# EFFECTS OF GRAZING ON UPLAND VEGETATION AT JEPSON PRAIRIE PRESERVE, SOLANO COUNTY, CA

Third year (2007) results and final report
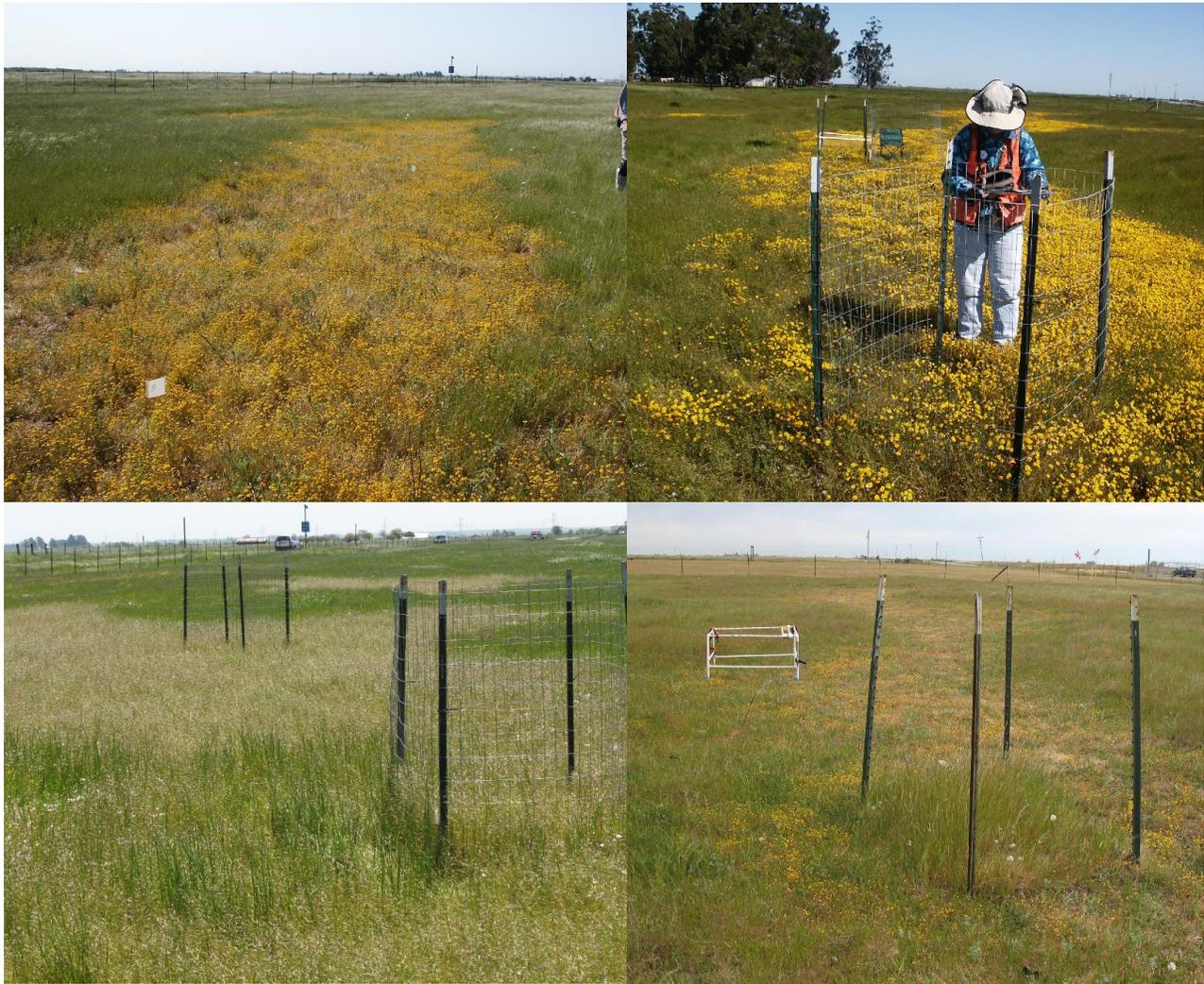
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Cover:

April photographs of one set of study plots (low position plots in set 9, field 20E) from 2004 to 2007. Upper left: View to south, April 2004, prior to start of experiment. Plot locations are marked by flags. Upper right: View to north, April 2005. The nongrazed mowed plot is visible in the foreground; sampling frame is over the nongrazed plot. Lower left: View to south, April 2006. *Pleuropogon californicus* dominates pools which had previously been dominated by *Lasthenia* spp. Lower right: View to northeast, April 2007. *Lasthenia* spp. have returned as the dominant native species in this very dry year. The nongrazed plot in the foreground is dominated by *Lolium perenne* ssp. *multiflorum*. The sampling frame in the background is over the grazed plot.

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

EXECUTIVE SUMMARY

The overall purpose of this study was to investigate how variations in the sheep grazing regime at Jepson Prairie Preserve affect vegetation. Weedy plant cover, especially exotic grass cover, predominates on the relatively high mound or upland areas of the Preserve, whereas native cover predominates in low lying areas. One goal of this study was to test whether the current sheep grazing regimes can be altered to increase cover of native plants in areas that are currently weed-dominated without adversely affecting areas that are currently dominated by native species. A second goal was to determine whether current grazing regimes used at Jepson Prairie Preserve are achieving conservation goals compared to a nongrazed condition. This final report presents results from the third year of this three-year study.

Eight plot locations with matched plots at adjacent mound/upland (high position) and pool/swale (low position) sites were established in each of three adjacent fields. Each field was grazed with a different prescribed grazing regime. For each plot location and topographic position (high or low), we established three plots: a grazed plot, a nongrazed multiyear control plot, and a nongrazed mowed control plot. Throughout the winter and spring, we assessed grazing impact to individual grazed plots by comparing vegetation height in adjacent grazed and nongrazed mowed control plots. A baseline assessment of native and exotic cover and species richness was conducted in the plots assigned to the grazed and nongrazed multiyear control treatments in late April 2004 prior to the exclusion of the control plots from grazing. Cover and species richness were reassessed again in April 2005, 2006, and 2007. Season-end vegetation height and residual dry matter (RDM) were assessed in August of 2004 through 2007.

Differential grazing impacts

In all three years of the study, adjacent high and low plots within fields were grazed at different intensities by sheep. In all years, sheep preferentially grazed the native-dominated low plots late in the season, when the exotic grasses began to dry out and set seed in the high plots. Weed-dominated high plots were grazed preferentially early in the winter when the low-lying native-dominated areas were flooded. However, if low positions plots were not flooded, sheep either preferentially grazed in low plots or grazing impacts in high and low plots were similar.

Variables describing grazing intensity and timing were related to the amount of August mulch and RDM in high and low position plots. Late season grazing was most closely correlated with reductions in RDM.

In high position grazed plots, none of the grazing variables tested were related to native or exotic species cover or richness. In low position grazed plots, grazing variables were related to native species cover but not to native species richness. Among low position grazed plots, increased grazing impact in the January-April grazing period was associated with less native cover in April. This trend was seen in all three years and was primarily associated with heavy grazing during the main spring bloom period. These results indicate that none of the grazing treatments tested were better than the pre-experiment grazing regimes with respect to increasing native cover or suppressing exotic cover.

Grazed versus nongrazed plots

In both high and low position plots, August RDM was significantly greater in all years in nongrazed plots than in grazed plots. In high plots, total exotic cover did not differ between nongrazed and grazed plots. However, when exotic cover in high plots was examined by plant guild, exotic forb cover was lower, and exotic grass cover was higher in nongrazed plots compared to grazed plots across the three years of the study. Medusahead (*Taeniatherum caput-medusae*) cover did not differ between grazed and nongrazed plots in either high or low positions.

Although exotic cover did not change in nongrazed high plots, native cover was significantly lower in nongrazed than in grazed high plots after three years of exclusion from grazing. After three years, the magnitude of the difference in native cover between high grazed (4.5% native cover) and nongrazed plots (1.5% native cover) was small. Most of the native cover in the high plots was saltgrass (*Distichlis spicata*).

In low position plots, native cover and the count of native species decreased significantly in nongrazed plots compared to grazed plots by the second year of exclusion from grazing. Cover of exotic species also increased significantly in nongrazed compared to grazed low plots by the second year. The primary component of exotic cover in low position nongrazed plots was exotic grasses, the most abundant of which was annual ryegrass (*Lolium perenne* ssp. *multiflorum*). The primary beneficial effect of sheep grazing in the low plots was the suppression of annual ryegrass. Exotic forb cover did not increase in nongrazed low plots.

Effects of environment

Over the three years of the study, vegetation growth was strongly affected by annual rainfall and temperature. Vegetation growth in 2006 was reduced relative to 2005 due to the late onset of winter rains and low temperatures in March. Vegetation growth and native cover were reduced in 2007 compared to the previous two years due to season-long reduced rainfall. Weather-related changes in vegetation outcomes associated with low rainfall were as large as or larger than the largest grazing-related vegetation changes. The decrease in native cover due to low rainfall in 2007 was equivalent to the effect of grazing cessation for three years, suggesting that on a year to year basis, weather has more potential to influence native cover than do most variations in grazing regimes.

INTRODUCTION

Grazing and fire are the two main management tools available for managing grassland vegetation at Jepson Prairie Preserve. However, due to the numerous constraints on controlled burning, grazing is the only vegetation management method that is utilized on an annual basis. Although grazing is widely acknowledged as a critical management input, the Jepson Prairie Management Committee and others have been concerned for some time that the current grazing practices may not be optimized for the Preserve's vegetation management objectives.

Although grazing may appear to be a simple process superficially, the use of grazing to accomplish specific vegetation management objectives at Jepson Prairie is a fairly complex problem. To begin with, vegetation in the preserve as a whole and within each field is a mosaic of species that vary considerably over relatively short distances. Species complexes tend to differ as a function of soils and microtopography. Higher mound/upland microsites are usually dominated by exotic species and lower swale/pool/playa microsites are commonly dominated by native species. Furthermore, while some weedy and native species occur in both of these general soil/microtopography units, most species are largely restricted to one unit or the other. Also, some species are widely distributed throughout the preserve whereas others, such as the introduced weed purple star thistle, are currently limited to certain areas near the points of introduction.

Environmental and management influences across the preserve also vary across space and time. Especially in semiarid and arid regions, annual vegetation is highly influenced by rainfall and temperature profiles that vary from year to year. Weather influences can easily outweigh the effects of management inputs, including grazing, in any given year (Jackson and Bartolome 2002). Weather interacts with edaphic factors, management factors, and the seed bank to increase the overall variation in vegetation outcomes. In other words, a given set of management inputs could have a variety of different effects on vegetation depending on environmental factors.

To further complicate matters, grazing cannot be considered to be a uniform or fixed effect either within years or between years. Grazing records from Jepson Prairie indicate that fields which nominally receive the same grazing prescription show considerable variation in the time periods that animals are present and actual stocking rates. Such variation is unavoidable, given the influence of annual weather conditions on the plant phenology and the spatio-temporal distribution of available forage throughout the reserve. In addition, because sheep tend to move as flocks, the large fields at Jepson are not grazed uniformly in space and time. As sheep move throughout the field, a mosaic of local grazing intensities and timings develop over the field. Furthermore, as noted in the grazing plan (Jepson Prairie Management Committee 1999), sheep, like other grazing animals, show varying levels of selectivity when they graze. At any given time, preferred species are likely to be grazed more intensely than non-preferred species. Hence, the amount of time that sheep remain in an area, and the impact that they have on different species within an area, are influenced by the existing vegetation at the time that the animals encounter it.

Because Jepson Prairie has a long history of grazing, it is reasonable to assume that all of the common species that occur at the reserve can tolerate some level of grazing. The use of grazing

as a management tool to manipulate species composition at Jepson Prairie relies on the hypotheses that within this complex of grazing-tolerant species (1) varying the timing and/or intensity of grazing impacts will differentially affect the competitive abilities of certain species and, (2) this change in competitive advantage will alter the total cover achieved by various species.

The overall purpose of this study was to investigate how variations in the sheep grazing regime at Jepson Prairie Preserve affect vegetation. Specific goals of this study, noted in the original study Request for Proposals, were to determine (1) if we can identify a grazing regime or regime(s) that will reduce cover of exotic species and increase cover of native species beyond levels achieved by the current grazing regimes and (2) whether the current grazing regime is achieving conservation goals compared to a nongrazed condition. To address the first goal, the study compared vegetation outcomes between plots that varied with respect to the timing and overall level of grazing. The second goal was addressed by comparing grazed and nongrazed plots.

In 2004, we established study plots and collected baseline data on cover and other vegetation parameters. Experimental grazing treatments and associated data collection began in 2005. Baseline data and results from the first (2005) and second (2006) years of the study have been reported previously (Swiecki and Bernhardt 2006, 2007). This report presents results through the end of the 2007 grazing year.

METHODS

The overall design of the experiment has been described previously (Swiecki and Bernhardt 2004). However, some of the original methods have been modified as needed to adapt to field conditions. This section describes the study methods, including procedures updated since the start of the study. To avoid confusion between geographical groups of plots (referred to as clusters in previous reports) and groups of plots defined through hierarchical clustering techniques, physical groups of nearby plots at each plot location are referred to as plot sets in this report.

The experiment was established in three adjacent fields, known as field 20 east (20E) or east eucalyptus (EEuc); field 19 east (19E) or east north section 24 (EN24); and field 18 east (18E) or east south section 24 (ES24). Using GIS software that showed the boundaries of the study fields, we used randomly-selected coordinates to establish an initial candidate plot set location in each field. Subsequent candidate plot set locations were generated by filling each field with non-overlapping circles 75 m in radius. Coordinates of the center point of each circle, each at least 150 m from an adjacent point within a field, were uploaded to a GPS receiver (Garmin® GPS76).

Between 20 April and 1 May 2004, we used a GPS receiver to locate the plot set areas in the fields. Upon reaching a candidate location, we determined whether we could establish three plots (1 m² each) in native dominated areas (generally pools or swales, i.e., low microtopographic positions) and three plots in exotic dominated areas nearby (generally uplands or mounds , i.e., high microtopographic positions). If suitable plots could be not be found within about 20 to 30 m of the preselected coordinates, the candidate area was rejected and we proceeded to another point. We continued inspecting candidate locations until we had eight plot sets in each field. The final distribution of the selected plot set locations is shown in *figure 1*.

The six plots in each set were in relatively close proximity to each other to ensure that all plots within each set had the same potential grazing exposure. The separation between plots in a set ranges from less than a meter (e.g., between adjacent grazed and nongrazed plots) to about 28 m (maximum distance between high and low plots in a single set). Flocks used on these fields typically consisted of 200 to 400 sheep (ranging from about 110 to 1260 head over the three years of the study), Sheep also tended to be somewhat attracted to the exclosures, so plots within each plot generally has the same potential exposure to sheep.

Plot setup

At each plot set location, we selected three high (upland) and three low (swale/pool) plots. The three plots within each microtopographic position (high or low) in each plot set were matched to the degree possible for vegetation characteristics, including plant height, species composition, and cover. The three plot types designated within the low and high halves of each plot set were as follows.
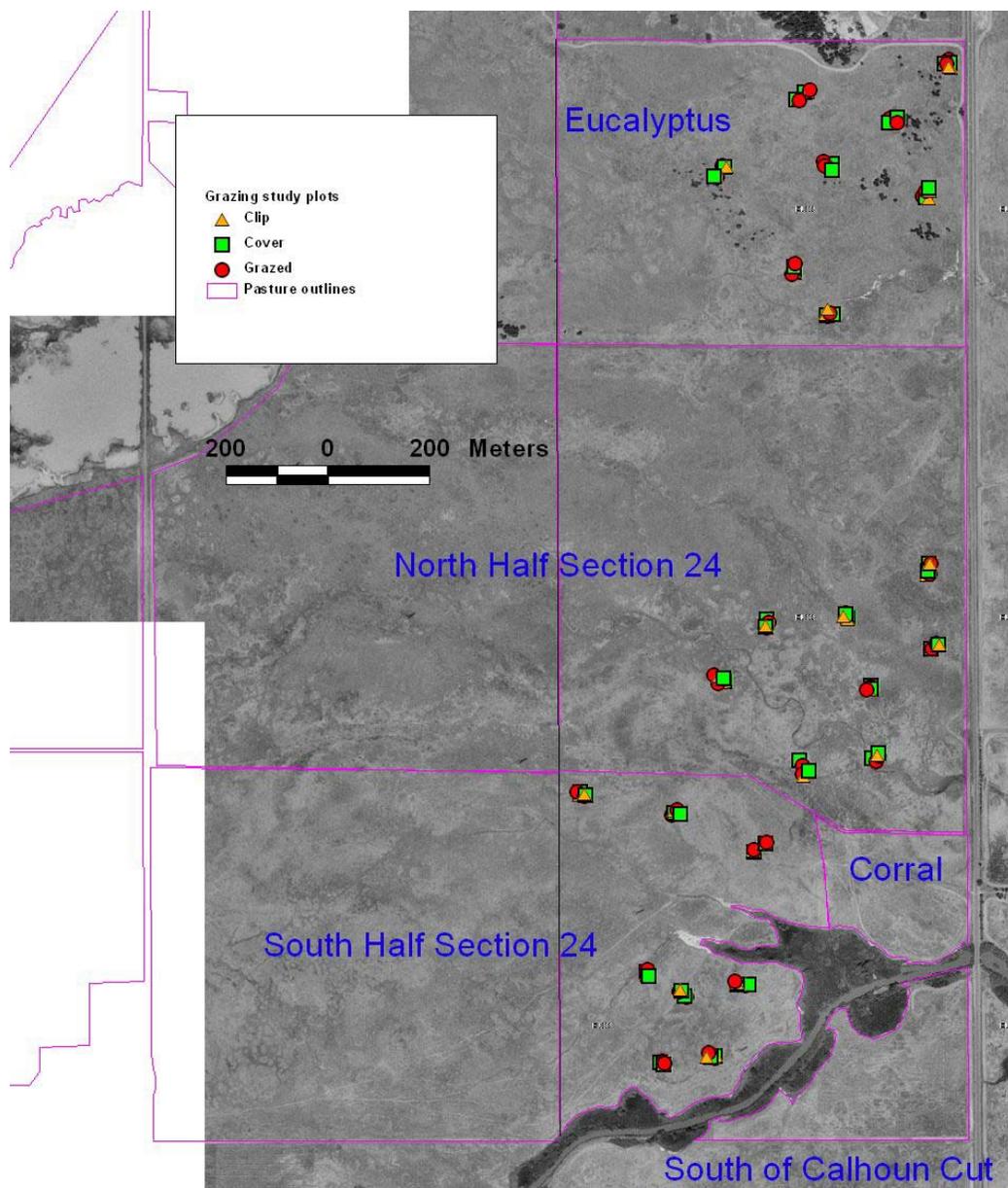
Figure 1. Plot set locations. The different symbols indicate different plot types (grazed, nongrazed cover, nongrazed mowed) within the sets.

Grazed plot: exposed to grazing; used to measure cover and composition changes and mulch accumulation in the presence of grazing.

Nongrazed multiyear control plot: excluded from grazing by fencing; used to measure cover and composition changes and mulch accumulation in the absence of grazing. These plots were referred to as nongrazed cover plots in previous reports (Swiecki and Bernhardt 2006, 2007). The exclosures for nongrazed multiyear control plots were larger than 1 m^2 to allow collection of nongrazed residual dry matter samples from inside of the exclosure but outside the area used to measure cover.

Nongrazed mowed plot: excluded from grazing by fencing; used as reference plot to estimate the amount of vegetation removed by grazing each month in the matched grazed plot. Vegetation in these plots was manually mowed as needed at each observation date to maintain average vegetation height within 5 cm of the average vegetation height in the grazed plot.

It was generally much easier to pick out two closely matched plots than three matched plots. If three nearly identical plots were identified, plot types were assigned randomly. For plot sets that were less closely matched, the two plots that were most closely matched for vegetation height and density were assigned to the grazed and nongrazed mowed treatments. This matching allowed us to estimate the impact of grazing on vegetation height as accurately as possible.

Two diagonal plot corners were marked by driving 15 cm long carriage bolts topped with 4 cm diameter fender washers into the ground so that the washer was flush with the soil surface. The legs of the 1 m square point frame that was used to collect cover data fit directly over the carriage bolts, so the frame could be positioned in the same exact location for all measurements using the frame.

Differential-corrected GPS coordinates were recorded for each plot. We also recorded distances and azimuths between the three plots in each half of the plot set to aid in relocation.

In October 2004, personnel from Solano Land Trust (SLT), and the University of California Davis, working with inmates from Delta Camp (a joint effort of the California Department of Corrections and the California Department of Forestry and Fire Protection), constructed exclosures around the nongrazed multiyear control plots and the nongrazed mowed plots. Exclosures were composed of 4 steel T-posts surrounded by 122 cm tall, 14 gauge galvanized welded wire mesh (5 by 10 cm) fence fabric. The fence fabric was secured to the posts with plastic cable ties, which facilitated the periodic removal of the fence fabric for data collection purposes. Exclosures were repaired and reinforced as needed throughout the course of the study. In areas that sheep tended to use more heavily, the exclosures were commonly pushed in along the areas between the T-posts. At these sites, we drove stakes made from 0.5 inch ID PVC pipe at the center of the wire fabric span between the T-posts to pin down the fabric.

Grazing

The initial grazing plan developed for 2005 by SLT and members of the Jepson Management Committee (JMC) was not fully implemented (Swiecki and Bernhardt 2006). For the 2006 grazing year, the JMC decided to replicate the grazing that occurred in 2005, with additional animal unit months (AUM) of grazing impact added to field 20E, which had been grazed very lightly in 2005. The 2006 grazing in field 20E matched its grazing prescription, but actual grazing in 19E and 18E varied from the 2006 prescriptions (Swiecki and Bernhardt 2007).

For 2007, the decision was made to replicate the grazing pattern used in 18E in 2005: 34% of the total annual AUM during late February/early March and 66% of total annual AUM during May/June. Field 18E, which is the smallest field in the study, was selected to have this pattern used at an AUM level twice that used in 2006. This high AUM grazing treatment for 18E matched the levels specified in the Greater Jepson Prairie Regional Management Plan (Witham 2006). Field 19E was assigned to have the same grazing pattern but at the lower AUM level

used in field 18E in 2006. Field 20E was assigned to receive the same grazing prescription it received in 2006 (Swiecki and Bernhardt 2007). The grazing plan for the 2006-2007 grazing season is shown in *table 1*.

