2007

Cattle grazing impacts on vegetation adjacent to ponds in Santa Clara County, CA

Dawn Elizabeth Lippe
San Jose State University

CATTLE GRAZING IMPACTS ON VEGETATION ADJACENT TO PONDS IN SANTA CLARA COUNTY, CA

A Thesis

Presented to

The Faculty of the Department of Biological Sciences

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Dawn Elizabeth Lippe

May 2007

UMI Number: 1445246

APPROVED FOR THE DEPARTMENT OF BIOLOGICAL SCIENCES

Dr. Shannon M. Bros, Professor of Biological Sciences

Dr. Howard Shellhammer, Emeritus Professor of Biology

Dr. Rodney G. Myatt, Professor of Biological Sciences

Dr. Susan C. Lambrecht, Assistant Professor of Biological Sciences

APPROVED FOR THE UNIVERSITY

04/24/07

ABSTRACT

CATTLE GRAZING IMPACTS ON VEGETATION ADJACENT TO PONDS IN SANTA CLARA COUNTY, CA

by Dawn E. Lippe

Grazing by domestic cattle is being considered an option for sustainable grassland management. Grassland habitats, including wetlands, have exhibited compatibility with cattle grazing, but adverse impacts have also been documented. This study assessed shoreline littoral vegetation of ponds located in California valley grasslands to evaluate cattle's use as a vegetation management tool and vegetation recovery after removal of cattle. Plant species diversity, composition, cover, and height, along with soil compaction and bare ground, were measured and compared among grazing treatments. Grazing significantly increased bare ground and reduced species diversity, species abundance, species height, and the richness of perennial and exotic plant species. This study demonstrated that cattle have a potential use in vegetation management, particularly in exotic species control. However, it also highlights the fact that a fine line exists between beneficial and detrimental grazing impacts to plant communities and substantiates the need for active management accompanied by intensive monitoring.

ACKNOWLEDGEMENTS

I would like to give a special thank you to my husband and entire family, all of whom played a role in this project from start to finish. I have been fortunate to work with outstanding faculty of the Department of Biological Sciences at San Jose State University, whom I am lucky to consider both mentors and friends. I am indebted to my thesis committee: Committee Chairperson Dr. Shannon Bros, Dr. Howard Shellhammer, Dr. Rodney Myatt, and Dr. Susan Lambrecht, as well as Dr. Jerry Smith and Dr. Jeff Honda. Thank you also to Henry Colletto who first introduced me to the issue of cattle grazing on County lands. This research would not have been possible without the permission and support of the Santa Clara County Parks and Recreation Department, Natural Resource Management team: Bill Ventura, Don Rocha, Dan Clark, and rangers at the County Parks where I conducted research. In addition to family, several friends provided company and assistance during many long days in the field. This thesis is dedicated to my newborn son, Aidan.

TABLE OF CONTENTS

Introduction	1
Methods	5
Results	19
Discussion	39
Literature Cited	52
Appendix 1. Minimal Detectable Differences (MDDs) of measure variables at the broad scale.	57
Appendix 2. Minimum Detectable Differences (MDDs) of measured variables at the fine scale.	59

LIST OF TABLES

Table		Page
1.	Grazing treatment categories and locations of study sites (ponds).	7
2.	List of plant species and habitat measurements recorded, showing analyses in which measured variables were included.	13
3.	Results of broad-scale *a priori* comparisons of the MANOVA for overall plant species diversity among grazing treatments.	19
4.	Results of fine-scale *a priori* comparisons of the MANOVA for overall plant species diversity among grazing treatments.	20
5.	Results of fine-scale planned comparisons of plant species origin (native/exotic) among grazing treatments.	21
6.	Results of broad-scale planned comparisons of plant species life cycle (annual/perennial) among grazing treatments.	23
7.	Results of fine-scale planned comparisons of plant species life cycle (annual/perennial) among grazing treatments.	23
8.	Results of broad-scale *a priori* comparisons of the MANOVA for plant species abundance among grazing treatments.	25
9.	Results of fine-scale *a priori* comparisons of the MANOVA for plant species abundance among grazing treatments.	26
10.	Results of fine-scale *a priori* comparisons of the MANOVA for plant height among grazing treatments.	26
11.	Results of broad-scale analyses (ANOVA [overall P] and two associated *a priori* comparisons) of individual plant species abundance, individual species height and other measurements among grazing treatments.	27
12.	Results of fine-scale analyses (ANOVA [overall P] and two associated a priori comparisons) of individual plant species abundance, individual species height and other measurements among grazing treatments.	31

LIST OF FIGURES

Figure		Page
1.	Location of the study area: Santa Clara County, California.	6
2.	Schematic of field design showing measurement locations at pond's edge and a magnified illustration of sampling layout at every measurement location.	10
3.	Species diversity recovery: Broad-scale changes in species evenness and richness after release from grazing pressure.	20
4.	Species diversity recovery: Fine-scale changes in species evenness and richness after release from grazing pressure.	21
5.	Species origin grazing effect: Fine-scale effect of cattle grazing on richness of native and exotic plant species.	22
6.	Species life cycle grazing effect: Broad-scale effect of cattle grazing on richness of annual and perennial plant species.	24
7.	Species life cycle grazing effect: Fine-scale effect of cattle grazing on richness of annual and perennial plant species.	24
8.	Species abundance grazing effect: Plant species with significant difference in mean percent abundance between grazed and ungrazed sites at the broad scale.	29
9.	Species abundance recovery: Plant species with significant differences in mean percent abundance after release from grazing pressure at the broad scale.	29
10.	Species abundance grazing effect: Plant species with significant differences in mean percent abundance between grazed and ungrazed sites at the fine scale.	33
11.	Species abundance recovery: Plant species with significant differences in mean percent abundance after release from grazing pressure at the fine scale.	33
12.	Species height grazing effect: Plant species with significant difference in mean height between grazed and ungrazed sites at the broad scale.	34

LIST OF FIGURES (con.)

Figure		Page
13.	Species height recovery: Plant species with significant differences in mean height after release from grazing pressure at the broad scale.	34
14.	Species height grazing effect: Plant species with significant difference in mean height between grazed and ungrazed sites at the fine scale.	36
15.	Species height recovery: Plant species with significant differences in mean height after release from grazing pressure at the fine scale.	36
16.	Bare ground grazing effect: Broad-scale effect of grazing on the amount of exposed soil.	37
17.	Bare ground grazing effect: Fine-scale effect of grazing on the amount of exposed soil.	37
18.	Bare ground recovery: Fine-scale changes in the amount of exposed soil after release from grazing pressure.	38

INTRODUCTION

Grazing by domestic cattle is being considered by land managers as a forthcoming option for sustainable grassland management. Grassland habitats, including wetlands, have exhibited compatibility with domestic cattle grazing, though both can respond differently to grazing pressure (Clary 1999). Grazed moist meadow communities have, under specific conditions, demonstrated significantly higher species richness and diversity than their ungrazed counterparts (Green 1995). Skovlin (1984) concluded that grazing by cattle in riparian ecosystems would improve forage quality in riparian areas, although results varied with life form. Through selective grazing, cattle have the potential to reduce exotic plant species such as yellow starthistle (*Centaurea solstitialis*), and it has been demonstrated that a reduction of accumulated plant residue from exotic grasses and forbs can help maintain a diversity of native herbaceous plants (Rana Creek Habitat Restoration [RCHR] 1998). Grazing can also reduce fuel loads for fire through removal of standing dead biomass and litter, and can increase inundation periods for vernal pools (Biondini 1998; Marty 2005; Pyke and Marty 2005). Furthermore, grazed grasslands provide preferred habitat for some small mammals and ground nesting birds such as killdeer and horned larks when adequate plant residue remains after grazing (Medin and Clary 1990; RCHR 1998; Vavra 2005; USDA 2006).

The use of cattle grazing in wetlands, however, creates some unique issues. Native grasslands and wetlands are diminishing to an extent that there is a focus on their conservation, with particular emphasis on controlling exotic plant species. As a result, native grasslands are a designated habitat of concern in California and wetlands are afforded Federal and State protection. Cattle exhibit a preference for mesic environments, so grazing impacts are magnified in these areas, though it is argued that a sufficient amount of rest from grazing will return an area to its previous condition. Bock and Bock (1993) and Medin and Clary (1990) observed reduced species diversity, richness and biomass, and alterations to species composition and vegetation stratification under grazed conditions. Cattle consume native annuals and create bare soil where invasive, non-native species can proliferate. The presence of cattle can increase runoff and erosion, indirectly reducing water quality by compaction and disruption of the soil, and contamination from excreta. Low population densities for a wide variety of taxa, including aquatic invertebrates, insects, birds, and mammals have been noted in grazed areas (Fleishner 1994; Kruess 2002; Allen-Diaz 2004; Marty 2005). Domestic cattle also compete with native herbivores for desirable forage, and can transmit disease to native animals (Harrison 1999). Furthermore, the presence of cattle and associated range improvements on public lands are considered by some recreational users to diminish their enjoyment of such lands (Mitchell 1996). Therefore, before a grassland management grazing program is instituted it is critical to understand the impact of domestic cattle grazing on grassland systems, particularly in wetland areas.

Unlike more conventional forms of vegetation management, grazing by domestic cattle has some economic advantages. Because cattle are a commercial crop, they provide a source of revenue through grazing permits. In addition, the use of cattle to manage vegetation would reduce reliance on expensive machinery, chemicals and manpower. Furthermore, the cost of herbicides and chemicals typically used by land managers to reduce exotic plant species is escalating and regulatory restrictions are increasing for prescribed burning, which is often used as a vegetation management tool (D. Rocha, personal communication, January 2001). Cattle grazing has the potential to effectively achieve management goals at a lower cost than current methods and is already a relatively common practice throughout western North America.

To be an ecologically effective grassland management tool, grazing must have a predictable impact on vegetation in a manner consistent with management objectives. Measures of a successful grassland management program would include the following elements: an increase in overall species diversity, a shift in species composition toward a reduction of exotic plant species and increase in native grasses, especially annual species, an increase in vegetation density and biomass (height) of desirable species, and a decrease in vegetative litter and undesirable vegetation. Plant diversity is important in maintaining the ecological health and stability of vegetation communities and habitats, and significant as a major determinant of diversity at higher trophic levels (Kruess 2002). The conservation and increase of native plant species is crucial because grasslands are being invaded by exotic, weed species that are displacing native species, particularly native annuals. The density of vegetation is a particularly important issue in grassland and wetland management since bare and disturbed soil provides a seedbed for invasive non-native plant species to become established, promotes the growth of weed species, and results in increased runoff and erosion. Reduced biomass directly affects the structure of a vegetation community, can indirectly hinder plant species germination and growth, and decreases habitat for some small mammals and ground-nesting birds (Giuliano 2004).

This study assessed the impact of domestic cattle on ponds in grasslands of Santa Clara County, California, to evaluate its potential as a vegetation management tool (Fig. 1). Research was focused on the shoreline littoral vegetation of selected ponds, where the aquatic system blends into the terrestrial grassland community, and where impacts from cattle grazing can be most apparent. Specifically, it described and compared aspects of the shoreline littoral vegetation community at similar ponds to determine if they were affected by the presence of cattle or time since release from grazing. Soil characteristics measured included soil compaction and bare ground. Community-level measurements consisted of species diversity, species origin (native or exotic), species life cycle (annual or perennial), and species composition in terms of both abundance and biomass. Biomass measurements included individual plant species abundance and height.

METHODS

The study area was located in the foothills of two mountain regions: the western foothills of the Mount Hamilton Range and the eastern foothills of the Santa Cruz Mountains, which flank the Santa Clara and Coyote Valleys. More specifically, study sites were located within four public parks of the Santa Clara County Parks System: Anderson Lake, Calero, Coyote Lake-Harvey Bear, and Joseph D. Grant (Table 1).

This valley-foothill area of California grasslands is home to over half of the State's grasslands, and over sixty-five percent of its livestock grazing (Crampton 1974; USDA 2006). Native plant associations include Foothill Oak Woodland, Valley Needlegrass Grassland, Riparian, Vernal Pool, and Sage Scrub. The study area is now generally a mosaic of open grasslands, oak woodlands, and shrublands, with a small amount of riparian and wet meadow habitat that often occur in apparent contrast with the surrounding drier landscape (RCHR 1998). These regions share a "Mediterranean" climate with predominantly a "heather" type subclimate in which warmest month averages are less than 80 degrees Fahrenheit (Sharsmith 1945; Worldclimate 2006). Most measurable rainfall occurs from mid-October to mid-April, while other times of the year tend to be dry (Worldclimate 2006).

Native grasses and forbs that have been documented in the study area include foothill needle grass (*Nassella lepida*), purple needlegrass (*Nassella pulchra*), blue wildrye (*Elymus glaucus*), one-sided bluegrass (*Poa secunda* var. *secunda*), annual fescue (*Vulpia spp.*), California brome (*Bromus carinatus*), and perennial flowers such as star lily (*Zigadenus fremontii*), blue-eyed grass (*Sisyrinchium bellum*), blue dicks

Figure 1. Location of the study area: Santa Clara County, CA (adapted and reprinted with permission from Graphic Maps, Inc.).

Table 1. Grazing treatment categories and locations of study sites (ponds).

	Pond Grazing Treatment [1]	Pond Location (lat / long)
Anderson Lake County Park		
	Long Ago	37° 9'44.88"N / 121°37'14.14"W
Calero County Park		
	Long Ago	37° 9'57.65"N / 121°46'51.05"W
	Long Ago	37°10'54.04"N / 121°45'29.97"W
	Long Ago	37°10'18.68"N / 121°45'42.97"W
Coyote Lake-Harvey Bear County Park		
	Recently	37° 4'19.88"N / 121°31'13.43"W
	Recently	37° 3'48.06"N / 121°31'21.83"W
	Currently	37° 6'37.92"N / 121°34'9.09"W
	Currently	37° 4'52.85"N / 121°32'1.61"W
Joseph D. Grant County Park		
	Recently	37°18'30.95"N / 121°40'40.06"W
	Recently	37°18'23.56"N / 121°40'27.34"W
	Currently	37°21'48.06"N / 121°43'53.92"W
	Currently	37°20'29.62"N / 121°44'9.79"W
	Currently	37°20'49.19"N / 121°41'14.02"W
	Currently	37°18'55.88"N / 121°41'26.78"W
	Currently	37°18'53.25"N / 121°41'6.43"W
	Currently	37°18'36.80"N / 121°41'40.94"W

[1] Long Ago = grazed >10 years prior to study, Recently = grazed 2-4 years prior to study, Currently = grazed during and prior to year of study.

(*Dichelostemma capitatum*), Johnny jump-ups (*Viola pendunculata*), and Mariposa lily (*Calochortus luteus*) (Sharsmith 1945; Hickman 1993; Brady and Associates 1996; RCHR 1998).

