambank	2	excluded	October	52
3	6	Streambank	3	excluded	October	38
3	6	Streambank	4	excluded	October	35
3	6	Middle	1	excluded	October	34
3	6	Middle	2	excluded	October	39
3	6	Middle	3	excluded	October	36
3	6	Middle	4	excluded	October	39
3	6	Edge	1	excluded	October	37
3	6	Edge	2	excluded	October	52
3	6	Edge	3	excluded	October	55
3	6	Edge	4	excluded	October	56

Appendix S. Cumulative soil microbial CO_2 respiration, nitrification, N mineralization, net N mineralization, and immobilization index (Immob. index) measured during 21-day incubations of Sheep Creek soils collected in 2005 and 2006.

Block	Transect	Location	Analytical replicate	Grazing treatment	Month	Year	Soil CO_2 respiration (mg CO_2 g^{-1} soil C)	Nitrification (mg NO_3^- g^{-1} soil N)	N mineralization (mg NH_4^+ g^{-1} soil N)	Net N mineralization (mg N g^{-1} soil N)	Immob. index
1	1	Streambank	1	grazed	June	2005	48.1	0.6	12.1	12.7	3.8
1	1	Streambank	2	grazed	June	2005	38.6	0.7	14.1	14.9	2.6
1	1	Middle	1	grazed	June	2005	40.8	2.5	6.1	8.6	4.7
1	1	Middle	2	grazed	June	2005	38.8	2.4	5.8	8.2	4.7
1	1	Edge	1	grazed	June	2005	45.8	0	9.0	9.0	5.1
1	1	Edge	2	grazed	June	2005	32.8	0.3	9.4	9.7	3.4
1	2	Streambank	1	excluded	June	2005	1.0	0.4	12.2	12.6	0.1
1	2	Streambank	2	excluded	June	2005	48.3	1.1	12.5	13.6	3.6
1	2	Middle	1	excluded	June	2005	22.3	4.4	6.2	10.6	2.1
1	2	Middle	2	excluded	June	2005	33.6	4.4	6.3	10.8	3.1
1	2	Edge	1	excluded	June	2005	32.6	1.7	7.4	9.1	3.6
1	2	Edge	2	excluded	June	2005	23.2	4.7	4.7	9.4	2.5
2	3	Streambank	1	grazed	June	2005	34.5	12.0	0	12.0	2.9
2	3	Streambank	2	grazed	June	2005	36.3	1.3	14.1	15.4	2.4
2	3	Middle	1	grazed	June	2005	24.1	6.8	0	6.8	3.5
2	3	Middle	2	grazed	June	2005	22.8	5.3	0	5.3	4.3
2	3	Edge	1	grazed	June	2005	26.6	9.7	1.5	11.2	2.4
2	3	Edge	2	grazed	June	2005	27.3	10.6	1.1	11.7	2.3
2	4	Streambank	1	excluded	June	2005	42.0	0.7	9.8	10.5	4.0
2	4	Streambank	2	excluded	June	2005	43.3	2.6	1.9	4.5	9.7
2	4	Middle	1	excluded	June	2005	24.4	4.5	0	4.5	5.4
2	4	Middle	2	excluded	June	2005	30.8	9.2	1.1	10.3	3.0
2	4	Edge	1	excluded	June	2005	31.4	4.7	0	4.7	6.7
2	4	Edge	2	excluded	June	2005	35.9	0.8	8.7	9.5	3.8
3	5	Streambank	1	grazed	June	2005	28.4	6.7	1.4	8.1	3.5
3	5	Streambank	2	grazed	June	2005	41.6	1.7	11.0	12.7	3.3
3	5	Middle	1	grazed	June	2005	24.5	8.4	1.4	9.8	2.5
3	5	Middle	2	grazed	June	2005	30.7	1.4	9.7	11.2	2.8
3	5	Edge	1	grazed	June	2005	0.9	7.4	0.8	8.2	0.1
3	5	Edge	2	grazed	June	2005	35.3	8.5	1.0	9.5	3.7
3	6	Streambank	1	excluded	June	2005	36.2	0	11.0	11.0	3.3

Appendix S. Continued.

Block	Transect	Location	Analytical replicate	Grazing treatment	Month	Year	Soil CO_2 respiration (mg CO_2 g^{-1} soil C)	Nitrification (mg NO_3^- g^{-1} soil N)	N mineralization (mg NH_4^+ g^{-1} soil N)	Net N mineralization (mg N g^{-1} soil N)	Immob. index
3	6	Streambank	2	excluded	June	2005	36.8	0	11.0	11.0	3.3
3	6	Middle	1	excluded	June	2005	28.1	1.4	10.2	11.6	2.4
3	6	Middle	2	excluded	June	2005	29.5	1.3	9.3	10.6	2.8
3	6	Edge	1	excluded	June	2005	28.5	6.1	1.9	8.0	3.6
3	6	Edge	2	excluded	June	2005	21.2	6.6	1.8	8.3	2.6
1	1	Streambank	1	grazed	August	2005	24.1	0.2	9.1	9.3	2.6
1	1	Streambank	2	grazed	August	2005	35.6	0.8	6.8	7.5	4.7
1	1	Middle	1	grazed	August	2005	41.9	5.5	9.4	15.0	2.8
1	1	Middle	2	grazed	August	2005	36.1	2.1	3.6	5.8	6.3
1	1	Edge	1	grazed	August	2005	41.8	0.3	7.1	7.4	5.6
1	1	Edge	2	grazed	August	2005	38.3	0.3	5.8	6.1	6.3
1	2	Streambank	1	excluded	August	2005	41.2	1.2	9.5	10.7	3.9
1	2	Streambank	2	excluded	August	2005	19.8	0.9	8.5	9.4	2.1
1	2	Middle	1	excluded	August	2005	25.3	5.9	1.6	7.5	3.4
1	2	Middle	2	excluded	August	2005	31.3	10.7	3.8	14.5	2.2
1	2	Edge	1	excluded	August	2005	17.8	5.3	3.1	8.5	2.1
1	2	Edge	2	excluded	August	2005	19.9	4.5	2.9	7.5	2.7
2	3	Streambank	1	grazed	August	2005	1.7	12.3	0	12.3	0.1
2	3	Streambank	2	grazed	August	2005	37.8	10.4	0	10.4	3.6
2	3	Middle	1	grazed	August	2005	30.9	8.3	0	8.3	3.7
2	3	Middle	2	grazed	August	2005	13.6	5.7	0	5.7	2.4
2	3	Edge	1	grazed	August	2005	30.5	11.2	0	11.2	2.7
2	3	Edge	2	grazed	August	2005	28.5	8.7	0.2	8.9	3.2
2	4	Streambank	1	excluded	August	2005	31.9	0.4	4.1	4.5	7.1
2	4	Streambank	2	excluded	August	2005	33.0	0.3	4.8	5.2	6.4
2	4	Middle	1	excluded	August	2005	1.7	4.8	1.2	6.0	0.3
2	4	Middle	2	excluded	August	2005	28.4	4.8	1.0	5.8	4.9
2	4	Edge	1	excluded	August	2005	29.1	5.7	3.9	9.7	3.0
2	4	Edge	2	excluded	August	2005	31.4	5.1	3.5	8.6	3.7
3	5	Streambank	1	grazed	August	2005	0.6	0.5	19.0	19.5	0.0
3	5	Streambank	2	grazed	August	2005	20.2	1.6	18.1	19.7	1.0
3	5	Middle	1	grazed	August	2005	1.1	5.6	2.5	8.1	0.1
3	5	Middle	2	grazed	August	2005	15.9	6.2	3.0	9.2	1.7

Appendix S. Continued.

Block	Transect	Location	Analytical replicate	Grazing treatment	Month	Year	Soil CO_2 respiration (mg CO_2 g^{-1} soil C)	Nitrification (mg NO_3^- g^{-1} soil N)	N mineralization (mg NH_4^+ g^{-1} soil N)	Net N mineralization (mg N g^{-1} soil N)	Immob. index
3	5	Edge	1	grazed	August	2005	1.5	7.6	0.9	8.5	0.2
3	5	Edge	2	grazed	August	2005	39.3	7.6	0.7	8.3	4.7
3	6	Streambank	1	excluded	August	2005	40.0	0.5	10.6	11.1	3.6
3	6	Streambank	2	excluded	August	2005	45.4	0.6	10.2	10.7	4.2
3	6	Middle	1	excluded	August	2005	25.7	0.9	9.4	10.3	2.5
3	6	Middle	2	excluded	August	2005	31.1	1.0	9.3	10.3	3.0
3	6	Edge	1	excluded	August	2005	27.3	5.1	2.5	7.6	3.6
3	6	Edge	2	excluded	August	2005	25.5	5.1	2.3	7.4	3.4
1	1	Streambank	1	grazed	October	2005	39.4	0.3	6.8	7.1	5.5
1	1	Streambank	2	grazed	October	2005	43.7	0.3	9.1	9.4	4.7
1	1	Middle	1	grazed	October	2005	55.0	1.5	7.4	9.0	6.1
1	1	Middle	2	grazed	October	2005	26.5	1.1	6.4	7.5	3.5
1	1	Edge	1	grazed	October	2005	36.5	0.2	6.7	6.9	5.3
1	1	Edge	2	grazed	October	2005	35.8	0.1	6.4	6.6	5.4
1	2	Streambank	1	excluded	October	2005	51.6	0.4	10.1	10.5	4.9
1	2	Streambank	2	excluded	October	2005	27.5	0.3	8.4	8.8	3.1
1	2	Middle	1	excluded	October	2005	31.3	3.5	5.9	9.4	3.3
1	2	Middle	2	excluded	October	2005	36.7	3.0	4.5	7.5	4.9
1	2	Edge	1	excluded	October	2005	38.8	1.8	4.2	6.0	6.4
1	2	Edge	2	excluded	October	2005	23.7	2.4	5.0	7.4	3.2
2	3	Streambank	1	grazed	October	2005	46.3	7.6	0.5	8.2	5.7
2	3	Streambank	2	grazed	October	2005	48.3	8.9	0.2	9.1	5.3
2	3	Middle	1	grazed	October	2005	40.1	5.9	0.1	6.0	6.7
2	3	Middle	2	grazed	October	2005	33.4	6.0	0.1	6.1	5.5
2	3	Edge	1	grazed	October	2005	33.7	4.3	5.4	9.7	3.5
2	3	Edge	2	grazed	October	2005	32.3	4.4	5.1	9.5	3.4
2	4	Streambank	1	excluded	October	2005	34.6	0.1	3.5	3.6	9.6
2	4	Streambank	2	excluded	October	2005	35.4	0.1	3.8	3.9	9.1
2	4	Middle	1	excluded	October	2005	34.1	1.9	2.5	4.4	7.8
2	4	Middle	2	excluded	October	2005	36.7	1.4	2.5	4.0	9.3
2	4	Edge	1	excluded	October	2005	41.0	2.2	5.3	7.5	5.5
2	4	Edge	2	excluded	October	2005	49.2	2.2	4.6	6.8	7.3
3	5	Streambank	1	grazed	October	2005	21.0	0.3	11.9	12.2	1.7

Appendix S. Continued.

Block	Transect	Location	Analytical replicate	Grazing treatment	Month	Year	Soil CO_2 respiration (mg CO_2 g^{-1} soil C)	Nitrification (mg NO_3^- g^{-1} soil N)	N mineralization (mg NH_4^+ g^{-1} soil N)	Net N mineralization (mg N g^{-1} soil N)	Immob. index
3	5	Streambank	2	grazed	October	2005	38.9	0.4	11.3	11.7	3.3
3	5	Middle	1	grazed	October	2005	1.0	5.6	4.8	10.4	0.1
3	5	Middle	2	grazed	October	2005	5.0	4.3	3.4	7.7	0.7
3	5	Edge	1	grazed	October	2005	20.3	6.9	2.2	9.1	2.2
3	5	Edge	2	grazed	October	2005	26.8	8.6	1.1	9.7	2.8
3	6	Streambank	1	excluded	October	2005	34.7	0.5	5.2	5.7	6.1
3	6	Streambank	2	excluded	October	2005	32.0	0.6	6.0	6.7	4.8
3	6	Middle	1	excluded	October	2005	9.5	0.2	8.5	8.7	1.1
3	6	Middle	2	excluded	October	2005	28.7	0.2	8.3	8.5	3.4
3	6	Edge	1	excluded	October	2005	38.2	3.9	2.2	6.2	6.2
3	6	Edge	2	excluded	October	2005	19.8	3.4	1.5	4.9	4.0
1	1	Streambank	1	grazed	June	2006	18.4	0.7	8.0	8.7	2.1
1	1	Streambank	2	grazed	June	2006	36.0	0.6	6.5	7.1	5.1
1	1	Middle	1	grazed	June	2006	36.7	3.2	1.8	5.0	7.4
1	1	Middle	2	grazed	June	2006	41.3	5.0	3.4	8.3	4.9
1	1	Edge	1	grazed	June	2006	31.7	4.1	3.6	7.7	4.1
1	1	Edge	2	grazed	June	2006	31.0	5.6	4.8	10.3	3.0
1	2	Streambank	1	excluded	June	2006	35.3	0.8	10.5	11.3	3.1
1	2	Streambank	2	excluded	June	2006	37.3	0.6	9.2	9.8	3.8
1	2	Middle	1	excluded	June	2006	34.0	5.7	5.6	11.3	3.0
1	2	Middle	2	excluded	June	2006	32.6	4.7	5.4	10.1	3.2
1	2	Edge	1	excluded	June	2006	34.1	4.0	3.9	7.9	4.3
1	2	Edge	2	excluded	June	2006	32.3	5.6	5.0	10.6	3.0
2	3	Streambank	1	grazed	June	2006	32.3	11.4	0	11.4	2.8
2	3	Streambank	2	grazed	June	2006	25.7	11.5	0	11.5	2.2
2	3	Middle	1	grazed	June	2006	26.8	6.7	0.4	7.0	3.8
2	3	Middle	2	grazed	June	2006	25.5	7.3	0.4	7.7	3.3
2	3	Edge	1	grazed	June	2006	24.1	7.9	0.7	8.6	2.8
2	3	Edge	2	grazed	June	2006	24.7	10.1	0.9	11.0	2.2
2	4	Streambank	1	excluded	June	2006	30.9	0.2	6.8	7.1	4.4
2	4	Streambank	2	excluded	June	2006	31.2	0.1	5.5	5.7	5.5
2	4	Middle	1	excluded	June	2006	24.5	3.2	1.9	5.2	4.7
2	4	Middle	2	excluded	June	2006	24.8	3.7	2.4	6.1	4.0

Appendix S. Continued.

Block	Transect	Location	Analytical replicate	Grazing treatment	Month	Year	Soil CO_2 respiration (mg CO_2 g^{-1} soil C)	Nitrification (mg NO_3^- g^{-1} soil N)	N mineralization (mg NH_4^+ g^{-1} soil N)	Net N mineralization (mg N g^{-1} soil N)	Immob. index
2	4	Edge	1	excluded	June	2006	29.8	2.8	3.9	6.7	4.4
2	4	Edge	2	excluded	June	2006	29.0	3.7	5.2	9.0	3.2
3	5	Streambank	1	grazed	June	2006	37.5	1.7	13.1	14.8	2.5
3	5	Streambank	2	grazed	June	2006	10.8	2.4	11.6	14.0	0.8
3	5	Middle	1	grazed	June	2006	31.8	4.9	3.9	8.8	3.6
3	5	Middle	2	grazed	June	2006	32.6	4.5	3.2	7.7	4.2
3	5	Edge	1	grazed	June	2006	10.9	7.0	0.4	7.5	1.5
3	5	Edge	2	grazed	June	2006	33.6	6.2	0.5	6.8	5.0
3	6	Streambank	1	excluded	June	2006	29.7	0.8	5.0	5.9	5.1
3	6	Streambank	2	excluded	June	2006	23.1	0.9	4.7	5.7	4.1
3	6	Middle	1	excluded	June	2006	19.8	0.3	7.9	8.2	2.4
3	6	Middle	2	excluded	June	2006	22.7	0.3	7.2	7.5	3.0
3	6	Edge	1	excluded	June	2006	26.6	3.8	3.8	7.6	3.5
3	6	Edge	2	excluded	June	2006	25.7	3.9	4.0	7.9	3.3
1	1	Streambank	1	grazed	August	2006	26.5	0.6	10.1	10.8	2.5
1	1	Streambank	2	grazed	August	2006	41.1	0.5	9.8	10.3	4.0
1	1	Middle	1	grazed	August	2006	37.6	5.2	---	5.2	7.3
1	1	Middle	2	grazed	August	2006	37.7	4.9	3.4	8.3	4.5
1	1	Edge	1	grazed	August	2006	29.8	3.5	8.3	11.8	2.5
1	1	Edge	2	grazed	August	2006	31.6	2.4	6.2	8.6	3.7
1	2	Streambank	1	excluded	August	2006	43.8	0.8	10.0	10.8	4.1
1	2	Streambank	2	excluded	August	2006	45.2	0.7	9.2	9.9	4.6
1	2	Middle	1	excluded	August	2006	35.3	4.0	7.7	11.7	3.0
1	2	Middle	2	excluded	August	2006	33.7	3.4	6.3	9.7	3.5
1	2	Edge	1	excluded	August	2006	31.9	3.1	---	3.1	10.2
1	2	Edge	2	excluded	August	2006	32.5	4.2	6.7	10.8	3.0
2	3	Streambank	1	grazed	August	2006	32.6	8.7	0	8.7	3.7
2	3	Streambank	2	grazed	August	2006	34.0	7.4	0	7.4	4.6
2	3	Middle	1	grazed	August	2006	29.2	8.1	0	8.2	3.6
2	3	Middle	2	grazed	August	2006	28.2	6.3	0	6.3	4.5
2	3	Edge	1	grazed	August	2006	27.2	6.6	0.5	7.1	3.8
2	3	Edge	2	grazed	August	2006	26.0	6.9	0.4	7.3	3.6
2	4	Streambank	1	excluded	August	2006	36.9	0.4	8.4	8.8	4.2

Appendix S. Continued.

Block	Transect	Location	Analytical replicate	Grazing treatment	Month	Year	Soil CO_2 respiration (mg CO_2 g^{-1} soil C)	Nitrification (mg NO_3^- g^{-1} soil N)	N mineralization (mg NH_4^+ g^{-1} soil N)	Net N mineralization (mg N g^{-1} soil N)	Immob. index
2	4	Streambank	2	excluded	August	2006	38.0	0.3	6.7	7.0	5.4
2	4	Middle	1	excluded	August	2006	24.0	2.9	2.2	5.1	4.7
2	4	Middle	2	excluded	August	2006	26.7	3.3	3.1	6.4	4.2
2	4	Edge	1	excluded	August	2006	31.9	2.0	4.5	6.5	4.9
2	4	Edge	2	excluded	August	2006	31.6	2.5	5.0	7.5	4.2
3	5	Streambank	1	grazed	August	2006	38.0	2.1	10.5	12.6	3.0
3	5	Streambank	2	grazed	August	2006	27.9	2.5	14.8	17.3	1.6
3	5	Middle	1	grazed	August	2006	37.8	2.6	3.7	6.2	6.1
3	5	Middle	2	grazed	August	2006	13.6	2.1	3.4	5.5	2.5
3	5	Edge	1	grazed	August	2006	43.1	4.5	1.3	5.8	7.5
3	5	Edge	2	grazed	August	2006	41.6	4.4	1.3	5.8	7.2
3	6	Streambank	1	excluded	August	2006	36.0	0.4	4.0	4.4	8.3
3	6	Streambank	2	excluded	August	2006	35.0	0.3	4.0	4.4	8.0
3	6	Middle	1	excluded	August	2006	25.6	0.1	6.6	6.7	3.8
3	6	Middle	2	excluded	August	2006	26.5	0.1	9.0	9.1	2.9
3	6	Edge	1	excluded	August	2006	22.5	2.5	3.1	5.6	4.0
3	6	Edge	2	excluded	August	2006	32.9	2.4	2.8	5.3	6.2
1	1	Streambank	1	grazed	October	2006	37.9	0	10.5	10.5	3.6
1	1	Streambank	2	grazed	October	2006	36.3	0.1	9.3	9.4	3.9
1	1	Middle	1	grazed	October	2006	41.6	1.9	4.6	6.5	6.4
1	1	Middle	2	grazed	October	2006	43.1	1.7	4.8	6.5	6.7
1	1	Edge	1	grazed	October	2006	28.3	1.0	8.1	9.1	3.1
1	1	Edge	2	grazed	October	2006	29.2	1.2	8.9	10.0	2.9
1	2	Streambank	1	excluded	October	2006	37.1	0.3	10.5	10.8	3.4
1	2	Streambank	2	excluded	October	2006	37.0	0.3	10.6	10.9	3.4
1	2	Middle	1	excluded	October	2006	33.1	2.2	8.3	10.6	3.1
1	2	Middle	2	excluded	October	2006	32.5	2.4	7.8	10.2	3.2
1	2	Edge	1	excluded	October	2006	29.4	2.3	6.0	8.2	3.6
1	2	Edge	2	excluded	October	2006	35.2	2.4	5.9	8.3	4.3
2	3	Streambank	1	grazed	October	2006	30.8	14.3	1.1	15.4	2.0
2	3	Streambank	2	grazed	October	2006	34.1	9.6	1.9	11.5	3.0
2	3	Middle	1	grazed	October	2006	27.3	6.0	1.2	7.3	3.8
2	3	Middle	2	grazed	October	2006	27.2	5.4	1.0	6.4	4.3

Appendix S. Continued.