Table 1. Grazing plan for the 2007-2008 grazing season.

	AUM		
Timing	**Field 18E**	**Field 19E**	**Field 20E**
mid-Jan	—	—	8-10
mid Feb-early March	—	—	18-20
late Feb-early March	37	45	—
late May-mid-June	73	111	—
Total annual AUM/acre	1.53	0.89	0.25
Recommended AUM/acre[1]	1.53	1.63	1.98

[1] Witham 2006

Data collection

Grazing impact measurements

To estimate grazing impacts over the growing season in grazed plots, vegetation height measurements were made in both grazed and nongrazed mowed plots over the following dates in 2007: 2-3 January, 14-15 February, 23-24 March, 15-20 April, and 13-15 August. At each observation period, all plots were photographed and average forage height was measured at five non-overlapping locations in each plot (center and four quadrants) using a modified falling plate meter (Barnhart 1998, Rayburn and Lozier 2003). The clear plastic plate of the meter was 25 cm square and was attached to a metal tube which was nested in a calibrated measuring rod (*fig. 2*). Areas of the plot that had been covered with soil due to gopher activity were excluded from measurement.

Average standing vegetation height at each measured location was estimated as the height at which about half of the plants under the plate contacted the bottom of the plate. The plate and attached tube (mass=1.2 kg) was then pushed down to compress the vegetation and allowed to rebound naturally. A second measurement was then made on the vegetation compressed by the falling plate/tube assembly. Because the dropped plate measurement is affected by plant density as well as plant height, it provides a better estimate of total vegetation biomass than does average vegetation height. We modified the method from dropping the plate/tube assembly (from a height of 30 cm above the top of the foliage) to manually pushing the plate down to obtain more repeatable measurements from nongrazed plots that had high amounts of stiff dry residue. Tests on grazed plots showed that readings made by dropping and pushing the plate down were nearly identical.

Figure 2. Falling plate meter in grazed plot.

If the average vegetation height in the nongrazed mowed plot exceeded that of the paired grazed plot by 5 cm or more, vegetation in the nongrazed mowed plot was mowed to match the height of the grazed plot with a battery-operated string trimmer. We also used the trimmer to remove vegetation in vertical slices down to the soil level if necessary to help match the overall density of the grazed plot. After mowing, residues were removed by raking and the vegetation height was remeasured as described above.

Spring assessments

In April 2004, near the time when native spring annual forb cover was maximal, we conducted a baseline assessment on all plots as described below. Plots were initially assessed between 20 April and 1 May 2004. The assessments were repeated between 20 April and 26 April 2005, between 25 April and 2 May 2006, and between 15 April and 20 April 2007. The assessment period was shifted as necessary each year to coincide with the peak spring bloom period of annual native forbs to the degree possible.

In the nongrazed multiyear control plots and the grazed plots, we estimated plant cover by species using a square, evenly-spaced 100 point grid. A point frame was mounted over the plot, using the bolts placed in the plot corners to maintain a consistent placement of the frame over a given plot. A high-intensity green laser pointer mounted on a sliding bracket suspended over the plot was used to highlight each of the 100 points. We recorded whether the laser dot fell on bare

soil, mulch (dried plant material from the previous or older growing season), or current-season plant species. Sample point hits were identified to species for all native species and for exotic forbs. Sample point hits on exotic grasses were differentiated only into categories of medusahead (*Taeniatherum caput-medusae*) or other exotic grasses. Cover was assessed on a first hit basis, so total cover for the plot sums to 100%.

In all plots, we recorded all plant species visible within the plot. For each plant species present within the sample frame area we also noted the phenological stage (vegetative, bolting, flowering, seed formation, senescent, dead). We also noted the dominant species within each plot. Average vegetation height and compressed vegetation height were also measured in all plots at this time, using the falling plate meter as described above.

Summer assessments

Plots were rephotographed and assessed in August 2004, 2005, 2006, and 2007, after grazing for the season was complete and all spring annual vegetation was completely dry. In the August assessments, we noted the presence and cover of summer annuals that were not visible in April and estimated residual dry matter (RDM) in the grazed and nongrazed multiyear control plots (Bartolome et al 2002).

In 2004 and 2005, we estimated RDM using a clipped and weighed sample from an area that was visually matched to have the same RDM as the plot but was not located within the plot itself. For grazed plots, the sample was collected from a nearby area outside of the plot. For the nongrazed plots, the sample was collected from within the area excluded from grazing, but outside of the area in which cover was measured. A square 30 cm metal frame was used to delimit the area from which the RDM sample was clipped. In addition, in 2004 we developed a set of photo standards taken of plots with known RDM levels. These photo standards were used each August as an aid to estimate RDM.

The falling plate meter was used in 2005, 2006, and 2007 to measure average vegetation height and compressed vegetation height at five points in each plot as described above. Mulch height was also measured at five points in each plot using a measuring tape.

The 2005 data showed that RDM was significantly ($p<0.0001$) correlated with the falling plate reading, August grass height, April bare cover and April native plant cover ($R^2=0.78$) in standard least squares multiple regression. We used the regression equation with values for these factors measured in 2006 to estimate 2006 RDM. The estimated RDMs for a sample of the plots were checked against 2004 RDM photo standards.

In 2007, in addition to collecting drop plate readings, we also clipped samples to measure RDM weights from 20 plots. For these 20 plots, RDM was highly correlated ($R^2=0.78$, $p<0.0001$) with the falling plate reading, August grass height and April native plant cover in a standard least squares multiple regression model. Including the April bare cover (used in the 2005 regression model) did not improve the fit of the 2007 regression model. However, based on comparison of the estimated RDM from the 2007 multiple regression model with RDM estimated from the photo standards, it was apparent that the 2007 multiple regression model tended to overestimate RDM in the low grazed plots, which are at the low end of the RDM range. A regression

equation using only drop height (R^2=0.66, p<0.0001) provided RDM estimates that closely matched RDM estimated from the photo standards across the range of RDM levels represented in 2007, so this simple regression model was used to estimate 2007 RDM.

After all evaluations were made, the nongrazed mowed plots were mowed and raked to match the height and approximate RDM of the paired grazed plots so that grazed and nongrazed mowed plots were matched with respect to RDM for the upcoming growing season.

Data analysis

Calculation of grazing impact — For the first reading in January, the difference between vegetation heights in the grazed and nongrazed mowed plots was used directly to calculate the grazing impact to that point (Equation 1). Grazing impacts were expressed as the percent of the potential vegetation height growth removed.

$$grazing\ impact_{January} = \frac{(height_{nongrazed} - height_{grazed})}{(height_{nongrazed})} \times 100$$

(Equation 1)

For all other time intervals, grazing impacts for grazed plots were calculated as shown in Equation 2; t_1 and t_2 represent the start and end of the grazing interval, respectively. If nongrazed mowed plots were mowed at the start of a time interval, vegetation height after mowing was used as the initial (t_1) nongrazed vegetation height.

$$grazing\ impact_{t_1 \rightarrow t_2} = \frac{(t_2 height_{nongrazed} - t_1 height_{nongrazed}) - (t_2 height_{grazed} - t_1 height_{grazed})}{(t_2 height_{nongrazed})} \times 100$$

(Equation 2)

Based on the limits of accuracy of our average vegetation height measurements, differences in vegetation heights of less than 2.5 cm were set to zero for purposes of data analysis.

Construction of grazing profiles — The grazing profile for each grazed plot consisted of the pattern of grazing impacts from each time interval. The initial January grazing impact, which was measured prior to the start of grazing, and the April-August grazing impact, which occurred after annual assessments of cover, were not used to construct seasonal grazing profiles.

We used hierarchical clustering to group plots with similar grazing profiles. Because high and low plots differ substantially in many ways, hierarchical clustering of grazing profiles was performed separately on high and low plots. We used Ward's minimum variance method for clustering. This method tends to join clusters with few observations and is strongly biased toward producing clusters with similar numbers of observations.

Statistical tests — We used JMP® statistical software (SAS Inc., Cary NC) for most data summary and analysis. Unless otherwise indicated, effects or differences are referred to as significant if p≤0.05. Effects of year and grazing variables were tested using repeated measures analysis of variance. For more complex repeated measures analyses involving predictor variables whose levels varied each year (e.g., previous August RDM), we used residual maximum likelihood (REML) random effects models.

We used appropriate variance-stabilizing transformations on percent and count data (arcsine and square root transformations, respectively) prior to analysis of variance or regression analyses. Paired t-tests, or matched pairs analyses were used for specific comparisons between paired observations.

We calculated Akaike's information criterion adjusted for small sample size (AIC_c) to compare the fit of alternative models using different sets of variables (Burnham and Anderson 1998). For models constructed for a given data set, smaller AIC values indicate better model fit. Recursive partitioning (also known as CART or regression trees) was used to develop models and investigate interactions between predictors. Recursive partitioning splits data in a dichotomous fashion, with each partition chosen to maximize the difference in the responses between the two branches of the split.

For some analyses, we calculated the confidence interval for the difference between the cover percentages for each given plot in different years (e.g., native cover 2005 vs. native cover 2006) using the Wilson (1927) test as adapted by Newcombe (1998) for testing unpaired differences of proportions. The procedure was executed using an Excel spreadsheet available at http://www.cardiff.ac.uk/medicine/epidemiology_statistics/research/statistics/newcombe/proportions/explanation.htm. Because pairing in the sense of this test refers to individual subjects (i.e., individual sample points within the point grid), the proportions are considered to be unpaired under the terminology of that test. We used the test to determine whether two measured percent cover values for a given plot in two different years were significantly different at p=0.05.

RESULTS

Effects of weather on vegetation growth in nongrazed mowed plots 2005 – 2007

Measurements of cumulative height growth of vegetation in the nongrazed mowed plots indicate the degree to which plant growth rates varied between different years and within each growing season. This information on seasonal and between-year vegetation growth patterns forms the basis for interpreting the superimposed effects of grazing on the vegetation in the plots.

We initially constructed a repeated measures MANOVA model on total seasonal cumulative height growth in the mowed control plots in all three years with plot position (high/low) as an explanatory variable. The effect of time was highly significant (p<0.0001) in this analysis, indicating that total height varied significantly from year to year in both high and low plots (*fig. 3*). The analysis also showed that low position plots had significantly less cumulative height growth than high position plots (p<0.0001) across all three years. The interaction between time by plot position was also significant (p =0.0294), indicating that the magnitude of the height differences between high and low plots varied by year (*fig. 3, 4*).
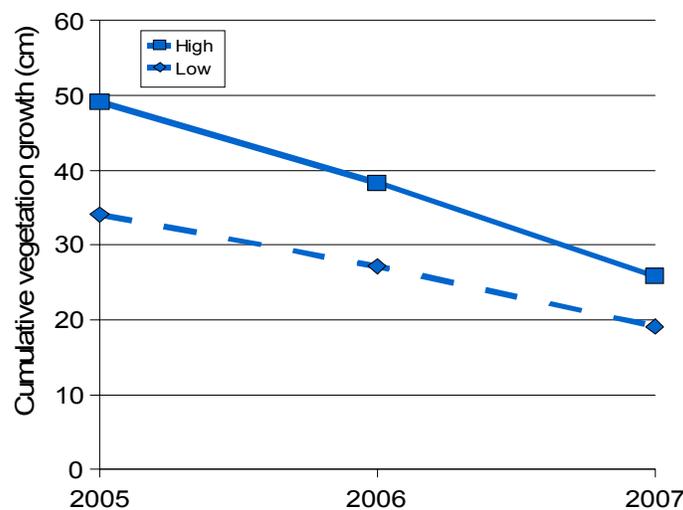
Figure 3. Total cumulative growth (January-August) of vegetation in mowed plots 2005 through 2007.

Year to year differences in vegetation growth are primarily due to the pattern and amount of precipitation in the three years. The reduced height growth in 2007 was associated with low rainfall in the 2006-2007 rainy season, which was only about half of that received in the other two years of the study (*table 2*). Although differences in height growth were less pronounced overall in the low plots than in the high plots, the growth patterns across the three years followed a similar pattern in high and low plots.

Effects of weather on vegetation growth in nongrazed mowed plots 2005 – 2007
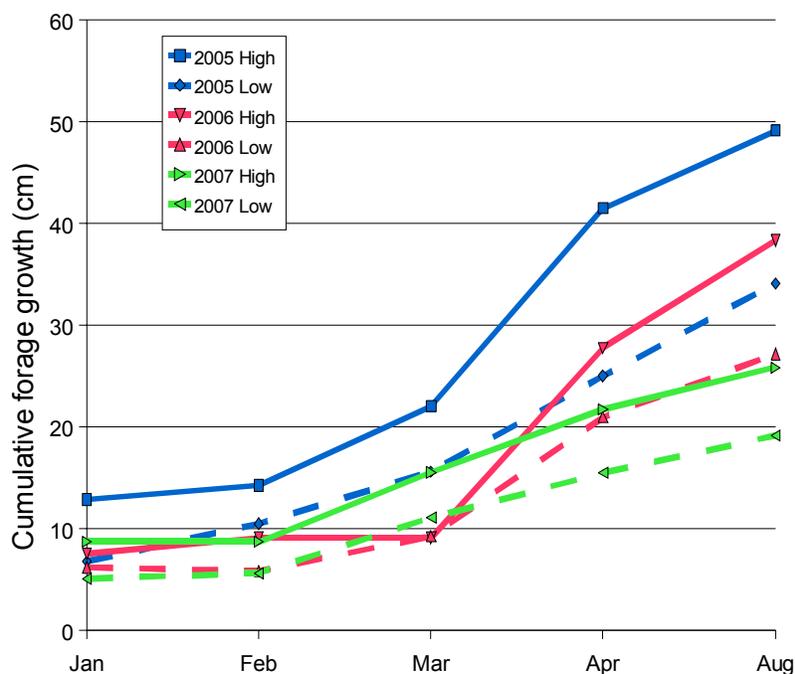
Figure 4. Cumulative height growth of vegetation in high (solid lines) and low (dashed lines) nongrazed mowed plots in 2005 (blue lines) and 2006 (red lines) and 2007 (green lines). Cumulative height growth was calculated by summing the growth increments for each interval.

Table 2. Rainfall measured at CIMIS station 122 (Hastings Tract, located about 2.4 km northeast of the study area) July 1 through June 30 of years shown.

Rainfall year	Rainfall total (cm)
2003-2004	37.5
2004-2005	54.2
2005-2006	56.6
2006-2007	23.4
average 1995-2007	51
average 1950-2007[1]	57.9

[1] Data for Fairfield, CA, from Western Regional Climate Center data (http://www.wrcc.dri.edu)

Although rainfall totals in the 2004-2005 and 2005-2006 seasons were similar (*table 2*), rainfall patterns in the two years were very different (*fig. 5*). Substantial amounts of early rainfall in October and November 2004 allowed annual grasses to germinate while temperatures were still warm. By January 2005, average vegetation height in the high plots was 12.8 cm. In 2006, the first rains of the season were delayed, so that winter annuals did not germinate until temperature and day length were near annual minimums. In addition, very heavy rain in late December 2006 and a cold winter led to prolonged soil saturation and low soil temperatures (*fig. 6*), which retarded early season growth of many annuals. Average vegetation height in the high plots was only 9.1 cm by the time of the mid-March evaluation in 2006 (*fig. 4*). Even though growth rates

Effects of weather on vegetation growth in nongrazed mowed plots 2005 – 2007

in late spring 2006 matched those seen in late spring 2005, the effect of the early season growth delay persisted to the end of the growing season.

Vegetation height in March 2007 was greater than that seen in March 2006. However, higher soil moisture levels persisted later in the season in 2006 than in 2007, due to the both early winter and later spring rains (*fig. 5*). As a result, plant senescence occurred later in 2006 than in 2007, and season-end vegetation heights were substantially greater in 2006 than in 2007.
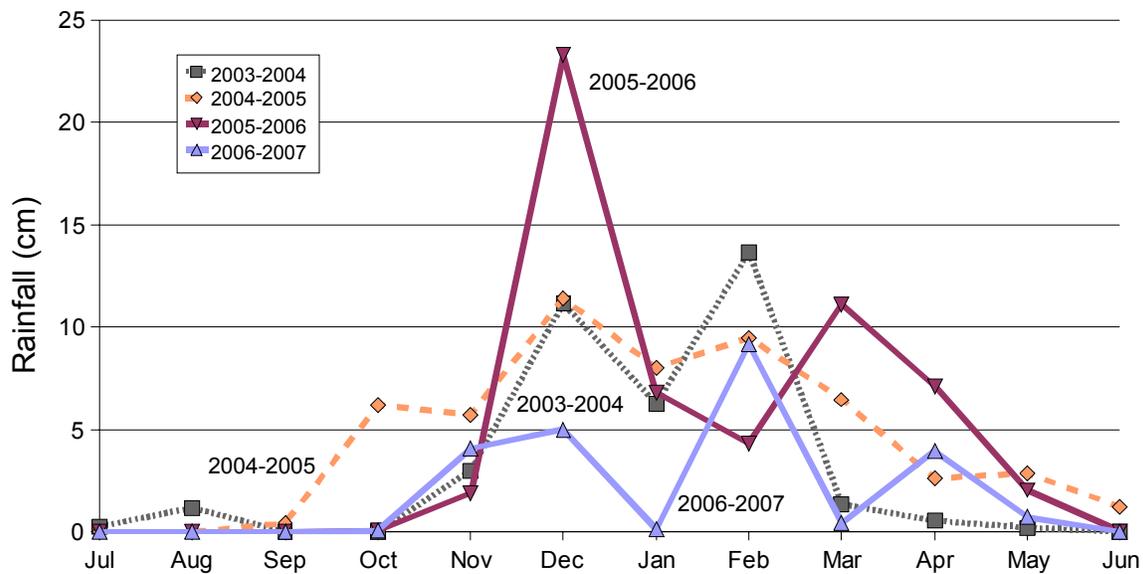
Figure 5. Rainfall measured at the CIMIS station 122 (Hastings Tract), located about 2.4 km northeast of the study area.

Effects of weather on vegetation growth in nongrazed mowed plots 2005 – 2007
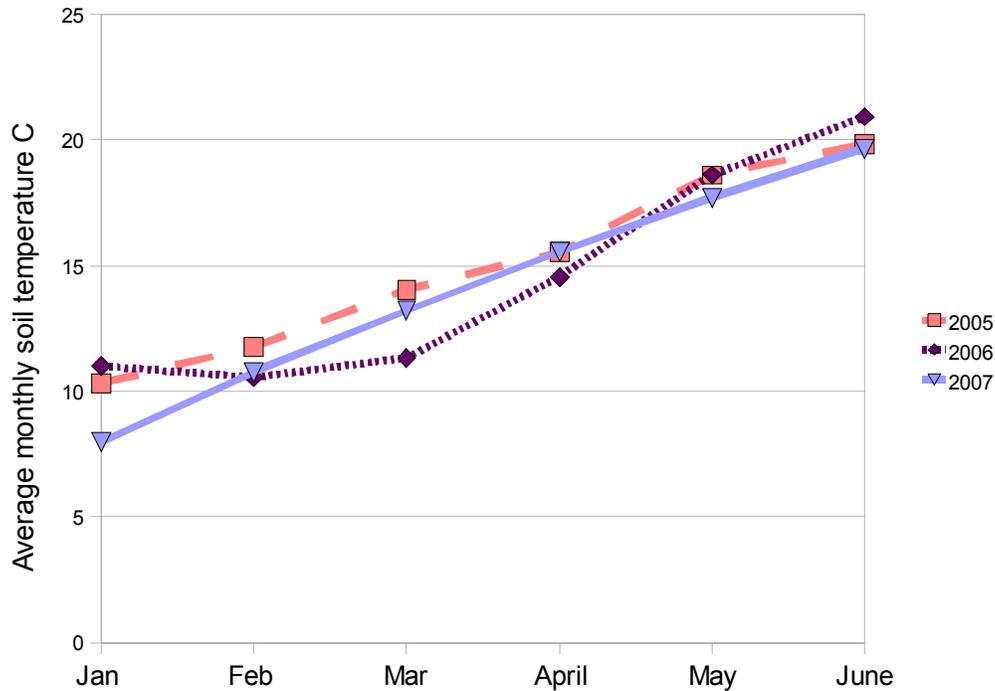
Figure 6. Average monthly soil temperature 15 cm below soil surface measured at CIMIS station 122 (Hastings Tract) for January through June in 2005 (dashed line), 2006 (dotted line), and 2007 (solid line).

When field was added as an explanatory variable to the repeated measures MANOVA for cumulative height growth, both the overall effect of field (p<0.0001), the field by time interaction (p<0.0001), and the field by position by time interaction (p=0.0395) were significant. The three fields showed different total height growth in high and low plots in the different years (*fig. 7*). However, all plots showed maximum height growth in 2005 and minimum height growth in 2007. Overall, field 20E showed less year to year variation in height growth than the other two fields.

Overall grazing regimes in fields
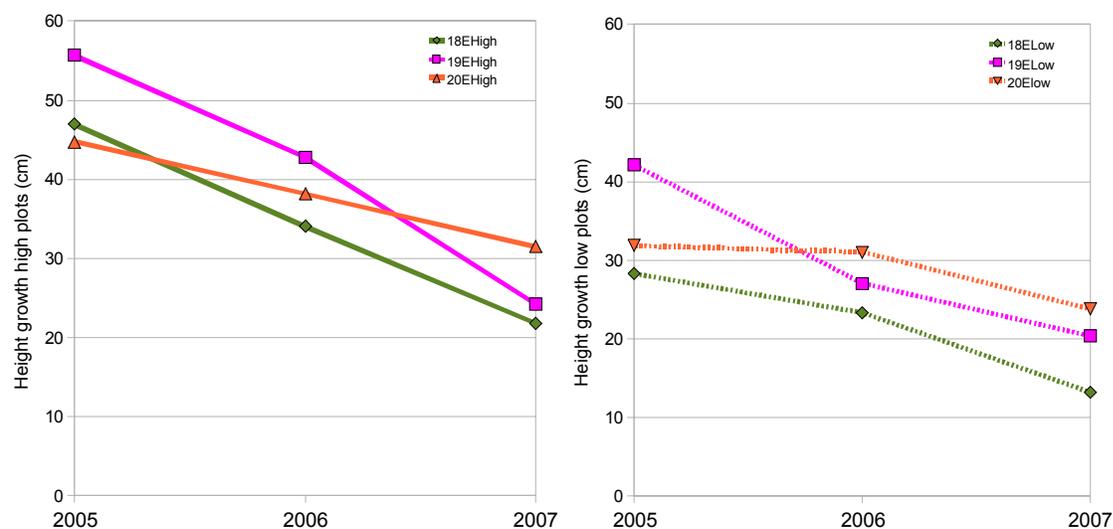
Figure 7. Cumulative height growth of vegetation in high (left) and low (right) nongrazed mowed plots in 2005-2007 in the three study fields. Cumulative height growth was calculated by summing the growth increments for each interval.