Dominant exotic grasses and forbs that have been found in the study area are Italian ryegrass (*Lolium multiflorum*), wild oats (*Avena barbata*), soft chess (*Bromus hordeaceus*), ripgut brome (*Bromus diandrus*), rattail fescue (*Vulpia myuros*), filaree (*Erodium cicutarium*), black mustard (*Brassica nigra)*, thistle (*Cirsium spp.*), rose clover (*Trifolium hirtum*), and yellow starthistle (Sharsmith 1945; Hickman 1993; Brady and Associates 1996; RCHR 1998).

Common wetland species that are known to exist in the study area include rushes (*Juncus spp.*), common spikerush (*Eleocharis macrostachya*), sedges (*Carex spp.*), annual beard grass (*Polypogon monospeliensis*), popcorn flower (*Plagiobothrys spp.*), monkeyflower (*Mimulus guttatus*), stinging nettles (*Urtica dioica*), watercress (*Rorippa nasturtium-aquaticum*), cudweed (*Gnaphalium palustre*), water smartweed (*Polygonum amphibium* var. *stipulaceum*), pondweed (*Potomageton spp.*), aquatic buttercup (*Ranunculus aquatilus* var. *hispidulus*), water starwort (*Callitriche heterophylla* var. *bolanderi*) and duckweed (*Lemna minor*) (Sharsmith 1945; Hickman 1993; Brady and Associates 1996; RCHR 1998).

To assess the impact of grazing on vegetation adjacent to ponds, I compared measures of plant species diversity, composition, cover and height along with soil characteristics among three grazing treatments: currently grazed, recently grazed and long ago grazed (reference Table 1). Eight ponds were subject to annual grazing at stocking rates averaging 93 Animal Unit Months (AUMs)[1] in 1998, 80 AUMs in 1999,

---

[1] One Animal Unit Month (AUM) is the amount of forage needed to sustain one animal unit (1000 pound cow, with or without calf), or its equivalent, for one month (30 days); approximately 800 pounds of forage (dry weight basis) (USDA 2006).

117 AUMs in 2000 and 82 AUMs in 2001, with grazing generally limited to winter and spring months; these were designated as "Currently Grazed" (D. Rocha, personal communication, July 2001). Prior to 1998, these ponds had been grazed seasonally on an annual basis, but at unknown timing and intensity. The remaining eight ponds had not been exposed to permit grazing for differing amounts of time: four ponds were classified as "Recently Grazed" (grazed 2-4 years prior) and four were classified as "Long Ago Grazed" (grazed more than 10 years prior).

Because the variation in habitat characteristics was large, pond sites were arranged as randomized blocks. Each block consisted of two ponds, one grazed and one ungrazed, that were matched with respect to habitat and vegetation characteristics. Preliminary field analyses of soil texture, pond size, general pond basin slope, pond seasonality, elevation and immediately adjacent habitat type were conducted to insure that ponds within a block were as physically homogeneous as possible. Out of sixty-five available ponds, sixteen ponds were selected that had the following characteristics: sandy loam soil texture,[2] basin slopes ranging from five to twenty percent, perennially astatic seasonality, range in elevation from approximately 200-800 meters, and surrounded by open grassland habitat with less than five percent canopy. Fields containing these ponds ranged in size from roughly 152 to 326 ha.

Sampling took place in August and September 2001 and used prevailing field methodologies, alternating between grazed and ungrazed sites. Five measurement locations were randomly selected along each pond's perimeter (Fig. 2). Within each

[2] Based on soil sedimentation analyses conducted as part of this study. The USDA defines soil material with a sandy loam texture as 7 to 20% clay, more than 52% sand, and the percentage of silt plus twice the percentage of clay is 30 or more; or less than 7% clay, less than 50% silt, and more than 43% sand.

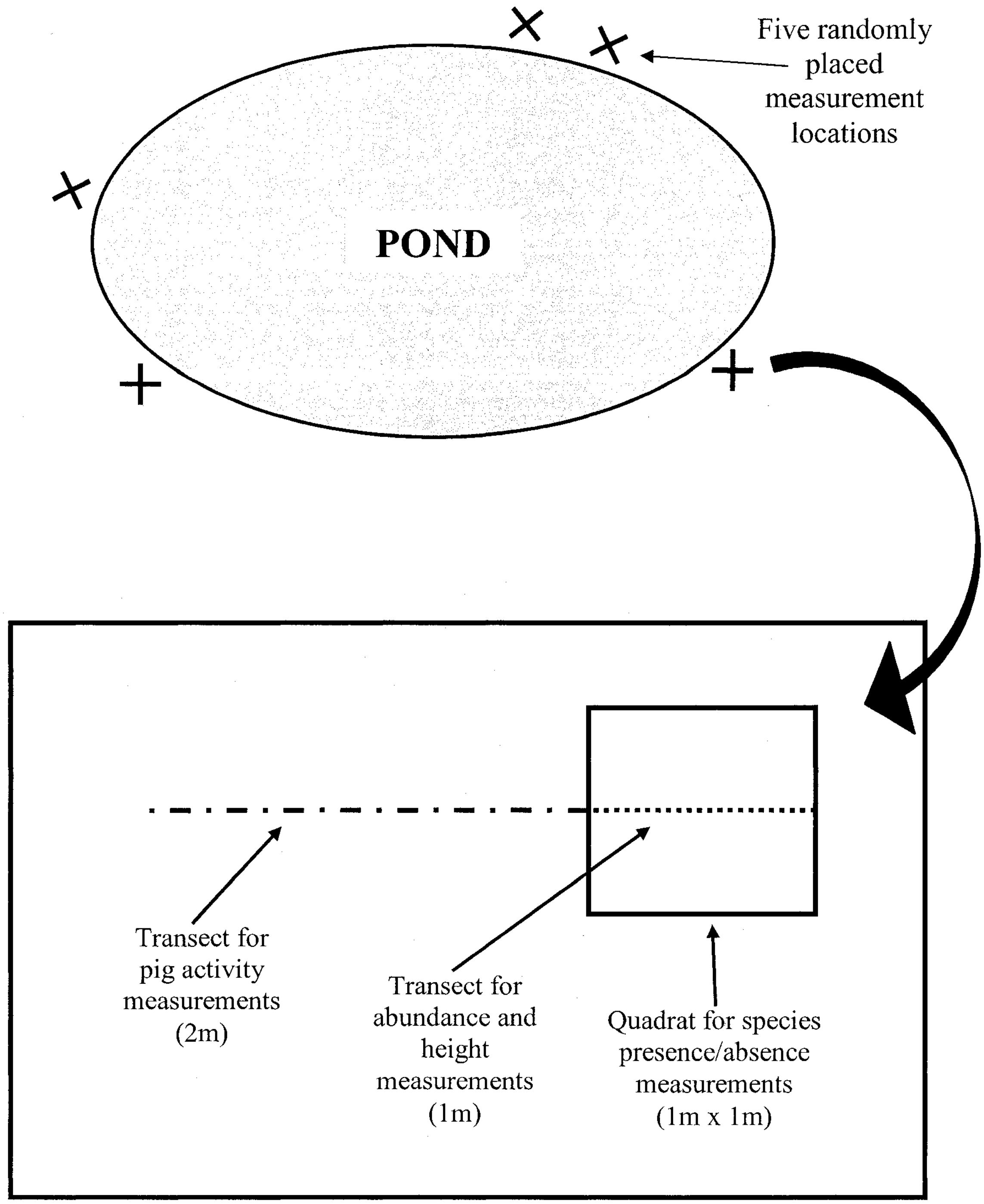

Figure 2. Schematic of field design showing measurement locations at pond's edge and a magnified illustration of sampling layout at every measurement location.

measurement location, 3-meter transects and 1m x 1m quadrats were set up in tandem, flush with the ground. The quadrats were placed just above the previous year's high water line, with one meter of the transect line bisecting the quadrat and extending two meters toward the water's edge. Changes in vegetation and habitat were examined at two scales; broad ($5m^2$) and fine ($1m^2$) scales. Broad-scale analyses were assessments at the pond level with all measurements averaged per pond (one value of each measurement per pond). Fine-scale analyses were possible since each location within a pond was randomly selected, and used every recorded measurement (five values of each measurement per pond).

Community-level changes in plant diversity with respect to cattle grazing were assessed by comparing species richness and evenness among cattle grazing treatments at both broad and fine scales. Species richness was quantified by totaling the number of different species present at each site, based on presence/absence data collected by recording every species that was present within each quadrat during field sampling. Samples of every plant species were collected and preserved in a plant press or alcohol vial for subsequent identification verification. Plants were identified following nomenclature of The Jepson Manual: Higher Plants of California (Hickman 1993). Sources for plant identification included keys in A Manual of Flowering Plants of California (Jepson 1963), The Jepson Manual: Higher Plants of California (Hickman 1993), descriptions in the Flora of Mount Hamilton Range (Sharsmith 1945), The California Native Plant Society Inventory of Rare and Endangered Plants (2001), the California Department of Fish and Game's California Natural Diversity Database List of

State and Federally Listed Endangered, Threatened, and Rare Plants List (2003) and specimens in the Sharsmith Herbarium at San Jose State University. Species evenness was computed using an index of evenness based on the Shannon-Wiener function[3] (Krebs 1989). Multivariate Analyses of Variance (MANOVAs) (Zar 1984) were performed at both scales to assess differences in species richness and evenness among grazing conditions with Systat 10.0 ™ (Table 2). Two *a priori* comparisons of the MANOVA were computed: one to compare overall species diversity among grazed and ungrazed areas (Currently Grazed v. Recently + Long Ago Grazed), and another to compare overall species diversity between Recently Grazed and Long Ago Grazed areas. A significant ($P < 0.025$) result from these analyses would indicate that cattle grazing had a measurable effect on species richness or evenness.

In order to ascertain if the diversity of native and exotic plant species were affected by cattle grazing, species richness for each group was compared across grazing treatments (Table 2). The richness of native and exotic species was quantified and analyzed at both the broad and fine scales based on presence/absence data of all plant species identified. Evenness of native and exotic species was not analyzed due to too few species in each group. Special *a priori* comparisons were created to answer specific research questions regarding variation in the richness of native and exotic plant species 1) in the presence of cattle and 2) in time since grazing had last occurred. A significant ($P < 0.025$) result from these comparisons would indicate that the presence of or time since grazing had an effect on the richness of native or exotic plant species.

---

[3] Calculated using the formula $J^1 = H^1 / H^1_{max}$ where J^1 = evenness measure (range 0-1), H^1 = Shannon-Wiener function, H^1_{max} = max value of $H^1 = \log S$. The Shannon-Weiner function is also known as the Shannon index or the Shannon-Weaver index.

Table 2. List of plant species and habitat measurements recorded, showing analyses in which measured variables were included.

		Overall Diversity [1]	Species Origin [1]	Species Life Cycle [1]	MANOVA [1]	MDS [1]	ANOVA [1]	ANCOVA [1]
PLANT SPECIES								
Family Asteraceae								
common cocklebur	*Xanthium strumarium*	P,B,F	P,B,F	P,B,F		P,F	A,H,B,F	
common tar weed	*Madia elegans*	P,B,F	P,B,F	P,B,F		P,F		
everlasting cudweed	*Gnaphalium luteo-album*	P,B,F	P,B,F	P,B,F			A,H,B,F	
oregon woolly marbles	*Psilocarphus oregonus*	P,B,F	P,B,F	P,B,F		P,F		
plumeless thistle spp.	*Carduus* spp.	P,B,F	P,B,F	P,B,F		P,F	A,H,B,F	
prickly lettuce	*Lactuca serriola*	P,B,F	P,B,F	P,B,F		P,F		
sow thistle spp.	*Sonchuus* spp.	P,B,F	P,B,F	P,B,F		P,F		
spiny cocklebur	*Xanthium spinosum*	P,B,F	P,B,F	P,B,F			A,H,F	
thistle spp.	*Cirsium* spp.	P,B,F	P,B,F	P,B,F				
western marsh cudweed	*Gnaphalium palustre*	P,B,F	P,B,F	P,B,F	A,B,F		A,H,B,F	
Family Boraginaceae								
chinese pusley	*Heliotropium curassavicum*	P,B,F	P,B,F	P,B,F			A,H,B,F	
Family Brassicaceae								
mustard spp. 1	*Brassica* spp.1	P,B,F	P,B,F	P,B,F				
mustard spp. 2	*Brassica* spp.2	P,B,F	P,B,F	P,B,F		P,F	A,H,B,F	
Family Caryophyllaceae								
baby's breath	*Gypsophila* spp.	P,B,F	P,B,F	P,B,F		P,F		
four-leaved allseed	*Polycarpon tetraphyllum*	P,B,F	P,B,F	P,B,F				
Family Convulvulaceae								
bindweed	*Convulvulus arvensis*	P,B,F	P,B,F	P,B,F				
morning glory	*Calystegia collina*	P,B,F	P,B,F	P,B,F				
Family Cyperaceae								
California bulrush	*Scirpus californicus*	P,B,F	P,B,F	P,B,F			A,H,B,F	
common spikerush	*Eleocharis macrostachya*	P,B,F	P,B,F	P,B,F	A,H,B,F		A,H,B,F	
umbrella sedge	*Cyperus eragrostis*	P,B,F	P,B,F	P,B,F			A,H,F	
Family Euphorbiaceae								
petty spurge	*Euphorbia peplus*	P,B,F	P,B,F	P,B,F	H,B,F	P,F	A,H,B,F	
turkey mullein, dove weed	*Eremocarpus setigerus*	P,B,F	P,B,F	P,B,F	H,B,F	P,F	A,H,B,F	
Family Fabaceae								
strawberry clover	*Trifolium fragiferum*	P,B,F	P,B,F	P,B,F				
sweet clover	*Melilotus* spp.	P,B,F	P,B,F	P,B,F		P,F		
Family Hydrophyllaceae								
canyon nemophila	*Nemophila hetrophyla*	P,B,F	P,B,F	P,B,F			A,H,F	
Family Juncaceae								
brownhead rush	*Juncus phaeocephalus*	P,B,F	P,B,F	P,B,F			A,H,B,F	
Family Lamiaceae								
pennyroyal	*Mentha pulegium*	P,B,F	P,B,F	P,B,F			A,H,B,F	
vinegar weed	*Trichostema lanceolatum*	P,B,F	P,B,F	P,B,F		P,F		
Family Lythraceae								
grass poly	*Lythrum hyssopifolia*	P,B,F	P,B,F	P,B,F	H,B,F		A,H,B,F	
Family Poaceae								
annual beard grass	*Polypogon monspeliensis*	P,B,F	P,B,F	P,B,F	H,B,F	P,F	A,H,B,F	A,H,B
bermuda grass	*Cynodon dactylon*	P,B,F	P,B,F	P,B,F		P,F	A,H,B,F	

[1] A=Abundance Data, H=Height Data, P= Presence/Absence Data, B=Broad Scale Analysis, F=Fine Scale Analysis

Table 2. Continued.