Block	Transect	Location	Analytical replicate	Grazing treatment	Month	Year	Soil CO_2 respiration (mg CO_2 g^{-1} soil C)	Nitrification (mg NO_3^- g^{-1} soil N)	N mineralization (mg NH_4^+ g^{-1} soil N)	Net N mineralization (mg N g^{-1} soil N)	Immob. index
2	3	Edge	1	grazed	October	2006	28.4	5.1	4.3	9.5	3.0
2	3	Edge	2	grazed	October	2006	28.8	5.7	4.9	10.6	2.7
2	4	Streambank	1	excluded	October	2006	29.9	0	6.0	6.0	5.0
2	4	Streambank	2	excluded	October	2006	32.0	0	6.4	6.5	4.9
2	4	Middle	1	excluded	October	2006	27.8	1.3	5.0	6.3	4.4
2	4	Middle	2	excluded	October	2006	27.7	1.1	4.9	6.0	4.6
2	4	Edge	1	excluded	October	2006	29.7	0.9	6.7	7.5	3.9
2	4	Edge	2	excluded	October	2006	29.2	0.8	6.7	7.5	3.9
3	5	Streambank	1	grazed	October	2006	40.6	0.2	8.6	8.8	4.6
3	5	Streambank	2	grazed	October	2006	47.5	0.2	10.6	10.8	4.4
3	5	Middle	1	grazed	October	2006	37.0	0.8	7.8	8.7	4.3
3	5	Middle	2	grazed	October	2006	38.0	1.0	8.2	9.2	4.1
3	5	Edge	1	grazed	October	2006	37.2	2.7	2.8	5.5	6.8
3	5	Edge	2	grazed	October	2006	36.9	3.9	3.9	7.8	4.8
3	6	Streambank	1	excluded	October	2006	33.8	0.1	8.5	8.7	3.9
3	6	Streambank	2	excluded	October	2006	33.5	0.1	7.5	7.6	4.4
3	6	Middle	1	excluded	October	2006	18.6	0	10.1	10.2	1.8
3	6	Middle	2	excluded	October	2006	25.1	0	10.1	10.1	2.5
3	6	Edge	1	excluded	October	2006	30.3	1.0	7.8	8.8	3.5
3	6	Edge	2	excluded	October	2006	30.8	0.9	6.1	7.0	4.4

Appendix T. Denitrification potential measured as denitrification enzyme activity (DEA) rate in short-term incubated soils collected at Sheep Creek in 2006.

Block	Transect	Location	Analytical replicate	Grazing treatment	Month	DEA (ug N_2O-N g^{-1} soil h^{-1})
1	1	Streambank	1	grazed	June	129
1	1	Streambank	2	grazed	June	46
1	1	Middle	1	grazed	June	281
1	1	Middle	2	grazed	June	205
1	1	Edge	1	grazed	June	225
1	1	Edge	2	grazed	June	186
1	2	Streambank	1	excluded	June	34
1	2	Streambank	2	excluded	June	248
1	2	Middle	1	excluded	June	43
1	2	Middle	2	excluded	June	79
1	2	Edge	1	excluded	June	80
1	2	Edge	2	excluded	June	218
2	3	Streambank	1	grazed	June	248
2	3	Streambank	2	grazed	June	298
2	3	Middle	1	grazed	June	922
2	3	Middle	2	grazed	June	686
2	3	Edge	1	grazed	June	---
2	3	Edge	2	grazed	June	815
2	4	Streambank	1	excluded	June	73
2	4	Streambank	2	excluded	June	131
2	4	Middle	1	excluded	June	510
2	4	Middle	2	excluded	June	438
2	4	Edge	1	excluded	June	403
2	4	Edge	2	excluded	June	588
3	5	Streambank	1	grazed	June	54
3	5	Streambank	2	grazed	June	55
3	5	Middle	1	grazed	June	505
3	5	Middle	2	grazed	June	118
3	5	Edge	1	grazed	June	878
3	5	Edge	2	grazed	June	897
3	6	Streambank	1	excluded	June	432
3	6	Streambank	2	excluded	June	153
3	6	Middle	1	excluded	June	565
3	6	Middle	2	excluded	June	124
3	6	Edge	1	excluded	June	460
3	6	Edge	2	excluded	June	1007
1	1	Streambank	1	grazed	August	16
1	1	Streambank	2	grazed	August	4
1	1	Middle	1	grazed	August	6
1	1	Middle	2	grazed	August	3
1	1	Edge	1	grazed	August	3
1	1	Edge	2	grazed	August	3
1	2	Streambank	1	excluded	August	5
1	2	Streambank	2	excluded	August	0
1	2	Middle	1	excluded	August	---
1	2	Middle	2	excluded	August	0
1	2	Edge	1	excluded	August	0
1	2	Edge	2	excluded	August	1

Appendix T. Continued.

Block	Transect	Location	Analytical replicate	Grazing treatment	Month	DEA (ug N_2O-N g^{-1} soil h^{-1})
2	3	Streambank	1	grazed	August	111
2	3	Streambank	2	grazed	August	46
2	3	Middle	1	grazed	August	127
2	3	Middle	2	grazed	August	225
2	3	Edge	1	grazed	August	279
2	3	Edge	2	grazed	August	813
2	4	Streambank	1	excluded	August	110
2	4	Streambank	2	excluded	August	70
2	4	Middle	1	excluded	August	44
2	4	Middle	2	excluded	August	97
2	4	Edge	1	excluded	August	55
2	4	Edge	2	excluded	August	174
3	5	Streambank	1	grazed	August	88
3	5	Streambank	2	grazed	August	---
3	5	Middle	1	grazed	August	17
3	5	Middle	2	grazed	August	10
3	5	Edge	1	grazed	August	---
3	5	Edge	2	grazed	August	24
3	6	Streambank	1	excluded	August	18
3	6	Streambank	2	excluded	August	200
3	6	Middle	1	excluded	August	44
3	6	Middle	2	excluded	August	22
3	6	Edge	1	excluded	August	13
3	6	Edge	2	excluded	August	50
1	1	Streambank	1	grazed	October	29
1	1	Streambank	2	grazed	October	10
1	1	Middle	1	grazed	October	6
1	1	Middle	2	grazed	October	14
1	1	Edge	1	grazed	October	9
1	1	Edge	2	grazed	October	14
1	2	Streambank	1	excluded	October	4
1	2	Streambank	2	excluded	October	3
1	2	Middle	1	excluded	October	9
1	2	Middle	2	excluded	October	7
1	2	Edge	1	excluded	October	9
1	2	Edge	2	excluded	October	16
2	3	Streambank	1	grazed	October	35
2	3	Streambank	2	grazed	October	28
2	3	Middle	1	grazed	October	16
2	3	Middle	2	grazed	October	727
2	3	Edge	1	grazed	October	169
2	3	Edge	2	grazed	October	396
2	4	Streambank	1	excluded	October	54
2	4	Streambank	2	excluded	October	10
2	4	Middle	1	excluded	October	816
2	4	Middle	2	excluded	October	84
2	4	Edge	1	excluded	October	177
2	4	Edge	2	excluded	October	63
3	5	Streambank	1	grazed	October	5
3	5	Streambank	2	grazed	October	23

Appendix T. Continued.

Block	Transect	Location	Analytical replicate	Grazing treatment	Month	DEA (ug N_2O-N g^{-1} soil h^{-1})
3	5	Middle	1	grazed	October	13
3	5	Middle	2	grazed	October	5
3	5	Edge	1	grazed	October	12
3	5	Edge	2	grazed	October	18
3	6	Streambank	1	excluded	October	9
3	6	Streambank	2	excluded	October	47
3	6	Middle	1	excluded	October	1195
3	6	Middle	2	excluded	October	91
3	6	Edge	1	excluded	October	58
3	6	Edge	2	excluded	October	317

Appendix U. Soil microbial biomass C and N pools and microbial C:N ratio of 2006 Sheep Creek soils estimated with the chloroform-fumigation extraction method.

Block	Transect	Location	Analytical replicate	Grazing treatment	Month	Microbial C (mg C m^{-2})	Microbial N (mg N m^{-2})	Microbial C:N
1	1	Streambank	1	grazed	June	23	1.0	24
1	1	Streambank	2	grazed	June	33	1.5	22
1	1	Middle	1	grazed	June	66	2.0	33
1	1	Middle	2	grazed	June	76	2.6	29
1	1	Edge	1	grazed	June	80	2.5	32
1	1	Edge	2	grazed	June	83	2.6	32
1	2	Streambank	1	excluded	June	78	2.8	28
1	2	Streambank	2	excluded	June	81	2.9	28
1	2	Middle	1	excluded	June	74	2.6	28
1	2	Middle	2	excluded	June	71	2.5	28
1	2	Edge	1	excluded	June	74	2.2	34
1	2	Edge	2	excluded	June	74	2.2	34
2	3	Streambank	1	grazed	June	88	2.8	32
2	3	Streambank	2	grazed	June	91	7.5	12
2	3	Middle	1	grazed	June	94	2.8	33
2	3	Middle	2	grazed	June	106	3.3	32
2	3	Edge	1	grazed	June	166	5.1	32
2	3	Edge	2	grazed	June	145	4.3	34
2	4	Streambank	1	excluded	June	66	6.2	11
2	4	Streambank	2	excluded	June	69	6.6	11
2	4	Middle	1	excluded	June	110	10.3	11
2	4	Middle	2	excluded	June	111	9.7	11
2	4	Edge	1	excluded	June	101	8.1	12
2	4	Edge	2	excluded	June	98	7.2	14
3	5	Streambank	1	grazed	June	40	4.2	9
3	5	Streambank	2	grazed	June	43	4.7	9
3	5	Middle	1	grazed	June	76	6.4	12
3	5	Middle	2	grazed	June	80	6.8	12
3	5	Edge	1	grazed	June	115	9.5	12
3	5	Edge	2	grazed	June	114	9.2	12
3	6	Streambank	1	excluded	June	108	8.3	13
3	6	Streambank	2	excluded	June	87	7.4	12
3	6	Middle	1	excluded	June	129	9.2	14
3	6	Middle	2	excluded	June	120	7.8	15
3	6	Edge	1	excluded	June	96	8.0	12
3	6	Edge	2	excluded	June	96	7.6	13
1	1	Streambank	1	grazed	August	34	3.0	11
1	1	Streambank	2	grazed	August	43	3.4	12
1	1	Middle	1	grazed	August	66	5.1	13
1	1	Middle	2	grazed	August	80	5.4	15
1	1	Edge	1	grazed	August	70	3.8	18
1	1	Edge	2	grazed	August	71	3.7	19
1	2	Streambank	1	excluded	August	79	4.7	17
1	2	Streambank	2	excluded	August	78	4.7	17
1	2	Middle	1	excluded	August	69	4.5	15
1	2	Middle	2	excluded	August	66	4.4	15
1	2	Edge	1	excluded	August	65	3.6	18
1	2	Edge	2	excluded	August	67	3.7	18

Appendix U. Continued.

Block	Transect	Location	Analytical replicate	Grazing treatment	Month	Microbial C (mg C m^{-2})	Microbial N (mg N m^{-2})	Microbial C:N
2	3	Streambank	1	grazed	August	87	7.5	12
2	3	Streambank	2	grazed	August	102	8.4	12
2	3	Middle	1	grazed	August	76	2.8	27
2	3	Middle	2	grazed	August	87	3.3	26
2	3	Edge	1	grazed	August	148	7.6	19
2	3	Edge	2	grazed	August	158	8.0	20
2	4	Streambank	1	excluded	August	81	7.3	11
2	4	Streambank	2	excluded	August	76	6.5	12
2	4	Middle	1	excluded	August	110	10.0	11
2	4	Middle	2	excluded	August	100	8.1	12
2	4	Edge	1	excluded	August	96	5.7	17
2	4	Edge	2	excluded	August	103	5.8	18
3	5	Streambank	1	grazed	August	41	3.4	12
3	5	Streambank	2	grazed	August	46	3.5	13
3	5	Middle	1	grazed	August	72	4.7	16
3	5	Middle	2	grazed	August	78	4.8	16
3	5	Edge	1	grazed	August	93	5.0	19
3	5	Edge	2	grazed	August	98	4.7	21
3	6	Streambank	1	excluded	August	85	4.8	18
3	6	Streambank	2	excluded	August	82	5.1	16
3	6	Middle	1	excluded	August	142	9.3	15
3	6	Middle	2	excluded	August	145	9.4	15
3	6	Edge	1	excluded	August	82	3.3	25
3	6	Edge	2	excluded	August	86	3.4	25
1	1	Streambank	1	grazed	October	44	3.2	14
1	1	Streambank	2	grazed	October	45	3.1	14
1	1	Middle	1	grazed	October	87	7.4	12
1	1	Middle	2	grazed	October	95	7.2	13
1	1	Edge	1	grazed	October	82	6.1	13
1	1	Edge	2	grazed	October	84	5.9	14
1	2	Streambank	1	excluded	October	89	6.0	15
1	2	Streambank	2	excluded	October	81	5.6	14
1	2	Middle	1	excluded	October	73	5.6	13
1	2	Middle	2	excluded	October	69	5.2	13
1	2	Edge	1	excluded	October	79	5.5	14
1	2	Edge	2	excluded	October	77	5.4	14
2	3	Streambank	1	grazed	October	108	9.4	12
2	3	Streambank	2	grazed	October	112	9.7	11
2	3	Middle	1	grazed	October	116	8.9	13
2	3	Middle	2	grazed	October	124	9.0	14
2	3	Edge	1	grazed	October	216	14.9	15
2	3	Edge	2	grazed	October	226	14.8	15
2	4	Streambank	1	excluded	October	69	6.4	11
2	4	Streambank	2	excluded	October	79	6.4	12
2	4	Middle	1	excluded	October	105	8.4	13
2	4	Middle	2	excluded	October	110	9.0	12
2	4	Edge	1	excluded	October	120	9.5	13
2	4	Edge	2	excluded	October	122	9.8	13
3	5	Streambank	1	grazed	October	58	4.1	14
3	5	Streambank	2	grazed	October	61	4.6	13

Appendix U. Continued.

Block	Transect	Location	Analytical replicate	Grazing treatment	Month	Microbial C (mg C m^{-2})	Microbial N (mg N m^{-2})	Microbial C:N
3	5	Middle	1	grazed	October	78	5.8	14
3	5	Middle	2	grazed	October	76	5.8	13
3	5	Edge	1	grazed	October	126	9.6	13
3	5	Edge	2	grazed	October	124	9.2	14
3	6	Streambank	1	excluded	October	95	6.5	15
3	6	Streambank	2	excluded	October	92	6.8	13
3	6	Middle	1	excluded	October	206	12.6	16
3	6	Middle	2	excluded	October	190	12.1	16
3	6	Edge	1	excluded	October	112	8.6	13
3	6	Edge	2	excluded	October	116	8.4	14

Appendix V. Statistical analyses of N pools and processes in aboveground and belowground ecosystem components at the Sheep Creek montane riparian zone.

Table V-1a. Analysis of variance (ANOVA) of location, grazing treatment (Trt), and year effects on aboveground primary production (APP, g A6m^{-2}). Significant differences were accepted at *P*-value < 0.10.

Covariance Parameter Estimates

Covariance Parameter	Estimate
Block	0
Block *Trt	2168
Block*Trt*Location	1093
Block*Trt*Location*Year	1997
Residual	0.97

Type III Tests of Fixed Effects

Effect	Numerator DF	Denominator DF	*F*-value	*P*-value
Location	2	8	6.13	0.02
Trt	1	2	0.23	0.68
Location*Trt	2	8	1.05	0.39
Year	1	12	34.44	<.0001
Location*Year	2	12	0.03	0.97
Trt*Year	1	12	1.57	0.23
Location*Trt*Year	2	12	0.51	0.61

Table V-1b. Differences of least square means in APP between Location and Year (significant effects in Table V-1a). Comparisons were made at *P* < 0.10, *P*-diff = difference between least square means.

Location	Location	Year	Year	*P*-diff	DF	*t*-value	*P*-value
Middle	Streambank			2	8	0.07	0.94
Middle	Edge			81	8	3.07	0.02
Streambank	Edge			79	8	2.99	0.02
		2005	2006	87	12	5.87	<.0001

Appendix V. Continued.

Table V-2a. Analysis of variance (ANOVA) of location, grazing treatment (Trt), and year effects on aboveground plant C and N pools (g m^{-2}) and C:N ratios. Plant C:N data were log-transformed and significant differences were accepted at P-value < 0.10.

Covariance Parameter Estimates		**Type III Tests of Fixed Effects**				
Covariance Parameter	**Estimate**	**Effect**	**Numerator DF**	**Denominator DF**	***F*-value**	***P*-value**
Plant C pool						
Block	0	Location	2	8	5.45	0.03
Block *Trt	383	Trt	1	2	0.65	0.50
Block*Trt*Location	209	Location*Trt	2	8	1.48	0.28
Block*Trt*Location*Year	590	Year	1	12	28.57	0.0002
Residual	1.16	Location*Year	2	12	0.07	0.94
		Trt*Year	1	12	0.28	0.61
		Location*Trt*Year	2	12	0.28	0.76
Plant N pool						
Block	0	Location	2	8	5.77	0.03
Block *Trt	0.16	Trt	1	2	0.62	0.51
Block*Trt*Location	0.06	Location*Trt	2	8	1.50	0.28
Block*Trt*Location*Year	0	Year	1	12	5.68	0.03
Residual	0.20	Location*Year	2	12	0.18	0.84
		Trt*Year	1	12	0.29	0.60
		Location*Trt*Year	2	12	0.02	0.98
Plant C:N						
Block	0.002	Location	2	8	0.97	0.42
Block *Trt	0	Trt	1	2	1.32	0.37
Block*Trt*Location	0	Location*Trt	2	8	2.62	0.13
Block*Trt*Location*Year	0	Year	1	12	27.75	0.0002
Residual	0.02	Location*Year	2	12	0.63	0.55
		Trt*Year	1	12	1.58	0.23
		Location*Trt*Year	2	12	0.88	0.44

Appendix V. Continued.

Table V-2b. Differences of least square means in aboveground plant C and N pools and C:N ratios between Location and Year (significant effects in Table V-2a). Comparisons were made at $P < 0.10$, P-diff = difference between least square means.

Location	Location	Year	Year	*P*-diff	DF	*t*-value	*P*-value
Plant C pool							
Middle	Streambank			10	8	0.79	0.45
Middle	Edge			41	8	3.17	0.01
Streambank	Edge			31	8	2.38	0.04
		2005	2006	43	12	5.35	0.0002
Plant N pool							
Middle	Streambank			0.26	8	1.12	0.30
Middle	Edge			0.77	8	3.34	0.01
Streambank	Edge			0.51	8	2.22	0.06
		2005	2006	0.35	12	2.38	0.03
Plant C:N							
Middle	Streambank			-0.05	8	-0.83	0.43
Middle	Edge			-0.08	8	-1.38	0.20
Streambank	Edge			-0.03	8	-0.55	0.60
		2005	2006	0.25	12	5.27	0.0002

Appendix V. Continued.

Table V-3. Analysis of variance (ANOVA) of location, grazing treatment (Trt), and month effects on root C and N pools (g m^{-2}) and C:N ratios. Root C pool and C:N data were log-transformed and significant differences were accepted at P-value < 0.10.