Overall grazing regimes in fields

The proposed grazing for 2007 was not implemented as planned. Flocks were not put on fields 18E and 19E for the late Feb/early March pulse, reportedly due to predation of lambs by coyotes. After consulting with the SLT project manager, the grazing plan was changed to duplicate the grazing that had occurred in the 2005 grazing season in these two fields. As shown in *figure 8* and *table 3*, the 2007 grazing regimes between January and April in fields 18E and 19E were similar to the regimes used in 2005, but were not identical. In addition, field 20E was grazed more heavily in March 2007 than it had been in March 2005 or 2006 (*tables 4, 5*). Furthermore, March grazing of 20E in 2005 and 2006 occurred early in the month, well before the start of the main spring bloom period. March 2007 grazing in field 20E extended beyond mid month (*fig. 10*) and overlapped the beginning of the peak spring bloom period. The 2007 peak bloom period was relatively early due to dry conditions.

Overall grazing regimes in fields

18E

19E

20E
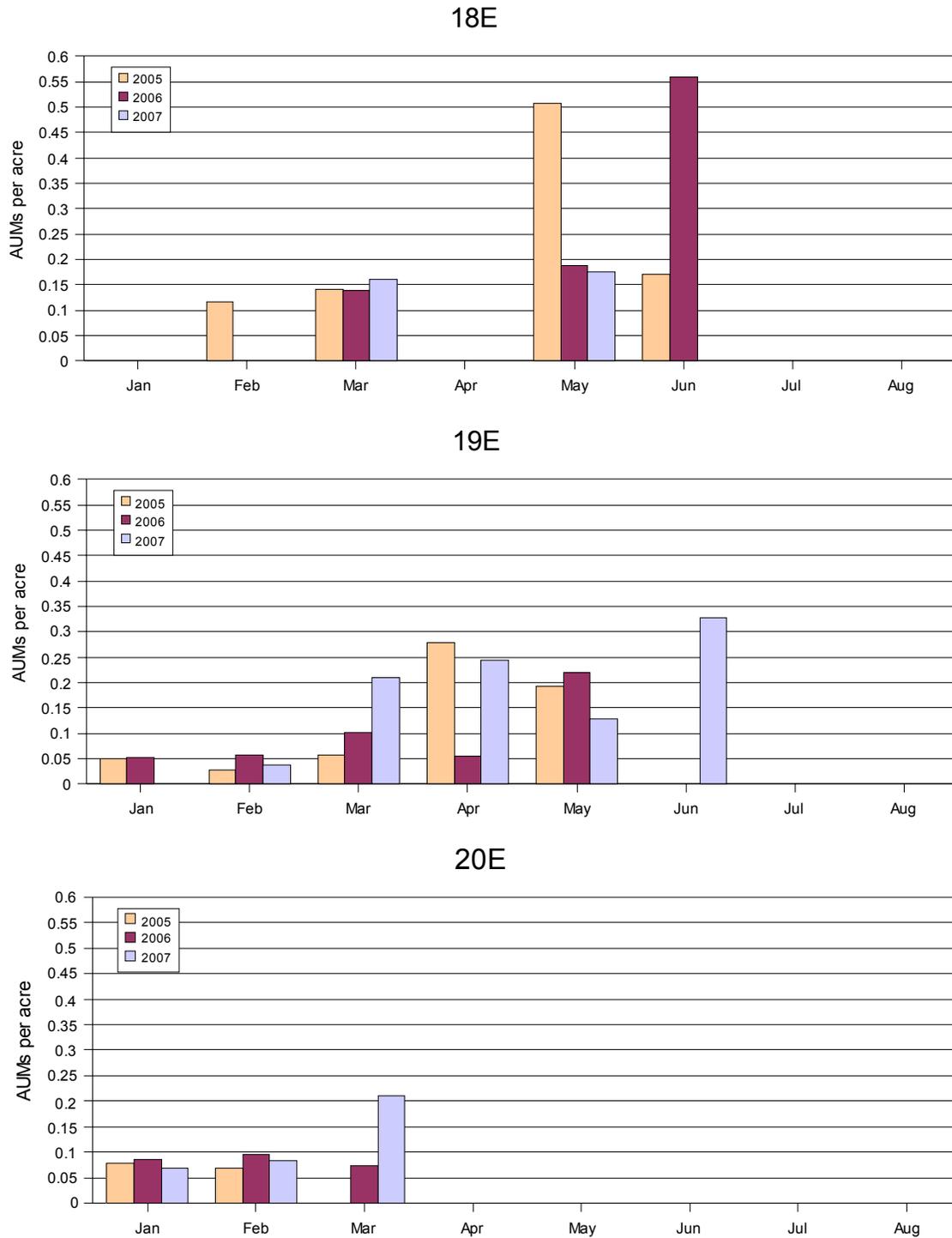
Figure 8. AUM per acre by month for 2005, 2006, and 2007 in the three study fields.

Overall grazing regimes in fields

Table 3. Total AUM and AUM per acre for grazing years ending in June of the year shown. Cross fencing built in summer 2004 reduced field sizes starting in 2005, so total AUM prior to 2005 cannot be used for comparative purposes.

	AUM			AUM per acre				
Field	**2005**	**2006**	**2007**	**2003**	**2004**	**2005**	**2006**	**2007**
18E	68	64	37	0.71	0.77	0.94	0.89	0.34
19E	106	86	167	0.40	0.27	0.6	0.49	0.95
20E	18	30	43	0.16	0.34	0.15	0.26	0.36

Table 4. AUM by month for experimental fields 2005-2007

Field	Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**
18 East	2005	—	8.40	10.27	—	36.59	12.34
	2006	—	—	10.08	—	13.6	40.33
	2007	—	—	17.70	—	19.29	—
19 East	2005	8.68	4.80	10.00	48.94	33.73	-
	2006	9.14	10.04	18.06	9.79	38.6	
	2007	—	6.80	36.78	43.09	9.14	59.74
20 East	2005	9.40	8.30	—	—	—	—
	2006	10.31	11.3	8.79	—	—	—
	2007	8.28	9.83	24.9	—	—	—

Table 5. Grazing periods in experimental fields 2005-2007.

Field	Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**
18 East	2005	—	2/21-2/28	3/1-3/6	—	5/14-5/29	6/8-6/18
	2006	—	—	3/13-3/17	—	5/24-5/31	6/1-6/2 6/6-6/19
	2007	—	—	3/10-3/20	—	5/1-5/6	—
19 East	2005	1/2-1/12	2/17-2/20	3/11-3/16	4/6-4/17 4/19-4/30	5/1-5/16	—
	2006	1/8-1/14	2/8-2/15	3/10-3/11 3/19-3/25	4/12-4/13 4/17-4/18 4/28-4/30	5/1-5/3 5/10-5/23	—
	2007	—	2/24-2/26	3/21-3/26 3/28-3/31	4/1-4/2 4/18-4/22	5/25-5/31	6/1-6/28
20 East	2005	1/13-1/24	2/11-2/16	—	—	—	—
	2006	1/15-1/22	2/20-2/28	3/1-3/6	—	—	—
	2007	1/21-1/25	2/5-2/10	3/10-3/20	—	—	—

Grazing profiles based on paired grazed and nongrazed plots

As shown in *figure 9,* similar stocking levels in terms of AUM can be associated with very different grazing patterns. In 2005, sheep grazed 19E at a stocking rate of about 2 head per acre for most of April. In 2007, a similar total AUM utilization was achieved for April (*fig. 8,* center), but grazing occurred in two short pulses with stocking rates of about 8 head per acre (*fig. 9).*

19E
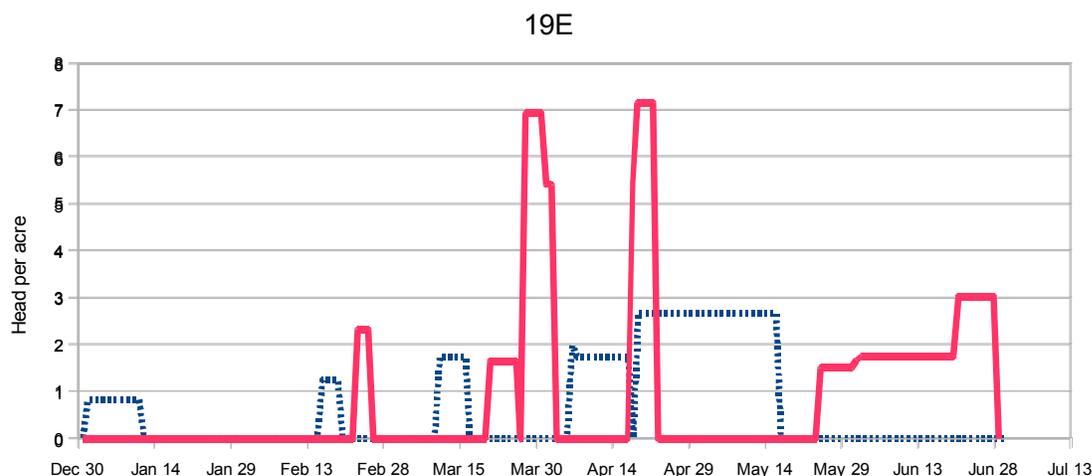
Figure 9. Grazing patterns for field 19E in 2005 (dashed line) and 2007 (solid line).

In reviewing the grazing records that listed the days that sheep were moved on and off fields, we noted that the records did not agree completely with observations we made while in the field during evaluations. For example, we observed sheep on 20E on 14 February 2007 and watched as they were moved to 19E from 20E on 15 February. However, the grazer's record for February 2007 indicates that sheep were on 20E from 5-10 February and on 19E from 24-26 February. Due to a lack of any other complete record of sheep stocking on the fields, the grazer's records are used to indicate grazing periods in *figures 8-12*, but the accuracy of these records has not been verified.

Grazing profiles based on paired grazed and nongrazed plots

In contrast to grazing records, our observations of vegetation growth in paired grazed and nongrazed plots provide a direct quantification of grazing impacts in each plot. We quantified grazing impacts for each grazed plot by comparing vegetation height in the grazed plot with that of the matched nearby nongrazed mowed plot in the same microtopographic position (high or low). We calculated grazing impacts based on monthly assessments for the months of January through April and a final season-end reading in August (*fig. 10*).

Grazing profiles based on paired grazed and nongrazed plots
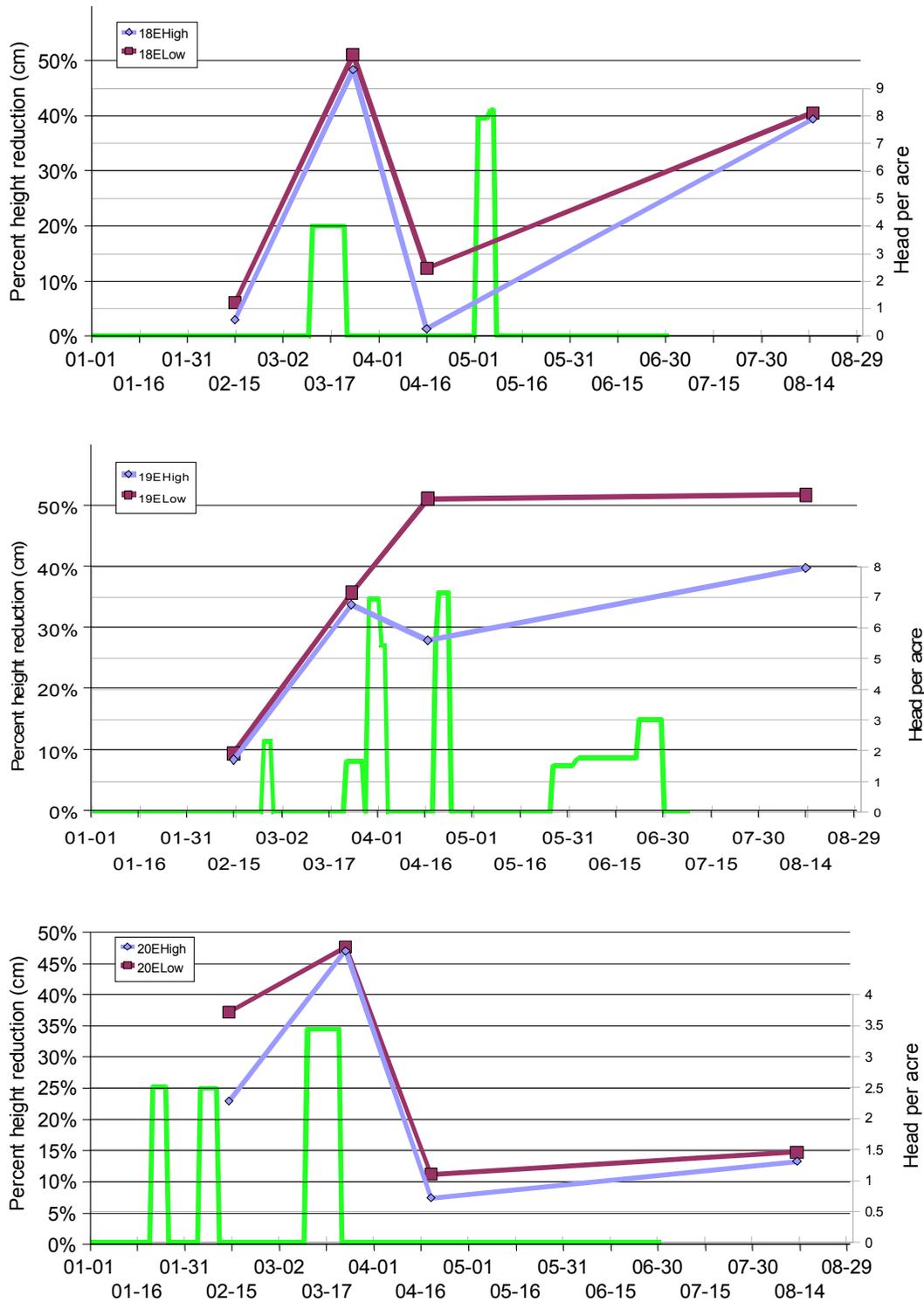
Figure 10. Grazing pattern and grazing impact, as percent height reduction in grazed plots compared to non-grazed mowed plots, for fields 18E, 19E, and 20E. Note differences in scale on the right hand y axis.

Grazing profiles based on paired grazed and nongrazed plots

The pattern of grazing impacts that a plot is subjected to over time is defined as the grazing profile for that plot. Grazing impacts measured in plots within fields were nonuniform, giving rise to multiple grazing profiles within fields (*fig. 11*). Variation in grazing intensity within a field arises from movements of the flock, the growth stage and composition of the vegetation at the time that sheep are present, presence of standing water in the field, and other factors.
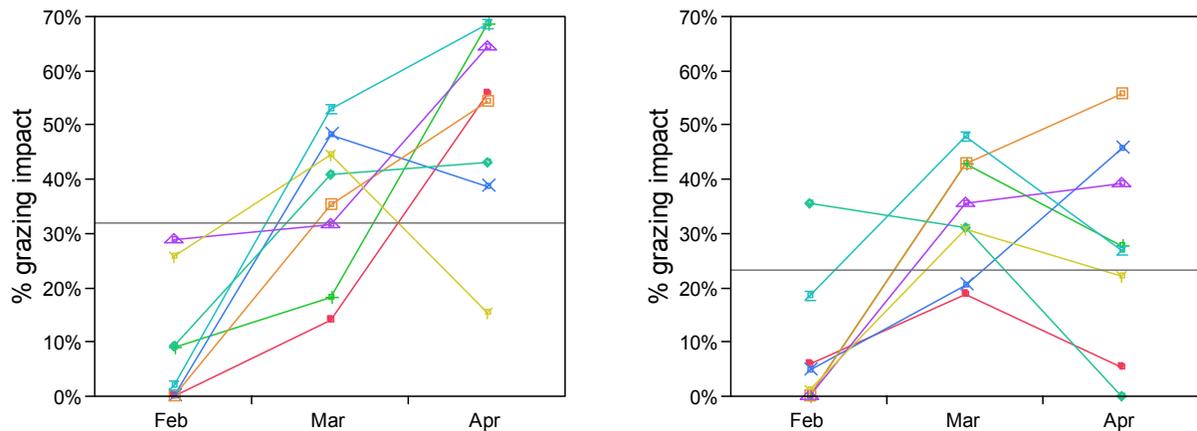
Figure 11. Grazing impact profiles for 2007 in field 19E of low (left) and high (right) plots. High and low plots within the same plot set have the same symbol /color combination.

Grazing profiles can differ both among plots within fields (which have a single overall grazing regime) and between plots from different fields (which have different grazing regimes). For purposes of data analysis, we grouped plots with similar grazing profiles so that grazing profiles could be tested as an explanatory variable for predicting vegetation outcomes. We used hierarchical clustering to group plots with similar seasonal grazing profiles irrespective of the field in which they were located. Because of the many differences that existed between high and low plots, clustering was performed separately on plots in these two different microtopographic positions. The same methodology was used in our previous analysis of 2005 and 2006 data (Swiecki and Bernhardt 2006, 2007).

Figure 12 shows the clustering dendrograms and grazing profile clusters developed from grazing impacts for January through April 2007. Grazing impacts after April were not used in the grazing profiles since the main cover variables of interest (plant cover and species richness) were measured in April and were therefore unaffected by grazing after April. We defined four grazing profiles for high plots and four for low plots based on clustering. Figure 13 shows the average grazing impact by month for these grazing profiles.

Grazing profiles based on paired grazed and nongrazed plots
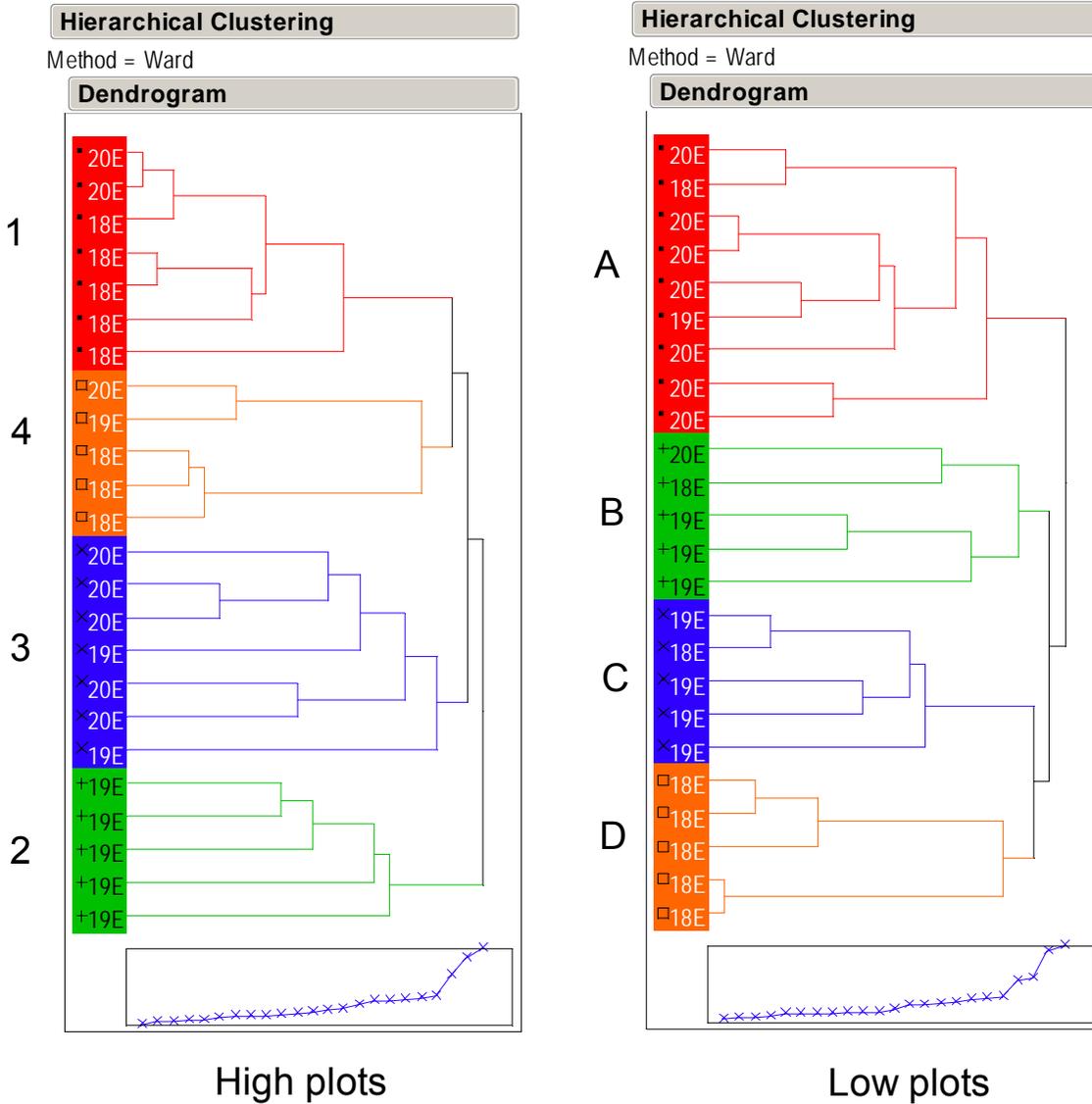
Figure 12. Hierarchical clustering diagrams of grazing impacts for high (left dendrogram) and low (right dendrogram) plots in 2007. Plots are identified by field numbers. Within high and low plots, hierarchical clusters are marked by colors.