		Overall Diversity [1]	Species Origin [1]	Species Life Cycle [1]	MANOVA [1]	MDS [1]	ANOVA [1]	ANCOVA [1]
PLANT SPECIES								
Family Poaceae (con.)								
creeping swampgrass	*Crypsis shoenoides*	P,B,F	P,B,F	P,B,F	H,B,F	P,F	A,H,B,F	
Italian ryegrass	*Lolium multiflorum*	P,B,F	P,B,F	P,B,F		P,F	A,H,B,F	
knotgrass	*Paspalum distichum*	P,B,F	P,B,F	P,B,F		P,F	A,H,B,F	
mediterranean barley	*Hordeum marinum*	P,B,F	P,B,F	P,B,F	A,H,B,F		A,H,B,F	
salt grass	*Distichlis spicata*	P,B,F	P,B,F	P,B,F			A,H,B,F	
Family Polygonaceae								
curly dock	*Rumex crispus*	P,B,F	P,B,F	P,B,F	A,B,F		A,H,B,F	
dock spp.	*Rumex* spp.	P,B,F	P,B,F	P,B,F				
douglas' knotweed	*Polygonum douglassi*	P,B,F	P,B,F	P,B,F	A,H,B,F		A,H,B,F	
smartweed spp.	*Polygonum* spp.	P,B,F	P,B,F	P,B,F			A,H,B,F	
water smartweed	*Polygonum amphibium (coccineum)*	P,B,F	P,B,F	P,B,F		P,F		
Family Scrophulariaceae								
american brookline	*Veronica americana*	P,B,F	P,B,F	P,B,F		P,F		
Family Typhaceae								
broad-leaved cattail	*Typha latifolia*	P,B,F	P,B,F	P,B,F	A,B,F		A,H,B,F	
Family Verbenaceae								
California vervain	*Verbena lasiostachys*	P,B,F	P,B,F	P,B,F		P,F		
Unknown Species								
Unknown Species 1		P,B,F	P,B,F	P,B,F				
Unknown Species 2		P,B,F	P,B,F	P,B,F				
Unknown Species 3		P,B,F	P,B,F	P,B,F		P,F		
Unknown Species 4		P,B,F	P,B,F	P,B,F	H,B,F	P,F	A,H,B,F	
OTHER MEASUREMENTS								
Bare Ground							A,B,F	
Percent Feral Pig Activity							A,B,F	
Rock							A,B,F	
Soil Compaction							F	
Species Richness							A,B,F	

[1] A=Abundance Data, H=Height Data, P= Presence/Absence Data, B=Broad Scale Analysis, F=Fine Scale Analysis

Community-level differences in diversity among annual and perennial plant species was also examined by comparing species richness for each group among grazing conditions (Table 2). The richness of annual and perennial species was quantified and analyzed at both the broad and fine scales based on presence/absence data of all plant species identified, but evenness of annual and perennial species was not analyzed due to a lack of species in each group. Special *a priori* comparisons were created to answer specific research questions regarding variation in the richness of annual and perennial plant species 1) in the presence of cattle and 2) in time since grazing had last occurred. A significant ($P < 0.025$) result from these analyses would indicate that the presence or time since cessation of grazing had a measurable impact on the richness of annual or perennial plant species.

In order to determine if species composition shifted at the community level as a result of cattle grazing, species composition was compared among the three grazing regimes with respect to overall plant abundance and plant height. Plant species abundances were recorded along the one-meter section of each transect line that bisected every quadrat (reference Fig. 2) and determined using the basal line-transect intercept technique, recording every intercept length to the nearest centimeter. Plant species heights were measured along the same transect, and recorded to the nearest centimeter for the tallest individual plant or clump of plants within every transect intercept. MANOVAs (Zar 1984) were performed at both broad and fine scales on abundance and height data of the most abundant, non-correlated plant species using Systat 10.0 ™ (Table 2). Two *a priori* comparisons were computed for each MANOVA as detailed above for overall plant species diversity. A significant ($P < 0.025$) result from these analyses would indicate that cattle grazing results in a measurable shift in overall plant species composition in terms of abundance or height. In addition, presence/absence data of all plant species, including those with low abundance, was compared across grazing conditions to determine if cattle grazing affected the composition of all species observed (Table 2). Similarities between treatments were computed at the fine scale using multidimensional scaling (MDS) of Bray-Curtis distances (Krebs 1989) of presence/absence data for all non-correlated plant species with Systat 10.0 ™. A significant result from this analysis would indicate that a difference or shift in the composition of all plant species occurred with a change in grazing condition.

To determine which individual plant species were affected by cattle grazing, measurements of individual species cover were compared across grazing treatments. One-way analyses of variance (ANOVAs) (Zar 1984) of abundance data, with grazing treatment (Currently Grazed, Recently Grazed and Long Ago Grazed) as the independent variable, were performed at both scales on measurements of abundance for twenty-eight individual plant species with Systat 10.0 ™ (Table 2). Two *a priori* comparisons of the ANOVA were conducted: one to compare abundance measurements among grazed and ungrazed areas (Currently Grazed v. Recently + Long Ago Grazed), and another to compare abundance measurements between Recently Grazed and Long Ago Grazed areas. A significant ($P < 0.025$) result from these analyses would indicate that the mean abundance of the measured plant species differs with the presence of cattle grazing or the time since cessation of grazing.

Measurements of individual plant species heights were compared among grazing treatments to ascertain which individual species exhibited a change in height as a result of cattle grazing. One-way ANOVAs (Zar 1984) and two associated *a priori* comparisons were computed for height measurements of twenty-eight plant species at both scales and in the same manner as detailed above for individual species abundance measurements (Table 2). A significant ($P < 0.025$) result from these analyses would indicate that the mean height of the measured species differs with the presence of cattle grazing or the time since grazing had last occurred.

In order to determine whether cattle grazing compressed soils or increased bare ground, measurements of soil compaction and exposed soil were recorded at every site and compared among grazing regimes (Table 2). Soil compaction readings were taken in the center of every quadrat with a penetrometer, using a weight to ensure equal pressure was applied for each reading. The presence of bare ground was measured along the same transect as species abundance and height data, recording every intercept length to the nearest centimeter. One-way ANOVAs (Zar 1984), and two associated *a priori* comparisons were performed on soil data at both scales as detailed above for individual species abundance measurements. A significant ($P < 0.025$) result from these analyses would indicate that the measured soil characteristic differs with the presence of grazing or the time since grazing had last occurred.

One complicating factor was that feral pigs were present at several sites and I was concerned that their activity might affect the results of this study. Feral pig activity was measured in order to avoid misinterpretation of effects from cattle grazing as those resulting from feral pig activity and to determine if feral pigs were having a greater impact upon measured variables than was the presence of cattle. To estimate feral pig activity at each study site, the quantity of soil disturbed by feral pig activity (rooting, wallowing, or traversing) was visually estimated and recorded to the nearest 10-

centimeter increment along the 3-meter transect line used at each measurement location. Disturbed soil intercepting or within twenty centimeters of either side of the transect line was recorded, and these data were used to compute a percent of feral pig activity for each study site. To test for potential effects of pig activity prior to analysis of cattle effects, a Pearson Product Moment Correlation (Zar 1984) analysis was conducted between the average percent of feral pig activity at each pond and all other measured variables (Zar 1984). A significant correlation (> 0.500) would indicate that feral pig activity potentially had a greater effect on a measured variable than did grazing by cattle, and that the observed condition of that variable could not be attributed solely to cattle grazing. An analysis of covariance (ANCOVA) (Zar 1984), with feral pig activity as a covariate, was performed on those variables previously found to have a significant correlation with the presence of feral pig activity in lieu of an ANOVA.

For all analyses, the minimum detectable difference (MDD) was computed for cases in which the null hypothesis was accepted. An MDD for an analysis is defined as the smallest difference for each measurement that could have been detected between grazing regimes with ninety percent confidence (a = 0.05). The MDD for each measured variable is based upon a standard statistical formula that incorporates the number of sites, the number of factors tested for each variable, the mean-square value from ANOVA analysis for each variable, the statistical power of an analysis, and degrees of freedom for each variable (Zar 1984). The broad-scale and fine-scale MDD for each measured variable are included in Appendix 1 and Appendix 2, respectively.

RESULTS

A total of forty-five plant species were identified and collected, with nine samples that were not identified beyond the generic level due to phenological age or highly disturbed condition and four completely unidentifiable due to age or condition. A mixture of plants classified as wetland species and grassland species were found, as would be expected in an ecotone of the two communities. A list of all species documented is included in Table 2. No Federal or State special status species were observed at any study sites.

Cattle grazing had broad-scale and fine-scale effects on overall plant species diversity (Tables 3 and 4). Preliminary correlation analysis showed that these effects were not influenced by feral pig activity at either scale. The first *a priori* comparison of the MANOVA showed that species evenness and richness did not differ significantly between grazed and ungrazed fields at both scales, however, the second *a priori* comparison demonstrated that species evenness and richness vary significantly (broad scale $P = 0.001$, fine scale $P < 0.001$) at both the broad and fine scale among areas recently grazed and those grazed long ago (Figs. 3 and 4).

Table 3. Results of broad-scale *a priori* comparisons of the MANOVA for overall plant species diversity among grazing treatments.

	Pillai's Trace	df	F	P
Grazing Treatments	0.787	4,26	4.216	0.009
Grazed vs. Ungrazed	0.084	2,12	0.552	0.590
Recent vs. Long Ago	0.707	2,12	14.445	0.001

Table 4. Results of fine-scale *a priori* comparisons of the MANOVA for overall plant species diversity among grazing treatments.

	Pillai's Trace	df	F	P
Grazing Treatments	0.347	4,154	8.071	<0.001
Grazed vs. Ungrazed	0.066	2,76	2.681	0.075
Recent vs. Long Ago	0.284	2,76	15.043	<0.001

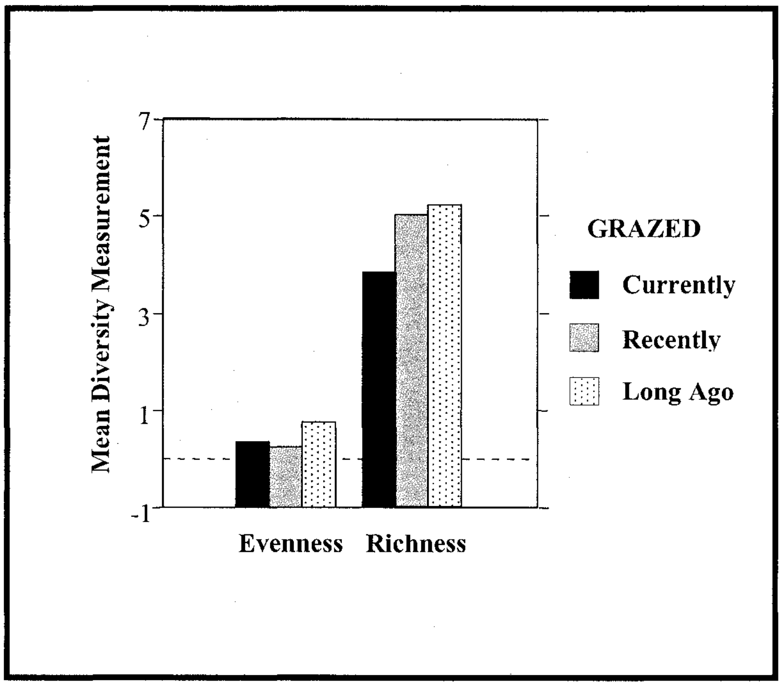

Figure 3. Species diversity recovery: Broad-scale changes in species evenness and richness after release from grazing pressure.

Grazing by domestic cattle also altered diversity in terms of the richness of native and exotic plant species, though this effect was evident only at the fine scale (Table 5). The first planned comparison showed that the richness of exotic plant species decreased

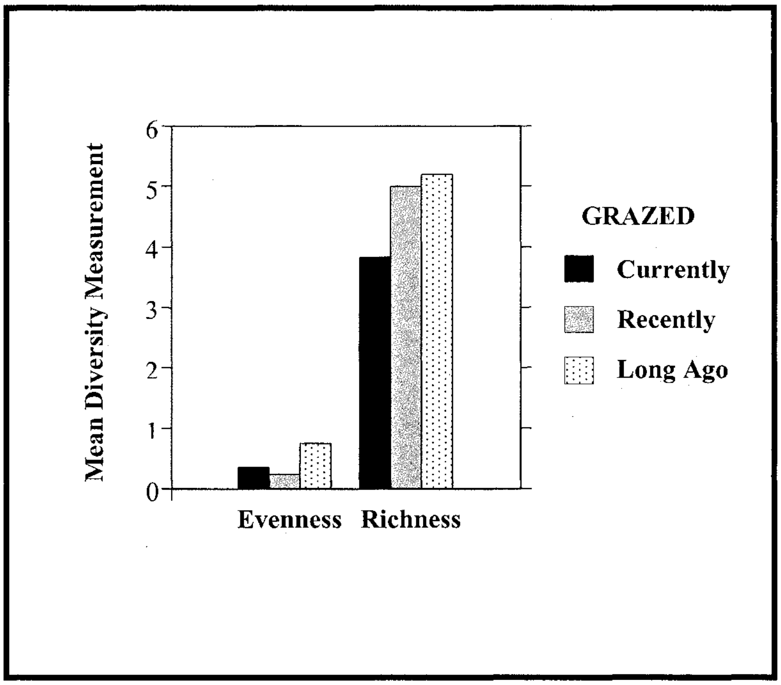

Figure 4. Species diversity recovery: Fine-scale changes in species evenness and richness after release from grazing pressure.

Table 5. Results of fine-scale planned comparisons of plant species origin (native/exotic) among grazing treatments.

Source	Sum-of-Squares	df	Mean-Square	F-Ratio	P
GRAZED	22.544	2	11.272	4.974	0.008
NATIVE	2.272	1	2.272	1.003	0.318
GRAZED*NATIVE	15.211	2	7.606	3.356	0.037
Native					
Grazed vs. Ungrazed	0.715	1	0.715	0.315	0.575
Recent vs. Long Ago	0.536	1	0.536	0.236	0.628
Exotic					
Grazed vs. Ungrazed	34.020	1	34.020	15.012	0.000
Recent vs. Long Ago	4.610	1	4.610	2.034	0.156
Error	348.994	154	2.266		

significantly ($P < 0.001$) with grazing, though no change in native species richness was evident (Fig. 5). However, the second planned comparison showed that the richness of both native and exotic species did not differ with the time since grazing had last occurred.