Covariance Parameter Estimates		Type III Tests of Fixed Effects				
Covariance Parameter	**Estimate**	**Effect**	**Numerator DF**	**Denominator DF**	***F*-value**	***P*-value**
Root C pool						
Block	0	Location	2	8	1.01	0.41
Block *Trt	0.14	Trt	1	2	0.29	0.65
Block*Trt*Location	0.67	Location*Trt	2	8	0.29	0.76
Block*Trt*Location*Year	0	Month	2	24	1.15	0.33
Residual	0.0005	Location*Month	4	24	0.81	0.53
		Trt*Month	2	24	0.60	0.56
		Location*Trt*Montl	4	24	1.80	0.16
Root N pool						
Block	0.22	Location	2	8	0.37	0.70
Block *Trt	0	Trt	1	2	0.02	0.90
Block*Trt*Location	8.75	Location*Trt	2	8	0.08	0.92
Block*Trt*Location*Year	0	Year	2	24	2.55	0.10
Residual	0.27	Location*Year	4	24	1.46	0.24
		Trt*Year	2	24	0.62	0.55
		Location*Trt*Year	4	24	0.90	0.48
Root C:N						
Block	0.0003	Location	2	8	0.16	0.85
Block *Trt	0.01	Trt	1	2	0.56	0.53
Block*Trt*Location	0.005	Location*Trt	2	8	0.42	0.67
Block*Trt*Location*Year	0	Year	2	24	3.05	0.07
Residual	0.01	Location*Year	4	24	1.04	0.40
		Trt*Year	2	24	0.88	0.43
		Location*Trt*Year	4	24	0.41	0.80

Appendix V. Continued.

Table V-4a. Analysis of variance (ANOVA) of location and grazing treatment (Trt) effects on absolute cover (%) of main functional groups (grass, sedge, forb). Forb data were log-transformed and significant differences were accepted at P-value < 0.10.

Covariance Parameter Estimates		Type III Tests of Fixed Effects				
Covariance Parameter	**Estimate**	**Effect**	**Numerator DF**	**Denominator DF**	***F*-value**	***P*-value**
Grass						
Block	1977	Location	2	8	4.99	0.04
Block *Trt	0	Trt	1	2	0.26	0.66
Block*Trt*Location	0	Location*Trt	2	8	0.29	0.75
Residual	2158					
Sedge						
Block	546	Location	2	8	0.80	0.48
Block *Trt	0	Trt	1	2	0.76	0.47
Block*Trt*Location	1232	Location*Trt	2	8	0.70	0.53
Residual	0.87					
Forb						
Block	0.14	Location	2	8	0.55	0.60
Block *Trt	0	Trt	1	2	0.43	0.58
Block*Trt*Location	0	Location*Trt	2	8	1.60	0.26
Residual	0.43					

Table V-4b. Differences of least square means in absolute cover (%) of grass, sedge, and forb functional groups between Location (significant effect in Table V-4a). Comparisons were made at $P < 0.10$, P-diff = difference between least square means.

Location	Location	*P*-diff	DF	*t*-value	*P*-value
Grass					
Middle	Streambank	11	8	0.85	0.42
Middle	Edge	56	8	4.41	0.002
Streambank	Edge	46	8	3.57	0.01
Sedge					
Middle	Streambank	12	8	0.57	0.59
Middle	Edge	26	8	1.27	0.24
Streambank	Edge	14	8	0.70	0.50
Forb					
Middle	Streambank	-0.05	8	-0.14	0.89
Middle	Edge	-0.37	8	-0.97	0.36
Streambank	Edge	-0.32	8	-0.83	0.43

Appendix V. Continued.

Table V-5. Analysis of variance (ANOVA) of location and grazing treatment (Trt) effects on total total plant cover (%) and species richness. Significant differences were accepted at P- value < 0.10.

Covariance Parameter Estimates		Type III Tests of Fixed Effects				
Covariance Parameter	**Estimate**	**Effect**	**Numerator DF**	**Denominator DF**	***F*-value**	***P*-value**
Total plant cover						
Block	1861	Location	2	8	1.65	0.25
Block *Trt	409	Trt	1	2	1.70	0.32
Block*Trt*Location	3179	Location*Trt	2	8	0.68	0.53
Residual	1					
Species richness						
Block	5.01	Location	2	8	1.81	0.22
Block *Trt	0	Trt	1	2	0.07	0.82
Block*Trt*Location	4.27	Location*Trt	2	8	0.17	0.85
Residual	0.97					

Table V-6a. Analysis of variance (ANOVA) of location and grazing treatment (Trt) effects on absolute cover (%) of most dominant species. Data were square-root transformed and significant differences were accepterd at P-value < 0.10.

Covariance Parameter Estimates		Type III Tests of Fixed Effects				
Covariance Parameter	**Estimate**	**Effect**	**Numerator DF**	**Denominator DF**	***F*-value**	***P*-value**
Achillea millefolium						
Block	0.69	Location	2	8	0.06	0.94
Block *Trt	0.02	Trt	1	2	2.18	0.28
Block*Trt*Location	0	Location*Trt	2	8	4.63	0.05
Residual	0.84					
Agrostis stolonifera						
Block	0.76	Location	2	8	2.38	0.15
Block *Trt	0	Trt	1	2	0.95	0.43
Block*Trt*Location	2.36	Location*Trt	2	8	1.68	0.25
Residual	0.75					
Carex aquatilis						
Block	0.86	Location	2	8	1.39	0.30
Block *Trt	0	Trt	1	2	5.06	0.15
Block*Trt*Location	2.72	Location*Trt	2	8	0.33	0.73
Residual	0.79					
Carex praticola						
Block	0	Location	2	8	1.00	0.41
Block *Trt	0.44	Trt	1	2	1.00	0.42
Block*Trt*Location	0.0002	Location*Trt	2	8	1.00	0.41
Residual	0.06					

Appendix V. Table V-6a. Continued.

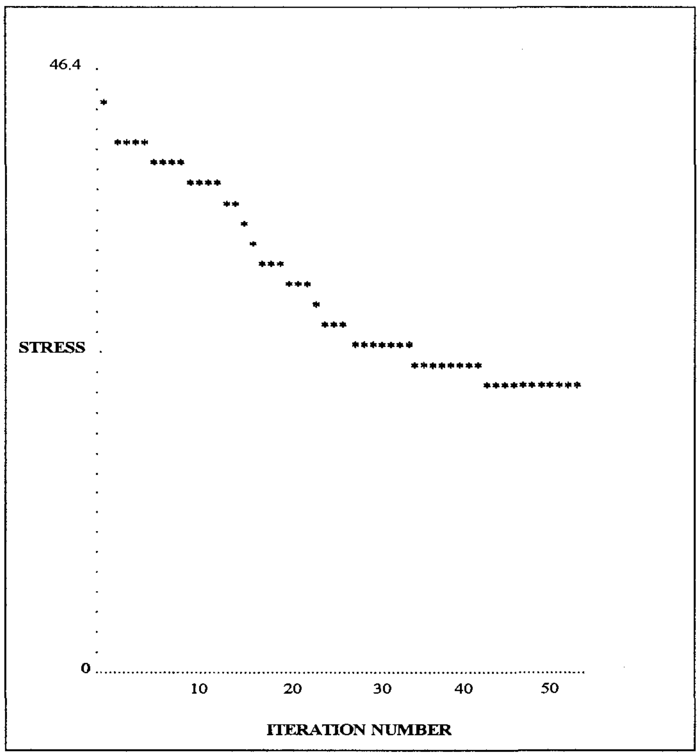
Covariance Parameter Estimates		Type III Tests of Fixed Effects				
Covariance Parameter	**Estimate**	**Effect**	**Numerator DF**	**Denominator DF**	***F*-value**	***P*-value**
Carex utriculata						
Block	0.74	Location	2	8	1.20	0.35
Block *Trt	0.57	Trt	1	2	0.00	0.95
Block*Trt*Location	1.45	Location*Trt	2	8	0.19	0.83
Residual	0.85					
Erigeron formosissimus						
Block	0	Location	2	8	18.91	0.001
Block *Trt	1.30	Trt	1	2	0.88	0.45
Block*Trt*Location	0	Location*Trt	2	8	15.63	0.002
Residual	0.34					
Fragaria spp.						
Block	0.15	Location	2	8	0.00	1.00
Block *Trt	0	Trt	1	2	8.37	0.10
Block*Trt*Location	0.96	Location*Trt	2	8	1.83	0.22
Residual	0.55					
Juncus arcticus						
Block	0.32	Location	2	8	0.34	0.72
Block *Trt	0.11	Trt	1	2	2.25	0.27
Block*Trt*Location	1.31	Location*Trt	2	8	0.30	0.75
Residual	0.72					
Juncus balticus						
Block	0	Location	2	8	0.54	0.60
Block *Trt	0	Trt	1	2	0.07	0.82
Block*Trt*Location	1.41	Location*Trt	2	8	0.97	0.42
Residual	0.56					
Phleum pratense						
Block	1.15	Location	2	8	1.26	0.34
Block *Trt	0.02	Trt	1	2	3.72	0.19
Block*Trt*Location	1.57	Location*Trt	2	8	1.20	0.35
Residual	0.84					
Potentilla spp.						
Block	0.81	Location	2	8	1.18	0.36
Block *Trt	0.12	Trt	1	2	0.14	0.75
Block*Trt*Location	0.82	Location*Trt	2	8	2.08	0.19
Residual	0.83					
Poa pratensis						
Block	0	Location	2	8	4.64	0.05
Block *Trt	0.78	Trt	1	2	0.06	0.83
Block*Trt*Location	1.04	Location*Trt	2	8	0.06	0.94
Residual	1.68					
Taraxacum officinale						
Block	0	Location	2	8	1.56	0.27
Block *Trt	0	Trt	1	2	1.81	0.31
Block*Trt*Location	0.84	Location*Trt	2	8	0.26	0.77
Residual	0.55					
Trifolium repens						
Block	0	Location	2	8	0.07	0.93
Block *Trt	0.75	Trt	1	2	0.86	0.45
Block*Trt*Location	0.56	Location*Trt	2	8	0.07	0.93
Residual	0.69					

Appendix V. Continued.

Table V-6b. Differences of least square means in absolute cover (%) of dominant species that differed between locations or grazing treatmenst (Trt) (significant Location or Trt effect in Table V-6a). Comparisons were made at $P < 0.10$, P-diff = difference between square-root transformed least square means.

Location	Location	Trt	Trt	*P*-diff	DF	*t*-value	*P*-value
Fragaria spp.							
Middle	Streambank			0.02	8	0.03	0.98
Middle	Edge			0.03	8	0.04	0.97
Streambank	Edge			0.01	8	0.01	0.99
		grazed	excluded	1.68	2	2.89	0.10
Erigeron formosissimus							
Middle	Streambank			-0.38	8	-1.14	0.29
Middle	Edge			-1.94	8	-5.80	0.0004
Streambank	Edge			-1.56	8	-4.66	0.002
Poa pratensis							
Middle	Streambank			1.70	8	1.78	0.11
Middle	Edge			2.89	8	3.03	0.02
Streambank	Edge			1.19	8	1.25	0.25

Table V-7a. Plot of stress vs. iteration number for non-metric multidimensional scaling (NMS) of species space in landscape location. Stress for a 2-dimensional solution was 20.5 and instability was 0.00046 after 53 iterations.



Appendix V. Continued.

Table V-8a. Analysis of variance (ANOVA) of location and grazing treatment (Trt) effects on soil particle distribution (% sand, clay, silt). Significant differences were accepted at *P*-value < 0.10.

Covariance Parameter Estimates		Type III Tests of Fixed Effects				
Covariance Parameter	**Estimate**	**Effect**	**Numerator DF**	**Denominator DF**	***F*-value**	***P*-value**
Sand						
Block	1.83	Location	2	8	6.22	0.02
Block *Trt	0	Trt	1	2	9.26	0.09
Block*Trt*Location	11.20	Location*Trt	2	8	2.09	0.19
Residual	0.91					
Clay						
Block	0.20	Location	2	8	9.48	0.01
Block *Trt	0.73	Trt	1	2	5.99	0.13
Block*Trt*Location	1.13	Location*Trt	2	8	0.98	0.42
Residual	0.79					
Silt						
Block	3.38	Location	2	8	3.42	0.08
Block *Trt	0	Trt	1	2	5.36	0.15
Block*Trt*Location	5.10	Location*Trt	2	8	2.76	0.12
Residual	0.84					

Table V-8b. Differences of least square means in soil particle sizes (% sand, clay, silt) between locations or grazing treatments (Trt) (significant Location or Trt effect in Table V-8a). Comparisons were made at *P* < 0.10, *P*-diff = difference between least square means.

Location	Location	Trt	Trt	*P*-diff	DF	*t*-value	*P*-value
Sand							
Middle	Streambank			-6.05	8	-3.01	0.02
Middle	Edge			0.18	8	0.09	0.93
Streambank	Edge			6.22	8	3.10	0.01
		grazed	excluded	-4.99	2	-3.04	0.09
Clay							
Middle	Streambank			2.66	8	3.33	0.01
Middle	Edge			-0.61	8	-0.76	0.47
Streambank	Edge			-3.27	8	-4.09	0.004
Silt							
Middle	Streambank			3.38	8	2.40	0.04
Middle	Edge			0.43	8	0.31	0.77
Streambank	Edge			-2.95	8	-2.10	0.07

Appendix V. Continued.

Table V-9. Analysis of variance (ANOVA) of location and grazing treatment (Trt) effects on soil bulk density. Significant differences were accepted at P-value < 0.10.

Covariance Parameter Estimates		Type III Tests of Fixed Effects				
Covariance Parameter	**Estimate**	**Effect**	**Numerator DF**	**Denominator DF**	***F*-value**	***P*-value**
Block	0	Location	2	8	0.49	0.63
Block *Trt	0	Trt	1	2	4.33	0.17
Block*Trt*Location	0.0003	Location*Trt	2	8	0.04	0.96
Residual	0.02					

Table V-10. Analysis of variance (ANOVA) of location, grazing treatment (Trt), and month effects on soil pH. Significant differences were accepted at P-value < 0.10.

Covariance Parameter Estimates		Type III Tests of Fixed Effects				
Covariance Parameter	**Estimate**	**Effect**	**Numerator DF**	**Denominator DF**	***F*-value**	***P*-value**
Block	0.06	Location	2	8	1.04	0.40
Block *Trt	0	Trt	1	2	0.01	0.92
Block*Trt*Location	0.07	Location*Trt	2	8	0.10	0.90
Block*Trt*Location*Month	0	Month	2	23	2.35	0.12
Residual	0.01	Location*Month	4	23	0.88	0.49
		Trt*Month	2	23	0.26	0.77
		Location*Trt*Month	4	23	0.62	0.65

Appendix V. Continued.

Table V-11a. Analysis of variance (ANOVA) of location, grazing treatment (Trt), month, and year effects on soil moisture (% gravimetric water content). Data were log-transformed and significant differences were accepted at P-value < 0.10.

Covariance Parameter Estimates

Covariance Parameter	Estimate
Block	0
Block *Trt	0
Block*Trt*Location	0.08
Block*Trt*Location*Month	0.002
Block*Trt*Location*Month*Year	0
Residual	0.17

Type III Tests of Fixed Effects

Effect	Numerator DF	Denominator DF	F-value	P-value
Location	2	8	1.48	0.28
Trt	1	2	0.60	0.52
Location*Trt	2	8	1.22	0.35
Month	2	24	9.04	0.001
Location*Month	4	24	0.60	0.67
Trt*Month	2	24	0.03	0.97
Location*Trt*Month	4	24	0.30	0.87
Year	1	35	17.97	0.0002
Location*Year	2	35	0.08	0.92
Trt*Year	1	35	0.56	0.46
Location*Trt*Year	2	35	0.17	0.85
Month*Year	2	35	0.63	0.54
Location*Month*Year	4	35	0.06	0.99
Trt*Month*Year	2	35	0.10	0.90
Location*Trt*Month*Year	4	35	0.13	0.97

Table V-11b. Differences of least square means in soil moisture between months and years (significant Month and Year effects in Table V-11a). Comparisons were made at P < 0.10, P-diff = difference between log-transformed least square means.

Month	Month	Year	Year	P-diff	DF	t-value	P-value
August	June			-0.35	24	-3.51	0.002
August	October			-0.38	24	-3.82	0.001
June	October			-0.03	24	-0.26	0.80
		2005	2006	0.34	35	4.24	0.0002

Appendix V. Continued.

Table V-12a. Analysis of variance (ANOVA) of location, grazing treatment (Trt), month, and year effects on soil C and N pools (kg m^{-2}) and C:N ratio. Data were log-transformed and significant differences were accepted at P-value < 0.10.

Covariance Parameter Estimates

Covariance Parameter	Estimate
Soil C pool	
Block	0.02
Block *Trt	0.05
Block*Trt*Location	0.01
Block*Trt*Location*Month	0
Block*Trt*Location*Month*Year	0
Residual	0.02
Soil N pool	
Block	0.04
Block *Trt	0.01
Block*Trt*Location	0.01
Block*Trt*Location*Month	0
Block*Trt*Location*Month*Year	0
Residual	0.007
Soil C:N	
Block	0
Block *Trt	0.005
Block*Trt*Location	0.02
Block*Trt*Location*Month	0
Block*Trt*Location*Month*Year	0
Residual	0.006

Appendix V. Table V-12a. Continued.

Type III Tests of Fixed Effects

Effect	Numerator DF	Denominator DF	*F*-value	*P*-value
Soil C pool				
Location	2	8	13.37	0.003
Trt	1	2	1.41	0.36
Location*Trt	2	8	10.90	0.01
Month	2	24	4.96	0.02
Location*Month	4	24	0.22	0.93
Trt*Month	2	24	0.31	0.73
Location*Trt*Month	4	24	0.10	0.98
Year	1	36	24.43	<.0001
Location*Year	2	36	1.42	0.26
Trt*Year	1	36	16.48	0.0003
Location*Trt*Year	2	36	0.25	0.78
Month*Year	2	36	0.65	0.53
Location*Month*Year	4	36	0.50	0.74
Trt*Month*Year	2	36	0.29	0.75
Location*Trt*Month*Year	4	36	0.13	0.97
Soil N pool				
Location	2	8	16.65	0.001
Trt	1	2	2.59	0.25
Location*Trt	2	8	3.42	0.08
Month	2	24	6.89	0.004
Location*Month	4	24	0.37	0.83
Trt*Month	2	24	0.45	0.64
Location*Trt*Month	4	24	0.26	0.90
Year	1	36	0.78	0.38
Location*Year	2	36	0.22	0.80
Trt*Year	1	36	16.87	0.0002
Location*Trt*Year	2	36	1.04	0.36
Month*Year	2	36	1.89	0.17
Location*Month*Year	4	36	0.55	0.70
Trt*Month*Year	2	36	0.40	0.67
Location*Trt*Month*Year	4	36	0.18	0.95
Soil C:N				
Location	2	8	1.03	0.40
Trt	1	2	0.58	0.52
Location*Trt	2	8	1.48	0.28
Month	2	24	1.34	0.28
Location*Month	4	24	0.09	0.99
Trt*Month	2	24	0.10	0.90
Location*Trt*Month	4	24	0.02	1.00
Year	1	36	59.73	<.0001
Location*Year	2	36	4.85	0.01
Trt*Year	1	36	6.50	0.02
Location*Trt*Year	2	36	0.97	0.39
Month*Year	2	36	0.03	0.97
Location*Month*Year	4	36	0.12	0.97
Trt*Month*Year	2	36	0.07	0.93
Location*Trt*Month*Year	4	36	0.17	0.95

Appendix V. Continued.

Table V-12b. Differences of least square means in soil C and N pools and C:N ratios by significant effects in Table V-12a. Comparisons were made at $P < 0.10$, P-diff = difference between log-transformed least square means.

Location	Trt	Trt	Month	Month	Year	Year	*P*-diff	DF	*t*-value	*P*-value
Soil C pool										
Streambank	excluded	grazed					0.40	8	1.97	0.08
Middle	excluded	grazed					0.39	8	1.91	0.09
Edge	excluded	grazed					-0.11	8	-0.55	0.60
			August	June			0.02	24	0.63	0.54
			August	October			-0.08	24	-2.36	0.03
			June	October			-0.10	24	-2.99	0.01
	excluded	excluded			2005	2006	0.25	36	6.37	<.0001
	excluded	grazed			2005	2005	0.34	36	1.75	0.09
	excluded	grazed			2006	2006	0.12	36	0.61	0.55
	grazed	grazed			2005	2006	0.02	36	0.62	0.54
Soil N pool										
Streambank	excluded	grazed					0.31	8	2.45	0.04
Middle	excluded	grazed					0.21	8	1.62	0.14
Edge	excluded	grazed					-0.03	8	-0.21	0.84
			August	June			0.01	24	0.64	0.53
			August	October			-0.06	24	-2.85	0.01
			June	October			-0.07	24	-3.49	0.002
	excluded	excluded			2005	2006	0.08	36	3.53	0.001
	excluded	grazed			2005	2005	0.23	36	2.25	0.03
	excluded	grazed			2006	2006	0.10	36	0.93	0.36
	grazed	grazed			2005	2006	-0.05	36	-2.28	0.03
Soil C:N										
Streambank					2005	2006	0.18	36	6.75	<.0001
Middle					2005	2006	0.11	36	4.28	0.0001
Edge					2005	2006	0.06	36	2.36	0.02
	excluded	excluded			2005	2006	0.16	36	7.27	<.0001
	excluded	grazed			2005	2005	0.11	36	1.19	0.24
	excluded	grazed			2006	2006	0.03	36	0.31	0.76
	grazed	grazed			2005	2006	0.08	36	3.66	0.001

Appendix V. Continued.