Grazing profiles based on paired grazed and nongrazed plots
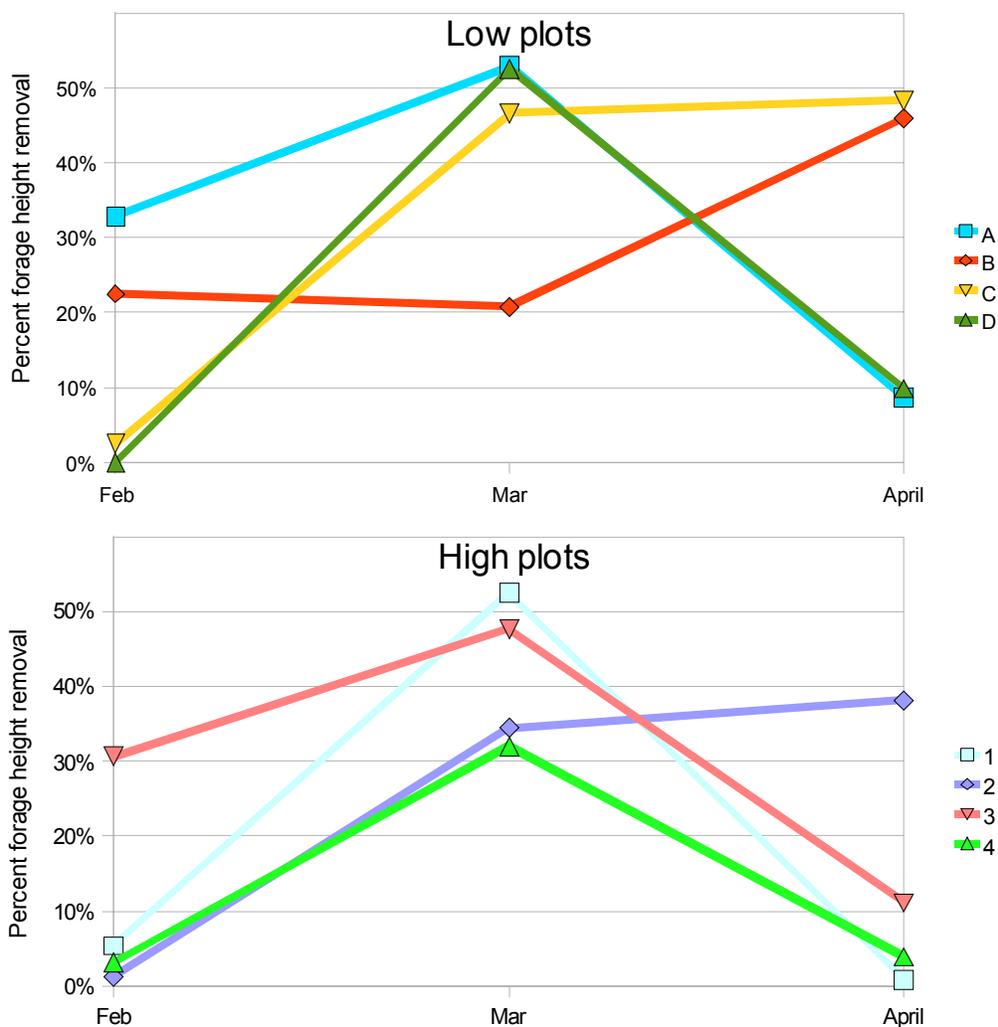
Figure 13. Average percent vegetation removed by month for hierarchical clusters of grazing profiles for 2007 for low and high plots.

Table 6 shows the correspondence between grazing profiles in high and low plots within plot sets. All of the high position grazing profiles were associated with multiple low profiles and vice versa. Grazing profiles in paired low and high plots were typically dissimilar (e.g., compare high plot profiles 1-4 with co-occurring low plot profile B in *figure 13*). Even when grazing profiles in high and low plots were similar, such as profiles A and 3 or D and 1 (*fig. 13*), these similar patterns only sometimes occurred within plot sets. Profiles A and 3 co-occur in 4 of 9 plot sets and D and 1 co-occur in 3 of 5 plot sets (*table 6*). The general lack of concurrence between grazing profiles in adjacent high and low plots developed from selective grazing by sheep at different periods over the growing season.

Grazing profiles based on paired grazed and nongrazed plots

Table 6. Co-occurrence within plot sets of low and high 2007 grazing profiles. Table cells show the number of plot sets in which each combination of high and low grazing profiles occurred. Each of the 24 plot sets has one grazed plot in the high and one in the low topographic position.

High grazing profile	Low grazing profile				Total plot sets
	A	B	C	D	
1	2	1	1	3	7
2	1	2	2	0	5
3	4	1	2	0	7
4	2	1	0	2	5
Total plot sets	9	5	5	5	24

We also constructed grazing profiles for the January-April period using impacts from each of the three years of the study. We defined 10 grazing profiles for the high plots and 11 grazing profiles for the low plots. All but three of the 21 hierarchical clusters developed from the multiple-year data (multiple year grazing profile clusters) were represented in more than one year, and nine were represented in all three years of the study (*table 7*).

Table 7. Hierarchical clusters of grazing profiles for high (left) and low (right) plots developed from grazing profiles from all three years of the study. Table cells show the number of plots within each hierarchical cluster in each year.

High plot cluster	2005	2006	2007	Total	Low plot cluster	2005	2006	2007	Total
M1	5	0	0	5	MA	5	2	0	7
M2	5	5	5	15	MB	2	1	9	12
M3	0	4	4	8	MC	7	2	1	10
M4	3	1	4	8	MD	4	6	1	11
M5	2	1	0	3	ME	0	3	0	3
M6	1	4	2	7	MF	0	0	2	2
M7	1	6	0	7	MG	2	1	5	8
M8	0	1	1	2	MH	0	1	0	1
M9	6	1	1	8	MI	0	6	1	7
M10	1	1	7	9	MJ	0	0	5	5
					MK	4	2	0	6

One shortcoming of clustering is that unless a relatively large number of clusters containing single plots are defined, some of the clusters may still be moderately variable. Figure 14 shows two of the 10 grazing profile clusters developed from data from all three years. Although both clusters include some variation with respect to the grazing impact at each time period, the cluster at right (M3) also includes substantial variation with respect to the relative magnitude of grazing in the different intervals. For example, although most plots in cluster M3 had progressively greater grazing impacts in each of the three successive time intervals, some plots had lower grazing impacts in March-April than in February-March. Each hierarchical cluster can be made more uniform by reducing its size, but as the number of plots represented in each cluster get smaller, the cluster becomes less useful as an explanatory variable.

Grazed plots: Impacts of grazing on vegetation height and biomass
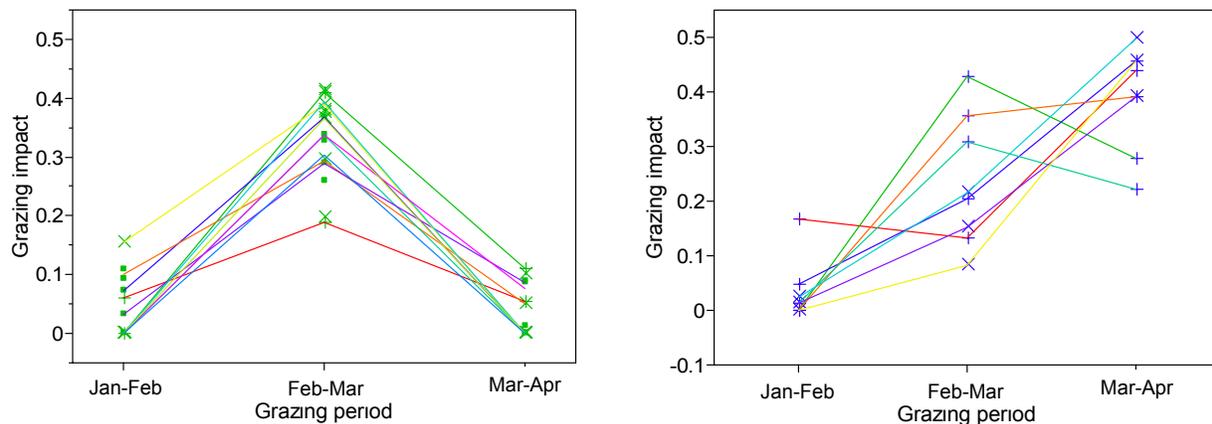
Figure 14. Grazing profiles of high plots grouped into clusters M2 (left) and M3 (right). Clusters were based on data from all three years of the study. The overall pattern of grazing impacts in M2 is more uniform than that in M3. Different symbols represent plots from different fields.

Grazed plots: Impacts of grazing on vegetation height and biomass

Differential grazing impacts in paired high and low plots

In all three years of the study, relative grazing impacts were generally greater in the low plots than in the high plots when grazing occurred in April (*fig. 10*, Swiecki and Bernhardt 2006, 2007). High plots were dominated by non-preferred grasses (e.g., medusahead, ripgut brome) which are typically flowering or setting seed and beginning to dry out by April, further reducing their palatability.

In contrast, relative grazing impacts were greater in high plots than in low plots when grazing occurred during periods when the low position plots were flooded in 2005 and 2006, (Swiecki and Bernhardt 2006, 2007). However, low plots were not inundated in 2007 for any substantial period. None of the low plots contained water at any of the sampling dates, even dates within a few days of rain events (*fig. 15*). Without flooding to deter sheep from grazing in the low plots, 2007 grazing impacts in the high plots never exceeded those seen in the low plots (*fig. 10, 15*). Furthermore, field 20E, which was grazed in January-February 2007, showed greater grazing impacts in the low plots than in the high plots (*fig. 10*). This was a reversal of the pattern seen in plots grazed during this period in 2005. High plots had greater amounts of residual dry matter present in January and February 2007 than did low plots (*fig. 16*). This residue appeared to be largely avoided by the sheep and may have contributed to the preferential grazing of the low plots during this period.

Grazed plots: Impacts of grazing on vegetation height and biomass
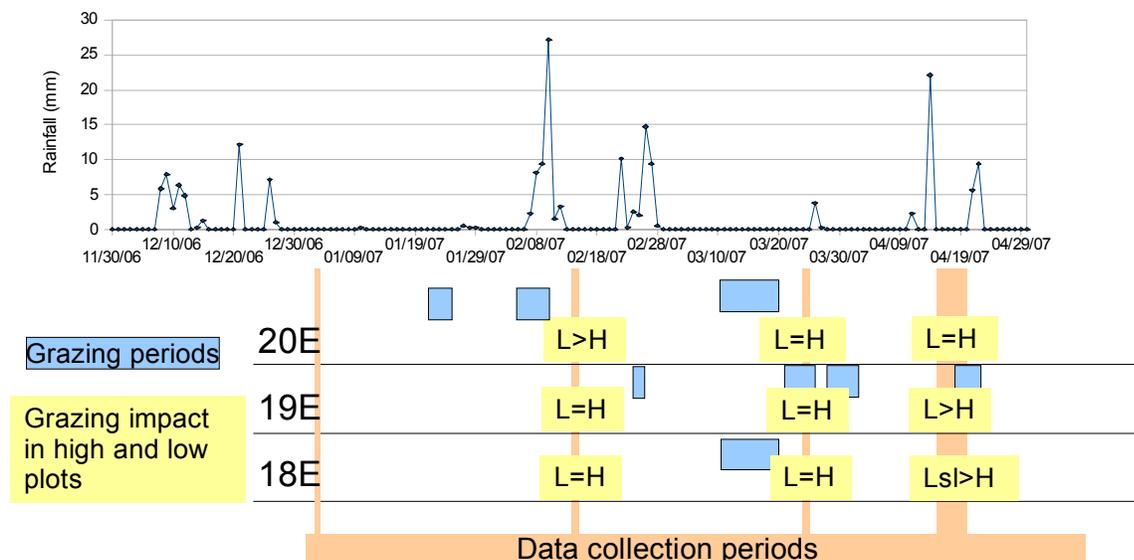
Figure 15. Temporal relationships between rainfall (top graph), grazing periods, and relative grazing impacts in high (H) and low (L) plots in fields 20E, 19E, and 18E (lower diagram) in 2007. Rainfall data are from CIMIS station 122 (Hastings Tract) located about 2.4 km northeast of the study area. None of the plots contained water at any of the evaluation dates. Blue bars indicate periods when sheep were present in the fields. Time intervals during which data were collected are shown by orange bars extending from the x-axis of the rainfall graph (note: blue grazing period bars are always superimposed over the orange bars). Overall grazing impact trends for the evaluation intervals are coded as follows: L=H similar level of impact in paired high and low plots; L>H greater impact in low plots than paired high plots; Lsl>H slightly greater impact in low than high plots.

Grazed plots: Impacts of grazing on vegetation height and biomass

High grazed plot   Low grazed plot
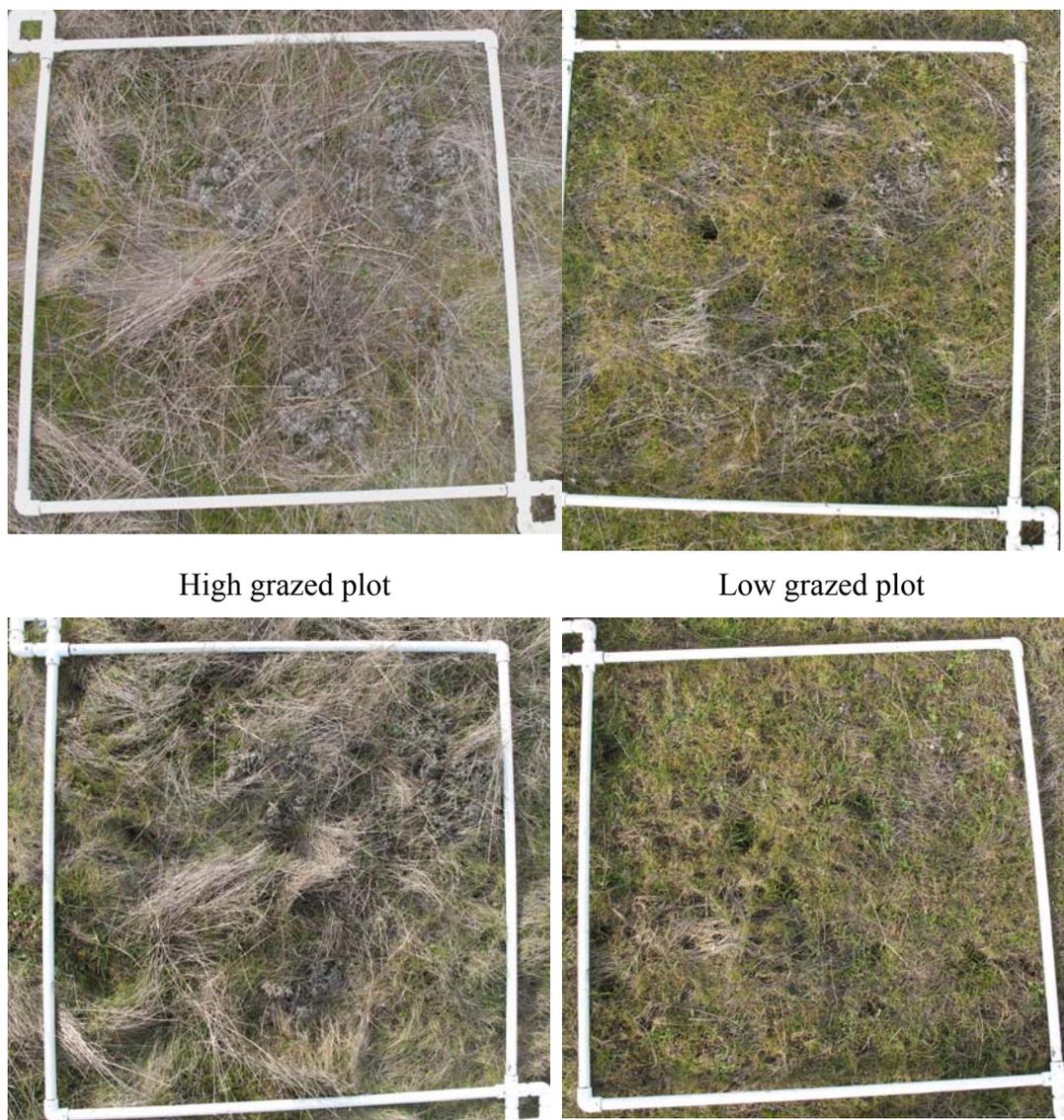
Figure 16. High (left) and low (right) grazed plots from plot set 9 in field 20E before grazing on 2 January 2007 (top row) and after grazing on 14 February 2007 (bottom row). Note that sheep generally avoided the old plant residues in both high and low plots (compare top and bottom photos). Low plots, which had low amounts of residual material were grazed preferentially during this period.

April vegetation height and biomass

2007 growing season

For the 2007 growing season, grazing profile groups (based on January-April grazing) developed through hierarchical clustering using either 2007 data only or data from all three years (multiple year data; cluster name begins with M) were not significant predictors of either April plot vegetation height or falling plate height. Grazing impacts from individual months also showed no significant relationship to April vegetation height or falling plate height. However, the sum of January-April grazing impact was negatively associated with April 2007 grass height in both

Grazed plots: Impacts of grazing on vegetation height and biomass

high (p<0.0001) and low (p=0.0020) plots and with April 2007 drop height for high plots only (p=0.0016). These results suggest that for the dry 2007 season, plant biomass was reduced as the total amount of grazing from January through April increased, with no clear differential effects related to the timing of grazing impacts during this period.

2005 through 2007

In contrast, variables related to the timing of grazing were significant in analyses that include data from all three years of the study for both high and low plots. Both January-April grazing impact and the multiple year grazing profile clusters (*table 7*) were predictors of April vegetation height (*table 8*) and falling plate height (*table 9*) for high plots. Overall model fit, based on AIC$_c$, was best for the model that included both grazing variables. As expected, plant height and biomass decreased as the total amount of January-April grazing impact increased. The significance of the grazing profile clusters in the model indicates that vegetation height and biomass in the high plots were also affected by the timing of grazing impacts. Most of the effect of the grazing profile clusters was associated with cluster M1, which includes plots grazed heavily in the January-February interval but not grazed in other months. Plots in cluster M1 had more biomass than other plots that were grazed between February and April.

For low plots, January-April grazing impact and multiple year grazing profile clusters were predictors of April vegetation height and falling plate height (*tables 8, 9*). Models using grazing profile clusters had better fit than those using January-April grazing impact. When both variables were used in the same models, only January-April grazing impact was significant (*table 9*). This is in part due to the confounding of these two variables for the low plots. The grazing profiles with the highest falling plate heights (MA, MD, MK) also had lower than average January-April grazing impact, while grazing profiles with the lowest falling plate heights (MC, ME) had higher than average January-April grazing impact. Due to this confounding, it is not possible to completely separate the effects of total grazing impact and the timing of grazing impacts in these plots.

In all models based on the multiple-year data for both high and low plots, the effect of year was also highly significant (*tables 8, 9*). Vegetation height and biomass were highest in 2005 and lowest in 2007 in grazed plots, as was seen in the mowed nongrazed plots (*fig. 3*). Other variables related to plot-specific factors were also significant in some models. Vegetation height in the preceding August, or alternatively, the preceding August RDM, were significant predictors in the model for falling plate height in the high plots. The significance of preceding August RDM can be explained by the fact that the falling plate measurement can be affected by both current season biomass and any residual biomass from previous seasons. As the amount of RDM in August increases, the amount of residue carried over to the next season increases, leading to higher falling plate readings.

Grazed plots: Impacts of grazing on vegetation height and biomass

Table 8. Summary of random effects repeated measures models for April vegetation height in 2005, 2006, and 2007 for plots in high and low positions using one or both of two grazing variables (n=72 for each model). Dash (—) indicates term not included in model. Plot was included as a random effect in all models.

	High plots			Low plots		
Predictor	**p level**			**p level**		
Year	<0.0001	0.0025	<0.0001	<0.0001	<0.0001	<0.0011
Jan-Apr grazing impact	<0.0001	—	0.0005	<0.0001	—	0.0023
Multiple year grazing profile cluster	—	<0.0001	0.0029	—	<0.0001	0.2244
Overall model R^2	0.906	0.925	0.944	0.900	0.865	0.900
AIC_c	417.19	406.93	391.49	368.73	369.57	358.13

Table 9. Summary of random effects repeated measures models for April falling plate height in 2005, 2006 and 2007 for plots in high and low positions using one or both of two grazing variables (n=72 for each model). Dash (—) indicates term not included in model. Plot was included as a random effect in all models.

	High plots			Low plots		
Predictor	**p level**			**p level**		
Year	<0.0001	<0.0001	<0.0001	<0.0001	0.0085	<0.0001
Jan-Apr grazing impact	<0.0001	—	0.0007	<0.0001	—	0.0191
Multiple year grazing profile cluster	—	<0.0001	<0.0001	—	<0.0001	0.2197
Overall model R^2	0.819	0.909	0.917	0.750	0.779	0.771
AIC_c	208.98	212.36	201.24	228.02	241.31	236.18

August residual dry matter

High vs. low plots

High grazed plots have consistently had significantly greater August RDM than low grazed plots, starting with the baseline data collected in 2004 and continuing through 2007 (p<0.0001 in repeated measures and individual year ANOVA models). For 2005-2007, August RDM in the high plots (mean 2360 lb/acre, sd=976) was more than double that of the low plots (mean 1095 lb/acre, sd=548).

Since the grazing profile clusters discussed above only consider grazing from January through April, we used an additional variable in the analyses to account for grazing impacts for the period from late April (after spring plot evaluation) through August. By using two variables rather than a single season-long grazing impact score, we were able to examine the relative effects of early season grazing (January-April) and late season grazing (April-August) on RDM levels.

Grazed plots: Impacts of grazing on vegetation height and biomass

2007 growing season

In 2007, August RDM in high plots was significantly related to both January-April grazing impact (p=0.0420) and April-August grazing impact (p<0.0001). For high plots, grazing profile clusters (either based on 2007 data only or the multiyear data) were not significant predictors of August 2007 RDM. These results suggest that August RDM in the high plots was more strongly influenced by April-August grazing impact than by early season grazing.

In low plots, only April-August grazing impact was significant (p=0.0029) when included in a two-variable model with January-April grazing impact. Both April-August grazing impact (p=0.0181) and 2007 grazing profile cluster (p=0.0282) were significant predictors of August 2007 RDM in a model for August 2007 RDM in low plots. The grazing profile clusters with the highest (A) and lowest (D) August RDM were grazed similarly between January and April (*fig. 13*) but plots in profile D had greater April-August grazing impact. Hence, it appears that the significance of grazing profile cluster may be related to collinearity between it and April-August grazing impact. Overall, these results suggest that in 2007, April-August grazing impact exerted the strongest influence on season-end RDM in low plots as well.

2005 through 2007

To look at broader trends, we used a repeated measures model to examine the effects of grazing profiles on August RDM in all three years of the study (*table 10*). For both high and low plots, year, April-August grazing impact, and the plot RDM from the previous year were highly significant predictors of current year RDM. Neither January-April grazing impact nor the multiyear grazing profile clusters were significant predictors for either high or low plots. A significant interaction between year and preceding August RDM was seen in the low plots only. This interaction is significant because the correlation between preceding August RDM and current year RDM in the low plots was much weaker in 2005 than in 2006 or 2007. Overall, these models indicate that: (1) RDM levels in August were reduced as the amount of late season (May-June) grazing increased, and (2) RDM levels in low plots tend to be similar in successive years.