Cattle grazing had broad-scale and fine-scale effects on the seasonality of grasslands by altering the diversity of perennial plant species (Tables 6 and 7). The first planned comparison showed a significant (broad scale $P = 0.011$, fine scale $P < 0.001$) decrease in the richness of perennial species with grazing at both broad and fine scales, but no change in the richness of annual plant species (Figs. 6 and 7). However, the

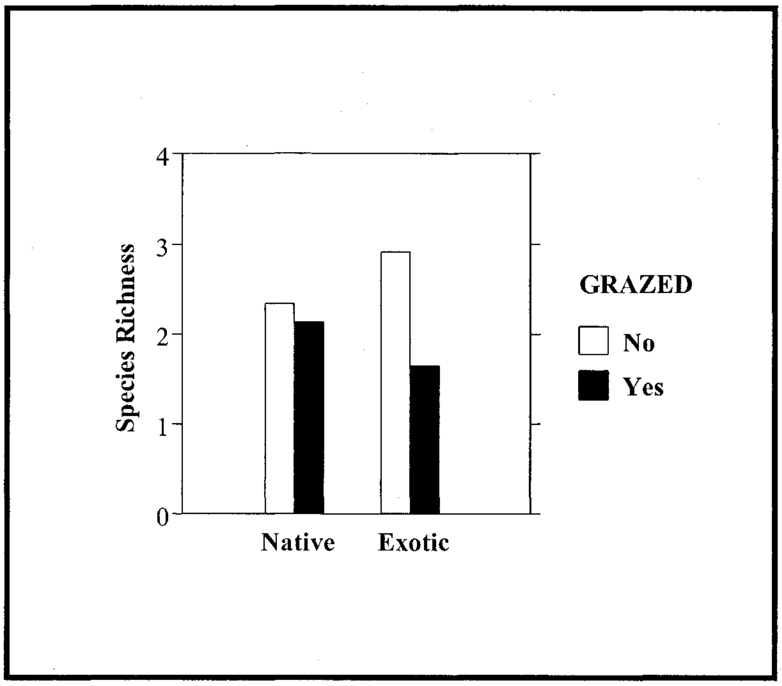

Figure 5. Species origin grazing effect: Fine-scale effect of cattle grazing on richness of native and exotic plant species.

Table 6. Results of broad-scale planned comparisons of plant species life cycle (annual/perennial) among grazing treatments.

Source	Sum-of-Squares	df	Mean-Square	F-Ratio	P
GRAZED	25.031	2	12.516	1.678	0.206
ANNUAL	13.613	1	13.613	1.826	0.188
GRAZED*NATIVE	43.031	2	21.516	2.885	0.074
Annual					
Grazed vs. Ungrazed	0.562	1	0.562	0.075	0.786
Recent vs. Long Ago	1.125	1	1.125	0.151	0.701
Perennial					
Grazed vs. Ungrazed	56.250	1	56.250	7.544	0.011
Recent vs. Long Ago	10.125	1	10.125	1.358	0.254
Error	193.875	26	7.457		

Table 7. Results of fine-scale planned comparisons of plant species life cycle (annual/perennial) among grazing treatments.

Source	Sum-of-Squares	df	Mean-Square	F-Ratio	P
GRAZED	31.902	2	15.951	5.276	0.006
ANNUAL	11.449	1	11.449	3.787	0.053
GRAZED*NATIVE	25.769	2	12.884	4.261	0.016
Annual					
Grazed vs. Ungrazed	0.715	1	0.715	0.236	0.627
Recent vs. Long Ago	1.260	1	1.260	0.417	0.520
Perennial					
Grazed vs. Ungrazed	49.816	1	49.816	16.476	0.000
Recent vs. Long Ago	9.752	1	9.752	3.226	0.074
Error	465.617	154	3.023		

second comparison revealed that the richness of both annual and perennial species did not vary with the time since cessation of grazing at both scales.

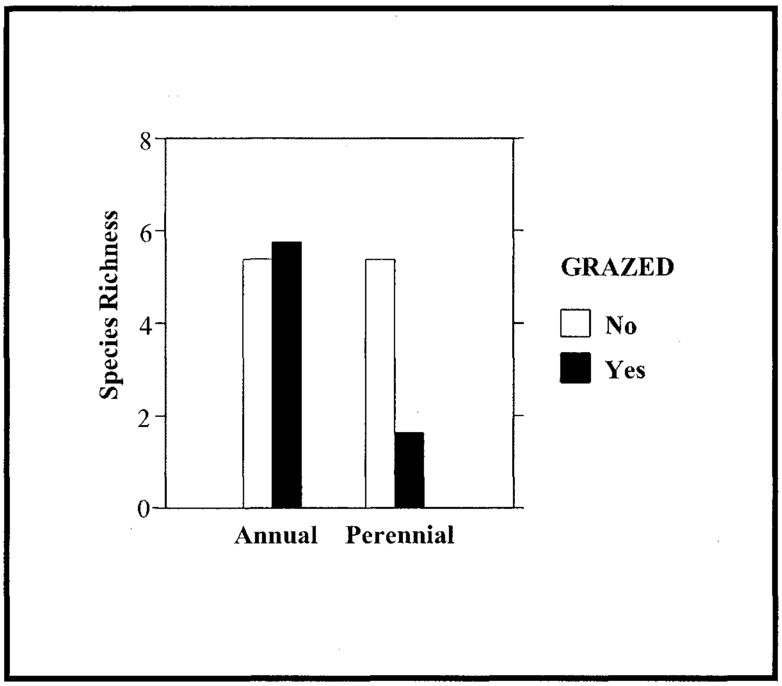

Figure 6. Species life cycle grazing effect: Broad-scale effect of cattle grazing on richness of annual and perennial plant species.

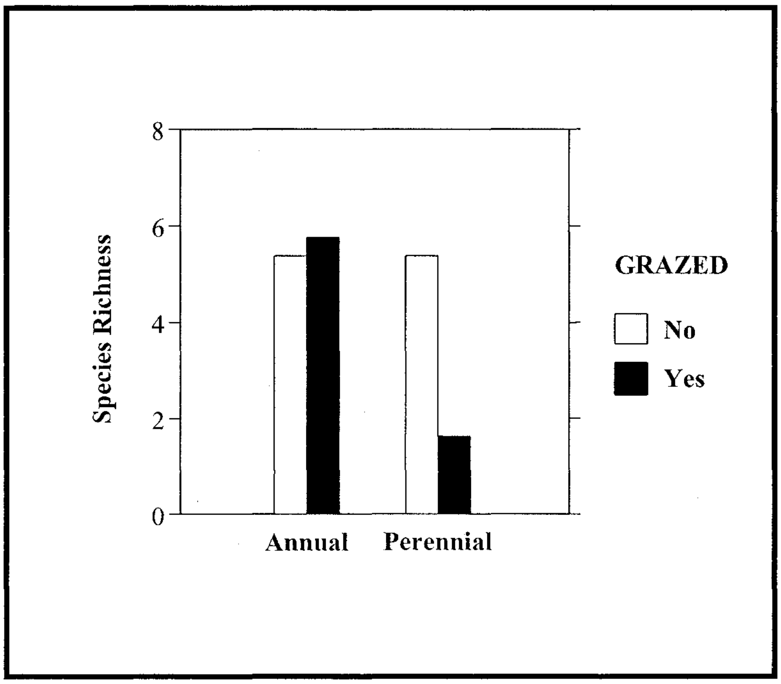

Figure 7. Species life cycle grazing effect: Fine-scale effect of cattle grazing on richness of annual and perennial plant species.

Cattle grazing had broad-scale community effects on species composition of the most abundant, non-correlated species (Table 8). The first *a priori* comparison of the MANOVA showed that species composition in terms of abundance did not differ significantly between grazed and ungrazed areas. However, the second *a priori* comparison showed that species composition varied significantly ($P = 0.007$) between fields recently grazed and those grazed long ago.

Table 8. Results of broad-scale *a priori* comparisons of the MANOVA for plant species abundance among grazing treatments.

	Pillai's Trace	df	F	P
Grazing Treatments	1.456	12,18	4.016	0.004
Grazed vs. Ungrazed	0.628	6,8	2.256	0.142
Recent vs. Long Ago	0.843	6,8	7.135	0.007

Grazing also altered the composition of the most abundant, non-correlated species at the fine scale (Table 9). The first *a priori* comparison showed that the abundance of these species varied significantly ($P < 0.001$) between grazed and ungrazed areas. Likewise, the second *a priori* comparison showed that composition in terms of species abundance differed significantly ($P < 0.001$) between areas recently grazed and those grazed long ago. In contrast, the MDS of presence/absence for all individual plant species, including species with low abundance, showed no apparent trend across grazing treatments even at the fine scale.

Table 9. Results of fine-scale *a priori* comparisons of the MANOVA for plant species abundance among grazing treatments.

	Pillai's Trace	df	F	P
Grazing Treatments	0.918	12,146	10.323	<0.001
Grazed vs. Ungrazed	0.462	6,72	10.299	<0.001
Recent vs. Long Ago	0.477	6,72	10.929	<0.001

Cattle grazing did not have broad-scale effects on species composition in terms of height. However, grazing had fine-scale effects on community height distributions for the most abundant, non-correlated plant species (Table 10). The first *a priori* comparison of the MANOVA showed that height distributions varied significantly ($P < 0.001$) across grazed and ungrazed fields. Likewise, the second *a priori* comparison showed significant ($P < 0.001$) height differences between areas grazed recently and those grazed long ago.

Table 10. Results of fine-scale *a priori* comparisons of the MANOVA for plant height among grazing treatments.

	Pillai's Trace	df	F	P
Grazing Treatments	1.028	18,140	8.226	<0.001
Grazed vs. Ungrazed	0.617	9,69	12.325	<0.001
Recent vs. Long Ago	0.414	9,69	5.415	<0.001

Grazing by domestic cattle had broad-scale effects on the abundance of two out of twenty eight plant species (Table 11). The first *a priori* comparison of the ANOVAs showed that the abundance of common spikerush (*Eleocharis macrostachya*) decreased significantly ($P = 0.008$) with grazing (Fig. 8). Although feral pig activity was correlated with the abundance of annual beard grass (*Polypogon monspeliensis*), an ANCOVA with feral pig activity as a covariate showed that pig activity did not influence the results. The second *a priori* comparison showed that for annual beard grass, abundance was significantly (P = 0.009) lower in recently grazed areas and for common spikerush abundance was significantly (P = 0.003) higher in recently grazed areas (Fig. 9).

Table 11. Results of broad-scale analyses (ANOVA [overall *P*] and two associated *a priori* comparisons) of individual plant species abundance, individual species height and other measurements among grazing treatments.

	df	2, 13	1, 13	1, 13
MEASURED VARIABLE [1]	Error	Overall P [1]	Currently Grazed v. Ungrazed [1]	Recently Grazed v. Long Ago Grazed [1]
Individual Species Abundance Measurements				
annual beard grass	16.279	**0.013**	0.106	**0.009**
bermuda grass	1.442	0.234	0.317	0.165
broad-leaved cattail	3.596	0.035	0.110	0.031
brownhead rush	0.231	0.234	0.317	0.165
California bulrush	0.519	0.234	0.317	0.165
chinese pusley	0.058	0.234	0.317	0.165
common spikerush	69.433	**0.001**	**0.008**	**0.003**
creeping swampgrass	2.019	0.142	0.240	0.105
curly dock	1.115	0.124	0.361	0.066
douglas' knotweed	0.760	0.385	0.175	1.000
everlasting cudweed	0.058	0.234	0.317	0.165
grass poly	0.788	0.490	0.783	0.254
Italian ryegrass	0.058	0.234	0.317	0.165
knotgrass	101.769	0.234	0.317	0.165
mediterranean barley	2.375	0.541	0.277	1.000
mustard spp. 1	0.067	0.639	0.353	1.000
pennyroyal	0.231	0.234	0.317	0.165
petty spurge	0.058	0.234	0.317	0.165
plumeless thistle spp.	0.067	0.639	0.353	1.000
polygonum spp.	0.058	0.234	0.317	0.165
salt grass	0.058	0.234	0.317	0.165
spiny cocklebur	0.606	0.639	0.353	1.000
turkey mullein, doveweed	0.115	0.367	0.165	1.000
unknown species 4	0.663	0.758	0.550	0.671
western marsh cudweed	0.673	0.612	0.377	0.674

[1] **Bold** = Significant interaction.

Table 11. Continued.

MEASURED VARIABLE [1]	Error	Overall P [1]	Currently Grazed v. Ungrazed [1]	Recently Grazed v. Long Ago Grazed [1]
df		2, 13	1, 13	1, 13
Individual Species Height Measurements				
annual beard grass	49.990	**0.002**	0.050	**0.002**
bermuda grass	2.827	0.234	0.317	0.165
broad-leaved cattail	1102.519	0.031	0.103	0.028
brownhead rush	5.769	0.234	0.317	0.165
California bulrush	87.750	0.234	0.317	0.165
canyon nemophila	0.058	0.234	0.317	0.165
chinese pusley	8.308	0.234	0.317	0.165
common cocklebur	11.375	0.639	0.353	1.000
common spikerush	66.019	**0.001**	**< 0.001**	0.377
creeping swampgrass	7.654	0.197	0.128	0.325
curly dock	43.510	0.029	0.105	0.026
douglas' knotweed	3.962	0.250	0.102	1.000
everlasting cudweed	0.058	0.234	0.317	0.165
grass poly	4.221	0.227	0.553	0.109
Italian ryegrass	4.942	0.297	0.445	0.176
knotgrass	42.058	0.234	0.317	0.165
mediterranean barley	1.192	0.414	0.193	1.000
mustard spp. 1	0.067	0.639	0.353	1.000
pennyroyal	19.154	0.133	0.231	0.099
petty spurge	0.288	0.335	0.186	0.522
plumeless thistle spp.	0.269	0.639	0.353	1.000
polygonum spp.	2.077	0.234	0.317	0.165
salt grass	0.519	0.234	0.317	0.165
spiny cocklebur	0.269	0.639	0.353	1.000
turkey mullein, doveweed	0.606	0.308	0.132	1.000
umbrella sedge	1.442	0.234	0.317	0.165
unknown species 4	0.990	0.307	0.465	0.179
western marsh cudweed	0.269	0.639	0.353	1.000
Other Measurements				
Bare Ground	161.827	**0.009**	**0.003**	0.684
Percent Feral Pig Activity	764.500	0.376	0.723	0.183
Rock	0.615	0.465	0.225	1.000
Species Richness	5.962	0.604	0.325	1.000

[1] **Bold** = Significant interaction.