Table V-13a. Analysis of variance (ANOVA) of location, grazing treatment (Trt), month, and year effects on soil organic matter (kg m^{-2}). Significant differences were accepted at P-value < 0.10.

Covariance Parameter Estimates

Covariance Parameter	Estimate
Block	1.19
Block *Trt	1.81
Block*Trt*Location	0.68
Block*Trt*Location*Month	0
Block*Trt*Location*Month*Year	0
Residual	0.37

Type III Tests of Fixed Effects

Effect	Numerator DF	Denominator DF	*F*-value	*P*-value
Location	2	8	15.54	0.002
Trt	1	2	0.45	0.57
Location*Trt	2	8	9.95	0.01
Month	2	24	13.70	0.0001
Location*Month	4	24	0.44	0.78
Trt*Month	2	24	2.22	0.13
Location*Trt*Month	4	24	0.52	0.72
Year	1	36	9.90	0.003
Location*Year	2	36	0.04	0.96
Trt*Year	1	36	10.88	0.002
Location*Trt*Year	2	36	1.97	0.15
Month*Year	2	36	1.46	0.24
Location*Month*Year	4	36	0.39	0.82
Trt*Month*Year	2	36	1.08	0.35
Location*Trt*Month*Year	4	36	0.23	0.92

Appendix V. Continued.

Table V-13b. Differences of least square means in soil organic matter by significant effects in Table V-13a. Comparisons were made at $P < 0.10$, P-diff = difference between least square means.

Location	Trt	Trt	Month	Month	Year	Year	*P*-diff	DF	*t*-value	*P*-value
Streambank	excluded	grazed					1.76	8	1.35	0.22
Middle	excluded	grazed					2.35	8	1.80	0.11
Edge	excluded	grazed					-1.75	8	-1.34	0.22
			August	June			-0.17	24	-1.18	0.25
			August	October			-0.71	24	-5.01	<.0001
			June	October			-0.55	24	-3.82	0.001
	excluded	excluded			2005	2006	0.75	36	4.56	0.0001
	excluded	grazed			2005	2005	1.17	36	1.00	0.33
	excluded	grazed			2006	2006	0.40	36	0.34	0.73
	grazed	grazed			2005	2006	-0.02	36	-0.11	0.91

Appendix V. Continued.

Table V-14a. Analysis of variance (ANOVA) of location, grazing treatment (Trt), and month effects on water soluble organic C (WSOCN) and water soluble total N (WSTN) pools (g m^{-2}). WSTN data were log-transformed and significant differences were accepted at P-value < 0.10.

Covariance Parameter Estimates

Covariance Parameter	Estimate
WSOC	
Block	0.59
Block *Trt	0.51
Block*Trt*Location	0.32
Block*Trt*Location*Month	0
Residual	0.47
WSTN	
Block	0.08
Block *Trt	0.02
Block*Trt*Location	0.11
Block*Trt*Location*Month	0
Residual	0.08

Appendix V. Table V-14a. Continued.

Type III Tests of Fixed Effects

Effect	Numerator DF	Denominator DF	*F*-value	*P*-value
WSOC				
Location	2	8	4.71	0.04
Trt	1	2	0.03	0.88
Location*Trt	2	8	4.51	0.05
Month	2	24	14.84	<.0001
Location*Month	4	24	0.10	0.98
Trt*Month	2	24	1.03	0.37
Location*Trt*Month	4	24	0.92	0.47
WSTN				
Location	2	8	3.43	0.08
Trt	1	2	1.27	0.38
Location*Trt	2	8	0.54	0.60
Month	2	24	17.95	<.0001
Location*Month	4	24	0.16	0.96
Trt*Month	2	24	0.85	0.44
Location*Trt*Month	4	24	0.17	0.95

Table V-14b. Differences of least square means in water soluble organic C (WSOCN) and water soluble total N (WSTN) pools by significant effects in Table V-14a. Comparisons were made at $P < 0.10$, P-diff = difference between least square means.

Location	Location	Trt	Trt	Month	Month	*P*-diff	DF	*t*-value	*P*-value
WSOCN									
Streambank		excluded	grazed			0.81	8	0.99	0.35
Middle		excluded	grazed			0.32	8	0.40	0.70
Edge		excluded	grazed			-1.47	8	-1.80	0.11
				August	June	1.24	24	5.45	<.0001
				August	October	0.62	24	2.74	0.01
				June	October	-0.62	24	-2.71	0.01
WSTN									
Middle	Streambank					0.43	8	2.04	0.08
Middle	Edge					-0.09	8	-0.41	0.69
Streambank	Edge					-0.52	8	-2.44	0.04
				August	June	0.27	24	2.87	0.01
				August	October	0.57	24	5.99	<.0001
				June	October	0.30	24	3.12	0.005

Appendix V. Continued.

Table V-15a. Analysis of variance (ANOVA) of location, grazing treatment (Trt), month and year effects on soil available inorganic N pools (2M KCl extractable N, g m^{-2}). Data were log-transformed and significant differences were accepted at P-value < 0.10.

Covariance Parameter Estimates

Covariance Parameter	Estimate
Nitrate(NO_3^-)	
Block	0.12
Block *Trt	0.19
Block*Trt*Location	0.24
Block*Trt*Location*Month	0
Block*Trt*Location*Month*Year	0
Residual	0.42
Ammonium (NH_4^+)	
Block	0
Block *Trt	0
Block*Trt*Location	0.005
Block*Trt*Location*Month	0
Block*Trt*Location*Month*Year	0
Residual	0.05
Total inorganic N	
Block	0.0001
Block *Trt	0
Block*Trt*Location	0.005
Block*Trt*Location*Month	0
Block*Trt*Location*Month*Year	0
Residual	0.05

Appendix V. Table V-15a. Continued.

Type III Tests of Fixed Effects

Effect	**Numerator DF**	**Denominator DF**	***F*-value**	***P*-value**
Nitrate(NO_3^-)				
Location	2	8	7.29	0.016
Trt	1	2	1.85	0.31
Location*Trt	2	8	1.00	0.41
Month	2	24	22.27	<.0001
Location*Month	4	24	0.74	0.57
Trt*Month	2	24	0.45	0.64
Location*Trt*Month	4	24	1.01	0.42
Year	1	34	1.12	0.30
Location*Year	2	34	1.43	0.25
Trt*Year	1	34	0.01	0.92
Location*Trt*Year	2	34	1.21	0.31
Month*Year	2	34	15.21	<.0001
Location*Month*Year	4	34	1.67	0.18
Trt*Month*Year	2	34	1.90	0.17
Location*Trt*Month*Year	4	34	0.66	0.63
Ammonium (NH_4^+)				
Location	2	8	0.96	0.42
Trt	1	2	0.17	0.72
Location*Trt	2	8	2.37	0.16
Month	2	24	3.10	0.06
Location*Month	4	24	0.41	0.80
Trt*Month	2	24	0.47	0.63
Location*Trt*Month	4	24	0.42	0.79
Year	1	36	16.49	0.0003
Location*Year	2	36	0.64	0.53
Trt*Year	1	36	0.61	0.44
Location*Trt*Year	2	36	0.50	0.61
Month*Year	2	36	4.12	0.02
Location*Month*Year	4	36	0.52	0.72
Trt*Month*Year	2	36	0.33	0.72
Location*Trt*Month*Year	4	36	0.64	0.64
Total inorganic N				
Location	2	8	1.84	0.22
Trt	1	2	0.51	0.55
Location*Trt	2	8	2.20	0.17
Month	2	24	4.46	0.02
Location*Month	4	24	0.49	0.75
Trt*Month	2	24	0.39	0.68
Location*Trt*Month	4	24	0.42	0.79
Year	1	36	16.39	0.0003
Location*Year	2	36	0.68	0.52
Trt*Year	1	36	0.45	0.51
Location*Trt*Year	2	36	0.54	0.59
Month*Year	2	36	4.90	0.01
Location*Month*Year	4	36	0.50	0.73
Trt*Month*Year	2	36	0.42	0.66
Location*Trt*Month*Year	4	36	0.60	0.66

Appendix V. Continued.

Table V-15b. Differences of least square means in soil available inorganic N pools by significant effects in Table V-15a. Comparisons were made at $P < 0.10$, P-diff = difference between log-transformed least square means.

Location	Location	Month	Month	Year	Year	P-diff	DF	t-value	P-value
Nitrate(NO_3^-)									
Middle	Streambank					1.22	8	3.79	0.01
Middle	Edge					0.48	8	1.50	0.17
Streambank	Edge					-0.74	8	-2.29	0.05
		August	June			-0.68	24	-4.44	0.0002
		August	October			0.34	24	2.18	0.04
		June	October			1.02	24	6.52	<.0001
Ammonium (NH_4^+)									
		August	June			-0.08	24	-1.42	0.17
		August	October			0.06	24	1.06	0.30
		June	October			0.13	24	2.48	0.02
				2005	2006	-0.18	36	-4.06	0.0003
		June	June	2005	2006	-0.28	36	-3.67	0.001
		August	August	2005	2006	0.00	36	-0.01	0.99
		October	October	2005	2006	-0.26	36	-3.36	0.002
Total inorganic N									
		August	June			-0.10	24	-1.83	0.08
		August	October			0.06	24	1.13	0.27
		June	October			0.16	24	2.96	0.01
				2005	2006	-0.18	36	-4.05	0.0003
		June	June	2005	2006	-0.28	36	-3.69	0.001
		August	August	2005	2006	0.02	36	0.22	0.83
		October	October	2005	2006	-0.27	36	-3.53	0.001

Appendix V. Continued.

Table V-16a. Analysis of variance (ANOVA) of location, grazing treatment (Trt), and month effects on litter decomposition (% ash-free dry mass remaining). Significant differences were accepted at *P*-value < 0.10.

Covariance Parameter Estimates

Covariance Parameter	Estimate
Block	27
Block *Trt	0
Block*Trt*Location	1.29
Block*Trt*Location*Month	56
Residual	1.09

Type III Tests of Fixed Effects

Effect	Numerator DF	Denominator DF	*F*-value	*P*-value
Location	2	8	1.23	0.34
Trt	1	2	0.96	0.43
Location*Trt	2	8	0.07	0.93
Month	3	36	138.14	<.0001
Location*Month	6	36	0.26	0.95
Trt*Month	3	36	0.14	0.94
Location*Trt*Month	6	36	0.08	1.00

Table V-16b. Differences of least square means in litter decomposition by month (significant Month effect in Table V-16a). Comparisons were made at $P < 0.10$, *P*-diff = difference between log-transformed least square means.

Month	Month	*P*-diff	DF	*t*-value	*P*-value
April	August	40	36	15.87	<.0001
April	June	9	36	3.69	0.001
April	October	41	36	16.14	<.0001
August	June	-31	36	-12.17	<.0001
August	October	1	36	0.27	0.79
June	October	31	36	12.44	<.0001

Appendix V. Continued.

Table V-17a. Analysis of covariance (ANCOVA) of location, grazing treatment (Trt), month and year effects on soil CO_2 respiration, nitrification, mineralization, net N mineralization and immobilization measured in incubated soils. Covariates were soil C and N pool, soil organic matter pool, and clay content. Significant differences were accepted at P-value < 0.10.

Covariance Parameter Estimates

Covariance Parameter	Estimate
Soil CO_2 respiration (mg CO_2 g^{-1} soil C)	
Block	0
Block *Trt	4.34
Block*Trt*Location	4.14
Block*Trt*Location*Month	0
Residual	39
Nitrification (mg NO_3^- g^{-1} soil N)	
Block	0
Block *Trt	1.58
Block*Trt*Location	1.89
Block*Trt*Location*Month	0
Residual	1.92
Ammonification (mg NH_4^+ g^{-1} soil N)	
Block	3.93
Block *Trt	0
Block*Trt*Location	5.12
Block*Trt*Location*Month	0
Residual	3.98
Net N mineralization (mg N g^{-1} soil N)	
Block	0
Block *Trt	2.31
Block*Trt*Location	1.00
Block*Trt*Location*Month	0
Residual	4.02
Immobilization index (soil CO_2 respiration : net N mineralization)	
Block	0
Block *Trt	0.82
Block*Trt*Location	0
Block*Trt*Location*Month	0
Residual	1.41

Appendix V. Table V-17a. Continued.

Type III Tests of Fixed Effects

Effect	Numerator DF	Denominator DF	*F*-value	*P*-value
Soil CO_2 respiration (mg CO_2 g^{-1} soil C)				
Location	2	8	2.18	0.18
Trt	1	2	0.32	0.63
Location*Trt	2	8	2.05	0.19
Month	2	24	2.35	0.12
Location*Month	4	24	0.11	0.98
Trt*Month	2	24	0.34	0.72
Location*Trt*Month	4	24	1.78	0.17
Year	1	32	0.01	0.92
Location*Year	2	32	1.31	0.28
Trt*Year	1	32	2.31	0.14
Location*Trt*Year	2	32	0.88	0.42
Month*Year	2	32	5.25	0.01
Location*Month*Year	4	32	0.63	0.65
Trt*Month*Year	2	32	0.24	0.79
Location*Trt*Month*Year	4	32	0.33	0.86
Soil C pool	1	32	0.22	0.64
Soil N pool	1	32	0.18	0.67
Soil organic matter pool	1	32	0.55	0.46
Clay	1	32	0.76	0.39
Nitrification (mg NO_3^- g^{-1} soil N)				
Location	2	8	0.44	0.66
Trt	1	2	4.86	0.16
Location*Trt	2	8	0.56	0.59
Month	2	24	14.14	<.0001
Location*Month	4	24	1.61	0.20
Trt*Month	2	24	0.10	0.91
Location*Trt*Month	4	24	0.15	0.96
Year	1	32	8.38	0.01
Location*Year	2	32	0.60	0.55
Trt*Year	1	32	1.23	0.28
Location*Trt*Year	2	32	0.20	0.82
Month*Year	2	32	1.51	0.24
Location*Month*Year	4	32	0.28	0.89
Trt*Month*Year	2	32	0.17	0.84
Location*Trt*Month*Year	4	32	0.61	0.66
Soil C pool	1	32	6.77	0.01
Soil N pool	1	32	9.46	0.004
Soil organic matter pool	1	32	0.13	0.72
Clay	1	32	0.62	0.44
Ammonification (mg NH_4^+ g^{-1} soil N)				
Location	2	8	0.41	0.68
Trt	1	2	1.57	0.34
Location*Trt	2	8	0.38	0.70
Month	2	24	0.96	0.40
Location*Month	4	24	1.77	0.17
Trt*Month	2	24	0.08	0.93
Location*Trt*Month	4	24	0.28	0.89
Year	1	32	2.01	0.17
Location*Year	2	32	0.60	0.55
Trt*Year	1	32	2.96	0.10
Location*Trt*Year	2	32	0.26	0.77
Month*Year	2	32	3.19	0.05
Location*Month*Year	4	32	0.19	0.94
Trt*Month*Year	2	32	0.12	0.89
Location*Trt*Month*Year	4	32	0.18	0.95
Soil C pool	1	32	2.89	0.10
Soil N pool	1	32	3.72	0.06
Soil organic matter pool	1	32	0.99	0.33
Clay	1	32	0.56	0.46

Appendix V. Table V-17a. Continued.

Type III Tests of Fixed Effects

Effect	Numerator DF	Denominator DF	*F*-value	*P*-value
Net N mineralization (mg N g^{-1} soil N)				
Location	2	8	1.66	0.25
Trt	1	2	2.13	0.28
Location*Trt	2	8	3.75	0.07
Month	2	24	4.30	0.03
Location*Month	4	24	0.24	0.91
Trt*Month	2	24	0.15	0.86
Location*Trt*Month	4	24	0.44	0.78
Year	1	32	23.79	<.0001
Location*Year	2	32	0.31	0.73
Trt*Year	1	32	4.26	0.05
Location*Trt*Year	2	32	0.02	0.98
Month*Year	2	32	6.50	0.00
Location*Month*Year	4	32	0.25	0.91
Trt*Month*Year	2	32	0.42	0.66
Location*Trt*Month*Year	4	32	0.46	0.77
Soil C pool	1	32	0.08	0.77
Soil N pool	1	32	1.00	0.33
Soil organic matter pool	1	32	0.04	0.84
Clay	1	32	0.31	0.58
Immobilization index (soil CO_2 respiration : net N mineralization)				
Location	2	8	0.21	0.82
Trt	1	2	0.23	0.68
Location*Trt	2	8	10.46	0.01
Month	2	24	4.22	0.03
Location*Month	4	24	0.22	0.93
Trt*Month	2	24	0.25	0.78
Location*Trt*Month	4	24	0.72	0.59
Year	1	32	5.73	0.02
Location*Year	2	32	1.74	0.19
Trt*Year	1	32	4.62	0.04
Location*Trt*Year	2	32	0.81	0.45
Month*Year	2	32	5.59	0.01
Location*Month*Year	4	32	0.16	0.95
Trt*Month*Year	2	32	1.49	0.24
Location*Trt*Month*Year	4	32	0.07	0.99
Soil C pool	1	32	0.29	0.59
Soil N pool	1	32	0.10	0.76
Soil organic matter pool	1	32	0.06	0.81
Clay	1	32	0.67	0.42

Appendix V. Continued.

Table V-17b. Differences of least square means in soil CO_2 respiration, nitrification, mineralization, net N mineralization and immobilization index by significant effects in Table V-17a. Comparisons were made at $P < 0.10$, P-diff = difference between log-transformed least square means.

Location	Trt	Trt	Month	Month	Year	Year	*P*-diff	DF	*t*-value	*P*-value
Soil CO_2 respiration (mg CO_2 g^{-1} soil C)										
			June	June	2005	2006	4.25	32	1.91	0.07
			August	August	2005	2006	-5.23	32	-2.40	0.02
			October	October	2005	2006	0.58	32	0.26	0.80
Nitrification (mg NO_3^- g^{-1} soil N)										
			August	June			-0.26	24	-0.78	0.44
			August	October			1.52	24	4.11	0.0004
			June	October			1.78	24	5.10	<.0001
					2005	2006	0.98	32	2.90	0.01
Ammonification (mg NH_4^+ g^{-1} soil N)										
	excluded	excluded			2005	2006	-1.42	32	-2.05	0.05
	excluded	grazed			2005	2005	1.31	32	0.77	0.45
	excluded	grazed			2006	2006	2.77	32	1.67	0.11
	grazed	grazed			2005	2006	0.04	32	0.06	0.95
			June	June	2005	2006	0.61	32	0.79	0.43
			August	August	2005	2006	-0.76	32	-1.05	0.30
			October	October	2005	2006	-1.92	32	-2.56	0.02
Net N mineralization (mg N g^{-1} soil N)										
Streambank	excluded	grazed					-4.75	8	-2.67	0.03
Middle	excluded	grazed					-0.64	8	-0.31	0.76
Edge	excluded	grazed					-1.60	8	-0.85	0.42
	excluded	excluded			2005	2006	1.39	32	2.09	0.04
	excluded	grazed			2005	2005	-3.19	32	-1.91	0.07
	excluded	grazed			2006	2006	-1.47	32	-0.90	0.37
	grazed	grazed			2005	2006	3.12	32	5.41	<.0001
			June	June	2005	2006	3.36	32	4.56	<.0001
			August	August	2005	2006	3.25	32	4.53	<.0001
			October	October	2005	2006	0.16	32	0.22	0.83
Immobilization index (soil CO_2 respiration : net N mineralization)										
Streambank	excluded	grazed					2.03	8	2.27	0.05
Middle	excluded	grazed					-0.44	8	-0.45	0.66
Edge	excluded	grazed					-0.37	8	-0.39	0.71
	excluded	excluded			2005	2006	-0.09	32	-0.25	0.80
	excluded	grazed			2005	2005	0.93	32	1.04	0.30
	excluded	grazed			2006	2006	-0.12	32	-0.14	0.89
	grazed	grazed			2005	2006	-1.14	32	-3.42	0.002
			June	June	2005	2006	-0.61	32	-1.45	0.16
			August	August	2005	2006	-1.59	32	-3.83	0.001
			October	October	2005	2006	0.35	32	0.81	0.42

Appendix V. Continued.

Table V-18a. Analysis of covariance (ANCOVA) of location, grazing treatment (Trt), and month effects on soil denitrification potential, soil microbial biomass C and N pools, and microbial C:N Covariates were soil C and N pool, soil organic matter pool, and clay content. Only denitrification data were log-transformed, and significant differences were accepted at P-value < 0.10.