Table 10. Summary of random effects repeated measures models for August RDM in 2005, 2006 and 2007 for plots in high and low positions (n=72 for each model).

	Prob > F	
Predictor	**High plots**	**Low plots**
year	<.0001	0.0001
Apr-Aug grazing impact	<.0001	0.0012
preceding Aug RDM	0.0004	<.0001
year $\times$ Apr-Aug grazing impact	0.3463	0.2380
year $\times$ preceding Aug RDM	0.1448	<.0001

Grazed plots: Impacts of grazing on vegetation height and biomass

August mulch

High vs. low plots

High grazed plots consistently had significantly greater mulch heights (i.e., the depth of residual dry matter from the previously growing season) than low grazed plots, starting with the baseline data collected in 2004 and continuing through 2007 ($p<0.0001$ in repeated measures and individual year ANOVA models). For 2005-2007, average August mulch height in the high plots (mean 0.76 cm, sd=0.63) was about eight times that of the low plots (0.09 cm, sd=0.12 cm).

2007 growing season

For 2007, mulch height measured in August was not significantly correlated with January-April grazing impact, April-August grazing impact or grazing profile clusters (either 2007 or multiyear). However, previous August RDM (2006) was a significant predictor of mulch height in both high ($p<0.0001$) and low ($p=0.0202$) plots. Mulch height from August 2006 was also a significant predictor of August 2007 mulch height for high plots only.

2005 through 2007

In contrast to the analysis of 2007 data only, models including data from all three years of the study showed that grazing variables had a significant influence on mulch height (*table 11*). Mulch heights were significantly reduced in plots that had higher April-August grazing impact in both high and low plots (*table 11*). Multiyear grazing cluster was also a significant predictor of mulch heights in high plots, mainly due to high mulch heights in cluster M1, which consists of plots grazed only in the January-February interval. This same cluster was associated with high April biomass readings, as noted above.

In high plots, the August RDM from the previous year was also positively correlated with mulch height in multivariate models (*table 11*), but not in single variable models. For low plots, which had much lower RDM levels, preceding August RDM was not a significant predictor of mulch height. However, mulch height in the previous year was positively correlated with current year mulch height in low plots. In general, residue counted as mulch does not persist for more than a year, especially in low grazed plots. Hence, the year to year correlation between mulch heights in the low plots is likely to indicate that vegetation from the previous season tends to persist better in certain low plots, due to the species present, flooding regimes, or other factors. The amount of mulch present in most grazed low plots was small; the highest average mulch depth in a plot was 0.44 cm.

Table 11. Summary of random effects repeated measures models for August mulch height in 2005, 2006 and 2007 for plots in high and low positions (n=72 for each model).

	Prob > F	
Predictor	**High plots**	**Low plots**
year	<.0001	0.0331
multiyear grazing impact cluster	0.0002	--[1]
Apr-Aug grazing impact	0.0158	0.0414
preceding Aug RDM	0.0001	--[1]
preceding Aug mulch height	--[1]	0.0026

[1]Nonsignificant effect not included in final model.

Grazed and nongrazed plots: relationships between plant cover variables

In order to understand how grazing may have influenced the balance between native and exotic plant cover in plots, various underlying relationships between these vegetation outcome variables need to be taken into account. This section discusses the basic relationships between plant cover variables in both grazed and nongrazed multiyear control plots.

Native and exotic cover

In both nongrazed control and grazed low plots, exotic cover and native cover measured in April have a strong inverse relationship (*fig. 17*). Variation due to mulch or bare soil cover did not seriously reduce the strength of the correlation between native and exotic cover because of the wide ranges of values represented for the plant cover variables and because mulch and bare soil were usually present at low values. Because of the strong correlation between native and exotic cover, these two factors were essentially interchangeable in regression models.
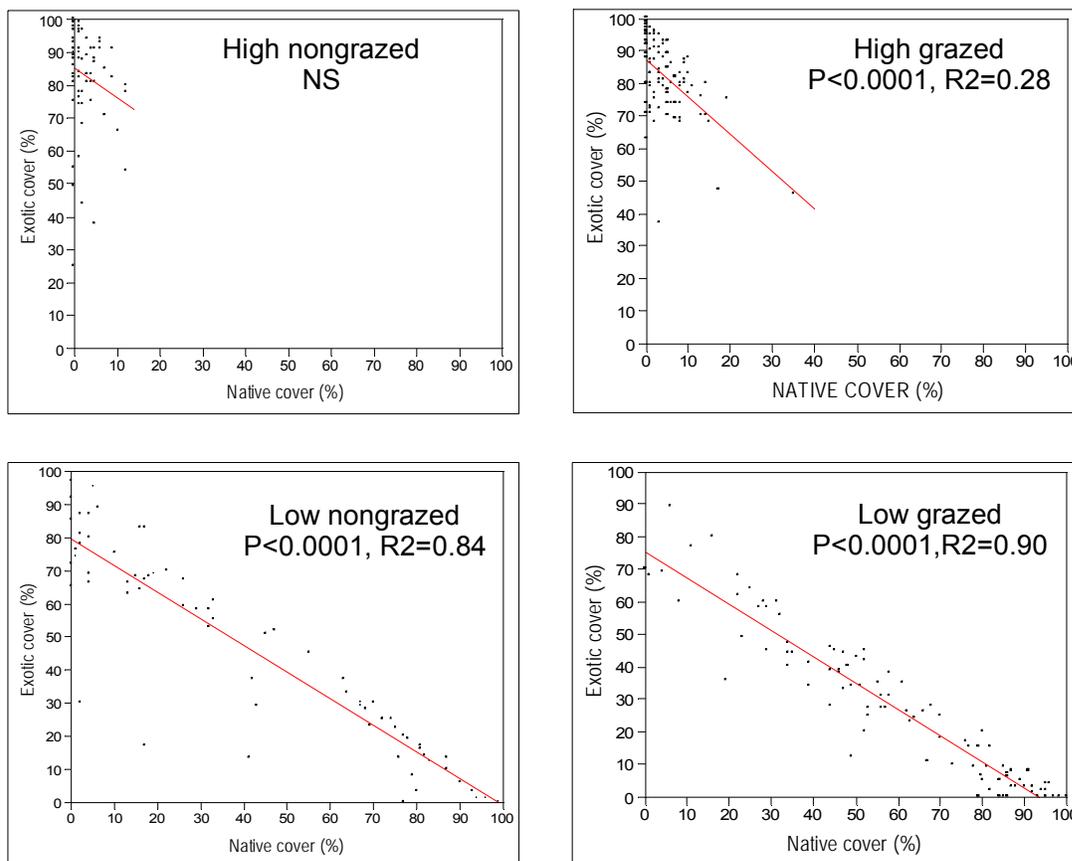
Figure 17. Relationship between native and exotic cover in low position and high position grazed and nongrazed multiyear control plots. Graphs show data collected in April 2004, 2005, 2006, and 2007 for grazed plots, 96 data points per graph; and in April 2005, 2006, and 2007 for nongrazed plots, 72 data points per graph. The nongrazed treatment began in November 2004.

Grazed and nongrazed plots: relationships between plant cover variables

In contrast, native cover levels were consistently low in high plots; only a single high plot (in 2006) exceeded 20% native cover. Because native cover and non-vegetative cover (mulch+bare) in high plots are commonly similar in magnitude, reductions in exotic cover were not as consistently related to increases in native cover as was seen in low plots (*fig. 17*).

Total native cover in all low plots was positively correlated in consecutive years, as was the total exotic cover. For nongrazed low plots, correlations between all consecutive year combinations were significant. For grazed low plots, native cover was significantly correlated between 2004-2005 and 2005-2006, but not for 2006-2007. These correlations indicate that even with year to year oscillations in native cover, total native cover in low plots tends to be conserved from year to year. For high plots, which had low levels of native cover overall, native cover in consecutive years was not significantly correlated.

Correlations between cover change variables

For both grazed and nongrazed low plots, changes in native cover in successive years were negatively correlated (*table 12*). If native cover in a low plot increased strongly in one year, it tended to decrease in the following year, and vice versa. In the nongrazed plots, this fluctuating trend was strong enough to result in a significant positive correlation in the change in native cover in the first and third year of the study (*table 12*). These correlations are largely related to the nature of the change in cover variable, which is calculated as (% cover in year n+1) – (% cover in year n). If plot cover is 0% in year n, the range of possible change in cover values is 0% to +100% for the following year; at a cover value of 100%; the possible range of the change variable is 0% to -100%. The constraint on the possible values of the change variable posed by the previous year's cover results in a negative correlation between two successive years.

Using simulated random cover data, we found that the strength of the correlation in cover change between successive years depends somewhat on the shape of the cover distribution (e.g., normal, skewed β (5,1), uniform). However, for all of these theoretical cover distributions as well as the actual plot native cover data (which is right-skewed for low plots and left-skewed for high plots) the differences between successive years are approximately normally distributed. On average, differences of randomly-generated cover values arranged in a series show negative correlations with R values of between -0.4 and -0.5. However, some subsamples (n=24) from these distributions sometimes had R values as high as those observed in the study data.

Table 12. Pairwise correlation coefficients between the year to year change in native cover for the three years of the study in low grazed and nongrazed multiyear control plots (n=24 for each regression).

Change interval	plot type	Change interval	
		2005-06	2006-07
2004-05	grazed	-0.6998*	0.2643
	nongrazed	-0.8026*	0.5363*
2005-06	grazed		-0.5398*
	nongrazed		-0.7501*

* correlation significant at p≤0.01

The same mathematical relationships give rise to a negative correlation between native plant cover in year n and the change in native plant cover from year n to year n+1. This correlation was observed in both grazed and nongrazed low and high plots. Plots with very low native cover in a given year can either stay the same or increase in the following year whereas plots with very high native cover can only stay the same or decrease in the following year. Thus, as long as some plots at either end of the scale show a change from one year to the next, a negative correlation develops.

Grazed plots: Changes in plant cover related to grazing impacts

High and low plots – magnitude of changes in plant cover over time

Year to year changes in the cover of native species in grazed plots were smaller in high plots than in low plots. With the exception of one outlying high plot, the year to year change in native cover in high plots ranged from –16% to +17%. In contrast, the year to year change in native cover in low plots ranged from –86% to +63%. Across all three years of the study, the average of the absolute value of the year to year changes in native cover in high plots was 4.5%; for low plots, the average annual change was 22.5%. In each of the three study years, the variance in the native cover change was also significantly greater in low plots than in high plots (p≤0.01, O'Brien test for homogeneity of variances).

By the end of the study, only 5 of 24 high plots had a significant net change in native cover (based on Wilson/Newcombe test) between April 2004 and April 2007 (four increased, one decreased). In comparison, native cover had changed significantly in 21 of 24 low plots between April 2004 and April 2007 (19 plots decreased, two plots increased).

High plots – changes in cover

As noted above, several grazing variables were related to the height and biomass of vegetation in the high grazed plots. However, none of these grazing variables were significantly correlated with year to year changes in the composition of vegetation in high position plots (*fig. 18*). Exotic grasses were the predominant cover in the high grazed plots in the baseline year 2004 and remained so through the three years of the study, irrespective of the variation in grazing intensity and associated biomass removal (*fig. 19*).

Low plots – changes in cover

2007 growing season

Dry conditions in 2007 and the resulting lack of inundation of pools and swales led to decreased native cover in most low plots in 2007. From 2006 to 2007, 16 low plots showed significant decreases in native cover; native cover was unchanged in six plots and increased significantly in two plots. A repeated measures model for native cover change from 2006 to 2007 (model R^2=0.79, p<0.0001) showed significant effects of 2006 native cover (p<0.0001) and 2006 August vegetation height (p<0.0001) but grazing variables were not significant.

Both predictors in the model were negatively correlated with change in native cover. As expected from the relationship described above (*table 12*), plots with the highest native cover in 2006 experienced the greatest loss of cover in 2007. Plots with greater vegetation heights in

Grazed plots: Changes in plant cover related to grazing impacts

August 2006 also experienced the greatest loss in native cover between 2006 and 2007. August vegetation height in 2006 was not correlated with exotic grass cover in April 2006 but was correlated with *Pleuropogon californicus* cover measured in April 2006 (R^2=0.255, model=0.0117). It appears that the effect of August 2006 vegetation height in the model is related to the fact that many stands that had high native cover in 2006 were dominated by relatively pure stands of tall *P. californicus* (cover photo). *P. californicus* was greatly reduced in 2007 due to lack of flooding. Hence, the August 2006 vegetation height variable does not appear to be related to grazing effects, which is consistent with the fact that other grazing impact variables were not significant in the model.

2005 through 2007

As expected from the relationship discussed above (*table 12*), native cover from the preceding April (arcsine transformed) was negatively correlated with the change in native cover in repeated measures models using data from all three years. Due to the strong inverse relationship between native and exotic cover, exotic grass cover from the preceding April could be substituted for preceding April native cover in the models with very little change in model fit.

Grazed plots: Changes in plant cover related to grazing impacts
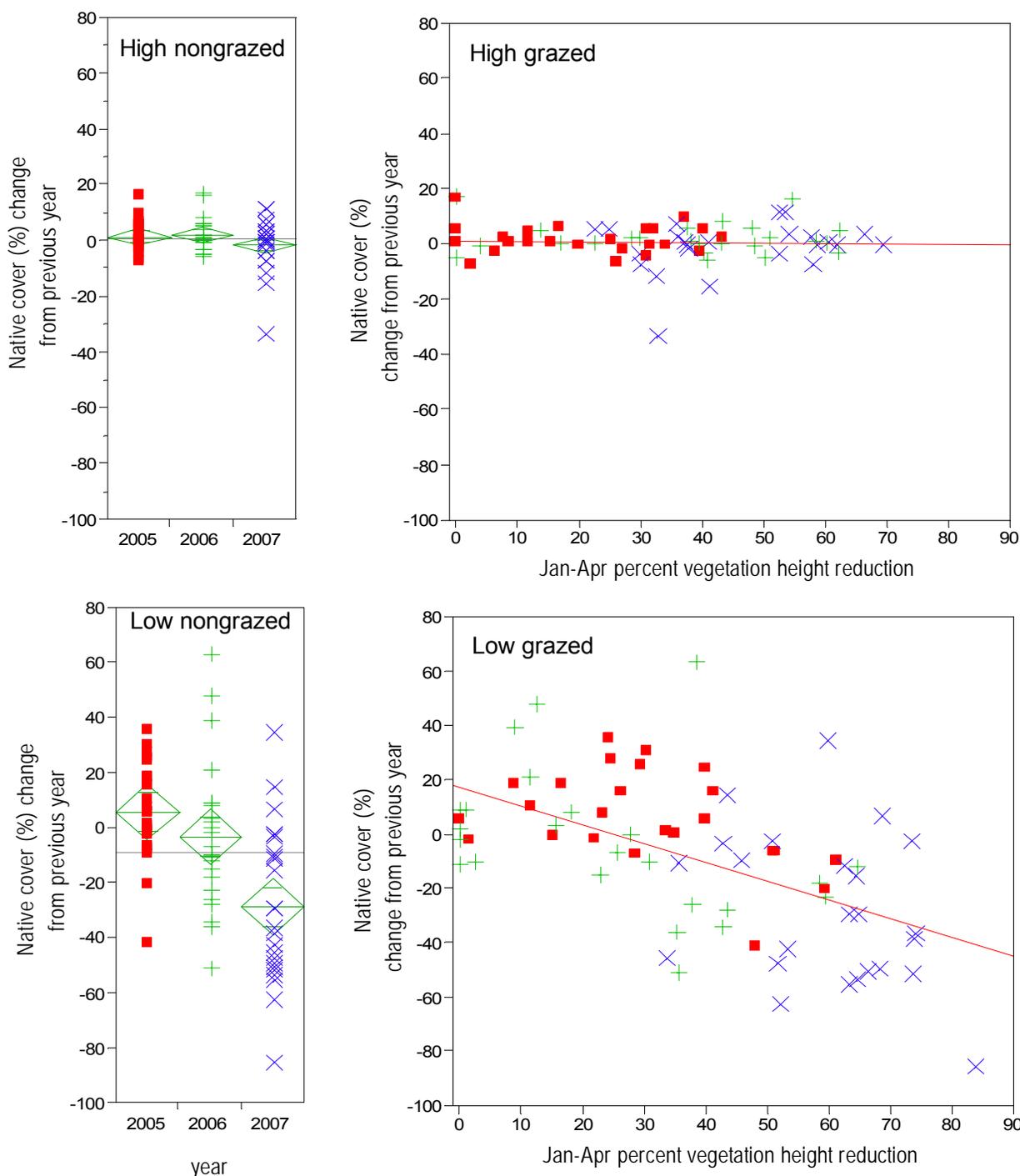
Figure 18. Change in percent native cover from the previous year plotted by year for nongrazed plots (left), and by percent vegetation height reduction January-April for grazed plots (right). Percent native cover: ■=2005 data; +=2006 data; ×=2007 data. The center line of each diamond represents the mean and the vertical extent of each diamond represents the 95% confidence interval from a one-way ANOVA of native cover change. Regression line for high grazed plots (upper right) nonsignificant, for low grazed plots (lower right) R^2=0.308, p<0.0001.

Grazed plots: Changes in plant cover related to grazing impacts
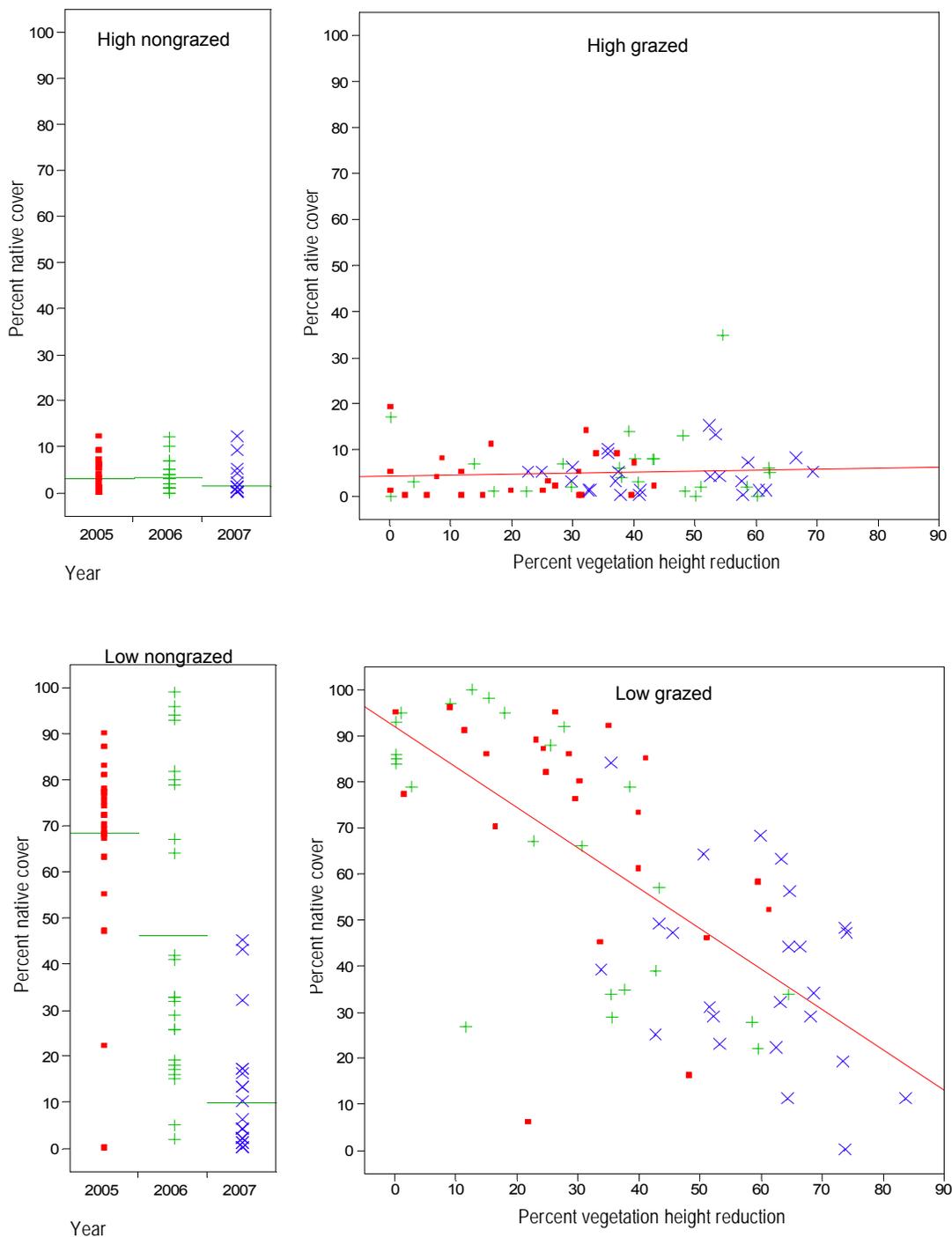
Figure 19. Percent native cover plotted by year for nongrazed plots (left), and by percent vegetation height reduction January-April in grazed plots (right). Percent native cover: ■=2005 data; +=2006 data; ×=2007 data. Horizontal lines in left graphs represent means for each year. Regression line for high grazed plots (upper right) nonsignificant, for low grazed plots (lower right) R^2=0.501, p<0.0001.

Grazed plots: Changes in plant cover related to grazing impacts

Unlike the high plots, several grazing variables were related to changes in native cover in the low plots. Grazing variables significant in the models for low plots included the multiple year grazing profile clusters, overall January-April grazing impact, and March-April grazing impact. Because these grazing variables are correlated, they are not all significant when included in a single model. Models using multiple year grazing profile clusters showed better fit overall than equivalent models that used January-April grazing impact (*table 13*) or March-April grazing impact.

Table 13. Summary of random effects repeated measures models for year to year change in native cover in grazed low plots for 2005 - 2007 (n=72).