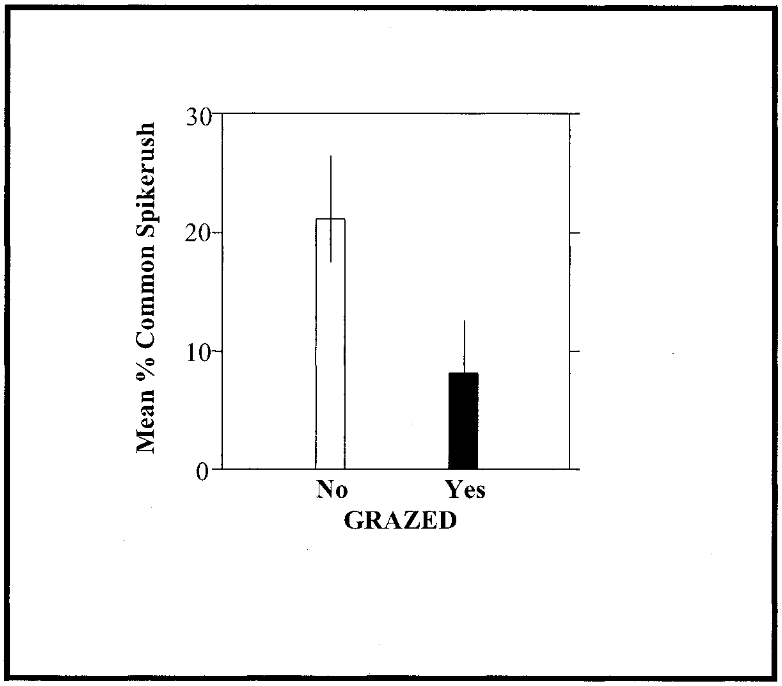

Figure 8. Species abundance grazing effect: Plant species with significant difference in mean percent abundance between grazed and ungrazed sites at the broad scale.

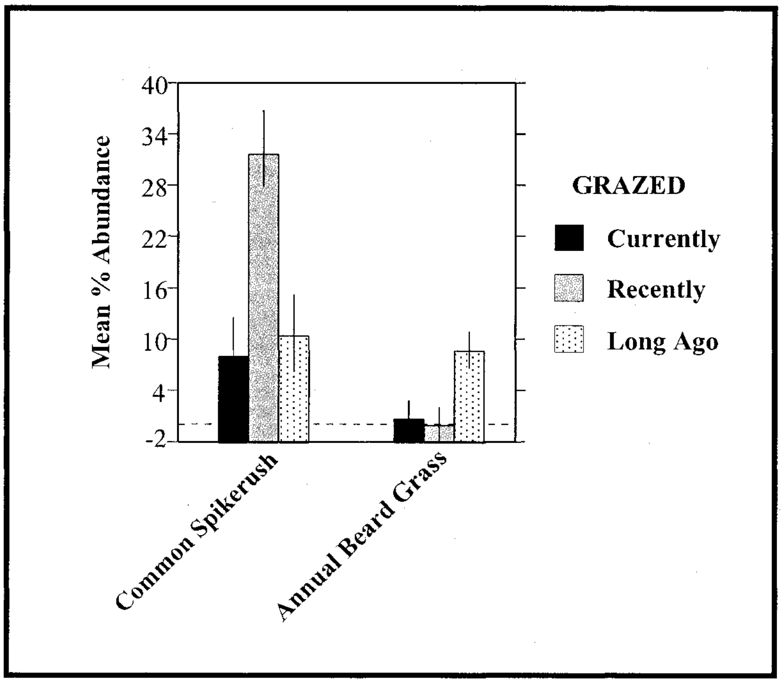

Figure 9. Species abundance recovery: Plant species with significant differences in mean percent abundance after release from grazing pressure at the broad scale.

At the fine scale, the analyses showed that the abundance of more plant species decreased in the presence of grazing than at the broad scale, and one species showed an increase (Table 12). The first *a priori* comparison showed that the abundances of four species decreased significantly with grazing: annual beard grass ($P = 0.006$), broad-leaved cattail (*Typha latifolia*) ($P = 0.005$), common spikerush ($P = 0.001$), and knotgrass (*Paspalum distichum*) ($P = 0.017$) (Fig. 10). However, the abundance of douglas' knotweed (*Polygonum douglassi*) increased significantly ($P = 0.009$) (Fig. 10). The second *a priori* comparison showed that the abundances of four species were significantly less in the most recently grazed areas: annual beard grass ($P < 0.001$), broad-leaved cattail ($P < 0.001$), curly dock (*Rumex crispus*) ($P = 0.019$), and knotgrass ($P < 0.001$) (Fig. 11).

Cattle grazing had broad-scale impacts to the height of two out of twenty eight plant species (Table 11). The first *a priori* comparison of the ANOVAs showed that the height of common spikerush decreased significantly ($P < 0.001$) with grazing (Fig. 12). Although feral pig activity was correlated with the height of annual beard grass, an ANCOVA with feral pig activity as a covariate showed that pigs did not influence the results. The second *a priori* comparison showed that for annual beard grass, height was significantly ($P = 0.002$) lower in recently grazed areas (Fig. 13).

Table 12. Results of fine-scale analyses (ANOVA [overall *P*] and two associated *a priori* comparisons) of individual plant species abundance, individual species height and other measurements among grazing treatments.

	df	2, 13	1, 13	1, 13
MEASURED VARIABLE [1]	Error	Overall P [1]	Currently Grazed v. Ungrazed [1]	Recently Grazed v. Long Ago Grazed [1]
Individual Species Abundance Measurements				
annual beard grass	28.208	**< 0.001**	**0.006**	**< 0.001**
bermuda grass	7.695	0.201	0.280	1.000
broad-leaved cattail	6.392	**< 0.001**	**0.005**	**< 0.001**
brownhead rush	1.777	0.264	0.317	0.104
California bulrush	2.776	0.264	0.317	0.104
canyon nemophila	0.049	0.264	0.317	1.000
chinese pusley	0.345	0.077	0.187	0.033
common cocklebur	0.719	0.058	0.052	0.110
common spikerush	91.641	**< 0.001**	**< 0.001**	0.368
creeping swampgrass	10.954	0.050	0.268	0.061
curly dock	3.628	**0.010**	0.221	**0.019**
douglas' knotweed	1.008	**0.004**	**0.009**	0.032
everlasting cudweed	0.111	0.264	0.317	1.000
grass poly	1.034	**0.005**	0.382	0.475
Italian ryegrass	0.124	0.287	0.527	0.198
knotgrass	93.052	**< 0.001**	**0.017**	**< 0.001**
mediterranean barley	3.589	0.043	0.042	0.096
mustard spp.	0.222	0.264	0.159	0.249
pennyroyal	0.818	0.116	0.220	0.047
petty spurge	0.248	0.312	0.655	0.715
plumeless thistle spp.	0.114	0.580	0.324	0.420
polygonum spp.	0.197	0.264	0.317	0.104
salt grass	0.197	0.264	0.317	1.000
spiny cocklebur	0.051	0.580	0.324	0.420
turkey mullein, doveweed	0.447	0.052	0.048	0.105
umbrella sedge	0.012	0.264	0.317	0.104
unknown species 4	1.999	0.266	0.529	0.336
western marsh cudweed	1.964	0.148	0.206	0.196

[1] **Bold** = Significant interaction.

Table 12. Continued.

	df	2, 13	1, 13	1, 13
MEASURED VARIABLE [1]	Error	Overall P [1]	Currently Grazed v. Ungrazed [1]	Recently Grazed v. Long Ago Grazed [1]
Individual Species Height Measurements				
annual beard grass	109.995	**< 0.001**	**0.002**	**< 0.001**
bermuda grass	8.775	0.087	0.196	1.000
broad-leaved cattail	1720.035	**< 0.001**	**0.002**	**< 0.001**
brownhead rush	28.426	0.264	0.317	0.104
California bulrush	465.538	0.264	0.317	0.104
canyon nemophila	0.605	0.264	0.317	1.000
chinese pusley	30.881	0.110	0.216	0.045
common cocklebur	12.652	0.050	0.047	0.103
common spikerush	92.244	**< 0.001**	**< 0.001**	**< 0.001**
creeping swampgrass	16.879	**0.002**	**0.018**	**0.006**
curly dock	171.543	**0.002**	0.051	**0.002**
douglas' knotweed	7.516	**0.002**	**0.006**	0.025
everlasting cudweed	0.111	0.264	0.317	1.000
grass poly	10.047	**0.006**	0.426	0.456
Italian ryegrass	24.434	0.276	0.453	0.161
knotgrass	39.997	**< 0.001**	**0.021**	**< 0.001**
mediterranean barley	2.102	0.026	0.030	0.076
mustard spp.	0.073	0.148	0.101	0.180
petty spurge	0.181	0.332	0.743	0.669
pennyroyal	112.532	0.150	0.246	0.060
plumeless thistle spp.	1.026	0.580	0.324	0.420
polygonum spp.	12.113	0.264	0.317	0.104
salt grass	2.418	0.264	0.317	1.000
spiny cocklebur	0.810	0.580	0.324	0.420
turkey mullein, doveweed	1.610	0.086	0.068	0.135
umbrella sedge	6.527	0.264	0.317	0.104
unknown species 4	3.562	0.084	0.281	0.860
western marsh cudweed	0.503	0.121	0.162	0.172
Other Measurements				
Bare Ground	192.617	**< 0.001**	**< 0.001**	**< 0.001**
Percent Feral Pig Activity	848.718	**< 0.001**	0.443	0.282
Rock	3.400	0.354	0.253	0.302
Soil Compaction	0.009	**< 0.001**	0.558	0.129
Species Richness	6.428	**< 0.001**	0.027	0.051

[1] **Bold** = Significant interaction.

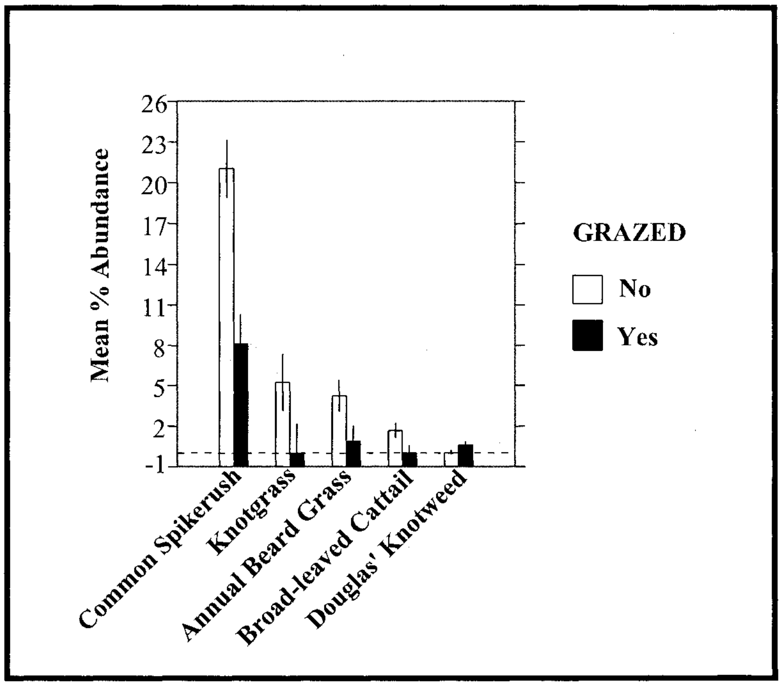

Figure 10. Species abundance grazing effect: Plant species with significant differences in mean percent abundance between grazed and ungrazed sites at the fine scale.

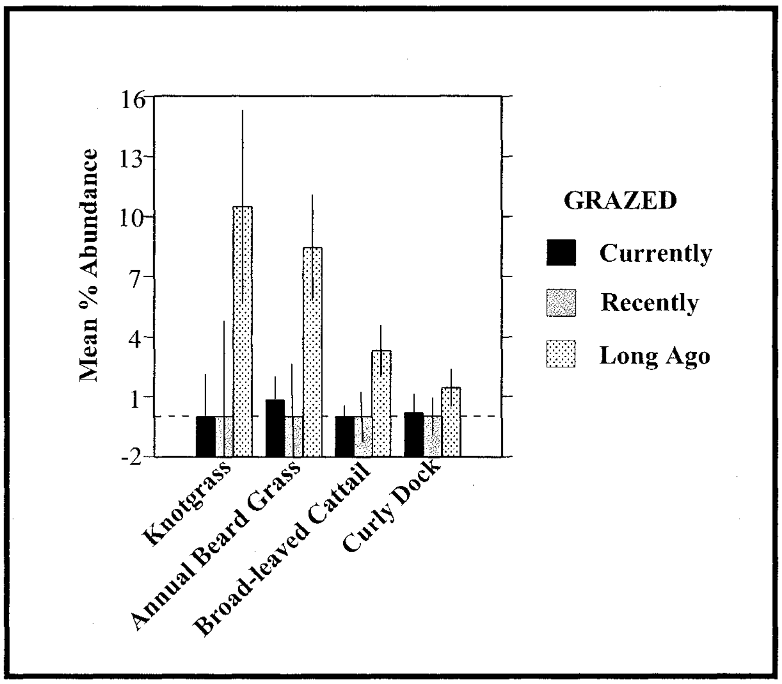

Figure 11. Species abundance recovery: Plant species with significant differences in mean percent abundance after release from grazing pressure at the fine scale.

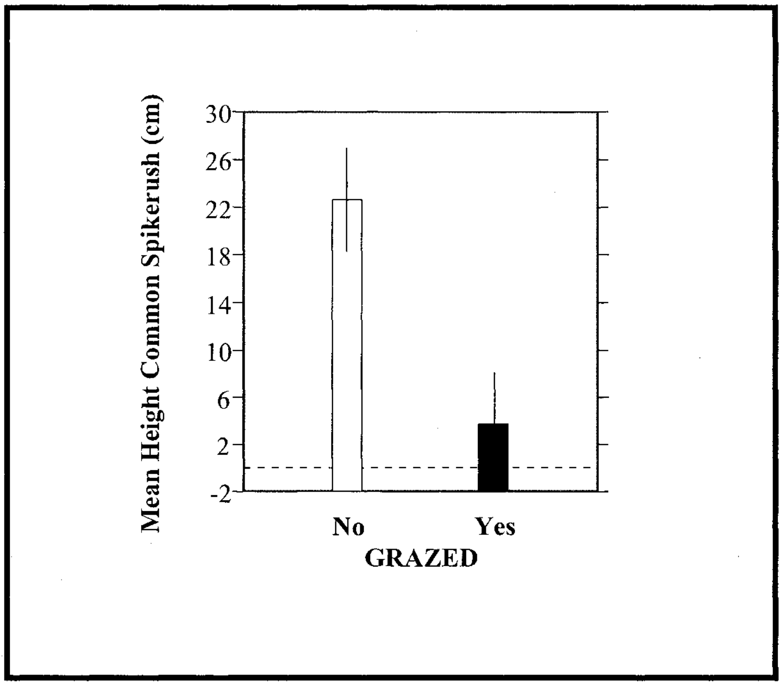

Figure 12. Species height grazing effect: Plant species with significant difference in mean height between grazed and ungrazed sites at the broad scale.