Covariance Parameter Estimates

Covariance Parameter	Estimate
Denitrification potential (mg N_2O-N g^{-1} soil h^{-1})	
Block	1.22
Block *Trt	0
Block*Trt*Location	0.21
Residual	0.71
Soil microbial biomass C pool (mg C m^{-2})	
Block	11
Block *Trt	0
Block*Trt*Location	54
Residual	173
Soil microbial biomass N pool (mg N m^{-2})	
Block	0.24
Block *Trt	0.80
Block*Trt*Location	0
Residual	2.63
Soil microbial biomass C:N	
Block	0
Block *Trt	0.04
Block*Trt*Location	0
Residual	0.08

Appendix V. Table V-18a. Continued.

Type III Tests of Fixed Effects

Effect	Numerator DF	Denominator DF	*F*-value	*P*-value
Denitrification potential (mg N_2O-N g^{-1} soil h^{-1})				
Location	2	7	0.02	0.98
Trt	1	2	1.23	0.38
Location*Trt	2	7	0.54	0.61
Month	2	19	35.59	<.0001
Location*Month	4	19	2.72	0.06
Trt*Month	2	19	0.36	0.70
Location*Trt*Month	4	19	1.66	0.20
Soil C pool	1	19	5.47	0.03
Soil N pool	1	19	0.05	0.83
Soil organic matter pool	1	19	0.80	0.38
Clay	1	19	3.59	0.07
Soil microbial biomass C pool (mg C m^{-2})				
Location	2	7	2.40	0.16
Trt	1	2	5.20	0.15
Location*Trt	2	7	0.72	0.52
Month	2	21	3.49	0.05
Location*Month	4	21	0.97	0.45
Trt*Month	2	21	0.36	0.70
Location*Trt*Month	4	21	0.71	0.60
Soil C pool	1	21	2.56	0.12
Soil N pool	1	21	6.28	0.02
Soil organic matter pool	1	21	6.44	0.02
Clay	1	21	0.08	0.78
Soil microbial biomass N pool (mg N m^{-2})				
Location	2	7	2.40	0.16
Trt	1	2	0.01	0.92
Location*Trt	2	7	0.25	0.79
Month	2	21	4.42	0.03
Location*Month	4	21	1.59	0.21
Trt*Month	2	21	0.62	0.55
Location*Trt*Month	4	21	0.31	0.87
Soil C pool	1	21	0.30	0.59
Soil N pool	1	21	2.85	0.11
Soil organic matter pool	1	21	0.48	0.49
Clay	1	21	1.26	0.27
Soil microbial biomass C:N				
Location	2	7	0.79	0.49
Trt	1	2	0.59	0.52
Location*Trt	2	7	1.31	0.33
Month	2	21	4.82	0.02
Location*Month	4	21	0.83	0.52
Trt*Month	2	21	0.26	0.77
Location*Trt*Month	4	21	0.77	0.56
Soil C pool	1	21	2.25	0.15
Soil N pool	1	21	0.00	0.98
Soil organic matter pool	1	21	0.53	0.48
Clay	1	21	2.84	0.11

Appendix V. Continued.

Table V-18b. Differences of least square means in soil denitrification potential, soil microbial biomass C and N, and microbial biomass C:N by significant effects in Table V-18a. Comparisons were made at $P < 0.10$, P-diff = difference between least square means (LSM), log-transformed LSMs only for denitrification.

Location	Month	Month	*P*-diff	DF	*t*-value	*P*-value
Denitrification potential (mg N_2O-N g^{-1} soil h^{-1})						
Streambank	August	June	-1.27	19	-2.60	0.02
Streambank	August	October	0.58	19	1.14	0.27
Streambank	June	October	1.85	19	3.63	0.002
Middle	August	June	-2.90	19	-5.34	<.0001
Middle	August	October	-1.50	19	-2.59	0.02
Middle	June	October	1.40	19	2.72	0.01
Edge	August	June	-3.00	19	-5.33	<.0001
Edge	August	October	-0.65	19	-1.13	0.27
Edge	June	October	2.35	19	4.72	0.0001
Soil microbial biomass C pool (mg C m^{-2})						
	August	June	-2.46	21	-0.54	0.60
	August	October	-12.91	21	-2.47	0.02
	June	October	-10.46	21	-2.21	0.04
Soil microbial biomass N pool (mg N m^{-2})						
	August	June	0.20	21	0.35	0.73
	August	October	-1.49	21	-2.31	0.03
	June	October	-1.69	21	-2.87	0.01
Soil microbial biomass C:N						
	August	June	-4.63	21	-2.38	0.03
	August	October	1.06	21	0.48	0.64
	June	October	5.69	21	2.80	0.01

APPENDIX

CHAPTER IV

Appendix W. Sheep Creek stream stage (cm) measured in 2005 at T-posts that were installed in the stream thalweg at each piezometer transect. Stream stage was not recorded at transect 6 because the T-post was washed out by high stream flow in early May.

Sampling date	Transect	Grazing treatment	Stream stage (cm)
5.12.05	1	grazed	65.3
5.12.05	2	control	57.3
5.12.05	3	grazed	104.8
5.12.05	4	control	87.0
5.12.05	5	grazed	68.8
5.19.05	1	grazed	65.3
5.19.05	2	control	57.3
5.19.05	3	grazed	104.8
5.19.05	4	control	87.0
5.19.05	5	grazed	68.8
5.26.05	1	grazed	90.9
5.26.05	2	control	79.5
5.26.05	3	grazed	118.4
5.26.05	4	control	109.2
5.26.05	5	grazed	80.7
6.03.05	1	grazed	85.5
6.03.05	2	control	81.3
6.03.05	3	grazed	120.1
6.03.05	4	control	---
6.03.05	5	grazed	82.4
6.09.05	1	grazed	89.6
6.09.05	2	control	85.0
6.09.05	3	grazed	123.5
6.09.05	4	control	116.6
6.09.05	5	grazed	80.7
6.16.05	1	grazed	32.1
6.16.05	2	control	34.7
6.16.05	3	grazed	64.6
6.16.05	4	control	55.4
6.16.05	5	grazed	31.6
6.23.05	1	grazed	36.9
6.23.05	2	control	39.8
6.23.05	3	grazed	67.5
6.23.05	4	control	58.8
6.23.05	5	grazed	35.6
6.30.05	1	grazed	38.2
6.30.05	2	control	61.0
6.30.05	3	grazed	72.0
6.30.05	4	control	54.2
6.30.05	5	grazed	34.6
7.07.05	1	grazed	35.8
7.07.05	2	control	36.1
7.07.05	3	grazed	74.0
7.07.05	4	control	51.7
7.07.05	5	grazed	33.9

Appendix W. Continued.

Sampling date	Transect	Grazing treatment	Stream stage (cm)
7.21.05	1	grazed	72.0
7.21.05	2	control	62.8
7.21.05	3	grazed	109.9
7.21.05	4	control	83.3
7.21.05	5	grazed	70.5
8.02.05	1	grazed	74.7
8.02.05	2	control	66.5
8.02.05	3	grazed	111.6
8.02.05	4	control	87.0
8.02.05	5	grazed	73.9
8.11.05	1	grazed	80.1
8.11.05	2	control	72.1
8.11.05	3	grazed	113.3
8.11.05	4	control	94.4
8.11.05	5	grazed	77.3
8.18.05	1	grazed	77.4
8.18.05	2	control	72.1
8.18.05	3	grazed	113.3
8.18.05	4	control	90.7
8.18.05	5	grazed	77.3
8.25.05	1	grazed	12.3
8.25.05	2	control	16.8
8.25.05	3	grazed	55.0
8.25.05	4	control	31.7
8.25.05	5	grazed	14.4
9.08.05	1	grazed	44.3
9.08.05	2	control	70.2
9.08.05	3	grazed	109.9
9.08.05	4	control	87.0
9.08.05	5	grazed	73.9
9.15.05	1	grazed	8.9
9.15.05	2	control	14.3
9.15.05	3	grazed	43.8
9.15.05	4	control	30.1
9.15.05	5	grazed	11.6
9.30.05	1	grazed	9.5
9.30.05	2	control	14.6
9.30.05	3	grazed	44.2
9.30.05	4	control	29.7
9.30.05	5	grazed	11.8

Appendix X. Piezometric potential or head (cm) measured in piezometers at 3 locations in the SheepCreek riparian zone: streambank, middle riparian, and riparian edge in 2005. Head and the soil surface were referenced to a common datum which was the bottom of the stream at the staff gage.

Sampling date	Transect	Location	Grazing treatment	Piezometer distance from channel thalweg (m)	Soil surface above datum (cm)	Head above datum (cm)
5.12.05	1	Streambank	grazed	6.5	57.5	21.9
5.12.05	1	Middle	grazed	13.2	79.1	53.1
5.12.05	1	Edge	grazed	20.2	83.4	56.6
5.19.05	1	Streambank	grazed	6.5	57.5	21.1
5.19.05	1	Middle	grazed	13.2	79.1	39.8
5.19.05	1	Edge	grazed	20.2	83.4	38.1
5.26.05	1	Streambank	grazed	6.5	57.5	57.9
5.26.05	1	Middle	grazed	13.2	79.1	35.1
5.26.05	1	Edge	grazed	20.2	83.4	38.1
6.03.05	1	Streambank	grazed	6.5	57.5	64.6
6.03.05	1	Middle	grazed	13.2	79.1	59.7
6.03.05	1	Edge	grazed	20.2	83.4	77.9
6.09.05	1	Streambank	grazed	6.5	57.5	70.8
6.09.05	1	Middle	grazed	13.2	79.1	69.0
6.09.05	1	Edge	grazed	20.2	83.4	74.9
6.16.05	1	Streambank	grazed	6.5	57.5	32.4
6.16.05	1	Middle	grazed	13.2	79.1	60.9
6.16.05	1	Edge	grazed	20.2	83.4	60.8
6.23.05	1	Streambank	grazed	6.5	57.5	38.2
6.23.05	1	Middle	grazed	13.2	79.1	39.3
6.23.05	1	Edge	grazed	20.2	83.4	42.0
6.30.05	1	Streambank	grazed	6.5	57.5	35.9
6.30.05	1	Middle	grazed	13.2	79.1	33.3
6.30.05	1	Edge	grazed	20.2	83.4	32.3
7.07.05	1	Streambank	grazed	6.5	57.5	34.9
7.07.05	1	Middle	grazed	13.2	79.1	28.5
7.07.05	1	Edge	grazed	20.2	83.4	25.4
7.21.05	1	Streambank	grazed	6.5	57.5	33.1
7.21.05	1	Middle	grazed	13.2	79.1	23.2
7.21.05	1	Edge	grazed	20.2	83.4	15.4
8.02.05	1	Streambank	grazed	6.5	57.5	39.1
8.02.05	1	Middle	grazed	13.2	79.1	25.7
8.02.05	1	Edge	grazed	20.2	83.4	14.7
8.11.05	1	Streambank	grazed	6.5	57.5	48.9
8.11.05	1	Middle	grazed	13.2	79.1	35.3
8.11.05	1	Edge	grazed	20.2	83.4	29.8
8.18.05	1	Streambank	grazed	6.5	57.5	43.6
8.18.05	1	Middle	grazed	13.2	79.1	35.8
8.18.05	1	Edge	grazed	20.2	83.4	32.8
8.25.05	1	Streambank	grazed	6.5	57.5	11.9
8.25.05	1	Middle	grazed	13.2	79.1	33.1
8.25.05	1	Edge	grazed	20.2	83.4	30.2

Appendix X. Continued.

Sampling date	Transect	Location	Grazing treatment	Piezometer distance from stream channel (m)	Soil surface above datum (cm)	Head above datum (cm)
9.08.05	1	Streambank	grazed	6.5	57.5	39.2
9.08.05	1	Middle	grazed	13.2	79.1	15.9
9.08.05	1	Edge	grazed	20.2	83.4	14.3
9.15.05	1	Streambank	grazed	6.5	57.5	10.1
9.15.05	1	Middle	grazed	13.2	79.1	12.7
9.15.05	1	Edge	grazed	20.2	83.4	8.8
9.30.05	1	Streambank	grazed	6.5	57.5	0.2
9.30.05	1	Middle	grazed	13.2	79.1	---
9.30.05	1	Edge	grazed	20.2	83.4	---
5.12.05	2	Streambank	conrol	3.0	97.7	29.3
5.12.05	2	Middle	conrol	9.7	100.4	37.3
5.12.05	2	Edge	conrol	16.7	102.5	42.9
5.19.05	2	Streambank	conrol	3.0	97.7	28.9
5.19.05	2	Middle	conrol	9.7	100.4	28.8
5.19.05	2	Edge	conrol	16.7	102.5	30.3
5.26.05	2	Streambank	conrol	3.0	97.7	44.3
5.26.05	2	Middle	conrol	9.7	100.4	29.1
5.26.05	2	Edge	conrol	16.7	102.5	31.4
6.03.05	2	Streambank	conrol	3.0	97.7	65.7
6.03.05	2	Middle	conrol	9.7	100.4	36.4
6.03.05	2	Edge	conrol	16.7	102.5	34.5
6.09.05	2	Streambank	conrol	3.0	97.7	73.5
6.09.05	2	Middle	conrol	9.7	100.4	40.6
6.09.05	2	Edge	conrol	16.7	102.5	38.7
6.16.05	2	Streambank	conrol	3.0	97.7	54.1
6.16.05	2	Middle	conrol	9.7	100.4	54.8
6.16.05	2	Edge	conrol	16.7	102.5	57.8
6.23.05	2	Streambank	conrol	3.0	97.7	38.4
6.23.05	2	Middle	conrol	9.7	100.4	43.0
6.23.05	2	Edge	conrol	16.7	102.5	56.2
6.30.05	2	Streambank	conrol	3.0	97.7	45.6
6.30.05	2	Middle	conrol	9.7	100.4	41.2
6.30.05	2	Edge	conrol	16.7	102.5	45.5
7.07.05	2	Streambank	conrol	3.0	97.7	43.3
7.07.05	2	Middle	conrol	9.7	100.4	37.7
7.07.05	2	Edge	conrol	16.7	102.5	41.7
7.21.05	2	Streambank	conrol	3.0	97.7	40.7
7.21.05	2	Middle	conrol	9.7	100.4	33.7
7.21.05	2	Edge	conrol	16.7	102.5	38.6
8.02.05	2	Streambank	conrol	3.0	97.7	46.0
8.02.05	2	Middle	conrol	9.7	100.4	31.7
8.02.05	2	Edge	conrol	16.7	102.5	32.5
8.11.05	2	Streambank	conrol	3.0	97.7	56.7
8.11.05	2	Middle	conrol	9.7	100.4	31.4
8.11.05	2	Edge	conrol	16.7	102.5	33.0
8.18.05	2	Streambank	conrol	3.0	97.7	55.7
8.18.05	2	Middle	conrol	9.7	100.4	21.9
8.18.05	2	Edge	conrol	16.7	102.5	28.8
8.25.05	2	Streambank	conrol	3.0	97.7	44.4
8.25.05	2	Middle	conrol	9.7	100.4	26.0
8.25.05	2	Edge	conrol	16.7	102.5	30.0

Appendix X. Continued.

Sampling date	Transect	Location	Grazing treatment	Piezometer distance from stream channel (m)	Soil surface above datum (cm)	Head above datum (cm)
9.08.05	2	Streambank	conrol	3.0	97.7	30.3
9.08.05	2	Middle	conrol	9.7	100.4	25.0
9.08.05	2	Edge	conrol	16.7	102.5	---
9.15.05	2	Streambank	conrol	3.0	97.7	---
9.15.05	2	Middle	conrol	9.7	100.4	---
9.15.05	2	Edge	conrol	16.7	102.5	---
9.30.05	2	Streambank	conrol	3.0	97.7	---
9.30.05	2	Middle	conrol	9.7	100.4	---
9.30.05	2	Edge	conrol	16.7	102.5	---
5.12.05	3	Streambank	grazed	3.7	114.4	93.5
5.12.05	3	Middle	grazed	18.0	144.6	133.9
5.12.05	3	Edge	grazed	28.6	146.7	149.7
5.19.05	3	Streambank	grazed	3.7	114.4	94.5
5.19.05	3	Middle	grazed	18.0	144.6	131.0
5.19.05	3	Edge	grazed	28.6	146.7	169.3
5.26.05	3	Streambank	grazed	3.7	114.4	95.0
5.26.05	3	Middle	grazed	18.0	144.6	125.3
5.26.05	3	Edge	grazed	28.6	146.7	149.2
6.03.05	3	Streambank	grazed	3.7	114.4	107.8
6.03.05	3	Middle	grazed	18.0	144.6	133.6
6.03.05	3	Edge	grazed	28.6	146.7	150.1
6.09.05	3	Streambank	grazed	3.7	114.4	112.7
6.09.05	3	Middle	grazed	18.0	144.6	137.0
6.09.05	3	Edge	grazed	28.6	146.7	150.2
6.16.05	3	Streambank	grazed	3.7	114.4	109.9
6.16.05	3	Middle	grazed	18.0	144.6	129.7
6.16.05	3	Edge	grazed	28.6	146.7	149.9
6.23.05	3	Streambank	grazed	3.7	114.4	103.7
6.23.05	3	Middle	grazed	18.0	144.6	117.5
6.23.05	3	Edge	grazed	28.6	146.7	149.7
6.30.05	3	Streambank	grazed	3.7	114.4	99.4
6.30.05	3	Middle	grazed	18.0	144.6	98.9
6.30.05	3	Edge	grazed	28.6	146.7	140.9
7.07.05	3	Streambank	grazed	3.7	114.4	94.9
7.07.05	3	Middle	grazed	18.0	144.6	82.6
7.07.05	3	Edge	grazed	28.6	146.7	125.2
7.21.05	3	Streambank	grazed	3.7	114.4	88.9
7.21.05	3	Middle	grazed	18.0	144.6	75.6
7.21.05	3	Edge	grazed	28.6	146.7	115.1
8.02.05	3	Streambank	grazed	3.7	114.4	82.8
8.02.05	3	Middle	grazed	18.0	144.6	77.8
8.02.05	3	Edge	grazed	28.6	146.7	98.2
8.11.05	3	Streambank	grazed	3.7	114.4	79.1
8.11.05	3	Middle	grazed	18.0	144.6	85.6
8.11.05	3	Edge	grazed	28.6	146.7	116.5
8.18.05	3	Streambank	grazed	3.7	114.4	74.7
8.18.05	3	Middle	grazed	18.0	144.6	85.6
8.18.05	3	Edge	grazed	28.6	146.7	114.7
8.25.05	3	Streambank	grazed	3.7	114.4	72.7
8.25.05	3	Middle	grazed	18.0	144.6	81.2
8.25.05	3	Edge	grazed	28.6	146.7	110.9

Appendix X. Continued.

Sampling date	Transect	Location	Grazing treatment	Piezometer distance from stream channel (m)	Soil surface above datum (cm)	Head above datum (cm)
9.08.05	3	Streambank	grazed	3.7	114.4	69.6
9.08.05	3	Middle	grazed	18.0	144.6	68.0
9.08.05	3	Edge	grazed	28.6	146.7	92.8
9.15.05	3	Streambank	grazed	3.7	114.4	65.0
9.15.05	3	Middle	grazed	18.0	144.6	64.8
9.15.05	3	Edge	grazed	28.6	146.7	88.1
9.30.05	3	Streambank	grazed	3.7	114.4	62.5
9.30.05	3	Middle	grazed	18.0	144.6	60.4
9.30.05	3	Edge	grazed	28.6	146.7	83.6
5.12.05	4	Streambank	conrol	3.9	115.5	89.1
5.12.05	4	Middle	conrol	18.6	160.3	125.3
5.12.05	4	Edge	conrol	29.9	187.1	124.1
5.19.05	4	Streambank	conrol	3.9	115.5	63.5
5.19.05	4	Middle	conrol	18.6	160.3	113.1
5.19.05	4	Edge	conrol	29.9	187.1	98.8
5.26.05	4	Streambank	conrol	3.9	115.5	69.0
5.26.05	4	Middle	conrol	18.6	160.3	118.3
5.26.05	4	Edge	conrol	29.9	187.1	99.4
6.03.05	4	Streambank	conrol	3.9	115.5	---
6.03.05	4	Middle	conrol	18.6	160.3	---
6.03.05	4	Edge	conrol	29.9	187.1	---
6.09.05	4	Streambank	conrol	3.9	115.5	75.1
6.09.05	4	Middle	conrol	18.6	160.3	124.0
6.09.05	4	Edge	conrol	29.9	187.1	105.4
6.16.05	4	Streambank	conrol	3.9	115.5	76.4
6.16.05	4	Middle	conrol	18.6	160.3	116.5
6.16.05	4	Edge	conrol	29.9	187.1	105.0
6.23.05	4	Streambank	conrol	3.9	115.5	75.5
6.23.05	4	Middle	conrol	18.6	160.3	105.2
6.23.05	4	Edge	conrol	29.9	187.1	104.5
6.30.05	4	Streambank	conrol	3.9	115.5	30.0
6.30.05	4	Middle	conrol	18.6	160.3	97.3
6.30.05	4	Edge	conrol	29.9	187.1	146.1
7.07.05	4	Streambank	conrol	3.9	115.5	75.0
7.07.05	4	Middle	conrol	18.6	160.3	87.3
7.07.05	4	Edge	conrol	29.9	187.1	93.1
7.21.05	4	Streambank	conrol	3.9	115.5	70.5
7.21.05	4	Middle	conrol	18.6	160.3	---
7.21.05	4	Edge	conrol	29.9	187.1	87.1
8.02.05	4	Streambank	conrol	3.9	115.5	67.2
8.02.05	4	Middle	conrol	18.6	160.3	---
8.02.05	4	Edge	conrol	29.9	187.1	---
8.11.05	4	Streambank	conrol	3.9	115.5	59.0
8.11.05	4	Middle	conrol	18.6	160.3	---
8.11.05	4	Edge	conrol	29.9	187.1	---
8.18.05	4	Streambank	conrol	3.9	115.5	56.5
8.18.05	4	Middle	conrol	18.6	160.3	---
8.18.05	4	Edge	conrol	29.9	187.1	---
8.25.05	4	Streambank	conrol	3.9	115.5	53.7
8.25.05	4	Middle	conrol	18.6	160.3	---
8.25.05	4	Edge	conrol	29.9	187.1	---

Appendix X. Continued.