Source	Prob > F	Prob > F
year	0.1172	0.0286
Preceding Aug vegetation height	0.0008	0.0001
Preceding Apr native cover (transformed)	<.0001	0.0003
Multiple year grazing profile cluster	—	0.0160
Jan-Apr grazing impact	<.0001	—
AIC_c	590.30	557.73

January-April grazing impact was negatively associated with native cover change in the models; higher levels of grazing impact over this period were associated with declines in native cover (*fig 18, 19*). March-April grazing impact was also negatively correlated with native cover change, although the significance of this variable varied by year. The effect of March-April grazing was most pronounced in 2005, when field 19E was grazed continuously throughout most of the peak bloom period. As noted above, March-April grazing impact and other related grazing variables were nonsignificant in 2007. In 2007, grazing occurred in 19E in relatively short pulses during April (*fig. 9*), and peak bloom was shifted earlier in the season. One or both of these factors, combined with reduced overall native cover in 2007, may account for the lack of a significant impact of March-April grazing in 2007.

Effects associated with multiyear grazing profile clusters were generally consistent with effects of other grazing variables. Decreases in native cover were seen in grazing profiles with high grazing impact in March-April. Increases in native cover were seen in grazing profiles with low overall grazing impact between January and April, such as plots grazed substantially only in January-February or February-March.

August RDM was negatively correlated with the change in native cover in low grazed plots, as was preceding August vegetation height (*fig. 20*). August RDM was significantly correlated with August vegetation height (R^2=0.319, p<0.0001). However, models which included August RDM were poorer at predicting native cover than models which contained preceding August vegetation height, based on the AIC_c for comparative models. Preceding August RDM was not a significant predictor of native cover change in models that included August vegetation height.

Grazed plots: Changes in plant cover related to grazing impacts
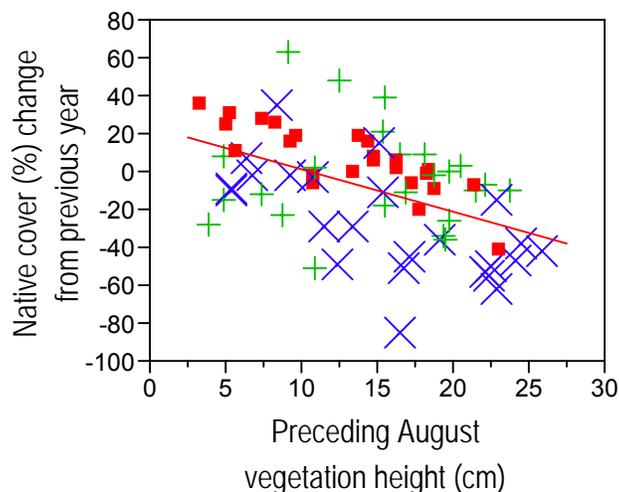
Figure 20. Change in percent native cover from the previous year for low grazed plots plotted by preceding August vegetation height (cm) for all the three years of the study: ■=2005 data; +=2006 data; ×=2007 data (regression line R^2=0.232, p<0.0001).

We also tested preceding April-August grazing impact as a predictor in models using 2006 and 2007 data only. Previous April-August grazing impact could not be calculated for 2005 because exclosures required to measure grazing impact were not constructed until after August 2004. In two year models, preceding April-August grazing impact was nonsignificant, suggesting that even though August RDM and vegetation height were significantly affected by grazing that occurred after April, this grazing did not influence native cover in the following year. Since this analysis is limited to two years, one with high (2006) and one with low rainfall (2007), it is possible that April-August grazing impacts could have effects on native cover under different conditions. However, existing data suggests at minimum that April-August grazing impact does not have a consistent effect on native cover in the following year.

We also constructed recursive partition models for change in native cover using all the grazing variables and other significant variables noted above as explanatory variables to further explore interactions between variables. Recursive partition models select variables to split the data in order to maximize the difference in the responses between the two branches of the split. Hence, the recursive partition model indicates which variables have the greatest influence on maximizing the difference between plots that showed positive or negative changes in native cover.

The result of the recursive partition model for grazed low plots is shown in *figure 21*. The first split in the model was based on January-April grazing impact. Plots with less grazing impact had more native cover. The next two splits were based on preceding April native cover. Plots with low levels of native cover in the preceding April were most likely to show an increase in native cover; the effect occurs across all levels of January-April grazing impact. In the fourth split, those plots in the partition with lower January-April grazing impact but higher native cover were split again based on January-April grazing impact. Again, plots with lower January-April grazing impact had more positive changes in native cover. The fifth split was based on vegetation height the previous August; lower vegetation height in the previous August was

Grazed plots: Changes in plant cover related to grazing impacts

associated with more positive changes in native cover. Subsequent splits did not substantially improve the model, so the model was terminated at five splits to avoid overfitting. As was seen in the repeated measures models, the partition model shows that January-April grazing impact, previous April native cover, and preceding August vegetation height were correlated with changes in native cover in low plots.

Figure 21. Recursive partition model for year to year change in native cover of low grazed plots using data from 2005, 2006, and 2007. Upper chart shows variables used for splitting the data. The numbers 1-5 in large font size indicate the sequential number of each split in the model. The cutting value for each variable used to partition the data at each split is listed in the cells to the right of the variable name. The partition showing the more positive change in native cover at each split is indicated in bold. The lower graph shows the improvement in model fit provided by each split. The blue line shows the R^2 value based on the entire data set. The green line shows the k-fold cross-validated R^2, with k=n=72.

Although increasing January-April grazing impact is associated with decreased native cover in grazed low plots, it is difficult to equate this impact to a given level of grazing intensity. As a possible way to relate grazing impact, which is based on reference non-grazed plots, to variables that could be observed directly in grazed fields, we looked at the correlation between April vegetation height and April percent native cover (*figure 22*). Data from all three years of the study show a positive correlation between April vegetation height and native cover in low plots.

We used recursive partition models to determine the April vegetation height that maximized the difference in percent native cover among the low plots. If data from all three years are used, the optimal split occurs at an April vegetation height of 12 cm. Plots with vegetation height less than 12 cm had significantly lower native cover (mean 39%) than plots with vegetation heights

Grazed plots: Effects of grazing on native and exotic species richness

greater than 12 cm (mean 75%). The 2007 data alone do not show a significant correlation between April vegetation height and native cover. When the 2007 data was excluded from the data set, the partition occurred at an April vegetation height of 15.6 cm. For 2005-2006 data, plots with vegetation height less than 15.6 cm had significantly lower native cover (mean 56%) than plots with greater vegetation heights (mean 85% native cover).
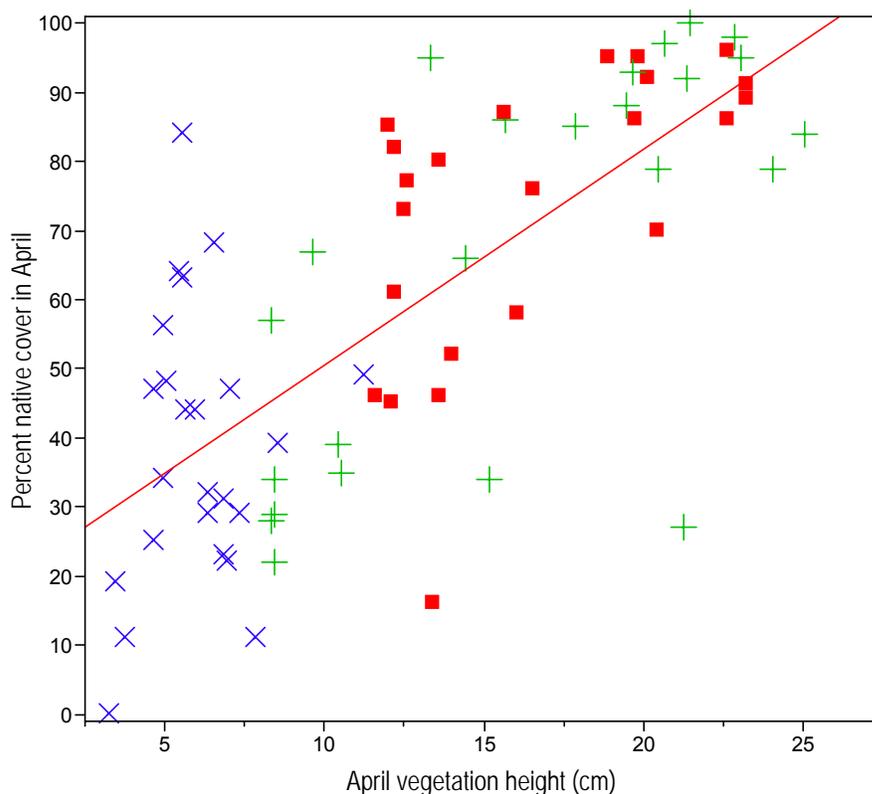
Figure 22. Percent native cover in April by April vegetation height (cm) in grazed plots across all three years of the study: ■=2005 data; +=2006 data; ×=2007 data. Regression line R^2=0.537, p<0.0001.

Grazed plots: Effects of grazing on native and exotic species richness

Repeated measures models for high and low grazed plots showed that changes in native species counts varied significantly by year (p<0.0001). Year was also highly significant for changes in exotic species counts (p=0.0008 for high plots, p<0.0001 for low plots).

For high plots only, previous April native cover was a significant negative predictor of the change in native species richness, but the significance of this effect was due to the negative correlation between the two variables for 2007 only. The high plots with the highest native cover in 2006 showed the strongest decline in native species richness in 2007. Repeated measures analyses showed no significant effects of January-April grazing impact, preceding August vegetation height, or preceding August vegetation height on changes in native or exotic species counts (species richness) for high or low plots.

Comparisons between nongrazed multiyear control and grazed plots

In a recursive partition model for change in native species counts in high plots, year was the first splitting variable. The change in native species richness from the previous year was negative for 2007 (mean –1.74 species) but positive overall for 2005 and 2006 (mean +0.75 species). In the second split, the 2007 partition was split based on 2006 native species richness. Plots with 4 or more native species in 2006 lost on average 3 native species whereas plots with less than 4 native species in 2006 lost on average 0.36 native species in 2007. Subsequent splits of the data did not improve model fit.

Similarly, in a recursive partition model for change in native species counts in low plots, year was the first splitting variable; 2007 was separated from 2005 and 2006. The 2005 + 2006 data was then split based on native species richness in the previous year. For 2005 and 2006, native species richness decreased (average -1.7 species) in plots that had 10 or more native species in the previous year; native species richness increased (average +1.5 species) in plots that had less than 10 native species in the previous year. The third split partitioned 2007 data based on previous April native cover. Between 2006 and 2007, plots with lower 2006 April native cover (less than 66%) lost 5.9 native species on average; plots with higher April 2006 native cover (66% or more) lost 1.5 species on average. Further partitioning of the data only slightly improved model fit, so fitting was terminated after these three splits.

In summary, changes in species richness from one year to the next among grazed plots were not related to differences in grazing intensity among the plots.

Comparisons between nongrazed multiyear control and grazed plots

April and August vegetation height

To examine the overall impact of grazing on vegetation height, we compared all grazed plots against the nongrazed multiyear control plots (*fig. 23*). All plots, including those that were subsequently assigned to be nongrazed, were grazed in May or June 2004 (Swiecki and Bernhardt 2006). This late season grazing is responsible for the decreases in average vegetation height seen in most plots between April and August 2004 (*fig. 23*).

In 2005 and 2006, soil moisture levels were high enough to support continued vegetation growth beyond April, so vegetation height in nongrazed multiyear control plots increased substantially between April and August in these years. In 2007, a relatively dry year, vegetation height growth after April was minimal (*fig. 23*).

Fields 18E and 19E, but not 20E, were grazed in May or June in 2005, 2006, and 2007. This late-season grazing consistently reduced average vegetation height in the low plots (*fig. 23*). In high plots, the late season grazing reduced vegetation height between April and August in 2005 and 2007, but not in 2006. Soil moisture levels in the fields would have been high in the late spring and early summer of 2006, due to the relatively high rainfall and delayed growth of vegetation in that year (*fig. 4*). This late season moisture supported enough late spring growth to more than offset the grazing impacts during this period. Grazed high plots in field 20E, which were not grazed after March, increased in height between April and August in all three years of the study and showed the greatest late-season growth in 2006 (*fig. 23*, top).

Comparisons between nongrazed multiyear control and grazed plots

April August high grazed and nongrazed

Legend: 20E,High,Cover 20E,High,Grazed 19E,High,Cover 19E,High,Grazed 18E,High,Cover 18E,High,Grazed

April August low grazed and nongrazed

Legend: 20E,Low,Cover 20E,Low,Grazed 19E,Low,Cover 19E,Low,Grazed 18E,Low,Cover 18E,Low,Grazed
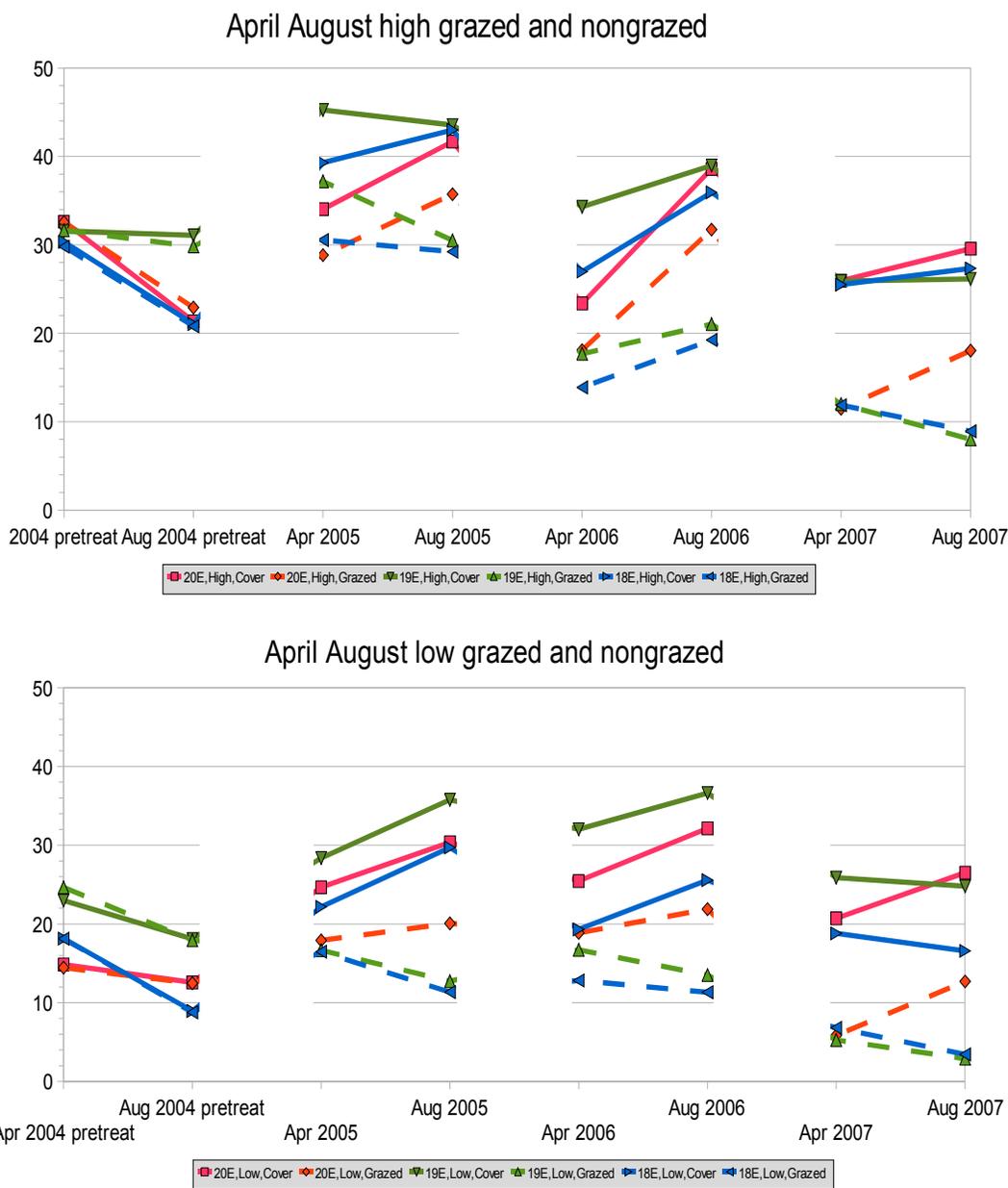
Figure 23. April and August average vegetation height for 2004 through 2007. The nongrazed multiyear control treatment began in November 2004. Grazed plots are shown by dashed lines and nongrazed plots by solid lines. Red lines and square or diamond markers represent 20E, green lines and vertical triangle markers represent 19E, and sideway triangles represent 18E. Fields 18E and 19E were grazed after the April evaluation in 2005, 2006, and 2007; field 20E was not grazed after April in those years.

April and August vegetation height data are summarized by position (high/low) and grazing (with/without) in *figure 24*. April falling plate biomass measurements (not shown) followed the same trend seen in April height measurements. Repeated measures analysis of both April and August height data for grazed and nongrazed-multiyear control plots showed that from 2005

Comparisons between nongrazed multiyear control and grazed plots

onward, vegetation height was significantly higher in the nongrazed plots. The effect of year was highly significant (p<0.0001) in all models. Height growth was strongly reduced in 2007, as has been shown above for both mowed (*fig. 3*) and grazed plots. Overall differences in height growth were most pronounced in the August heights. The year × position interaction was highly significant (p<0.0001) for April and August height models, indicating that the overall differences between high and low plots varied by year. The position × grazing and year × position × grazing interaction terms were nonsignificant in the models for both April and August height data. This indicates that the overall grazing effect was the same for both high and low plots and the effect did not change significantly over the three years of the study.
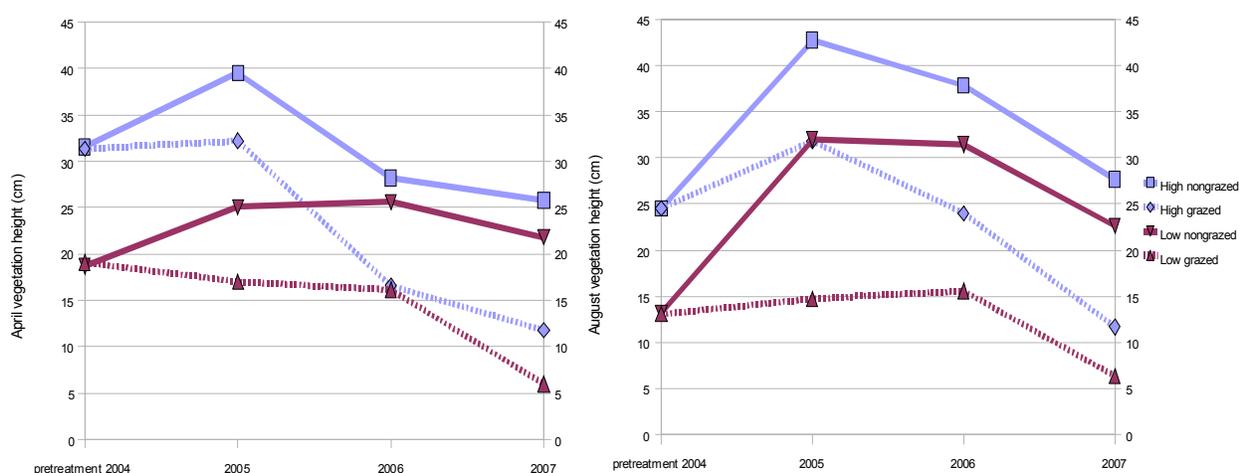
Figure 24. April (left) and August (right) vegetation heights in grazed and nongrazed multiyear control plots. Nongrazed plots were excluded from grazing starting in November 2004. Solid lines represent nongrazed plots and dotted lines represent grazed plots.

As shown in *figure 25*, although August mean vegetation heights of grazed and nongrazed plots differed significantly, the height ranges overlapped substantially. It is also clear that the total variation in height growth was greatest in 2006. However, within each year by position combination, the variance in height growth did not differ significantly (O'Brien's test for homogeneity of variance) between grazed and nongrazed plots. This result shows that plots vary widely in their ability to support vegetation growth irrespective of superimposed grazing impacts.

This result also emphasizes the value of using paired grazed and nongrazed plots to assess grazing impacts. Without information on the variation in growth in the absence of grazing, such variation in growth could be erroneously attributed to grazing. Although grazing substantially decreased height growth in most grazed plots compared to nongrazed controls, there was little or no difference in vegetation height between paired grazed and nongrazed plots in some plot sets, particularly in 2006 (points connected by nearly horizontal lines in *figure 25*). These pairs include grazed plots that showed low grazing impacts based on comparisons with nongrazed mowed plots.

Comparisons between nongrazed multiyear control and grazed plots
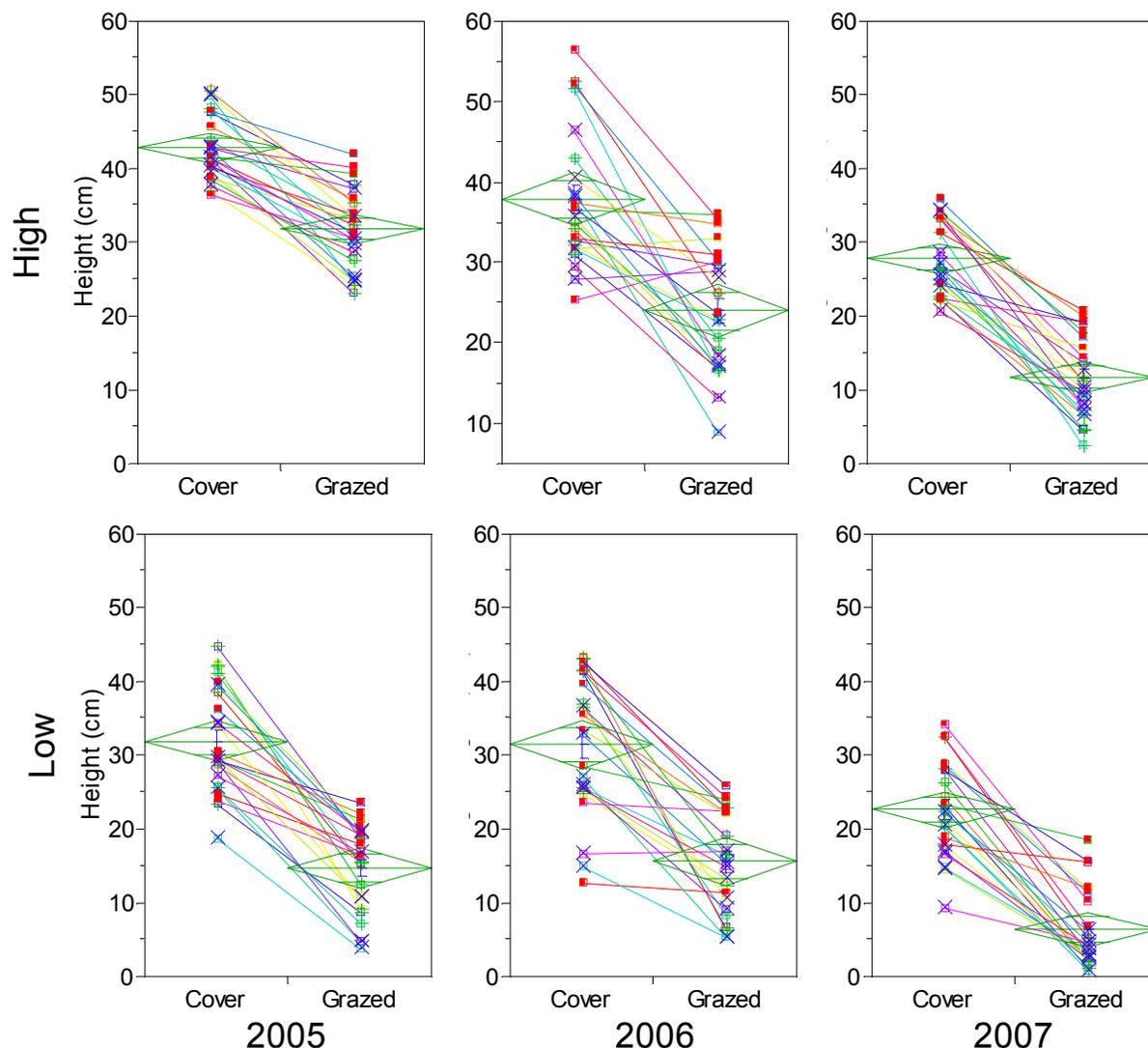
Figure 25. August vegetation heights for 2005 through 2007 in paired grazed and nongrazed-multiyear control plots; lines connect values for paired plots within plot sets. The nongrazed treatment began in November 2004. Center line through each diamond represents the treatment mean; the vertical extent of each diamond represents the 95% confidence interval for each mean.