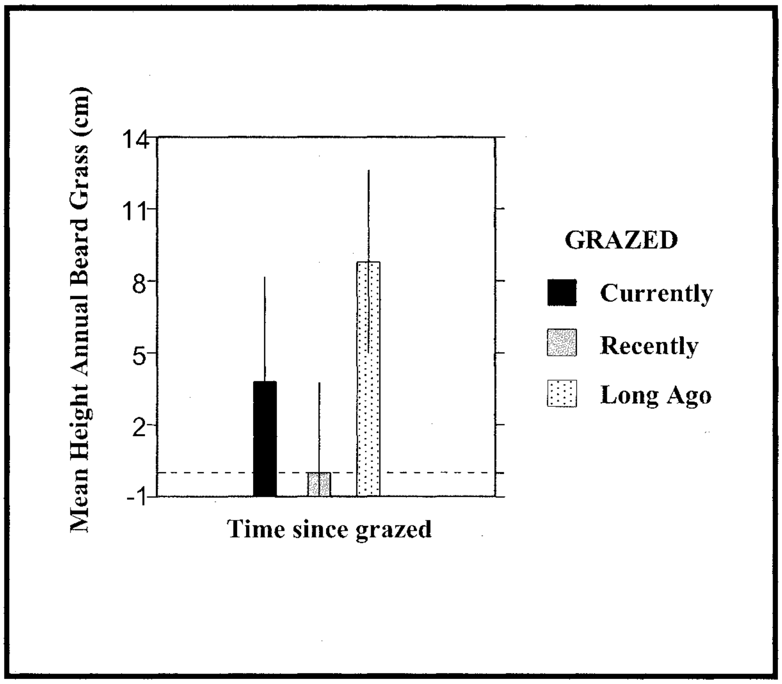

Figure 13. Species height recovery: Plant species with significant differences in mean height after release from grazing pressure at the broad scale.

Fine-scale analyses revealed that the height of more plant species decreased in the presence of grazing than at the broad scale, and one species showed an increase (Table 12). The first *a priori* comparison showed that the height of five species decreased significantly with grazing; annual beard grass ($P = 0.002$), broad-leaved cattail ($P = 0.002$), common spikerush ($P < 0.001$), creeping swampgrass (*Crypsis shoenoides*) ($P = 0.018$) and knotgrass ($P = 0.021$) (Fig. 14). However, the height of douglas' knotweed increased significantly ($P = 0.006$) (Fig. 14). The second *a priori* comparison showed that the height of five species were significantly lower in the most recently grazed areas: annual beard grass ($P < 0.001$), broad-leaved cattail ($P < 0.001$), creeping swampgrass ($P = 0.006$), curly dock ($P = 0.002$), and knotgrass ($P < 0.001$) (Fig. 15). However, the height of common spikerush was significantly ($P < 0.001$) higher in recently grazed areas (Fig. 15).

Grazing by domestic cattle increased the amount of bare ground at both broad and fine scales, and had no effect on soil compaction at either scale (Tables 11 and 12). The first broad-scale *a priori* comparison of the ANOVA showed that the amount of bare ground increased significantly ($P = 0.003$) in grazed areas, however, the second *a priori* comparison showed that the amount of bare ground did not vary significantly between areas recently grazed and those grazed long ago (Fig. 16). At the fine scale, *a priori* comparisons showed that the amount of bare ground was significantly ($P < 0.001$) higher in grazed areas (Fig. 17) and was significantly ($P < 0.001$) higher in the most recently grazed areas (Fig. 18).

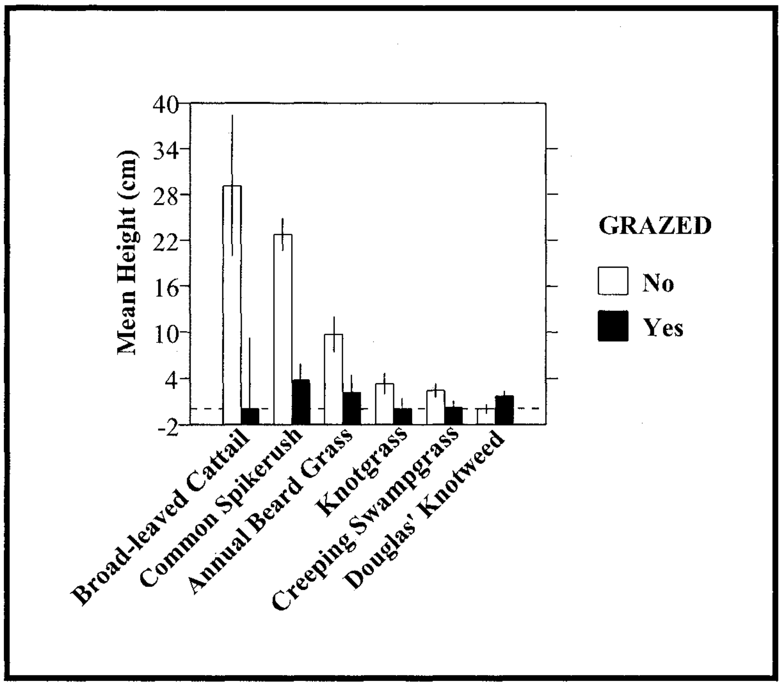

Figure 14. Species height grazing effect: Plant species with significant difference in mean height between grazed and ungrazed sites at the fine scale.

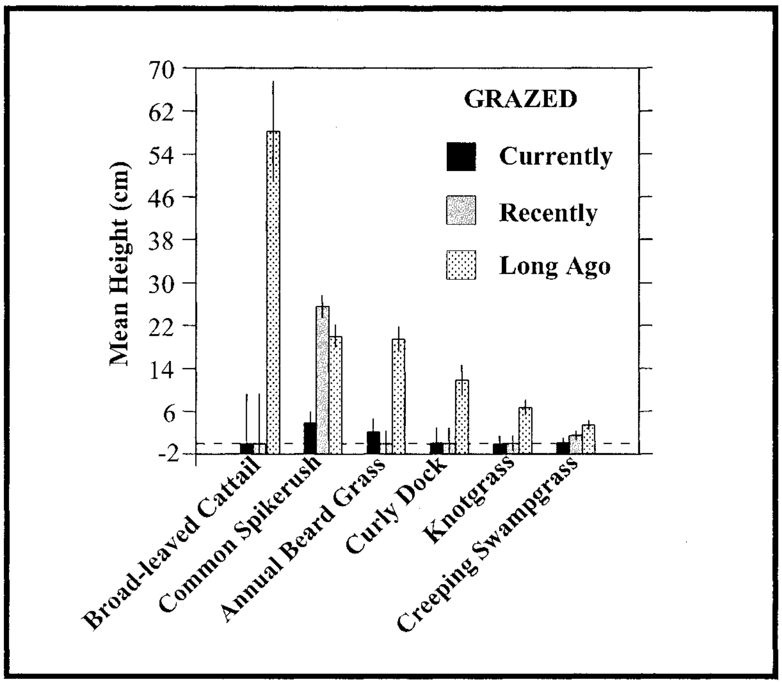

Figure 15. Species height recovery: Plant species with significant differences in mean height after release from grazing pressure at the fine scale.

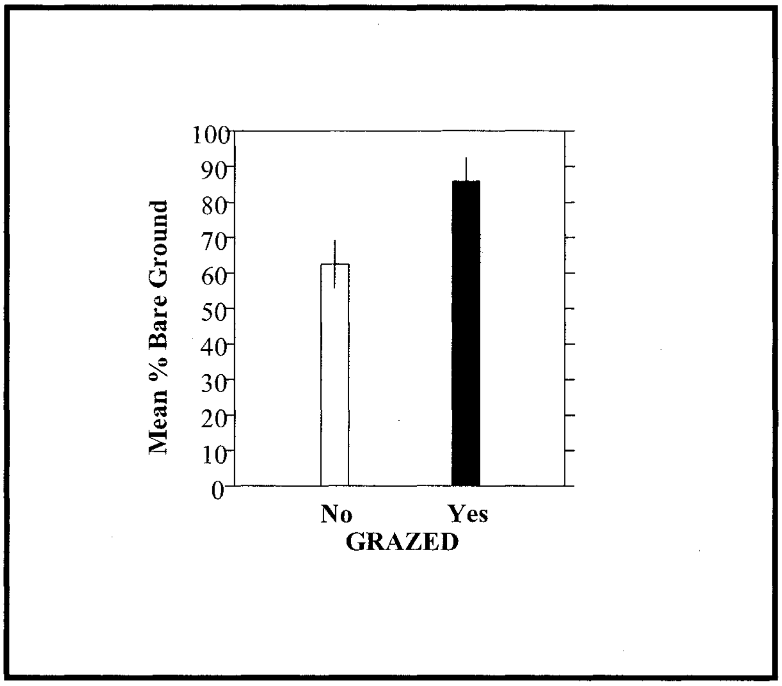

Figure 16. Bare ground grazing effect: Broad-scale effect of grazing on the amount of exposed soil.

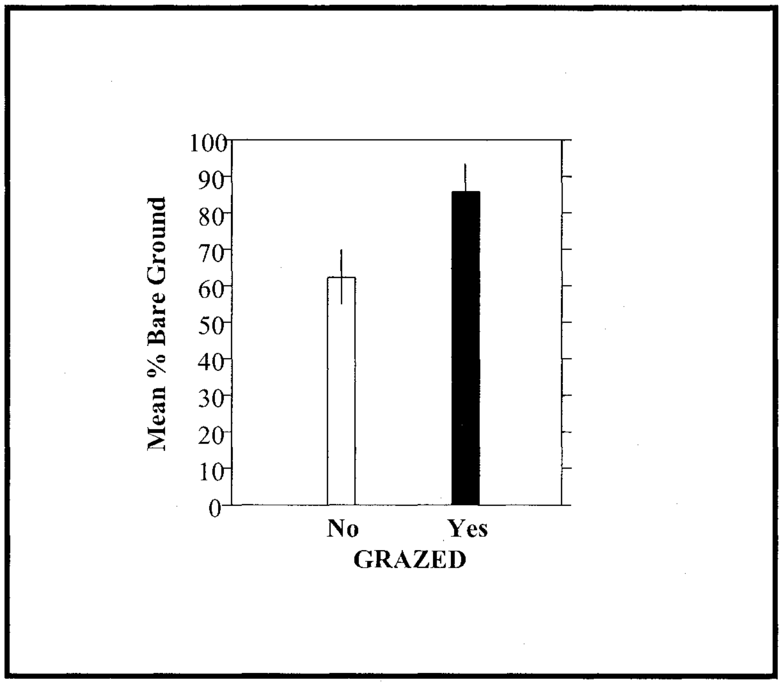

Figure 17. Bare ground grazing effect: Fine-scale effect of grazing on the amount of exposed soil.

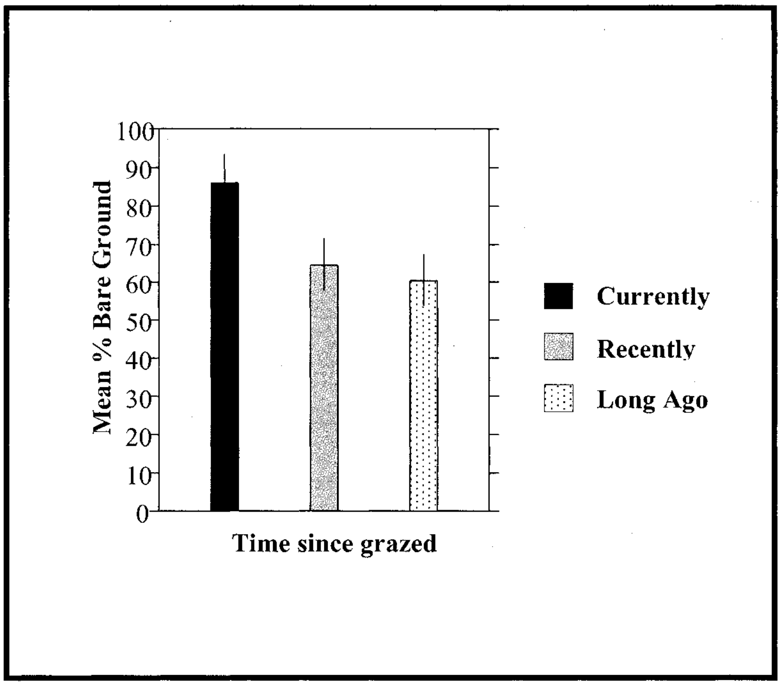

Figure 18. Bare ground recovery: Fine-scale changes in the amount of exposed soil after release from grazing pressure.

DISCUSSION

In this study, as well as others, domestic cattle have caused immediate and extensive impacts on the plant communities in which they graze. Community-level effects appear to be variable and include impacts upon plant species diversity and composition, while more predictable impacts include a decrease in plant cover and height, and an increase in bare ground.

Overall species diversity has been researched with regard to cattle grazing, but findings among this and other studies vary greatly. This study found that cattle grazing caused significant, broad-scale changes in plant species diversity, but these changes were not apparent until after grazing had ceased and species evenness then increased over time. This suggests that grazing by cattle can suppress species diversity in plant communities. However, in this study, increased evenness after grazing is attributed primarily to changes in the most abundant species, common spikerush (a native perennial species common in marshes, ponds and vernal pools), which exhibited a short-term increase in abundance 2 to 4 years after grazing followed by a dramatic decrease in abundance after ten years' rest from grazing (reference Fig. 9). Other studies in California grasslands have indicated that the presence of cattle grazing can increase diversity by reducing the dominance of highly competitive species (Harrison 1999) and by causing a loss of localized rare native species thereby increasing evenness (Kimball 2003). Few results, however, specify which plant species are driving a change in diversity so it is difficult to determine if increased diversity is a benefit to the communities in these cases; even an increase in undesirable species can increase species diversity.

Less research on plant species diversity has been conducted in mesic areas like this study (vs. xeric areas) and with divergent results, so direct comparisons and trends are difficult to discern. For example, in mesic environments, Medin and Clary (1990) documented reduced mat muhly (*Muhlenbergia richardsonis*)/hummock and mesic herbaceous grass species richness in the presence of grazing. These results are similar to those of Stromberg (1996) and Marty (2005), who found lower overall diversity in grazed California coastal grasslands and vernal pools, respectively. Green (1995), however, found significantly higher species diversity and richness in the presence of cattle grazing on riparian areas. Yet grazing has also been found to maintain overall diversity, richness and equitability in moist meadow communities (Kauffman 1983). Furthermore, grazing has maintained herbaceous species richness and evenness on spring-fed wetlands, though a decrease in diversity was apparent in these areas after one year's rest from grazing pressure (Allen-Diaz *et. al.* 2004). As a general trend, an increase in species evenness appears to be a long-term response to release from grazing. Evenness has increased in studies ten years (this study), eight to nine years (Rambo 1999) and nine years (Fleishner 1994) after removal of cattle. Among the findings of this and previous research, no distinguishable pattern was found with regard to plant species richness or evenness in terms of grazing management. However, it is clear that any consequences can be apparent immediately and under grazing intensities as low as 0.04 AUM (Bock and Bock 1993).