Sampling date	Transect	Location	Grazing treatment	Piezometer distance from stream channel (m)	Soil surface above datum (cm)	Head above datum (cm)
9.08.05	4	Streambank	conrol	3.9	115.5	---
9.08.05	4	Middle	conrol	18.6	160.3	---
9.08.05	4	Edge	conrol	29.9	187.1	---
9.15.05	4	Streambank	conrol	3.9	115.5	---
9.15.05	4	Middle	conrol	18.6	160.3	---
9.15.05	4	Edge	conrol	29.9	187.1	---
9.30.05	4	Streambank	conrol	3.9	115.5	---
9.30.05	4	Middle	conrol	18.6	160.3	---
9.30.05	4	Edge	conrol	29.9	187.1	---
5.12.05	5	Streambank	grazed	6.5	52.7	22.2
5.12.05	5	Middle	grazed	16.5	63.3	48.2
5.12.05	5	Edge	grazed	25.6	81.6	43.6
5.19.05	5	Streambank	grazed	6.5	52.7	18.9
5.19.05	5	Middle	grazed	16.5	63.3	35.2
5.19.05	5	Edge	grazed	25.6	81.6	16.0
5.26.05	5	Streambank	grazed	6.5	52.7	30.8
5.26.05	5	Middle	grazed	16.5	63.3	39.7
5.26.05	5	Edge	grazed	25.6	81.6	23.2
6.03.05	5	Streambank	grazed	6.5	52.7	55.8
6.03.05	5	Middle	grazed	16.5	63.3	44.7
6.03.05	5	Edge	grazed	25.6	81.6	30.2
6.09.05	5	Streambank	grazed	6.5	52.7	43.9
6.09.05	5	Middle	grazed	16.5	63.3	47.1
6.09.05	5	Edge	grazed	25.6	81.6	34.1
6.16.05	5	Streambank	grazed	6.5	52.7	32.3
6.16.05	5	Middle	grazed	16.5	63.3	48.3
6.16.05	5	Edge	grazed	25.6	81.6	37.3
6.23.05	5	Streambank	grazed	6.5	52.7	27.7
6.23.05	5	Middle	grazed	16.5	63.3	47.0
6.23.05	5	Edge	grazed	25.6	81.6	37.8
6.30.05	5	Streambank	grazed	6.5	52.7	23.5
6.30.05	5	Middle	grazed	16.5	63.3	44.6
6.30.05	5	Edge	grazed	25.6	81.6	37.5
7.07.05	5	Streambank	grazed	6.5	52.7	21.3
7.07.05	5	Middle	grazed	16.5	63.3	40.0
7.07.05	5	Edge	grazed	25.6	81.6	35.3
7.21.05	5	Streambank	grazed	6.5	52.7	19.5
7.21.05	5	Middle	grazed	16.5	63.3	36.8
7.21.05	5	Edge	grazed	25.6	81.6	32.3
8.02.05	5	Streambank	grazed	6.5	52.7	21.0
8.02.05	5	Middle	grazed	16.5	63.3	34.5
8.02.05	5	Edge	grazed	25.6	81.6	27.9
8.11.05	5	Streambank	grazed	6.5	52.7	28.3
8.11.05	5	Middle	grazed	16.5	63.3	32.9
8.11.05	5	Edge	grazed	25.6	81.6	25.3
8.18.05	5	Streambank	grazed	6.5	52.7	23.9
8.18.05	5	Middle	grazed	16.5	63.3	29.1
8.18.05	5	Edge	grazed	25.6	81.6	20.3
8.25.05	5	Streambank	grazed	6.5	52.7	21.7
8.25.05	5	Middle	grazed	16.5	63.3	28.5
8.25.05	5	Edge	grazed	25.6	81.6	21.6

Appendix X. Continued.

Sampling date	Transect	Location	Grazing treatment	Piezometer distance from stream channel (m)	Soil surface above datum (cm)	Head above datum (cm)
9.08.05	5	Streambank	grazed	6.5	52.7	15.9
9.08.05	5	Middle	grazed	16.5	63.3	16.6
9.08.05	5	Edge	grazed	25.6	81.6	19.4
9.15.05	5	Streambank	grazed	6.5	52.7	---
9.15.05	5	Middle	grazed	16.5	63.3	23.9
9.15.05	5	Edge	grazed	25.6	81.6	19.0
9.30.05	5	Streambank	grazed	6.5	52.7	---
9.30.05	5	Middle	grazed	16.5	63.3	21.3
9.30.05	5	Edge	grazed	25.6	81.6	16.0
5.12.05	6	Streambank	conrol	4.0	113.7	82.5
5.12.05	6	Middle	conrol	14.6	109.4	86.2
5.12.05	6	Edge	conrol	23.3	129.2	122.7
5.19.05	6	Streambank	conrol	4.0	113.7	81.9
5.19.05	6	Middle	conrol	14.6	109.4	54.5
5.19.05	6	Edge	conrol	23.3	129.2	120.1
5.26.05	6	Streambank	conrol	4.0	113.7	104.8
5.26.05	6	Middle	conrol	14.6	109.4	65.2
5.26.05	6	Edge	conrol	23.3	129.2	123.3
6.03.05	6	Streambank	conrol	4.0	113.7	---
6.03.05	6	Middle	conrol	14.6	109.4	---
6.03.05	6	Edge	conrol	23.3	129.2	---
6.09.05	6	Streambank	conrol	4.0	113.7	107.9
6.09.05	6	Middle	conrol	14.6	109.4	99.4
6.09.05	6	Edge	conrol	23.3	129.2	125.4
6.16.05	6	Streambank	conrol	4.0	113.7	82.2
6.16.05	6	Middle	conrol	14.6	109.4	104.0
6.16.05	6	Edge	conrol	23.3	129.2	125.3
6.23.05	6	Streambank	conrol	4.0	113.7	88.4
6.23.05	6	Middle	conrol	14.6	109.4	105.9
6.23.05	6	Edge	conrol	23.3	129.2	124.2
6.30.05	6	Streambank	conrol	4.0	113.7	84.2
6.30.05	6	Middle	conrol	14.6	109.4	107.8
6.30.05	6	Edge	conrol	23.3	129.2	124.2
7.07.05	6	Streambank	conrol	4.0	113.7	84.2
7.07.05	6	Middle	conrol	14.6	109.4	106.8
7.07.05	6	Edge	conrol	23.3	129.2	123.2
7.21.05	6	Streambank	conrol	4.0	113.7	109.8
7.21.05	6	Middle	conrol	14.6	109.4	104.8
7.21.05	6	Edge	conrol	23.3	129.2	123.3
8.02.05	6	Streambank	conrol	4.0	113.7	79.0
8.02.05	6	Middle	conrol	14.6	109.4	100.6
8.02.05	6	Edge	conrol	23.3	129.2	121.7
8.11.05	6	Streambank	conrol	4.0	113.7	82.4
8.11.05	6	Middle	conrol	14.6	109.4	95.7
8.11.05	6	Edge	conrol	23.3	129.2	120.2
8.18.05	6	Streambank	conrol	4.0	113.7	77.9
8.18.05	6	Middle	conrol	14.6	109.4	93.4
8.18.05	6	Edge	conrol	23.3	129.2	117.7
8.25.05	6	Streambank	conrol	4.0	113.7	66.9
8.25.05	6	Middle	conrol	14.6	109.4	79.6
8.25.05	6	Edge	conrol	23.3	129.2	106.2

Appendix X. Continued.

Sampling date	Transect	Location	Grazing treatment	Piezometer distance from stream channel (m)	Soil surface above datum (cm)	Head above datum (cm)
9.08.05	6	Streambank	conrol	4.0	113.7	70.1
9.08.05	6	Middle	conrol	14.6	109.4	86.5
9.08.05	6	Edge	conrol	23.3	129.2	95.4
9.15.05	6	Streambank	conrol	4.0	113.7	56.8
9.15.05	6	Middle	conrol	14.6	109.4	85.3
9.15.05	6	Edge	conrol	23.3	129.2	85.7
9.30.05	6	Streambank	conrol	4.0	113.7	54.0
9.30.05	6	Middle	conrol	14.6	109.4	79.6
9.30.05	6	Edge	conrol	23.3	129.2	69.9

Appendix Y. Slope of groundwater between channel thalweg and streambank piezometers (1), streambank and middle riparian piezometers (2), and middle and edge of riparian piezometers (3). Slopes were calculated as change in piezometric potential (head) between locations (cm) divided by distance between locations (cm).

Sampling date	Transect	Slope 1: thalweg to streambank	Slope 2: streambank to middle riparian	Slope 3: middle riparian to edge of riparian
5.12.05	1	0.034	0.046	0.005
5.19.05	1	0.033	0.028	-0.002
5.26.05	1	0.090	-0.034	0.004
6.03.05	1	0.100	-0.007	0.026
6.09.05	1	0.110	-0.003	0.008
6.16.05	1	0.050	0.042	0.000
6.23.05	1	0.059	0.002	0.004
6.30.05	1	0.056	-0.004	-0.001
7.07.05	1	0.054	-0.010	-0.004
7.21.05	1	0.051	-0.015	-0.011
8.02.05	1	0.061	-0.020	-0.016
8.11.05	1	0.076	-0.020	-0.008
8.18.05	1	0.068	-0.012	-0.004
8.25.05	1	0.018	0.031	-0.004
9.08.05	1	0.061	-0.035	-0.002
9.15.05	1	0.016	0.004	-0.005
9.30.05	1	0.000	dry	dry
5.12.05	2	0.098	0.012	0.008
5.19.05	2	0.096	0.000	0.002
5.26.05	2	0.148	-0.023	0.003
6.03.05	2	0.219	-0.044	-0.003
6.09.05	2	0.245	-0.049	-0.003
6.16.05	2	0.180	0.001	0.004
6.23.05	2	0.128	0.007	0.019
6.30.05	2	0.152	-0.007	0.006
7.07.05	2	0.144	-0.008	0.006
7.21.05	2	0.136	-0.010	0.007
8.02.05	2	0.153	-0.021	0.001
8.11.05	2	0.189	-0.038	0.002
8.18.05	2	0.186	-0.050	0.010
8.25.05	2	0.148	-0.027	0.006
9.08.05	2	0.101	-0.008	dry
9.15.05	2	dry	dry	dry
9.30.05	2	dry	dry	dry
5.12.05	3	0.256	0.028	0.015
5.19.05	3	0.259	0.026	0.036
5.26.05	3	0.260	0.021	0.022
6.03.05	3	0.295	0.018	0.016
6.09.05	3	0.309	0.017	0.012
6.16.05	3	0.301	0.014	0.019
6.23.05	3	0.284	0.010	0.030
6.30.05	3	0.272	0.000	0.039
7.07.05	3	0.260	-0.009	0.040
7.21.05	3	0.244	-0.009	0.037

Appendix Y. Continued.

Sampling date	Transect	Slope 1: thalweg to streambank	Slope 2: streambank to middle riparian	Slope 3: middle riparian to edge of riparian
8.02.05	3	0.227	-0.004	0.019
8.11.05	3	0.217	0.005	0.029
8.18.05	3	0.205	0.008	0.027
8.25.05	3	0.199	0.006	0.028
9.08.05	3	0.191	-0.001	0.023
9.15.05	3	0.178	0.000	0.022
9.30.05	3	0.171	-0.001	0.022
5.12.05	4	0.229	0.025	-0.001
5.19.05	4	0.163	0.034	-0.013
5.26.05	4	0.177	0.034	-0.017
6.03.05	4	rained out	rained out	rained out
6.09.05	4	0.193	0.033	-0.016
6.16.05	4	0.196	0.027	-0.010
6.23.05	4	0.194	0.020	-0.001
6.30.05	4	0.077	0.046	0.043
7.07.05	4	0.192	0.008	0.005
7.21.05	4	0.181	dry	dry
8.02.05	4	0.172	dry	dry
8.11.05	4	0.151	dry	dry
8.18.05	4	0.145	dry	dry
8.25.05	4	0.138	dry	dry
9.08.05	4	dry	dry	dry
9.15.05	4	dry	dry	dry
9.30.05	4	dry	dry	dry
5.12.05	5	0.034	0.026	-0.005
5.19.05	5	0.029	0.016	-0.021
5.26.05	5	0.048	0.009	-0.018
6.03.05	5	0.086	-0.011	-0.016
6.09.05	5	0.068	0.003	-0.014
6.16.05	5	0.050	0.016	-0.012
6.23.05	5	0.043	0.019	-0.010
6.30.05	5	0.036	0.021	-0.008
7.07.05	5	0.033	0.019	-0.005
7.21.05	5	0.030	0.017	-0.005
8.02.05	5	0.033	0.014	-0.007
8.11.05	5	0.044	0.005	-0.008
8.18.05	5	0.037	0.005	-0.010
8.25.05	5	0.034	0.007	-0.008
9.08.05	5	0.025	0.001	0.003
9.15.05	5	dry	+	-0.005
9.30.05	5	dry	+	-0.006
5.12.05	6	0.209	0.004	0.042
5.19.05	6	0.207	-0.026	0.075
5.26.05	6	0.265	-0.037	0.067
6.03.05	6	rained out	rained out	rained out
6.09.05	6	0.273	-0.008	0.030
6.16.05	6	0.208	0.021	0.024

Appendix Y. Continued.

Sampling date	Transect	Slope 1: thalweg to streambank	Slope 2: streambank to middle riparian	Slope 3: middle riparian to edge of riparian
6.23.05	6	0.224	0.016	0.021
6.30.05	6	0.213	0.022	0.019
7.07.05	6	0.213	0.021	0.019
7.21.05	6	0.278	-0.005	0.021
8.02.05	6	0.200	0.020	0.024
8.11.05	6	0.209	0.013	0.028
8.18.05	6	0.197	0.015	0.028
8.25.05	6	0.169	0.012	0.031
9.08.05	6	0.177	0.015	0.010
9.15.05	6	0.144	0.027	0.000
9.30.05	6	0.137	0.024	-0.011

Appendix Z. Concentrations of NO_3^- and NH_4^+(mg·L^{-1}) in stream water (Sheep Creek) and groundwater collected from piezometers at streambank, middle riparian, and riparian edge in 2005.

Sampling date	Transect	Location	Grazing treatment	NO_3^- (mg L^{-1})	NH_4^+ (mg L^{-1})
5.12.05	1	Sheep Creek	grazed	0.08	0.01
5.19.05	1	Sheep Creek	grazed	0.03	0.04
5.26.05	1	Sheep Creek	grazed	0.09	0.04
6.03.05	1	Sheep Creek	grazed	0.06	0.04
6.09.05	1	Sheep Creek	grazed	0.06	0.02
6.16.05	1	Sheep Creek	grazed	0.08	0.04
6.23.05	1	Sheep Creek	grazed	0.07	0.04
6.30.05	1	Sheep Creek	grazed	0.05	0.08
7.07.05	1	Sheep Creek	grazed	0.07	0.04
7.21.05	1	Sheep Creek	grazed	0.08	0.06
8.01.05	1	Sheep Creek	grazed	0.07	0.07
8.10.05	1	Sheep Creek	grazed	0.05	0.06
8.18.05	1	Sheep Creek	grazed	0.07	0.08
8.25.05	1	Sheep Creek	grazed	0.14	0.05
9.08.05	1	Sheep Creek	grazed	0.02	0.06
9.15.05	1	Sheep Creek	grazed	0.03	0.08
9.30.05	1	Sheep Creek	grazed	0.02	0.09
5.12.05	2	Sheep Creek	control	0.09	0.02
5.19.05	2	Sheep Creek	control	0.04	0.05
5.26.05	2	Sheep Creek	control	0.10	0.07
6.03.05	2	Sheep Creek	control	0.05	0.03
6.09.05	2	Sheep Creek	control	0.06	0.01
6.16.05	2	Sheep Creek	control	0.08	0.04
6.23.05	2	Sheep Creek	control	0.07	0.06
6.30.05	2	Sheep Creek	control	0.04	0.09
7.07.05	2	Sheep Creek	control	0.06	0.04
7.21.05	2	Sheep Creek	control	0.08	0.08
8.01.05	2	Sheep Creek	control	0.07	0.09
8.10.05	2	Sheep Creek	control	0.06	0.08
8.18.05	2	Sheep Creek	control	0.07	0.10
8.25.05	2	Sheep Creek	control	0.13	0.07
9.08.05	2	Sheep Creek	control	0.02	0.04
9.15.05	2	Sheep Creek	control	0.03	0.07
9.30.05	2	Sheep Creek	control	0.02	0.09
5.12.05	3	Sheep Creek	grazed	0.08	0.03
5.19.05	3	Sheep Creek	grazed	0.04	0.06
5.26.05	3	Sheep Creek	grazed	0.09	0.04
6.03.05	3	Sheep Creek	grazed	0.05	0.04
6.09.05	3	Sheep Creek	grazed	0.06	0.01
6.16.05	3	Sheep Creek	grazed	0.08	0.04
6.23.05	3	Sheep Creek	grazed	0.07	0.08
6.30.05	3	Sheep Creek	grazed	0.03	0.05
7.07.05	3	Sheep Creek	grazed	0.06	0.06
7.21.05	3	Sheep Creek	grazed	0.07	0.08

Appendix Z. Continued.

Sampling date	Transect	Location	Grazing treatment	NO_3^- (mg L^{-1})	NH_4^+ (mg L^{-1})
8.01.05	3	Sheep Creek	grazed	0.08	0.08
8.10.05	3	Sheep Creek	grazed	0.06	0.07
8.18.05	3	Sheep Creek	grazed	0.06	0.07
8.25.05	3	Sheep Creek	grazed	0.12	0.05
9.08.05	3	Sheep Creek	grazed	0.03	0.09
9.15.05	3	Sheep Creek	grazed	0.03	0.09
9.30.05	3	Sheep Creek	grazed	0.01	0.06
5.12.05	4	Sheep Creek	control	0.12	0.03
5.19.05	4	Sheep Creek	control	0.02	0.04
5.26.05	4	Sheep Creek	control	0.08	0.05
6.03.05	4	Sheep Creek	control	---	---
6.09.05	4	Sheep Creek	control	0.05	0.01
6.16.05	4	Sheep Creek	control	0.05	0.04
6.23.05	4	Sheep Creek	control	0.05	0.14
6.30.05	4	Sheep Creek	control	0.02	0.04
7.07.05	4	Sheep Creek	control	0.03	0.05
7.21.05	4	Sheep Creek	control	0.08	0.10
8.01.05	4	Sheep Creek	control	0.06	0.05
8.10.05	4	Sheep Creek	control	0.05	0.07
8.18.05	4	Sheep Creek	control	0.07	0.15
8.25.05	4	Sheep Creek	control	0.07	0.05
9.08.05	4	Sheep Creek	control	0.03	0.07
9.15.05	4	Sheep Creek	control	0.02	0.10
9.30.05	4	Sheep Creek	control	0.02	0.10
5.12.05	5	Sheep Creek	grazed	0.13	0.04
5.19.05	5	Sheep Creek	grazed	0.03	0.06
5.26.05	5	Sheep Creek	grazed	0.10	0.04
6.03.05	5	Sheep Creek	grazed	0.06	0.04
6.09.05	5	Sheep Creek	grazed	0.06	0.03
6.16.05	5	Sheep Creek	grazed	0.07	0.04
6.23.05	5	Sheep Creek	grazed	0.07	0.12
6.30.05	5	Sheep Creek	grazed	0.03	0.07
7.07.05	5	Sheep Creek	grazed	0.05	0.04
7.21.05	5	Sheep Creek	grazed	0.10	0.07
8.01.05	5	Sheep Creek	grazed	0.06	0.07
8.10.05	5	Sheep Creek	grazed	0.05	0.05
8.18.05	5	Sheep Creek	grazed	0.07	0.07
8.25.05	5	Sheep Creek	grazed	0.11	0.06
9.08.05	5	Sheep Creek	grazed	0.02	0.08
9.15.05	5	Sheep Creek	grazed	0.02	0.06
9.30.05	5	Sheep Creek	grazed	0.02	0.06
5.12.05	6	Sheep Creek	control	0.12	0.04
5.19.05	6	Sheep Creek	control	0.02	0.04
5.26.05	6	Sheep Creek	control	0.09	0.04
6.03.05	6	Sheep Creek	control	---	---
6.09.05	6	Sheep Creek	control	0.04	0.02
6.16.05	6	Sheep Creek	control	0.05	0.03

Appendix Z. Continued.