August RDM

Plots were visually matched in 2004 to be similar in residual dry matter before being assigned to grazed and nongrazed treatments. As shown in *figure 26*, the 2004 RDM for both types of plots within plot position (high or low) were not statistically different. In 2007, RDM in grazed plots was lower than in previous years, particularly for plots in high positions (*fig. 26*). This is related to the reduced vegetation growth that occurred in 2007 compared to previous years (*fig. 3*). The repeated measures MANOVA showed that across all three years of the study, RDM was significantly reduced in grazed plots compared with nongrazed plots and that high plots had

Comparisons between nongrazed multiyear control and grazed plots

more RDM than low plots. The year × grazing and year × position interactions were also significant, indicating that differences in RDM due to grazing and position varied significantly over the three years of the study. The grazing × position and year × grazing × position interactions were not significant in this model. This indicates that the overall effect of grazing vs. nongrazing on RDM was similar for both high and low plots both overall and over time.
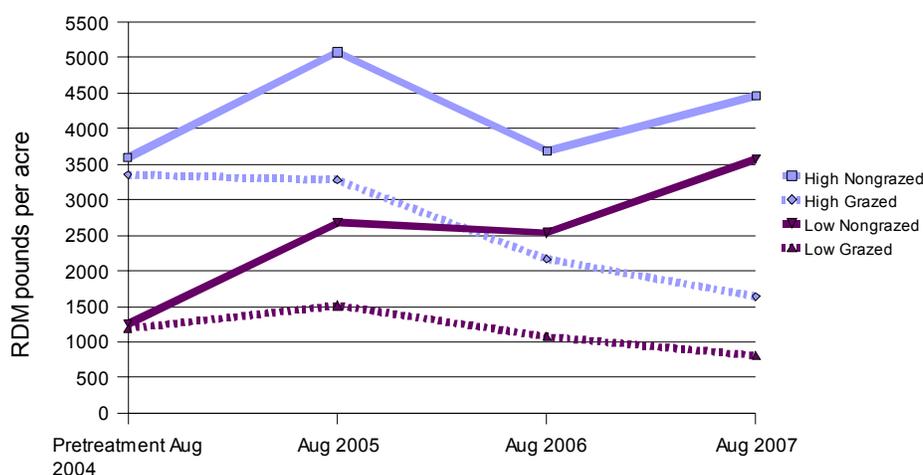
Figure 26. Changes in residual dry matter over time in grazed and nongrazed multiyear control plots in high and low positions. The nongrazed treatment began in November 2004. Each data point is the average of 24 plots.

August mulch height

Both grazing and position had significant effects on mulch height over time according to repeated measures MANOVA of 2004 through 2007 data. Average mulch height was significantly greater in nongrazed plots than in grazed plots and greater in high plots than low plots (*fig. 27*). Especially in high positions, mulch height in grazed plots was reduced below the 2004 baseline level in all three years of the study. Over the same period, mulch height has progressively increased in the nongrazed plots, showing a sharp increase between 2006 and 2007 (*fig. 27*). At least some of this increase in 2007 is associated with the presence of two-year old plant residues in plots. These residues were able to persist due to both the absence of the mechanical disturbance provided by grazing animals and low rates of decomposition due to the low rainfall in the 2007 season.

Comparisons between nongrazed multiyear control and grazed plots
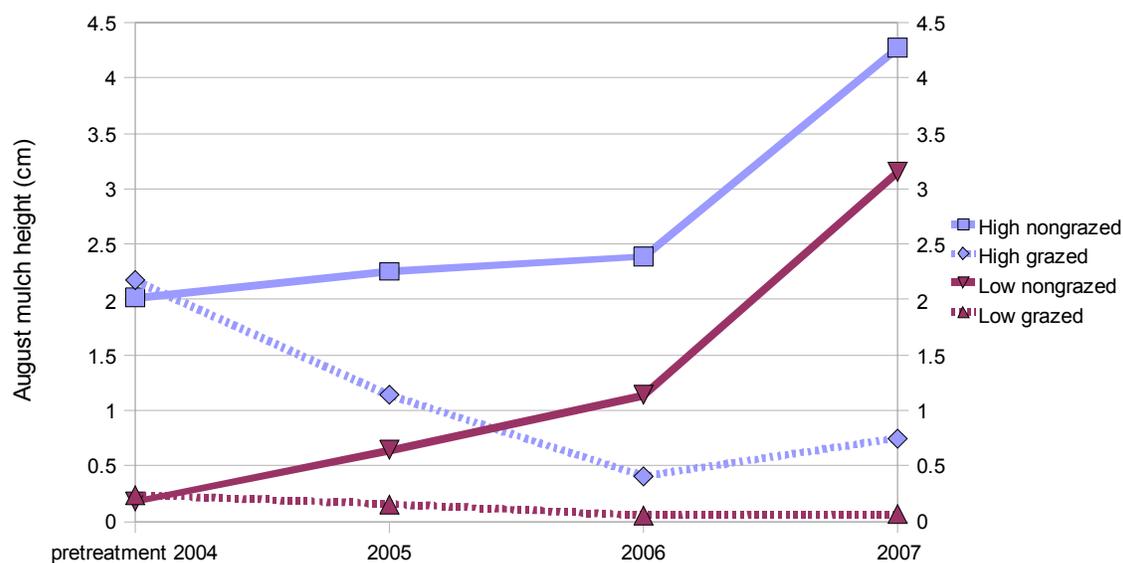
Figure 27. Average August mulch height by position in grazed and nongrazed multiyear control plots.

Native and exotic cover

Native cover

Native cover varied over time by both plot position (high/low) and overall grazing status (grazed/nongrazed) (*fig. 28*). A repeated measures MANOVA of native cover for 2004-2007 showed that the overall effects of plot position (high/low) and grazing (grazed/nongrazed) were highly significant (p<0.0001 for both variables). All interactions with time were also significant (time × plot position p<0.0001; time × grazed/nongrazed p<0.0001; time × plot position × grazed/nongrazed p=0.0021). By 2007, native cover was significantly greater in grazed plots than in nongrazed plots for both high (p=0.0001) and low plots (p<0.0001) (paired *t*-tests), but the magnitude of the difference in native cover in grazed and nongrazed plots was much greater in the low plots (*fig. 28*).

High plots — Total native cover in high plots was very low in both grazed and nongrazed plots in all years (*fig. 28*). Native cover did not differ between the nongrazed and grazed high plots except in 2007 (one-way ANOVA for 2007 p=0.0055), but even in that year, the magnitude of the difference was small (1.5% native cover in nongrazed versus 4.6% in grazed plots). Almost all of the native cover in the high plots in 2007 was saltgrass (*Distichlis spicata*), a low-growing perennial (*fig. 29*). Saltgrass cover was elevated in grazed plots in 2007 because growth of overtopping exotic grasses was reduced in the dry 2007, which promoted saltgrass growth somewhat and allowed more point frame hits on the understory saltgrass. In nongrazed plots, saltgrass was overtopped by exotic grass residues from the previous season.

Other small changes in native cover were associated with weather conditions. Native clover species, which occurred commonly in high plots, showed peak cover and constancy (frequency of occurrence in plots) in 2005 (*fig. 30*), a year with substantial early rainfall. In 2006, which

Comparisons between nongrazed multiyear control and grazed plots

was characterized by heavy rains in early winter, native grass cover increased slightly (*fig. 29*) mainly due to increased cover of *Juncus bufonis*, which was favored by wetter conditions. The native bunchgrass *Nassella pulchra*, which was found in about 20% of the high plots, was present at very low cover levels in plots (*fig. 30*) which did not change significantly over the study period.
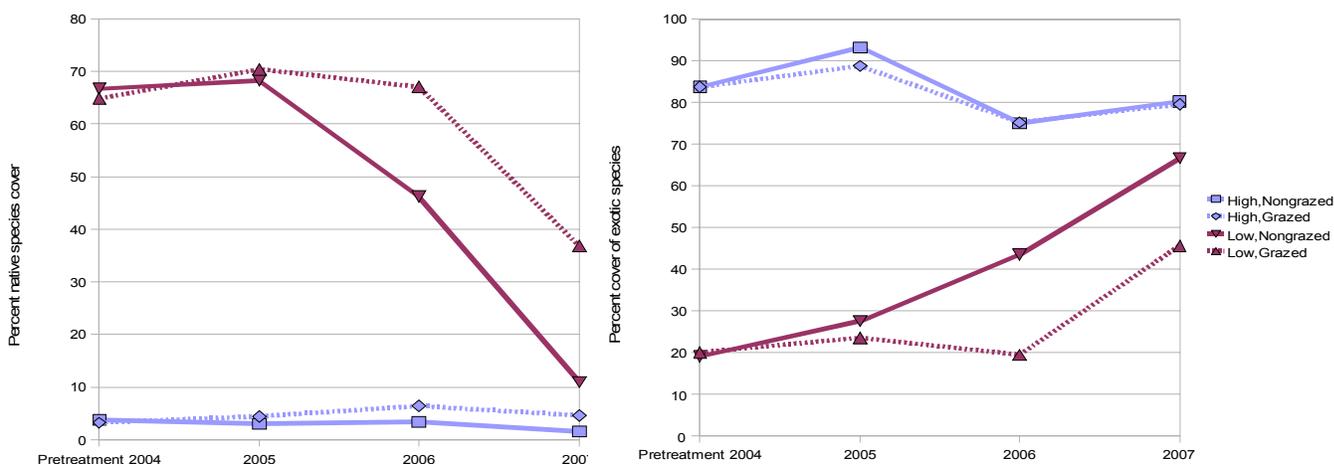
Figure 28. Changes in cover of native species (left) and exotic species (right) measured in April in nongrazed multiyear control and grazed plots by plot position (high/low). Grazed plots are shown by dotted lines. The nongrazed treatment was imposed in November 2004. Each data point is the average of 24 plots. Note differences of scale on the y axes.

Low plots — As shown in *figure 28*, native cover in low nongrazed plots declined significantly below that seen in grazed plots by 2006. Native cover in both grazed and nongrazed plots was sharply lower in 2007 than in 2006. The absolute difference in native cover in the grazed plots between 2006 and 2007 (30%) was greater than the absolute differences in cover between grazed and nongrazed plots in either 2006 or 2007 (21% and 26%, respectively). However, on a relative basis, the reduction in native cover seen in 2007 in nongrazed plots after 3 years (nongrazed plots reduced by 70% compared to the grazed), exceeded the relative weather-related change seen between 2006 and 2007 (2007 reduced by 45% compared to 2006).

Both native forb cover and native grass cover (*fig. 29*) were reduced substantially in 2007, presumably due to dry conditions in that year (*table 2*). Most of the decrease in native grass cover between 2006 and 2007 was due to a reduction in *Pleuropogon californicus* cover (*fig. 31*). *P. californicus* cover was strongly elevated in 2006 (*fig. 31*) due to prolonged flooding that occurred in late December 2005 (Swiecki and Bernhardt 2007). In contrast, cover of the native annual grass *Deschampsia danthonioides* was relatively constant (average about 5%) in grazed low plots over all four years.

At the time of the cover evaluations in April, goldfields (*Lasthenia* spp.) were the dominant native forb species. Other native forbs, although commonly present in low plots, were present at relatively low cover values (e.g., *fig. 30*). Native forb cover declined strongly in 2006 (*fig. 29*), primarily due decreased goldfields cover (*fig. 31*). Goldfields were largely replaced by *P. californicus* in many of the plots (cover photos).

Comparisons between nongrazed multiyear control and grazed plots

For all four major plant guilds in the low plots, differences in cover that developed over time between grazed and nongrazed low position plots (*fig. 29*) were significant in repeated measures analysis (native grass cover: year × grazed/nongrazed p=0.0302; native forb cover: year × grazed/nongrazed p=0.0003; exotic grass cover: year × grazed/nongrazed p=0.0001; exotic forb cover: year × grazed/nongrazed p=0.0046).
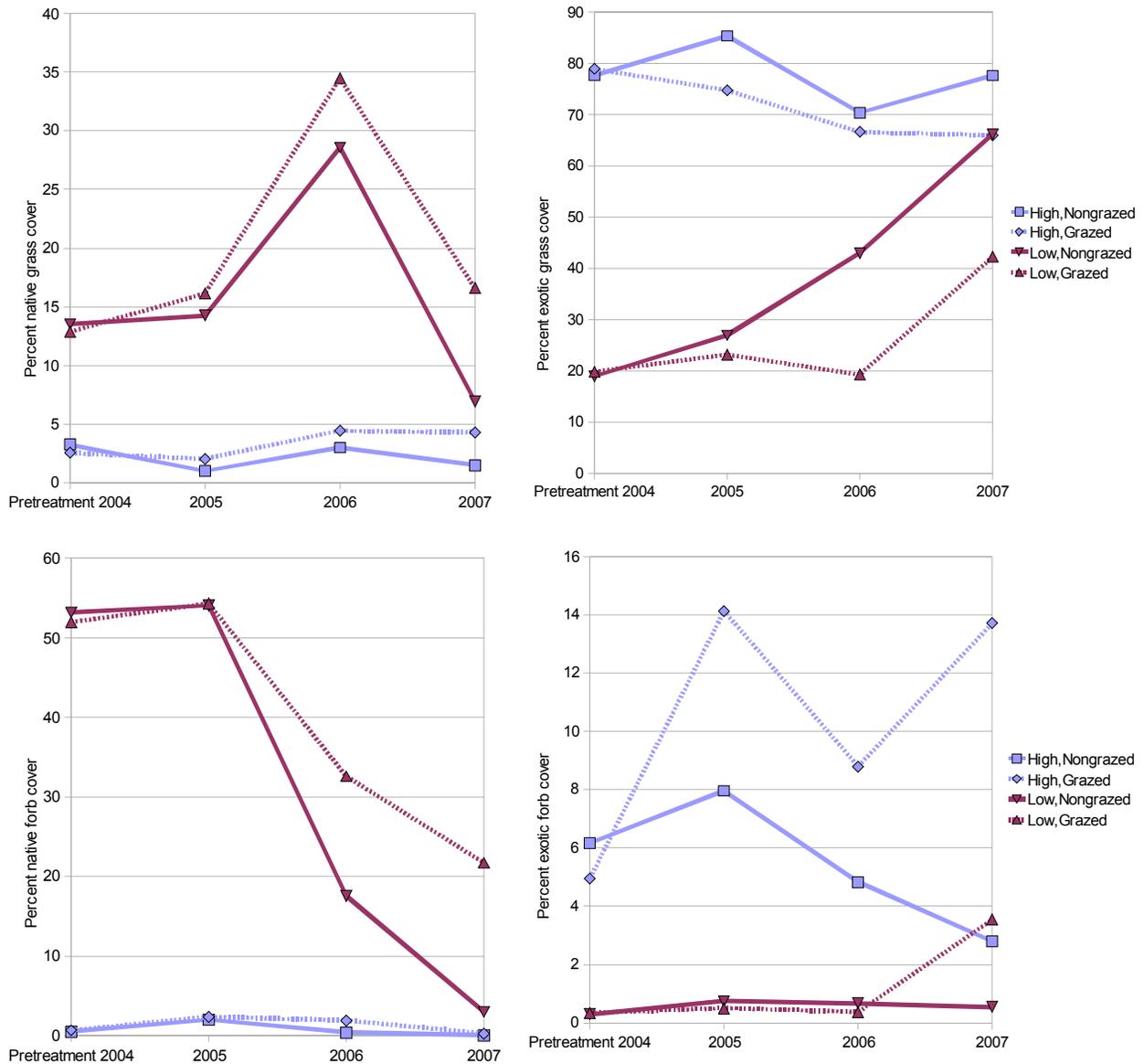
Figure 29. Average cover percentages for native grasses (upper left), native forbs (lower left), exotic grasses (upper right) and exotic forbs (lower right) measured in April in nongrazed multiyear control and grazed plots by plot position (high/low). Grazed plots are shown by dotted lines. Note differences of scale on the y axes. The nongrazed treatment was imposed in November 2004. Each data point is the average of 24 plots.

Comparisons between nongrazed multiyear control and grazed plots
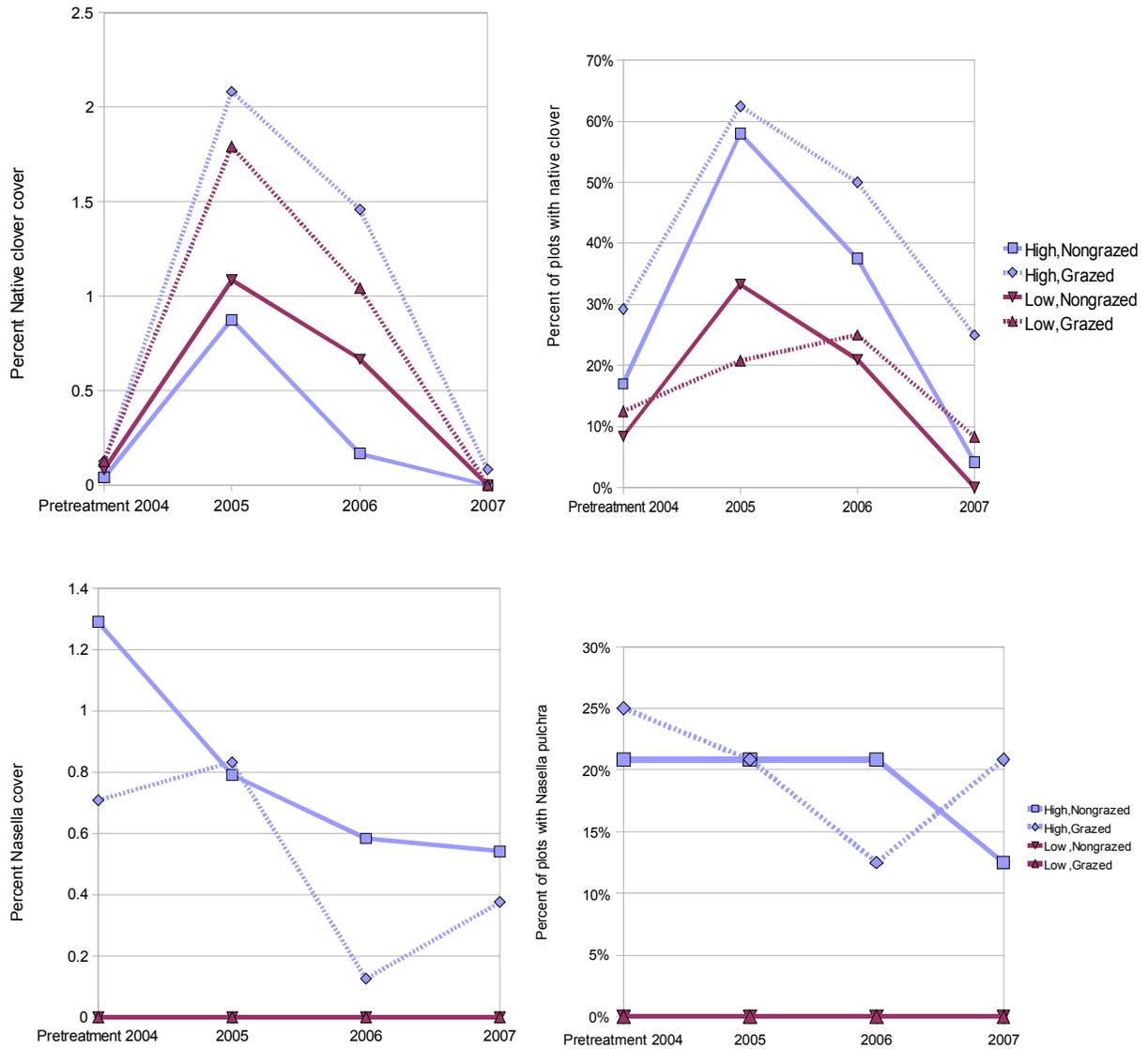
Figure 30. Cover (left) and constancy (percent of plots in which the species occurred; right) for native clovers (*Trifolium* spp.; top) and the perennial bunchgrass *Nasella pulchra* (bottom) in April in nongrazed multiyear control and grazed plots by plot position (high/low). Grazed plots are shown by dotted lines. The nongrazed treatment was imposed in November 2004. Each data point is the average of 24 plots.