Effects on plant diversity are apparent beyond overall species diversity to include changes in diversity of native and exotic species. This study showed that grazing can result in localized, or patchy, decreases in the richness of exotic plant species. Native plant species richness, however, was not affected by grazing, which indicates that native species were not replacing exotic species in this system. Three of the significantly affected species in this study were non-native in origin (annual beard grass [annual species], creeping swampgrass [annual species], and curly dock [perennial species]), and all three exhibited reduced abundance under grazing pressure. However, the most abundant exotic species (annual beard grass) appears to recover after long term rest (in this case ten years) from grazing. In contrast, previous grassland surveys near the study area report that relict native grasslands are relatively rich in native species with as many as eleven to sixteen native forb species, in contrast with heavily grazed areas that contain only two to three total plant species (Brady and Associates 1996; HCHR 1998). Likewise, Kimball (2003) concluded that livestock grazing harms native California valley grassland species and promotes exotic plant growth.

While few studies of exotic and native species richness relative to cattle grazing have been conducted in mesic areas, it is apparent from existing research that effects are variable in these areas. Ungrazed mesic environments have exhibited comparatively higher richness of native species than grazed areas. For example, Cottarn (1945) documented ten native species in ungrazed riparian areas that were not present at "heavily" grazed sites. Similarly, Hayes (2003) found that native perennial forb cover and species richness were higher in ungrazed mesic grasslands, but that native grass cover and species richness did not differ in the presence of grazing. Stromberg (1996) found that grazing did not eliminate established native coastal grasslands, but that species composition shifted in grazed grasslands to include invasive exotics. In contrast, grazed mesic grasslands have also demonstrated an increase in native annual forb species richness and cover, and exotic annual grass and forb cover (Hayes 2003). Marty (2005) found that grazing helped to maintain native plant diversity in vernal pools, and exotic annual grass cover increased dramatically after removal of grazing; ungrazed pools had substantially higher cover of exotic annual grasses, and lower cover and richness of native species. On the contrary, Allen-Diaz (2004) observed no difference in relative richness of native and exotic plant species with light grazing on spring-fed wetlands. Still other studies such as Rambo (1999) have simply concluded that differences in native and exotic species relative to grazing treatment were too inconsistent to predict. Nonetheless, it has been shown that the overall richness of exotic and native species is influenced to some degree by the seasonality and intensity of grazing, although previous research (Kimball 2003) of native plant diversity in valley grasslands like this study area suggests that the mere presence of cattle can determine community composition.

That cattle grazing can also alter the diversity of annual and perennial grassland species is clear in this study, though these findings are not largely supported by the literature. The results of this study indicate that grazing can cause broad- and fine-scale alterations to the life cycle of littoral plant species, with a decrease in perennial species but no concomitant change in the richness of annual species. Because perennial species do not appear to have been replaced by annual species, these effects suggest that they could be due in part to an overall decrease in species richness under grazed conditions. These changes were long term; after at least ten years without cattle these areas had not shown recovery from grazing pressure. This is an interesting finding because California valley grasslands like those of this study are usually dominated by annual species, with an increase in perennial species often thought to occur as a result of disturbance (D'Antonio 2001). Littoral zones are often comparatively richer in perennial than annual species. Grazed Mediterranean grasslands have exhibited a greater richness of perennial species, both in terms of species response and group dominance (Noy-Meir 1989). Historical observation also indicates that the richness of perennial species tends to increase under higher grazing pressures, and for this reason California grasslands have gradually shifted in seasonality of plant species from annual grasses to more dominant perennials (Fleishner 1994; RCHR 1998). Stromberg (1996), however, found that cattle do not change established perennial coastal grassland stands. Overall, too few studies have addressed the impact of cattle grazing on the proportion of annual and perennial grassland species, particularly in mesic environments, to form the basis for a grazing strategy. However, because perennial plant species grow for more than one season, these results and others indicate that cattle have the potential to greatly alter the communities in which they graze.

Cattle can influence plant composition in terms of abundance and height both directly through selective grazing and indirectly as a result of differential plant tolerances to herbivory. Changes in cover and height are often the first and most visible signs that grazing has occurred, with plant height identified as the single best indicator of grazing response (RCHR 1998). For this reason, existing range management plans often refer to the height and cover of grasses as gauges of grazing intensity and indicators of overgrazing (Budzinski 1993). Grazing and plant height are interrelated to the extent that fewer tall grasses are found in grazed areas and grazing resistant species are smaller and shorter (Diaz 2001; Hickman 2004). In this study, cattle grazing significantly altered species composition of the littoral community in terms of plant abundance and height. However, these effects were localized, or patchy, and driven by substantial changes in a relatively few number of species. Five plant species exhibited significant changes in abundance; four species that decreased in the presence of grazing (decreasers) (annual beard grass, broad-leaved cattail, common spikerush, and knotgrass), and one species that increased under grazing pressure (increaser) (douglas' knotweed). Six plant species showed significant changes in height; five decreasers (annual beard grass, broad-leaved cattail, common spikerush, creeping swampgrass, and knotgrass), and one increaser (douglas' knotweed). Recovery of abundance and height after release from grazing pressure was widespread, with only two species not exhibiting recovery: common spikerush, the most abundant species, exhibited short term but not long term recovery and douglas' knotweed increased under grazing pressure and persisted after removal of grazing. The results of this study also indicate that cattle grazing caused widespread, long term effects on ground exposure, with substantially increased bare ground in grazed areas that showed little evidence of recovery ten years after cessation from grazing.

Previous research of mesic environments supports these findings, with grazing impacts on plant biomass and cover the most documented and consistent consequences of grazing despite differences in environment and/or grazing management (Taylor 1997). Kauffman (1983) found completely different dominant species between grazed and ungrazed moist meadow communities, though these effects were not apparent until after three years of grazing. Likewise, Szaro and Pase (1983) found significant differences in herbaceous species composition between grazed and ungrazed cottonwood ash-willow riparian plots, with the exception of three dominant species. When compared to their ungrazed counterparts, grazed riparian areas have exhibited less than half the density of herbaceous cover (Szaro and Pase 1983) and overall plant cover (Cottarn 1945). Medin and Clary (1990) measured a significant decrease in the biomass, height and canopy of herbaceous riparian graminoid and forb species under grazed conditions, and found more bare ground on grazed sites than on ungrazed sites. Likewise, Kauffman (1983) documented significantly lower density of moist meadow species outside of cattle exclosures. Hayes (2003) found that overall vegetation height and litter of mesic California grasslands decreased significantly with grazing. Volesky (2004) found similar results and concluded that the height of cool-season vegetation in wet meadows decreased linearly with increased stocking rate. Interestingly, Allen-Diaz (2004) documented a significant decrease in herbaceous cover in grazed spring-fed wetlands, but this effect was not evident until after seven years of grazing. The results of this study suggest that biomass effects of grazing can be long term and this appears to be the case in other mesic environments such as riparian meadows where no recovery was evident after four years' rest from grazing (Dobkin 1998).

Overall, studies examining the effects of cattle grazing show great variability in results and there are several possible reasons for the variation. A major reason is the number of factors involved in grazing management and a lack of consistent definitions of these factors. An understanding of the following factors and their interaction is essential to the effective use of cattle in vegetation management: stocking rate, or grazing intensity (measured in AUMs), species and class of cattle, seasonality of grazing (timing), length of grazing period (movement pattern), degree of active management, animal nutrition, animal reproduction, and water and forage availability (Fleishner 1994; RCHR 1998; Barry 2000). Of these, stocking rate is generally acknowledged as the most important though it is not clearly defined in most grazing studies or management plans, with broad categories such as "light" or "heavy" used to describe grazing intensity. It is thought that management objectives will not be met regardless of other grazing practices employed if stocking rate is not near the proper level (Walker 1995). Also key is the movement pattern of cattle, of which the most widely accepted patterns are cyclic; alternating periods of grazing and rest, with adjustment in stocking levels to achieve management goals (Brady and Associates 1996; RCHR 1998). According to Platts (1990), among others, the element of animal movement most essential to vegetation is the period of rest, which allows for plant species to recover from grazing by flowering, reproducing and expanding cover with increased rest (Turner 1993). The disparity in grazing study results is further confounded by the inherent complexity of environmental aspects that influence the effects of grazing on vegetation. These factors include, but are not limited to: vegetation type, plant production, plant phenology, weather, presence of other herbivores, soil type, slope, temperature, terrain, timing/amount of rainfall, history of fire, and past/present land use. In addition, vegetation responses are highly site-specific, and variation can be seen in plant composition, density, height and physiognomy across seasons and years. Wetland systems are particularly variable (Allen-Diaz 2004). Furthermore, because truly ungrazed land is rare, little real ecological benchmark or pre-treatment data exists.

One of the implications of this study is that grazing by domestic cattle might be an effective tool to control exotic plant species in wetland and grassland communities. This is a significant finding because one of the greatest and imminent threats to California grasslands, particularly in wetland areas, is invasion by exotic species and some level of management is typically needed to control their growth (Belsky 2000). For this reason, the restoration of native species in California grasslands and wetlands is a conservation goal on many public lands. It should be noted, however, that while some studies have indicated an increase in native bunchgrass abundance in California grasslands with grazing, there is little evidence to suggest that cattle grazing can return a community to native-dominated once it is invaded by exotics, even after several decades of rest from grazing pressure (Harrison 1999; D'Antonio 2001). Given the localized nature of impact on exotic species in this study, the area of cattle grazing's greatest applicability would likely be in controlling localized outbreaks of exotics, in situations where the use of herbicides is undesirable, or as one part of a larger restoration project. The use of cattle to aid in exotic species control would reduce the use of herbicides/chemicals, machinery and manpower, and lessen dependence upon prescribed burns, which are increasingly restricted due to air quality concerns, to accomplish the same results. It has even been found that fire was not sufficient to manage grasslands, but that grazing was needed as well (Collins 1998). Furthermore, revenue is generated from the sale of grazing permits on public land and grazing requires little expense other than the cost of personnel to monitor and manage cattle.

There are several hypotheses cited in the literature as to why grazing by domestic cattle decreases the richness of exotic species, with most theories related in some respect the effect of grazing on grass canopy. Invasive exotic species (harding grass [*Phalaris aquatica*], yellow starthistle, and other thistle spp. [*Cirsium spp.*], for example) have been known to form dense stands in California wetlands and/or grasslands that exclude native vegetation. Grazing by cattle inherently decreases grass cover and creates a more open canopy. This, in effect, reduces the ability of exotic species to competitively suppress other species since exotic species often maintain dominance in a community by competing for soil moisture and light, and accumulation of thatch (Marty 2005; D'Antonio 2001). Native plant species, particularly forb species, have been found to benefit from decreased litter and canopy brought about by domestic cattle grazing (Hayes 2003). Though this study found little recovery of exotic species richness after grazing, Marty (2005) theorizes that California grasslands have historically adapted to changes brought about by cattle and for this reason can become rapidly populated with exotic plant species when cattle are removed.

It appears that cattle can be used to reduce the richness of exotic plant species as a group or as specific target species, particularly perennial plant species. The richness of exotic plant species as a group seems to be most affected by the seasonality of grazing, though intensity of grazing is also a major factor since "heavy" grazing (no AUMs available) has been shown to increase exotic species as a group (Cottarn 1945). For example, early season or spring grazing has been shown to suppress the faster germinating exotic annual grasses, thereby reducing competition for perennial bunchgrasses whose seedlings germinate slightly later and grow more slowly early in the season (D'Antonio 2001). For a species-level approach to exotic species control, the timing of grazing in relation to the target species' phenology is the primary determinant of a species' response to grazing, and can either suppress or promote species. The ecology of the target species should determine the timing and intensity of grazing since some exotic plant species are palatable or most susceptible to disturbance at particular growth stages and because species vary in their resistance to grazing pressure. The most promising approach is low intensity grazing during the season of highest vulnerability for the target species. For example, the pest species yellow starthistle, which is prolific in this study area and throughout California valley grasslands, is only consumed by cattle in its young, leafy stage before thistles are present. Once thistles develop, it becomes completely unpalatable and is avoided by cattle.

However, there are consequences of using cattle to achieve this objective since removal of biomass through cattle can produce profound changes in vegetation communities (Kimball 2003). Grazing can rapidly surpass thresholds for exotic species control to the extent that the ground is bare. Exposed ground is a major problem since it contributes to increased runoff and erosion, particularly in wetland areas where water quality is a concern. Loss of biomass also alters or diminishes habitat for some small mammals and ground-nesting birds, directly affects the stratification and structure of a vegetation community and indirectly hinders plant species germination and growth.

Removal of mulch or litter on the soil surface can alter patterns of germination and seedling establishment of native grasses in California valley grasslands, which have been shown to grow best with high levels of mulch (Kimball 2003). Furthermore, since cattle will inevitably consume plant species that are desirable, the potential for incidental impact is high. In other words, grazing for vegetation management or restoration can quickly become counterproductive when effects beyond those of the management goals are likely and often damaging.

Monitoring for effects of cattle grazing is key to a successful vegetation management program and essential in order to limit grazing impacts on non-target plant species and groups. This study, among others, substantiates the need for a monitoring program that includes more than just plant height or forage amounts since there are extensive and immediate effects to other aspects of grassland communities such as plant cover, density, species composition and diversity that may not happen concurrently or to the same degree; indeed, grazing differentially affects vegetation guilds, and even various species within guilds (Hayes 2003). Because mesic and xeric plant species often respond in unlike ways to grazing pressure, monitoring should also include both wetland and surrounding xeric areas. The most effective monitoring approach would be the use of a block design to systematically compare grazed and ungrazed areas with regard to plant density, height, cover, and species composition of all species present to identify potential impacts. Special attention should be given to the monitoring of wetland areas and their protection from cattle, while taking into account access by wildlife and the need for alternate water sources for cattle. Monitoring should be accompanied by the subsequent manipulation of cattle if impacts beyond those managed for become apparent. This may include rotating cattle between fields to allow for greater periods of vegetative rest to promote increased compensation, limiting the intensity of grazing or controlling grazing timing in order to achieve management goals.

The solution would be to have in place a very controlled grazing program accompanied by an intensive monitoring agenda. As this study highlights, a fine line exists between beneficial and detrimental impacts to grasslands species when cattle are used as a tool for exotic species control, so active grazing management and monitoring are essential. Grazing must be conducted carefully and conservatively. The best overall approach is a spatial and temporal mosaic of grazed and ungrazed areas; seasonal grazing at a low intensity, rotating between periods of grazing and rest with adjustments made to stocking levels or rest periods based on the results of monitoring and local conditions, in order to achieve management objectives. Multiple studies indicate that early, wet season grazing suppresses exotic annual grasses and potentially benefits native perennial grasses, while dry season grazing has been shown to benefit exotic forbs and adversely affect mesic vegetation (Kauffman 1983; D'Antonio 2001; Marty 2005). For this reason and to lessen the potential for impact to desirable native species, grazing should be limited to spring months. Monitoring should be performed rigorously as discussed above, in order to limit impacts of cattle. Without proper monitoring and active management, grazing can quickly become a detriment to wetland and grassland systems.