Sampling date	Transect	Location	Grazing treatment	NO_3^- (mg L^{-1})	NH_4^+ (mg L^{-1})
6.23.05	6	Sheep Creek	control	0.05	0.05
6.30.05	6	Sheep Creek	control	0.02	0.06
7.07.05	6	Sheep Creek	control	0.04	0.07
7.21.05	6	Sheep Creek	control	0.07	0.06
8.01.05	6	Sheep Creek	control	0.06	0.05
8.10.05	6	Sheep Creek	control	0.05	0.08
8.18.05	6	Sheep Creek	control	0.07	0.09
8.25.05	6	Sheep Creek	control	0.08	0.07
9.08.05	6	Sheep Creek	control	0.02	0.10
9.15.05	6	Sheep Creek	control	0.02	0.05
9.30.05	6	Sheep Creek	control	0.02	0.08
5.12.05	1	Middle	grazed	0.06	0.01
5.19.05	1	Middle	grazed	0.05	0.06
5.26.05	1	Middle	grazed	0.05	0.05
6.03.05	1	Middle	grazed	0.06	0.03
6.09.05	1	Middle	grazed	0.05	0.01
6.16.05	1	Middle	grazed	0.06	0.06
6.23.05	1	Middle	grazed	---	---
6.30.05	1	Middle	grazed	0.12	0.05
7.07.05	1	Middle	grazed	0.09	0.03
7.21.05	1	Middle	grazed	0.21	0.05
8.01.05	1	Middle	grazed	0.08	0.06
8.10.05	1	Middle	grazed	0.05	0.07
8.18.05	1	Middle	grazed	0.02	0.06
8.25.05	1	Middle	grazed	0.04	0.05
9.08.05	1	Middle	grazed	0.15	0.09
9.15.05	1	Middle	grazed	0.21	0.07
9.30.05	1	Middle	grazed	---	---
5.12.05	2	Middle	control	0.45	0.07
5.19.05	2	Middle	control	0.04	0.10
5.26.05	2	Middle	control	0.04	0.11
6.03.05	2	Middle	control	0.05	0.10
6.09.05	2	Middle	control	0.00	0.12
6.16.05	2	Middle	control	0.06	0.16
6.23.05	2	Middle	control	0.10	0.12
6.30.05	2	Middle	control	0.07	0.11
7.07.05	2	Middle	control	0.13	0.21
7.21.05	2	Middle	control	0.24	0.24
8.01.05	2	Middle	control	0.27	0.11
8.10.05	2	Middle	control	0.22	0.09
8.18.05	2	Middle	control	0.18	0.17
8.25.05	2	Middle	control	0.21	0.26
9.08.05	2	Middle	control	---	---
9.15.05	2	Middle	control	---	---
9.30.05	2	Middle	control	---	---
5.12.05	3	Middle	grazed	0.03	0.03
5.19.05	3	Middle	grazed	0.02	0.04

Appendix Z. Continued.

Sampling date	Transect	Location	Grazing treatment	NO_3^- (mg L^{-1})	NH_4^+ (mg L^{-1})
5.26.05	3	Middle	grazed	0.01	0.04
6.03.05	3	Middle	grazed	0.02	0.02
6.09.05	3	Middle	grazed	0.01	0.01
6.16.05	3	Middle	grazed	0.02	0.07
6.23.05	3	Middle	grazed	0.01	0.04
6.30.05	3	Middle	grazed	0.01	0.06
7.07.05	3	Middle	grazed	0.01	0.04
7.21.05	3	Middle	grazed	0.02	0.07
8.01.05	3	Middle	grazed	0.02	0.06
8.10.05	3	Middle	grazed	0.02	0.12
8.18.05	3	Middle	grazed	0.04	0.19
8.25.05	3	Middle	grazed	0.02	0.15
9.08.05	3	Middle	grazed	0.08	0.17
9.15.05	3	Middle	grazed	0.15	0.20
9.30.05	3	Middle	grazed	0.11	0.15
5.12.05	4	Middle	control	0.11	0.04
5.19.05	4	Middle	control	0.03	0.04
5.26.05	4	Middle	control	0.03	0.03
6.03.05	4	Middle	control	---	---
6.09.05	4	Middle	control	0.05	0.01
6.16.05	4	Middle	control	0.06	0.04
6.23.05	4	Middle	control	0.07	0.05
6.30.05	4	Middle	control	0.09	0.10
7.07.05	4	Middle	control	0.08	0.04
7.21.05	4	Middle	control	---	---
8.01.05	4	Middle	control	---	---
8.10.05	4	Middle	control	---	---
8.18.05	4	Middle	control	---	---
8.25.05	4	Middle	control	---	---
9.08.05	4	Middle	control	---	---
9.15.05	4	Middle	control	---	---
9.30.05	4	Middle	control	---	---
5.12.05	5	Middle	grazed	0.20	0.04
5.19.05	5	Middle	grazed	0.05	0.19
5.26.05	5	Middle	grazed	0.06	0.15
6.03.05	5	Middle	grazed	0.14	0.10
6.09.05	5	Middle	grazed	0.19	0.09
6.16.05	5	Middle	grazed	0.23	0.05
6.23.05	5	Middle	grazed	0.24	0.04
6.30.05	5	Middle	grazed	0.23	0.03
7.07.05	5	Middle	grazed	0.23	0.03
7.21.05	5	Middle	grazed	0.22	0.05
8.01.05	5	Middle	grazed	0.22	0.23
8.10.05	5	Middle	grazed	0.10	0.51
8.18.05	5	Middle	grazed	0.08	0.38
8.25.05	5	Middle	grazed	0.05	0.44
9.08.05	5	Middle	grazed	0.06	0.59

Appendix Z. Continued.

Sampling date	Transect	Location	Grazing treatment	NO_3^- (mg L^{-1})	NH_4^+ (mg L^{-1})
9.15.05	5	Middle	grazed	0.07	0.48
9.30.05	5	Middle	grazed	0.51	0.06
5.12.05	6	Middle	control	0.04	0.08
5.19.05	6	Middle	control	0.01	0.09
5.26.05	6	Middle	control	0.01	0.09
6.03.05	6	Middle	control	---	---
6.09.05	6	Middle	control	0.01	0.05
6.16.05	6	Middle	control	0.04	0.06
6.23.05	6	Middle	control	0.03	0.06
6.30.05	6	Middle	control	0.02	0.04
7.07.05	6	Middle	control	0.02	0.07
7.21.05	6	Middle	control	0.02	0.08
8.01.05	6	Middle	control	0.02	0.04
8.10.05	6	Middle	control	0.01	0.06
8.18.05	6	Middle	control	0.02	0.04
8.25.05	6	Middle	control	0.02	0.06
9.08.05	6	Middle	control	0.02	0.09
9.15.05	6	Middle	control	0.03	0.14
9.30.05	6	Middle	control	0.01	0.06
5.12.05	1	Streambank	grazed	0.05	0.02
5.19.05	1	Streambank	grazed	0.09	0.05
5.26.05	1	Streambank	grazed	0.04	0.05
6.03.05	1	Streambank	grazed	0.06	0.04
6.09.05	1	Streambank	grazed	0.03	0.02
6.16.05	1	Streambank	grazed	0.03	0.05
6.23.05	1	Streambank	grazed	0.06	0.04
6.30.05	1	Streambank	grazed	0.10	0.09
7.07.05	1	Streambank	grazed	0.11	0.11
7.21.05	1	Streambank	grazed	0.74	0.06
8.01.05	1	Streambank	grazed	0.61	0.04
8.10.05	1	Streambank	grazed	0.42	0.05
8.18.05	1	Streambank	grazed	0.46	0.07
8.25.05	1	Streambank	grazed	0.42	0.14
9.08.05	1	Streambank	grazed	0.05	0.13
9.15.05	1	Streambank	grazed	0.11	0.26
9.30.05	1	Streambank	grazed	0.12	0.13
5.12.05	2	Streambank	control	0.18	0.05
5.19.05	2	Streambank	control	0.02	0.09
5.26.05	2	Streambank	control	0.02	0.04
6.03.05	2	Streambank	control	0.01	0.02
6.09.05	2	Streambank	control	0.00	0.01
6.16.05	2	Streambank	control	0.02	0.07
6.23.05	2	Streambank	control	0.04	0.05
6.30.05	2	Streambank	control	0.02	0.08
7.07.05	2	Streambank	control	0.03	0.12
7.21.05	2	Streambank	control	0.10	0.16
8.01.05	2	Streambank	control	0.04	0.08

Appendix Z. Continued.

Sampling date	Transect	Location	Grazing treatment	NO_3^- (mg L^{-1})	NH_4^+ (mg L^{-1})
8.10.05	2	Streambank	control	0.06	0.12
8.18.05	2	Streambank	control	0.14	0.14
8.25.05	2	Streambank	control	0.25	0.06
9.08.05	2	Streambank	control	0.05	0.13
9.15.05	2	Streambank	control	---	---
9.30.05	2	Streambank	control	---	---
5.12.05	3	Streambank	grazed	0.06	0.29
5.19.05	3	Streambank	grazed	0.14	0.13
5.26.05	3	Streambank	grazed	0.07	0.16
6.03.05	3	Streambank	grazed	0.08	0.17
6.09.05	3	Streambank	grazed	0.08	0.18
6.16.05	3	Streambank	grazed	0.18	0.16
6.23.05	3	Streambank	grazed	0.36	0.06
6.30.05	3	Streambank	grazed	0.39	0.03
7.07.05	3	Streambank	grazed	0.46	0.05
7.21.05	3	Streambank	grazed	0.48	0.09
8.01.05	3	Streambank	grazed	0.65	0.06
8.10.05	3	Streambank	grazed	0.16	0.26
8.18.05	3	Streambank	grazed	0.67	0.32
8.25.05	3	Streambank	grazed	1.09	0.06
9.08.05	3	Streambank	grazed	0.52	0.10
9.15.05	3	Streambank	grazed	0.51	0.15
9.30.05	3	Streambank	grazed	0.47	0.07
5.12.05	4	Streambank	control	0.08	0.06
5.19.05	4	Streambank	control	0.02	0.10
5.26.05	4	Streambank	control	0.02	0.07
6.03.05	4	Streambank	control	---	---
6.09.05	4	Streambank	control	0.01	0.07
6.16.05	4	Streambank	control	0.01	0.07
6.23.05	4	Streambank	control	0.01	0.05
6.30.05	4	Streambank	control	0.01	0.06
7.07.05	4	Streambank	control	0.01	0.05
7.21.05	4	Streambank	control	0.05	0.18
8.01.05	4	Streambank	control	0.03	0.16
8.10.05	4	Streambank	control	0.04	0.24
8.18.05	4	Streambank	control	0.22	0.40
8.25.05	4	Streambank	control	0.04	0.16
9.08.05	4	Streambank	control	---	---
9.15.05	4	Streambank	control	---	---
9.30.05	4	Streambank	control	---	---
5.12.05	5	Streambank	grazed	0.06	0.10
5.19.05	5	Streambank	grazed	0.02	0.12
5.26.05	5	Streambank	grazed	0.01	0.12
6.03.05	5	Streambank	grazed	0.02	0.03
6.09.05	5	Streambank	grazed	0.02	0.03
6.16.05	5	Streambank	grazed	0.02	0.05
6.23.05	5	Streambank	grazed	0.02	0.06

Appendix Z. Continued.

Sampling date	Transect	Location	Grazing treatment	NO_3^- (mg L^{-1})	NH_4^+ (mg L^{-1})
6.30.05	5	Streambank	grazed	0.01	0.08
7.07.05	5	Streambank	grazed	0.02	0.11
7.21.05	5	Streambank	grazed	0.03	0.27
8.01.05	5	Streambank	grazed	0.02	0.44
8.10.05	5	Streambank	grazed	0.01	0.30
8.18.05	5	Streambank	grazed	0.02	0.35
8.25.05	5	Streambank	grazed	0.02	0.36
9.08.05	5	Streambank	grazed	0.53	0.78
9.15.05	5	Streambank	grazed	---	---
9.30.05	5	Streambank	grazed	---	---
5.12.05	6	Streambank	control	0.07	0.07
5.19.05	6	Streambank	control	0.04	0.05
5.26.05	6	Streambank	control	0.06	0.03
6.03.05	6	Streambank	control	---	---
6.09.05	6	Streambank	control	0.02	0.03
6.16.05	6	Streambank	control	0.06	0.08
6.23.05	6	Streambank	control	0.09	0.04
6.30.05	6	Streambank	control	0.09	0.06
7.07.05	6	Streambank	control	0.14	0.08
7.21.05	6	Streambank	control	0.12	0.07
8.01.05	6	Streambank	control	0.25	0.06
8.10.05	6	Streambank	control	0.22	0.18
8.18.05	6	Streambank	control	0.29	0.06
8.25.05	6	Streambank	control	0.36	0.05
9.08.05	6	Streambank	control	0.44	0.08
9.15.05	6	Streambank	control	0.45	0.10
9.30.05	6	Streambank	control	0.37	0.08
5.12.05	1	Edge	grazed	0.13	0.07
5.19.05	1	Edge	grazed	0.11	0.06
5.26.05	1	Edge	grazed	0.08	0.10
6.03.05	1	Edge	grazed	0.04	0.07
6.09.05	1	Edge	grazed	0.03	0.05
6.16.05	1	Edge	grazed	0.06	0.04
6.23.05	1	Edge	grazed	---	---
6.30.05	1	Edge	grazed	0.14	0.07
7.07.05	1	Edge	grazed	0.13	0.04
7.21.05	1	Edge	grazed	0.19	0.15
8.01.05	1	Edge	grazed	0.17	0.12
8.10.05	1	Edge	grazed	0.11	0.11
8.18.05	1	Edge	grazed	0.10	0.12
8.25.05	1	Edge	grazed	0.15	0.13
9.08.05	1	Edge	grazed	0.24	0.17
9.15.05	1	Edge	grazed	0.19	0.12
9.30.05	1	Edge	grazed	---	---
5.12.05	2	Edge	control	0.79	0.06
5.19.05	2	Edge	control	0.06	0.20
5.26.05	2	Edge	control	0.03	0.23

Appendix Z. Continued.

Sampling date	Transect	Location	Grazing treatment	NO_3^- (mg L^{-1})	NH_4^+ (mg L^{-1})
6.03.05	2	Edge	control	0.02	0.23
6.09.05	2	Edge	control	0.00	0.27
6.16.05	2	Edge	control	0.02	0.29
6.23.05	2	Edge	control	0.01	0.19
6.30.05	2	Edge	control	0.02	0.26
7.07.05	2	Edge	control	0.02	0.35
7.21.05	2	Edge	control	0.09	0.32
8.01.05	2	Edge	control	0.27	0.15
8.10.05	2	Edge	control	0.30	0.16
8.18.05	2	Edge	control	0.14	0.11
8.25.05	2	Edge	control	0.13	0.11
9.08.05	2	Edge	control	---	---
9.15.05	2	Edge	control	---	---
9.30.05	2	Edge	control	---	---
5.12.05	3	Edge	grazed	0.05	0.05
5.19.05	3	Edge	grazed	0.06	0.06
5.26.05	3	Edge	grazed	0.05	0.03
6.03.05	3	Edge	grazed	0.06	0.03
6.09.05	3	Edge	grazed	0.05	0.01
6.16.05	3	Edge	grazed	0.26	0.06
6.23.05	3	Edge	grazed	0.07	0.05
6.30.05	3	Edge	grazed	0.07	0.04
7.07.05	3	Edge	grazed	0.09	0.11
7.21.05	3	Edge	grazed	0.08	0.04
8.01.05	3	Edge	grazed	0.12	0.09
8.10.05	3	Edge	grazed	0.09	0.07
8.18.05	3	Edge	grazed	0.19	0.19
8.25.05	3	Edge	grazed	0.21	0.20
9.08.05	3	Edge	grazed	0.29	0.08
9.15.05	3	Edge	grazed	0.32	0.05
9.30.05	3	Edge	grazed	0.26	0.14
5.12.05	4	Edge	control	---	---
5.19.05	4	Edge	control	0.04	0.09
5.26.05	4	Edge	control	0.10	0.08
6.03.05	4	Edge	control	---	---
6.09.05	4	Edge	control	0.14	0.03
6.16.05	4	Edge	control	0.19	0.03
6.23.05	4	Edge	control	0.19	0.06
6.30.05	4	Edge	control	0.20	0.05
7.07.05	4	Edge	control	0.21	0.11
7.21.05	4	Edge	control	---	---
8.01.05	4	Edge	control	---	---
8.10.05	4	Edge	control	---	---
8.18.05	4	Edge	control	---	---
8.25.05	4	Edge	control	---	---
9.08.05	4	Edge	control	---	---
9.15.05	4	Edge	control	---	---

Appendix Z. Continued.

Sampling date	Transect	Location	Grazing treatment	NO_3^- (mg L^{-1})	NH_4^+ (mg L^{-1})
9.30.05	4	Edge	control	---	---
5.12.05	5	Edge	grazed	0.27	0.03
5.19.05	5	Edge	grazed	0.01	0.08
5.26.05	5	Edge	grazed	0.01	0.04
6.03.05	5	Edge	grazed	0.02	0.02
6.09.05	5	Edge	grazed	0.04	0.02
6.16.05	5	Edge	grazed	0.02	0.03
6.23.05	5	Edge	grazed	0.02	0.05
6.30.05	5	Edge	grazed	0.02	0.04
7.07.05	5	Edge	grazed	0.01	0.18
7.21.05	5	Edge	grazed	0.03	0.18
8.01.05	5	Edge	grazed	0.02	0.30
8.10.05	5	Edge	grazed	0.06	0.26
8.18.05	5	Edge	grazed	0.04	0.14
8.25.05	5	Edge	grazed	0.15	0.12
9.08.05	5	Edge	grazed	0.15	0.22
9.15.05	5	Edge	grazed	0.10	0.23
9.30.05	5	Edge	grazed	0.27	0.07
5.12.05	6	Edge	control	0.02	0.05
5.19.05	6	Edge	control	0.01	0.04
5.26.05	6	Edge	control	0.01	0.03
6.03.05	6	Edge	control	---	---
6.09.05	6	Edge	control	0.00	0.03
6.16.05	6	Edge	control	0.01	0.05
6.23.05	6	Edge	control	0.02	0.05
6.30.05	6	Edge	control	0.01	0.03
7.07.05	6	Edge	control	0.02	0.07
7.21.05	6	Edge	control	0.02	0.07
8.01.05	6	Edge	control	0.02	0.13
8.10.05	6	Edge	control	0.02	0.17
8.18.05	6	Edge	control	0.03	0.15
8.25.05	6	Edge	control	0.03	0.16
9.08.05	6	Edge	control	0.21	0.10
9.15.05	6	Edge	control	0.33	0.05
9.30.05	6	Edge	control	0.30	0.07

Appendix AA. Nitrification and nitrogen mineralization in surface soils of Sheep Creek riparian zone measured with ion-exchange resin (IER) bags on a monthly basis in 2005.