LITERATURE CITED

Allen-Diaz, B., R. D. Jackson, J. W. Bartolome, K. W. Tate, and L. G. Oates. 2004. Long-term grazing study in spring-fed wetlands reveals management tradeoffs. *California Agriculture* 58:144-148.

Barry, S. 2000. Guidelines for describing grazing management and utilization when conduction botanical surveys. University of California Division of Agriculture and Natural Resources, California: 3p.

Belsky, A. J. and J. L. Gerbard. 2000. Livestock grazing and weed invasions in the arid west. Oregon Natural Desert Association. Bend, Oregon: 31p.

Biondini, M., B. Patton, and P. Nyren. 1998. Grazing intensity and ecosystem processes in a northern mixed-grass prairie, USA. *Ecological Applications* 8:469-479.

Bock, C. E. and J. H. Bock. 1993. Cover of perennial grasses in southeastern Arizona in relation to livestock grazing. *Conservation Biology* 7:371-377.

Brady and Associates, Inc. 1996. Joseph D. Grant and Ed. R. Levin County Parks resource management plan. Santa Clara County, CA: Santa Clara County Parks and Recreation Department 232p.

Budzinski, R. 1993. Range management plan for Ed R. Levin County Park and Joseph D. Grant County Park. Santa Clara County, CA: Santa Clara County Parks and Recreation Department 33p.

California Native Plant Society. 2001. California Native Plant Society inventory of rare and endangered vascular plants of California, 6^{th} Edition. Sacramento, CA: California Native Plant Society. 386 p.

Clary, W. P. 1999. Stream channel and vegetation responses to late spring cattle grazing. *Journal of Range Management* 52:218-227.

Collins, S., A. Knapp, J. Briggs, J. Blair, and E. Steinauer. 1998. Modulation of diversity by grazing and mowing in native tallgrass prairie. *Science* 280:745-747.

Cottarn, W. and F. Evans. 1945. A comparative study of the vegetation of grazed and ungrazed canyons of the Wasatch Range, Utah. *Ecology* 26:171-181.

Crampton, B. 1974. Grasses in California. Berkeley, CA: University of California Press. 178 p.

D'Antonio, C., S. Bainbridge, C. Kennedy, J. Bartolome, and S.Reynolds. 2001. Ecology and restoration of California grasslands with special emphasis on the influence of fire and grazing on native grassland species. Department of Integrative Biology, University of California, Berkeley, California: 99p.

Diaz, S., I. Noy-Meir, and M. Cabido. 2001. Can grazing response of herbaceous plants be predicted from simple vegetative traits? *The Journal of Applied Ecology* 38:497-508.

Dobkin, D. S., A. C. Rich, and W. H. Pyle. 1998. Habitat and avifaunal recovery from livestock grazing in a riparian meadow system of the northwestern Great Basin. *Conservation Biology* 12:209-221.

Fleischner, T. L. 1994. Ecological costs of livestock grazing in western North America. *Conservation Biology* 8:629-644.

Gardner, J. 1950. Effects of thirty years of protection from grazing in desert grassland. *Ecology* 31:44-50.

Giuliano, W. 2004. Short-term grazing exclusion on riparian small mammal communities. *Journal of Range Management* 57:346-350.

Grant, S., L. Torvell, T. Common, E. Sim, and J. Small. 1996. Controlled grazing studies on Molinia grassland: effects of different seasonal patterns and levels of defoliation on Molinia growth and responses of swards to controlled grazing by cattle. *The Journal of Applied Ecology* 33:1267-1280.

Green, D. M. and J. B. Kauffman. 1995. Succession and livestock grazing in a northeastern Oregon riparian ecosystem. *Journal of Range Management* 48:307-313.

Harrison, S. 1999. Native and alien species diversity at the local and regional scales in a grazed California grassland. *Oecologia* 121:99-106.

Hayes, G. and K. Holl. 2003. Cattle grazing impacts on annual forbs and vegetation composition of mesic grasslands in California. *Conservation Biology* 17:1694-1702.

Hickman, J. C. [ed.]. 1993. The Jepson manual: higher plants of California . Berkeley, CA: University of California Press. 1424 p.

Hickman, K., D. Hartnett, R. Cochran, and C. Owensby. 2004. Grazing management effects on plant species diversity in tallgrass prairie. *Journal of Range Management* 57:58-65.

Jepson, W.L. 1963. *A manual of flowering plants of California.* University of California Press, Berkeley, California. 1238 p.

Kauffman, J., W. Krueger, and M. Vavra. 1983. Effects of late season cattle grazing on riparian plant communities. *Journal of Range Management* 36:685-691.

Kimball, S. and P. Schiffman. 2003. Differing effects of cattle grazing on native and alien plants. *Conservation Biology* 17:1681-1693.

Krebs, C. J. 1989. *Ecological Methodology.* New York, NY: 654 p.

Kruess, A. and T. Tscharntke. 2002. Grazing intensity and the diversity of grasshoppers, butterflies, and trap-nesting bees and wasps. *Conservation Biology* 16:1570-1580.

Marty, J. 2005. Effects of cattle grazing on diversity in ephemeral wetlands. *Conservation Biology* 19:1626-1632.

Medin, D. E. and Clary, W. P. 1990. Bird and small mammal populations in a grazed and ungrazed riparian habitat in Idaho. Research Paper INT-425, Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station 8p.

Mitchell, J., G. Wallace, and M. Wells. 1996. Visitor perception about cattle grazing on National Forest land. *Journal of Range Management* 49:81-86.

Noy-Meir, I., M. Gutman, and Y. Kaplan. 1989. Responses of Mediterranean grassland plants to grazing and protection. *The Journal of Ecology* 77:290-310.

Platts, W. S. 1990. Managing fisheries and wildlife on rangelands grazed by livestock: a guidance and reference document for biologists. Nevada Department of Wildlife Report, Reno, Nevada 114p.

Pyke, C. and J. Marty. 2005. Cattle grazing mediates climate change impacts on ephemeral wetlands. *Conservation Biology* 19:1619-1625.

Rambo, J. and S. Faeth. 1999. Effect of vertebrate grazing on plant and insect community structure. *Conservation Biology* 13:1047-1054.

Rana Creek Habitat Restoration. 1998. Coyote Lake County Park: a resource management transition plan. Santa Clara County, CA: Santa Clara County Parks and Recreation Department 224p.

Rocha, Don. 2001 January – July. Grazing history in Santa Clara County Parks.

Sharsmith, H. K. 1945. Flora of the Mount Hamilton Range. *The American Midland Naturalist* 34:289-367.

Skovlin, J. M. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge. *In:* Developing strategies for Rangeland Management. National Research Council/National Academy of Sciences. Boulder, CO: Westview Press. p. 1001-1103.

Smith, M. and A. Knapp. 1999. Exotic plant species in a C4-dominated grassland: invisibility, disturbance, and community structure. *Oecologia* 120:605-612.

State of California, The Resources Agency, Department of Fish and Game, Habitat Conservation Division, Wildlife and Habitat Data Analysis Branch. 2003. *California Natural Diversity Database: State and Federally Listed Endangered, Threatened, and Rare Plants of California. Available at*: http://www.dfg.ca.gov/bdb/html/plants.html. *Accessed 2 January 2007.*

Stromberg, M. and J. Griffin. 1996. Long-term patterns in coastal California grasslands in relation to cultivation, gophers, and grazing. *Ecological Applications* 6:1189-1211.

Szaro, R. and C. Pase. 1983. Short-term changes in a cottonwood-ash-willow association on a grazed and an ungrazed portion of Little Ash Creek in central Arizona. *Journal of Range Management* 36:382-384.

Taylor, C., M. Ralphs, and M. Kothmann. 1997. Technical note: vegetation response to increasing stocking rate under rotational stocking. *Journal of Range Management* 50:439-442.

Turner, C., T. Seastedt, and M. Dyer. 1993. Maximization of aboveground grassland production: the role of defoliation frequency, intensity, and history. *Ecological Applications* 3:175-186.

USDA, NRCS. 2006. State facts sheets: California. *Available at*: http://www.ers.usda.gov/statefacts/CA.htm. *Accessed 2 December 2006*.

USDA, NRCS. 2006. National range and pasture handbook. *Available at*: http://www.glti.nrcs.usda.gov/technical/publications/nrph.html/. *Accessed 2 December 2006.*

Vavra, M. 2005. Livestock grazing and wildlife: developing compatibilities. *Rangeland Ecology and Management* 58:128-134.

Volesky, J., W. Schacht, and D. Richardson. 2004. Stocking rate and grazing frequency effects on Nebraska Sandhills meadows. *Journal of Range Management* 57:553-560.

Walker, J. W. 1995. Grazing management and research now and in the next millennium. *Journal of Range Management* 48:350-357.

WorldClimate. 2006. *WorldClimate, Version 271. Available at*: http://www.worldclimate.com/. *Accessed 1 December 2006.*

Zar, J. H. 1984. Biostatistical analysis, 2nd ed. Englewood Cliffs, New Jersey: Prentice-Hall. 718 p.

Appendix 1. Minimal Detectable Differences (MDDs) of measured variables at the broad scale. [1]

MEASURED VARIABLE	MDD
Individual Species Abundance Measurements	
annual beard grass	4.54 cm
bermuda grass	1.35 cm
broad-leaved cattail	2.13 cm
brownhead rush	0.54 cm
California bulrush	0.81 cm
chinese pusley	0.27 cm
common cocklebur	0.88 cm
common spikerush	9.37 cm
creeping swampgrass	1.60 cm
curly dock	1.19 cm
douglas' knotweed	0.98 cm
everlasting cudweed	0.27 cm
grass poly	1.00 cm
Italian ryegrass	0.27 cm
knotgrass	11.35 cm
mediterranean barley	1.73 cm
mustard spp.	0.29 cm
pennyroyal	0.54 cm
petty spurge	0.27 cm
plumeless thistle spp.	0.29 cm
polygonum spp.	0.27 cm
salt grass	0.27 cm
turkey mullein, doveweed	0.38 cm
unknown species 4	0.92 cm
western marsh cudweed	0.92 cm
Individual Species Height Measurements	
annual beard grass	7.95 cm
bermuda grass	1.89 cm
broad-leaved cattail	37.35 cm
brownhead rush	2.70 cm
California bulrush	10.54 cm
canyon nemophila	0.27 cm
chinese pusley	3.24 cm
common cocklebur	3.79 cm

Appendix 1. Continued. [1]

MEASURED VARIABLE	**MDD**
Individual Species Height Measurements (con.)	
common spikerush	9.14 cm
creeping swampgrass	3.11 cm
curly dock	7.42 cm
douglas' knotweed	2.24 cm
everlasting cudweed	0.27 cm
grass poly	2.31 cm
Italian ryegrass	2.50 cm
knotgrass	7.30 cm
mediterranean barley	1.23 cm
mustard spp.	0.29 cm
pennyroyal	4.92 cm
petty spurge	0.60 cm
plumeless thistle spp.	0.58 cm
polygonum spp.	1.62 cm
salt grass	0.81 cm
spiny cocklebur	0.58 cm
turkey mullein, doveweed	0.88 cm
umbrella sedge	1.35 cm
unknown species 4	1.12 cm
western marsh cudweed	0.58 cm
Other Measurements	
Bare Ground	14.31 cm
Percent Feral Pig Activity	31.11 cm
Pond Fluctuation	2734.65 m^2
Rock	0.88 cm
Slope of Pond Basin	5.07 degrees
Species Richness	2.75 spp

[1] MDDs stated with 90% confidence (power=0.90) and alpha=0.05. Formula used (Zar 1984): MDD = square root ($[2ks^2f^2]/n$), with $k = 2$, $n = 16$, $v_1 = 2$, $v_2 = 13$, s^2 = MS from one-way ANOVA, phi = 2.25. Variables excluded from Appendix 1 exhibited no variation between grazing treatments.

Appendix 2. Minimum Detectable Differences (MDDs) of measured variables at the fine scale. [1]

MEASURED VARIABLE	MDD
Individual Species Abundance Measurements	
annual beard grass	2.20 cm
bermuda grass	1.15 cm
broad-leaved cattail	1.05 cm
brownhead rush	0.55 cm
California bulrush	0.69 cm
canyon nemophila	0.09 cm
chinese pusley	0.24 cm
common cocklebur	0.35 cm
common spikerush	3.96 cm
creeping swampgrass	1.37 cm
curly dock	0.79 cm
douglas' knotweed	0.42 cm
everlasting cudweed	0.14 cm
grass poly	0.42 cm
Italian ryegrass	0.15 cm
knotgrass	3.99 cm
mediterranean barley	0.78 cm
mustard spp.	0.19 cm
pennyroyal	0.37 cm
petty spurge	0.21 cm
plumeless thistle spp.	0.14 cm
polygonum spp.	0.18 cm
salt grass	0.18 cm
spiny cocklebur	0.09 cm
turkey mullein, doveweed	0.28 cm
umbrella sedge	0.05 cm
unknown species 4	0.58 cm
western marsh cudweed	0.58 cm
Individual Species Height Measurements	
annual beard grass	4.34 cm
bermuda grass	1.23 cm
broad-leaved cattail	17.16 cm
brownhead rush	2.21 cm
California bulrush	8.93 cm

Appendix 2. Continued. [1]

MEASURED VARIABLE	MDD
Individual Species Height Measurements (con.)	
canyon nemophila	0.32 cm
chinese pusley	2.30 cm
common cocklebur	1.47 cm
common spikerush	3.97 cm
creeping swampgrass	1.70 cm
curly dock	5.42 cm
douglas' knotweed	1.13 cm
everlasting cudweed	0.14 cm
grass poly	1.31 cm
Italian ryegrass	2.04 cm
knotgrass	2.62 cm
mediterranean barley	0.60 cm
mustard spp.	0.11 cm
pennyroyal	4.39 cm
petty spurge	0.18 cm
plumeless thistle spp.	0.42 cm
polygonum spp.	1.44 cm
salt grass	0.64 cm
spiny cocklebur	0.37 cm
turkey mullein, doveweed	0.52 cm
umbrella sedge	1.06 cm
unknown species 4	0.78 cm
western marsh cudweed	0.29 cm
Other Measurements	
Bare Ground	5.74 cm
Percent Feral Pig Activity	12.05 cm
Rock	0.76 cm
Slope of Pond Basin	2.30 degrees
Species Richness	1.05 spp

[1] MDDs stated with 90% confidence (power=0.90) and alpha=0.05. Formula used (Zar 1984): MDD = square root ($[2ks^2f^2]/n$), with $k = 2$, $n = 80$, $v_1 = 3$, $v_2 = 77$, s^2 = MS from one-way ANOVA, phi = 1.85. Variables excluded from Appendix 2 exhibited no variation between grazing treatments.