Transect	Location	Grazing treatment	Month	Nitrification ($mg\ NO_3^-\ g^{-1} resin\ month^{-1}$)	N mineralization ($mg\ NH_4^+\ g^{-1} resin\ month^{-1}$)
1	Streambank	grazed	June	0.004	0.025
1	Streambank	grazed	July	0.002	0.008
1	Streambank	grazed	August	0.002	0.005
1	Streambank	grazed	September	0.002	0.010
2	Streambank	control	June	0.008	0.022
2	Streambank	control	July	0.004	0.018
2	Streambank	control	August	0.004	0.013
2	Streambank	control	September	0.004	0.002
3	Streambank	grazed	June	0.003	0.033
3	Streambank	grazed	July	0.004	0.022
3	Streambank	grazed	August	0.003	0.012
3	Streambank	grazed	September	0.004	0.013
4	Streambank	control	June	0.002	0.041
4	Streambank	control	July	0.016	0.025
4	Streambank	control	August	0.011	0.016
4	Streambank	control	September	0.004	0.022
5	Streambank	grazed	June	0.001	0.025
5	Streambank	grazed	July	0.007	0.025
5	Streambank	grazed	August	0.004	0.020
5	Streambank	grazed	September	0.003	0.008
6	Streambank	control	June	0.001	0.063
6	Streambank	control	July	0.006	0.017
6	Streambank	control	August	0.002	0.015
6	Streambank	control	September	0.003	0.018
1	Middle	grazed	June	0.003	0.024
1	Middle	grazed	July	0.003	0.002
1	Middle	grazed	August	0.004	0.007
1	Middle	grazed	September	0.002	0.002
2	Middle	control	June	---	0.033
2	Middle	control	July	0.004	0.006
2	Middle	control	August	0.006	0.010
2	Middle	control	September	0.005	0.003
3	Middle	grazed	June	0.007	0.018
3	Middle	grazed	July	0.002	0.031
3	Middle	grazed	August	0.005	0.013
3	Middle	grazed	September	0.007	0.002
4	Middle	control	June	0.003	0.018
4	Middle	control	July	0.002	0.005
4	Middle	control	August	0.004	0.005
4	Middle	control	September	0.002	0.001
5	Middle	grazed	June	0.010	0.030
5	Middle	grazed	July	0.004	0.006
5	Middle	grazed	August	0.006	0.024
5	Middle	grazed	September	0.003	0.009

Appendix AA. Continued.

Transect	Location	Grazing treatment	Month	Nitrification (mg NO_3^- g^{-1}resin $month^{-1}$)	N mineralization (mg NH_4^+ g^{-1}resin $month^{-1}$)
6	Middle	control	June	0.001	0.073
6	Middle	control	July	0.003	0.022
6	Middle	control	August	0.000	0.035
6	Middle	control	September	0.003	0.010
1	Edge	grazed	June	0.002	0.011
1	Edge	grazed	July	0.003	0.002
1	Edge	grazed	August	0.003	0.003
1	Edge	grazed	September	0.002	0.003
2	Edge	control	June	0.003	0.009
2	Edge	control	July	0.002	0.002
2	Edge	control	August	0.003	0.006
2	Edge	control	September	0.007	0.001
3	Edge	grazed	June	0.001	0.021
3	Edge	grazed	July	0.005	0.015
3	Edge	grazed	August	0.005	0.010
3	Edge	grazed	September	0.008	0.004
4	Edge	control	June	0.001	0.022
4	Edge	control	July	0.006	0.006
4	Edge	control	August	0.006	0.004
4	Edge	control	September	0.002	0.000
5	Edge	grazed	June	0.003	0.005
5	Edge	grazed	July	0.002	0.005
5	Edge	grazed	August	0.003	0.005
5	Edge	grazed	September	0.005	0.003
6	Edge	control	June	0.002	0.026
6	Edge	control	July	0.003	0.019
6	Edge	control	August	0.005	0.015
6	Edge	control	September	0.005	0.009

Appendix AB. Statistical analyses of Sheep Creek stream stage, groundwater piezometric potential, stream NO_3^- and NH_4^+, and groundwater NO_3^- and NH_4^+.

Table AB-1a. Analysis of variance (ANOVA) of location (Sheep Creek, streambank, middle riparian, riparian edge), grazing treatment (Trt), and month effects on water elevations in stream (stage) and piezometers (head). Significant differences were accepted at *P*- value < 0.05.

Covariance Parameter Estimates

Covariance Parameter	Estimate
Block	303
Block *Trt	786
Block*Trt*Location	204
Block*Trt*Location*Month	88
Residual	1.01

Type III Tests of Fixed Effects

Effect	Numerator DF	Denominator DF	*F*-value	*P*-value
Location	3	11	1.18	0.36
Trt	1	2	0.41	0.59
Location*Trt	3	11	0.17	0.92
Month	4	54	30.40	<0.0001
Location*Month	12	54	2.46	0.01
Trt*Month	4	54	1.36	0.26
Location*Trt*Month	12	54	0.91	0.54

Appendix AB. Continued.

Table AB-1b. Differences of least square means in water elevations for the Location*Month interaction in Table Y-1a. Comparisons were made between locations within each month at $P < 0.05$, P-diff = difference between least square means.

Month	Location	Location	*P*-diff	DF	*t*-value	*P*-value
May	Sheep Creek	Middle	15.59	54	1.47	0.15
May	Sheep Creek	Streambank	29.49	54	2.78	0.01
May	Sheep Creek	Edge	5.67	54	0.53	0.60
May	Middle	Streambank	13.90	54	1.41	0.17
May	Middle	Edge	-9.92	54	-1.00	0.32
May	Streambank	Edge	-23.82	54	-2.41	0.02
June	Sheep Creek	Middle	-13.68	54	-1.29	0.20
June	Sheep Creek	Streambank	-0.63	54	-0.06	0.95
June	Sheep Creek	Edge	-21.60	54	-2.03	0.05
June	Middle	Streambank	13.05	54	1.32	0.19
June	Middle	Edge	-7.92	54	-0.80	0.43
June	Streambank	Edge	-20.97	54	-2.12	0.04
July	Sheep Creek	Middle	12.07	54	1.14	0.26
July	Sheep Creek	Streambank	14.40	54	1.36	0.18
July	Sheep Creek	Edge	2.77	54	0.26	0.80
July	Middle	Streambank	2.33	54	0.24	0.81
July	Middle	Edge	-9.30	54	-0.94	0.35
July	Streambank	Edge	-11.63	54	-1.18	0.24
August	Sheep Creek	Middle	10.63	54	0.98	0.33
August	Sheep Creek	Streambank	17.42	54	1.64	0.11
August	Sheep Creek	Edge	4.01	54	0.37	0.71
August	Middle	Streambank	6.78	54	0.67	0.51
August	Middle	Edge	-6.62	54	-0.64	0.53
August	Streambank	Edge	-13.41	54	-1.32	0.19
September	Sheep Creek	Middle	-4.29	54	-0.40	0.69
September	Sheep Creek	Streambank	6.39	54	0.59	0.56
September	Sheep Creek	Edge	0.75	54	0.06	0.95
September	Middle	Streambank	10.68	54	1.03	0.31
September	Middle	Edge	5.04	54	0.46	0.65
September	Streambank	Edge	-5.64	54	-0.51	0.61

Appendix AB. Continued.

Table AB-2a. Analysis of variance (ANOVA) of grazing treatment (Trt) and month effects on stream NO_3^- and NH_4^+. Significant differences were accepted at P-value < 0.05.

Covariance Parameter Estimates		Type III Tests of Fixed Effects				
Covariance Parameter	**Estimate**	**Effect**	**Numerator DF**	**Denominator DF**	**F-value**	**P-value**
Stream NO_3^-		***Stream NO_3^-***				
Block	0	Trt	1	2	2.91	0.23
Block *Trt	0.00001	Month	4	16	98.86	<0.0001
Block*Trt*Month	0	Trt*Month	4	16	2.05	0.14
Residual	0.00003					
Stream NH_4^+		***Stream NH_4^+***				
Block	0	Trt	1	2	3.89	0.19
Block *Trt	0	Month	4	16	26.22	<0.0001
Block*Trt*Month	0	Trt*Month	4	16	1.41	0.27
Residual	0.00005					

Table AB-2b. Differences of least square means in stream NO_3^- and NH_4^+ by month (Month effects in Table Y-2a). Comparisons were made between locations within each month at P < 0.05, P-diff = difference between square means.

Stream NO_3^-

Month	**Month**	**P-diff**	**DF**	**t-value**	**P-value**
August	July	0.01	16	3.02	0.01
August	June	0.02	16	6.59	<0.0001
August	May	-0.002	16	-0.56	0.58
August	September	0.05	16	16.64	<0.0001
July	June	0.01	16	3.57	0.003
July	May	-0.01	16	-3.58	0.002
July	September	0.04	16	13.62	<0.0001
June	May	-0.02	16	-7.15	<0.0001
June	September	0.03	16	10.04	<0.0001
May	September	0.05	16	17.20	<0.0001

Stream NH_4^+

Month	**Month**	**P-diff**	**DF**	**t-value**	**P-value**
August	July	0.01	16	2.62	0.02
August	June	0.03	16	5.94	<0.0001
August	May	0.031	16	7.41	<0.0001
August	September	-0.004	16	-0.90	0.38
July	June	0.01	16	3.32	0.004
July	May	0.02	16	4.79	0.0002
July	September	-0.01	16	-3.52	0.003
June	May	0.01	16	1.48	0.16
June	September	-0.03	16	-6.84	<0.0001
May	September	-0.04	16	-8.31	<0.0001

Appendix AB. Continued.

Table AB-3a. Analysis of covariance (ANCOVA) of riparian location, grazing treatment (Trt) and month effects on groundwater NO_3^- and NH_4^+ with piezometric potential (head) as covariate. Data were log transformed and significant differences were accepted at P-value < 0.05, R^2 = coefficient of determination for proportion of variability in N concentrations explained by piezometric potential (head).

Covariance Parameter Estimates

Covariance Parameter	Estimate
Groundwater NO_3^-	
Block	0.02
Block *Trt	0
Block*Trt*Location	0.77
Residual	0.49
Groundwater NH_4^+	
Block	0
Block *Trt	0.08
Block*Trt*Location	0.04
Residual	0.20

Type III Tests of Fixed Effects

Effect	Numerator DF	Denominator DF	F-value	P-value	R^2
Groundwater NO_3^-					0.34
Location	2	8	0.40	0.68	
Trt	1	2	0.14	0.75	
Location*Trt	2	8	0.23	0.80	
Month	4	40	4.10	0.01	
Location*Month	8	40	1.75	0.12	
Trt*Month	4	40	0.60	0.66	
Location*Trt*Month	8	40	0.82	0.59	
Head	1	40	0.87	0.36	
Groundwater NH_4^+					0.56
Location	2	8	0.84	0.47	
Trt	1	2	0.06	0.83	
Location*Trt	2	8	1.28	0.33	
Month	4	40	5.75	0.0009	
Location*Month	8	40	0.84	0.58	
Trt*Month	4	40	2.18	0.09	
Location*Trt*Month	8	40	0.51	0.84	
Head	1	40	3.76	0.06	

Appendix AB. Continued.

Table AB-3b. Differences of least square means in groundwater NO_3^- and NH_4^+ by month (Month effects in Table Y-3a). Comparisons were made between locations within each month at $P < 0.05$, P-diff = difference between log-transformed least square means.

Groundwater NO_3^-					
Month	**Month**	***P*-diff**	**DF**	***t*-value**	***P*-value**
August	July	0.19	40	0.78	0.44
August	June	0.76	40	2.85	0.007
August	May	0.46	40	1.80	0.08
August	September	-0.55	40	-1.81	0.08
July	June	0.57	40	2.30	0.03
July	May	0.26	40	1.11	0.27
July	September	-0.74	40	-2.44	0.02
June	May	-0.31	40	-1.29	0.20
June	September	-1.31	40	-3.83	0.0004
May	September	-1.00	40	-3.15	0.003

Groundwater NH_4^+					
Month	**Month**	***P*-diff**	**DF**	***t*-value**	***P*-value**
August	July	0.30	40	1.90	0.06
August	June	0.71	40	4.27	0.0001
August	May	0.56	40	3.52	0.001
August	September	0.02	40	0.13	0.89
July	June	0.42	40	2.68	0.01
July	May	0.26	40	1.77	0.08
July	September	-0.27	40	-1.45	0.15
June	May	-0.15	40	-1.00	0.32
June	September	-0.69	40	-3.32	0.002
May	September	-0.54	40	-2.75	0.009

Appendix AB. Continued.

Table AB-4a. Analysis of covariance (ANCOVA) of location, grazing treatment (Trt) and month effects on groundwater NO_3^- and NH_4^+ with stream stage and piezometric potential (head) as the covariate. Data were log transformed and significant differences were accepted at P-value < 0.05.

Covariance Parameter Estimates

Covariance Parameter	Estimate
Groundwater NO_3^-	
Block	0.03
Block *Trt	0
Block*Trt*Location	0.60
Residual	0.38
Groundwater NH_4^+	
Block	0
Block *Trt	0.05
Block*Trt*Location	0.05
Residual	0.16

Type III Tests of Fixed Effects

Effect	Numerator DF	Denominator DF	F-value	P-value
Groundwater NO_3^-				
Location	3	11	0.70	0.57
Trt	1	2	0.19	0.71
Location*Trt	3	11	0.20	0.89
Month	4	52	3.21	0.02
Location*Month	12	52	4.32	<0.0001
Trt*Month	4	52	0.63	0.65
Location*Trt*Month	12	52	0.76	0.69
Head	1	52	1.13	0.29
Groundwater NH_4^+				
Location	3	11	3.94	0.04
Trt	1	2	0.09	0.79
Location*Trt	3	11	0.92	0.46
Month	4	52	7.92	<0.0001
Location*Month	12	52	0.87	0.58
Trt*Month	4	52	2.05	0.10
Location*Trt*Month	12	52	0.66	0.78
Head	1	52	5.09	0.03

Appendix AB. Continued.

Table AB-4b. Differences of least square means in groundwater NO_3^- and NH_4^+ for the Location*Month interaction in Table Y-4a. Comparisons were made between locations within each month at $P < 0.05$, P-diff = difference between log-transformed least square means.

Groundwater NO_3^-

Month	Location	Location	*P*-diff	DF	*t*-value	*P*-value
May	Sheep Creek	Middle	0.39	52	0.64	0.52
May	Sheep Creek	Streambank	0.46	52	0.74	0.46
May	Sheep Creek	Edge	0.02	52	0.03	0.98
May	Middle	Streambank	0.07	52	0.11	0.91
May	Middle	Edge	-0.37	52	-0.65	0.52
May	Streambank	Edge	-0.44	52	-0.75	0.46
June	Sheep Creek	Middle	-0.03	52	-0.05	0.96
June	Sheep Creek	Streambank	0.36	52	0.59	0.56
June	Sheep Creek	Edge	0.12	52	0.20	0.85
June	Middle	Streambank	0.39	52	0.68	0.50
June	Middle	Edge	0.15	52	0.27	0.79
June	Streambank	Edge	-0.24	52	-0.40	0.69
July	Sheep Creek	Middle	-0.16	52	-0.27	0.79
July	Sheep Creek	Streambank	-0.46	52	-0.76	0.45
July	Sheep Creek	Edge	0.03	52	0.05	0.96
July	Middle	Streambank	-0.30	52	-0.52	0.60
July	Middle	Edge	0.19	52	0.34	0.74
July	Streambank	Edge	0.49	52	0.86	0.40
August	Sheep Creek	Middle	0.30	52	0.49	0.63
August	Sheep Creek	Streambank	-0.69	52	-1.12	0.27
August	Sheep Creek	Edge	-0.42	52	-0.67	0.50
August	Middle	Streambank	-0.99	52	-1.68	0.10
August	Middle	Edge	-0.72	52	-1.19	0.24
August	Streambank	Edge	0.27	52	0.45	0.65
September	Sheep Creek	Middle	-1.37	52	-2.04	0.05
September	Sheep Creek	Streambank	-2.09	52	-3.35	0.002
September	Sheep Creek	Edge	-3.05	52	-4.55	<0.0001
September	Middle	Streambank	-0.71	52	-1.09	0.28
September	Middle	Edge	-1.67	52	-2.40	0.02
September	Streambank	Edge	-0.96	52	-1.47	0.15

Appendix AB. Table AB-4b. Continued.

Groundwater NH_4^+						
Month	**Location**	**Location**	***P*-diff**	**DF**	***t*-value**	***P*-value**
May	Sheep Creek	Middle	-0.36	52	-1.29	0.20
May	Sheep Creek	Streambank	-0.47	52	-1.62	0.11
May	Sheep Creek	Edge	-0.50	52	-1.79	0.08
May	Middle	Streambank	-0.11	52	-0.41	0.69
May	Middle	Edge	-0.14	52	-0.52	0.61
May	Streambank	Edge	-0.03	52	-0.11	0.92
June	Sheep Creek	Middle	-0.26	52	-0.93	0.35
June	Sheep Creek	Streambank	-0.24	52	-0.86	0.40
June	Sheep Creek	Edge	-0.32	52	-1.13	0.27
June	Middle	Streambank	0.02	52	0.09	0.93
June	Middle	Edge	-0.06	52	-0.22	0.82
June	Streambank	Edge	-0.08	52	-0.31	0.76
July	Sheep Creek	Middle	-0.01	52	-0.03	0.98
July	Sheep Creek	Streambank	-0.51	52	-1.82	0.07
July	Sheep Creek	Edge	-0.74	52	-2.66	0.01
July	Middle	Streambank	-0.50	52	-1.93	0.06
July	Middle	Edge	-0.73	52	-2.79	0.01
July	Streambank	Edge	-0.23	52	-0.87	0.39
August	Sheep Creek	Middle	-0.33	52	-1.13	0.26
August	Sheep Creek	Streambank	-0.64	52	-2.26	0.03
August	Sheep Creek	Edge	-0.67	52	-2.29	0.03
August	Middle	Streambank	-0.30	52	-1.10	0.27
August	Middle	Edge	-0.34	52	-1.17	0.25
August	Streambank	Edge	-0.03	52	-0.12	0.91
September	Sheep Creek	Middle	-0.70	52	-2.11	0.04
September	Sheep Creek	Streambank	-0.79	52	-2.70	0.01
September	Sheep Creek	Edge	-0.46	52	-1.41	0.17
September	Middle	Streambank	-0.09	52	-0.28	0.78
September	Middle	Edge	0.23	52	0.65	0.52
September	Streambank	Edge	0.32	52	0.99	0.33

Appendix AB. Continued.

Table AB-5a. Analysis of variance (ANOVA) of location, grazing treatment (Trt) and month effects on nitrification and N mineralization estimated with ion-exchange resin (IER) Data were log transformed and significant differences were accepted at P-value < 0.05.

Covariance Parameter Estimates

Covariance Parameter	Estimate
Groundwater NO_3^-	
Block	0
Block *Trt	0.07
Block*Trt*Location	0.04
Block*Trt*Location*Month	0.06
Residual	0.37
Groundwater NH_4^+	
Block	0.07
Block *Trt	0.19
Block*Trt*Location*Month	0.11
Block*Trt*Location	0
Residual	0.42

Type III Tests of Fixed Effects

Effect	Numerator DF	Denominator DF	F-value	P-value
Nitrification				
Location	2	8	0.23	0.80
Trt	1	2	0.07	0.82
Location*Trt	2	8	1.82	0.22
Month	3	36	0.68	0.57
Location*Month	6	36	2.07	0.08
Trt*Month	3	36	0.13	0.94
Location*Trt*Month	6	36	0.37	0.89
N mineralization				
Location	2	8	8.47	0.01
Trt	1	2	0.02	0.91
Location*Trt	2	8	0.15	0.87
Month	3	36	25.29	<0.0001
Location*Month	6	36	1.50	0.21
Trt*Month	3	36	2.04	0.13
Location*Trt*Month	6	36	0.57	0.75

Appendix AB. Continued.

TableAB-5b. Differences of least square means in nitrification and N mineralization by month and location (Month and Location effects in Table Y-5a). Comparisons were made between at $P < 0.05$, P-diff = difference between log-transformed least square means.

Nitrification (NO_3^-)

Month	Month	Location	Location	P-diff	DF	t-value	P-value
August	July			-0.04	36	-0.17	0.87
August	June			0.23	36	1.07	0.29
August	September			-0.02	36	-0.11	0.91
July	June			0.27	36	1.23	0.23
July	September			0.01	36	0.06	0.95
June	September			-0.26	36	-1.18	0.25
		Middle	Streambank	0.02	8	0.07	0.95
		Middle	Edge	0.14	8	0.62	0.55
		Streambank	Edge	0.12	8	0.55	0.60

N mineralization (NH_4^+)

Month	Month	Location	Location	P-diff	DF	t-value	P-value
August	July			0.04	36	0.20	0.85
August	June			-0.85	36	-3.97	0.0003
August	September			1.01	36	4.73	<0.0001
July	June			-0.90	36	-4.17	0.0002
July	September			0.97	36	4.53	0.0001
June	September			1.87	36	8.70	<0.0001
		Middle	Streambank	-0.54	8	-1.99	0.08
		Middle	Edge	0.57	8	2.13	0.07
		Streambank	Edge	1.11	8	4.12	0.003