Comparisons between nongrazed multiyear control and grazed plots
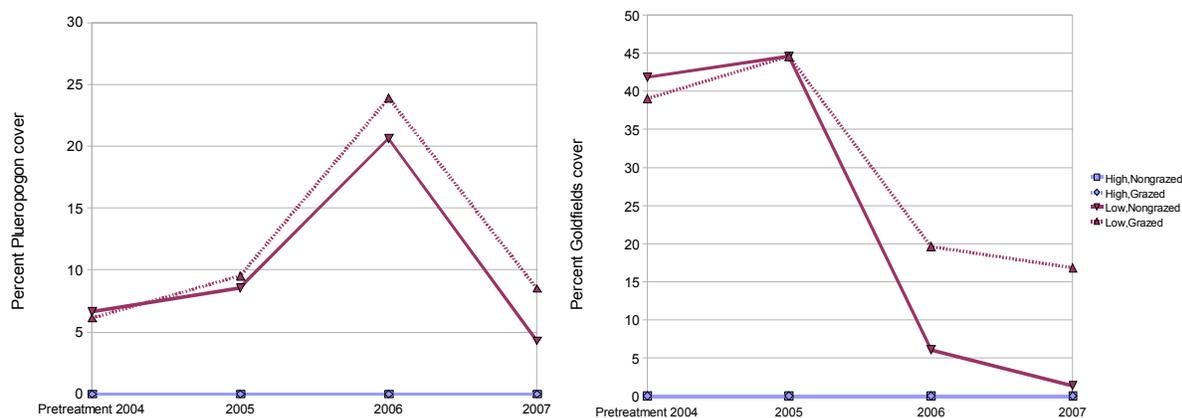
Figure 31. Cover of *Pleuropogon californicus* (left) and *Lasthenia* spp. (right) in April in nongrazed multiyear control and grazed plots. Grazed plots are shown by dotted lines. The nongrazed treatment was imposed in November 2004. Each data point is the average of 24 plots. Note differences of scale on the y axis.

Exotic cover

As seen for native cover, a repeated measures MANOVA of exotic cover (*fig. 28*) showed significant effects of year (p<0.0001), plot position (high/low) (p <0.0001), and year × plot position (p<0.0001). The year × plot position × grazed/nongrazed interaction was also significant (p=0.0006), indicating that the grazed/nongrazed effect differed by plot position. For both high and low plots, most of the exotic plant cover consisted of exotic annual grasses (*fig. 29*), but high plots had significantly higher exotic forb cover than low plots (p<0.0001).

High plots —Repeated measures analysis indicated that exotic grass cover was significantly greater in nongrazed than in grazed plots (*fig. 29*; year p<0.0001, year × grazed/nongrazed p=0.0408). Exotic forb cover showed the opposite trend and was significantly greater in grazed plots than in nongrazed plots (*fig. 29*; year p=0.0788; and year × grazed/nongrazed interaction p=0.0026). Most of the increase in exotic forb cover in grazed plots was due to *Erodium* spp. (*fig. 32*). Due to these two opposing trends in grazed plots, the increase in exotic forb cover offset the decrease in exotic grass cover, and total exotic cover did not differ significantly between grazed and nongrazed high plots (*fig. 28*).

Low plots — Exotic cover increased each year in nongrazed plots, but was unchanged in grazed plots until it increased sharply in 2007 (*fig. 28*). Almost all of the increase in exotic cover over time was due to increased exotic grass cover (*fig. 29*). Repeated measures analysis showed highly significant effects of year (p<0.0001) and year × grazed/nongrazed (p<0.0001) for both total exotic cover and exotic grass cover. Exotic forb cover differed significantly between grazed and nongrazed plots only in 2007 (*fig. 29*). About three-quarters of the increase in exotic forb cover seen between 2006 and 2007 in grazed low plots was due to an increase in *Erodium* spp. cover (*fig.29, 32*).

Comparisons between nongrazed multiyear control and grazed plots
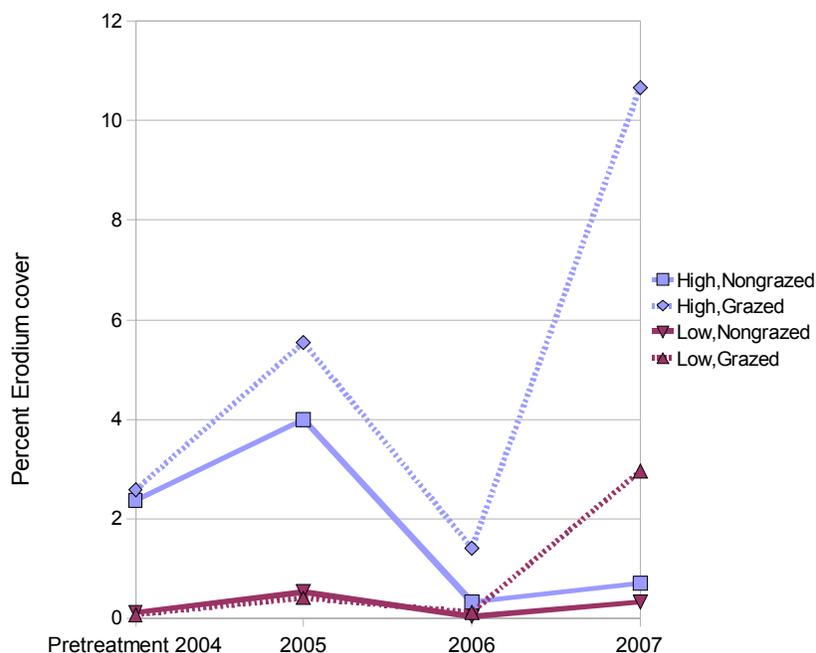
Figure 32. *Erodium* spp. cover in April in nongrazed multiyear control and grazed plots by plot position (high/low). Grazed plots are shown by dotted lines. The nongrazed treatment was imposed in November 2004. Each data point is the average of 24 plots.

Medusahead—The only component of exotic grass cover that we measured separately was medusahead (*Taeniatherum caput-medusae*). Our results indicate that medusahead was largely unaffected by grazing pressure: grazed and nongrazed plots showed no significant differences in medusahead cover or constancy (*fig. 33*). The apparent decline in medusahead cover in April 2006 was probably due to delayed development in 2006 relative to other years. A comparison of plot photos taken in August of 2004, 2005, and 2006 did not indicate that medusahead cover at the end of season in August 2006 was substantially different from that observed in August 2004 or 2005. Medusahead cover in the low plots remained minimal even in the absence of grazing, although both grazed and nongrazed low plots showed an increase in medusahead cover in 2007. Dry conditions that occurred in 2007 presumably allowed medusahead to establish better in the low plots, but its overall cover in the low plots was still minimal.

Comparisons between nongrazed multiyear control and grazed plots
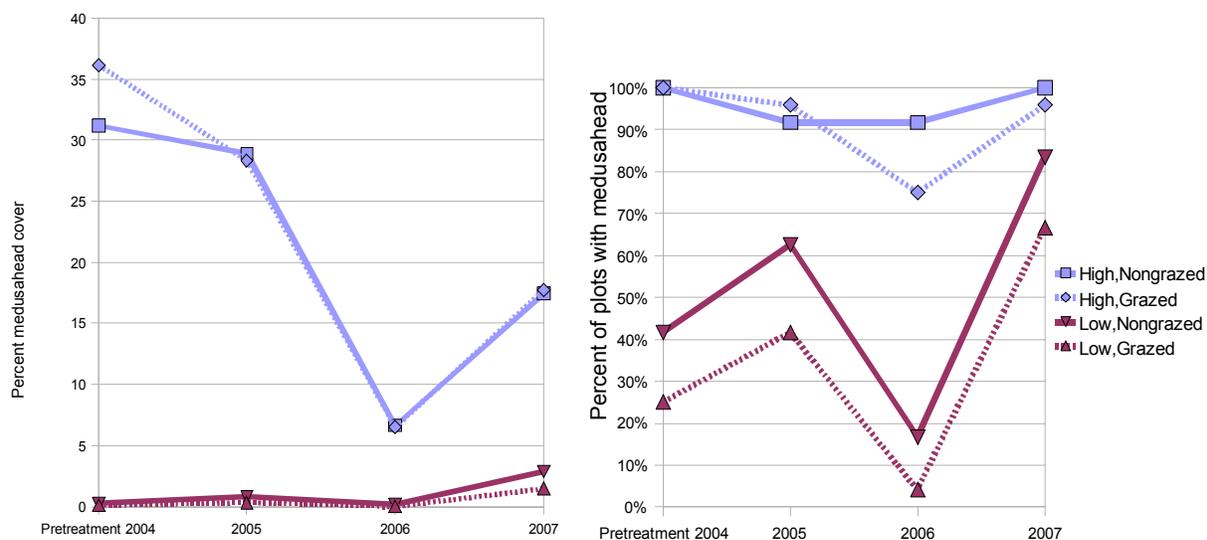
Figure 33. Medusahead cover (left) and constancy (right) in April in nongrazed multiyear control and grazed plots by plot position (high/low). Grazed plots are shown by dotted lines. The nongrazed treatment was imposed in November 2004. Each data point is the average of 24 plots.

Mulch and bare soil cover

In some nongrazed plots, nondecomposed vegetation from the previous season contributed strongly to cover (*fig.34*). Starting in 2006, mulch cover in both high and low plots was significantly greater in nongrazed than grazed plots (*fig. 35*).

Bare soil cover, which was also substantial in many plots, was mostly associated with two distinct factors: gopher activity and grazing intensity. In both high and low plots, gopher activity led to significant amounts of bare soil cover. We removed freshly mounded soil on top of live vegetation to minimize the cover artifacts associated with this phenomenon. However, when gopher activity buried the soil surface early in the growing season, much of the covered area remained free of vegetation and was counted as bare soil in the April evaluation. High grazing intensity was associated with elevated levels of bare soil almost exclusively in low grazed plots. Parts of some grazed low plots had all vegetation removed to bare mineral soil, due to very intense grazing and/or trampling (e.g., sheep trails). Due to this effect, among grazed plots, bare soil cover was greater in the low plots than in the high plots overall (*fig. 35*). Also, for both high and low plots, bare soil cover was greater overall in grazed plots than in nongrazed plots (*fig. 35*).

Comparisons between nongrazed multiyear control and grazed plots

Figure 34. Nongrazed low position plot in April 2007 showing a large buildup of vegetation from previous seasons. The wire exclosing the plot has been removed in this picture.
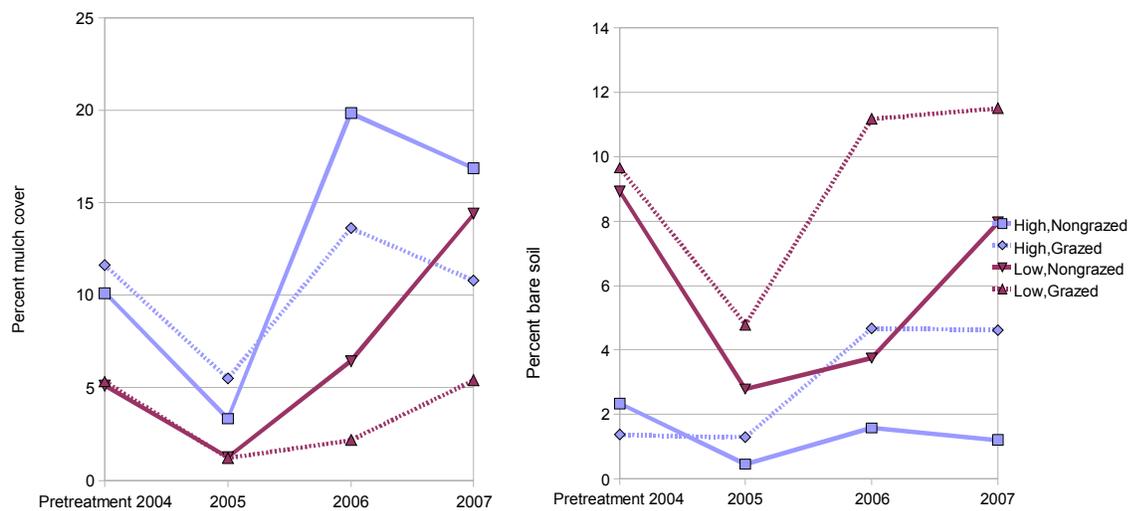
Figure 35. Changes in the percent mulch cover (left) and bare soil cover (right) measured in April in nongrazed multiyear control and grazed plots by plot position (high/low). Grazed plots are shown by dotted lines.   The nongrazed treatment was imposed in November 2004. Each data point is the average of 24 plots. Note differences of scale on the y axes.

Comparisons between nongrazed multiyear control and grazed plots

Native and exotic species richness

Native species

Over time, the number of native species in nongrazed plots declined below that seen in grazed plots in both high and low plot positions (*fig. 36*). Substantial differences did not develop between grazed and nongrazed plots until 2006, after nongrazed plots had been exclosed for two years.

The number of native species in all plots also declined sharply in 2007. The decline in native species richness in 2007 was greater in the low plots than in the high plots. In the low plots, the loss in native species richness from 2006 to 2007 was significantly greater in nongrazed than grazed plots (*fig. 36*). In the grazed plots, the loss of species richness associated with the dry 2007 growing season (about 3 fewer species on average) was about the same as the difference between the grazed and nongrazed plots after 3 years of exclusion from grazing (*fig. 36*).

Exotic species

The mean number of exotic species in high plots varied significantly by year but did not differ significantly between grazed and nongrazed plots (*fig. 36*). In low plots, effects of year and the year × plot type (grazed /nongrazed) interaction were significant in a repeated measures model. Although low grazed plots had fewer exotic species than nongrazed plots in 2005 and 2006, the situation was reversed in 2007 due to a sharp increase in the number of exotic species in the grazed plots (*fig. 36*). Most of the increase in exotic species richness was due to an increase in exotic grass species richness. Exotic grass species richness increased from an average of 1.5 species per plot in 2006 to 4 species in 2007. Exotic forb richness increased from an average of 0.6 species per plot in 2006 to 2 species per plot in 2007.

In grazed low plots, increases and decreases in native and exotic species counts essentially cancelled each other out, so that total species richness was virtually unchanged between 2004 and 2007 (*fig. 37*). Nongrazed low plots and both grazed and nongrazed high plots showed little change in total species richness until 2007, when total species count declined significantly (*fig. 37*).

Comparisons between nongrazed multiyear control and grazed plots
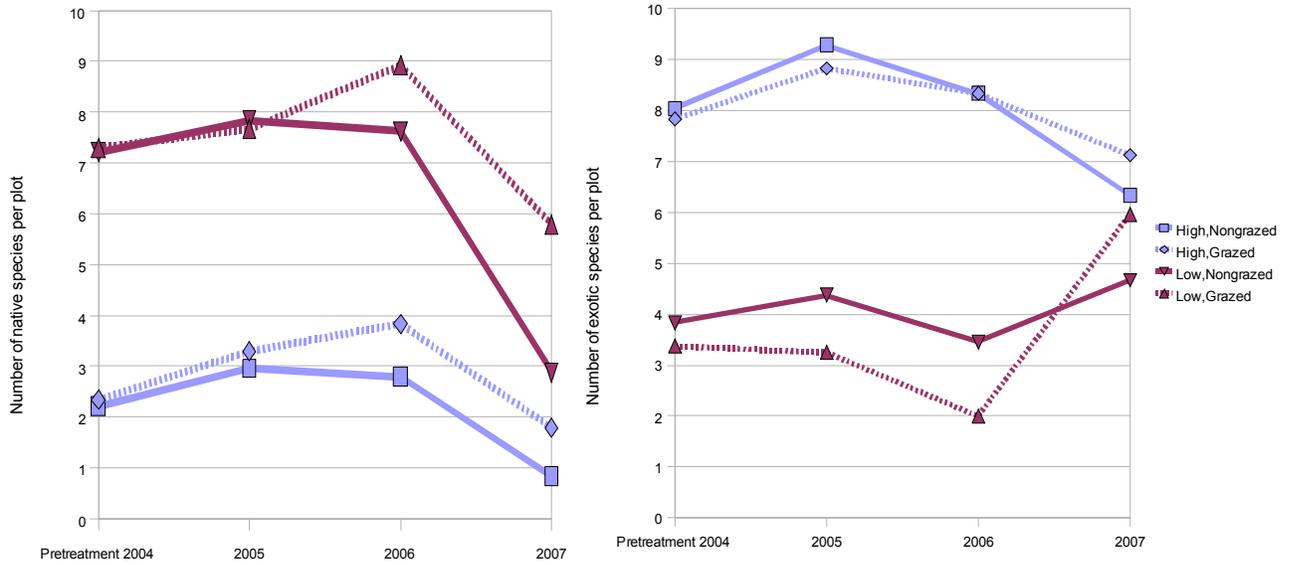
Figure 36. Changes in the mean number of native species (left) and exotic species (right) present per plot in April in nongrazed multiyear control and grazed plots by plot position (high/low). Grazed plots are shown by dotted lines. The nongrazed treatment was imposed in November 2004. Each data point is the average of 24 plots.
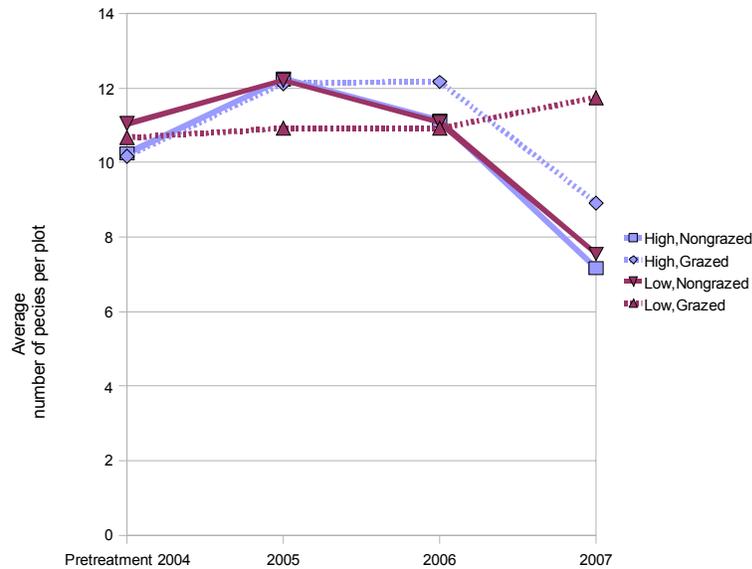
Figure 37. Changes in the mean total number of species (native + exotic) per plot in April in nongrazed multiyear control and grazed plots by plot position (high/low). Grazed plots are shown by dotted lines. The nongrazed treatment was imposed in November 2004. Each data point is the average of 24 plots.

Comparisons between nongrazed multiyear control and grazed plots

Constancy of exotic grass species in plots

For grasses, we collected cover data by species only for native species and for the exotic medusahead (*fig. 33*). However, we noted which other exotic grass species occurred in each plot in the April evaluations; the results are summarized in *table 14* below. Of these exotic grasses, ripgut brome (*Bromus diandrus)* showed the strongest differential in constancy between high and low plots. Soft chess (*Bromus hordeaceus*), wild oats (*Avena fatua*), and rat-tail fescue (*Vulpia myuros*) were also more commonly present in high plots than in low plots. In contrast, annual ryegrass (*Lolium perenne* ssp. *multiflorum)* showed high constancy in both high and low plots.

Constancy of many exotic grasses fluctuated widely from year to year in both grazed and nongrazed high and low plots (*table 14*). In 2007, nongrazed high plots had significantly higher constancy of ripgut brome and annual ryegrass than grazed high plots (Wilson / Newcombe test), but constancy did not differ in other years (*table 14*). Wild oat followed the opposite trend, being more common in grazed than nongrazed high plots only in 2007. In low plots, annual ryegrass and *V. myuros* showed single year differences in constancy between grazed and nongrazed plots. Significant differences in constancy were not seen in multiple years for any species. These results indicate that cessation of grazing for up to three years did not cause strong shifts in the presence of common exotic grasses.

Comparisons between nongrazed multiyear control and grazed plots

Table 14. Constancy (percent of plots containing a given species) by plot position, grazing/nongrazing and year for the most commonly occurring exotic grasses. Light gray highlight indicates constancy between 20 and 49%; darker highlighting indicates constancy of 50% or higher. Within columns, significant differences between grazed and nongrazed plots for a given year and plot position (high/low) combination are noted with asterisks. Number of plots per treatment per year = 24.

	Year	*Briza minor*	*Aira caryo-phyllea*	*Bromus diandrus*	*Bromus hordeaceus*	*Hordeum* spp. (exotic)	*Lolium perenne* ssp. *multiflorum*	*Avena fatua*	*Vulpia myuros*
Low, Nongrazed	2004	8	13	0	42	50	96	13	25
	2005	21	29	0	33	42	92	17	46
	2006	17	21	8	38	33	96*	17	17
	2007	0	8	13	54	71	100	4	21*
Low, Grazed	2004	8	8	0	58	21	100	8	21
	2005	4	21	0	33	29	92	17	21
	2006	8	17	4	17	8	54*	8	21
	2007	13	25	4	63	50	96	17	54*
High, Nongrazed	2004	21	17	75	88	21	67	33	67
	2005	33	25	79	92	25	92	67	88
	2006	25	21	67	96	25	92	17	83
	2007	8	0	83*	92	29	96	13*	42
High, Grazed	2004	1	0	67	88	25	75	38	67
	2005	17	17	75	83	8	88	79	79
	2006	21	17	54	92	21	88	33	71
	2007	21	4	50*	96	42	75	42*	42

DISCUSSION

At the outset of the study, we identified six hypotheses to be addressed by the study. These are listed in *table 15*, along with specific results and conclusions as to whether the study results support each hypothesis. Hypotheses 1 through 5 were generally supported by the results of the study. Hypothesis 6 was only supported in part. If the scope of hypothesis 6 is restricted to low plots, it is generally supported by the data as well.

Hypothesis 2 presents a unique situation because the dichotomy suggested by the original hypothesis did not really exist for this experimental system. To quantify grazing impact, we compared the height of grazed plots with that of nongrazed mowed plots throughout the grazing season. However, because most of the vegetation height growth and biomass accumulation occurs late in the growing season (*fig. 4*), aggregate variables such as January-April grazing impact have an implicit weighting. January and February grazing (when vegetation is short) always contributes less to the season-long grazing impact than does March and April grazing (when vegetation is taller) for a given percentage of height reduction. Hence, in a practical sense, it is difficult to separate the effects related to total biomass removal from effects related to the timing of grazing impacts. Nonetheless, study data clearly indicate that various vegetation outcomes are influenced strongly by the timing of grazing impacts. The hypothesis, if restated as follows, is clearly supported by the study: vegetation change outcomes are influenced by both the intensity and timing of grazing impacts.

Table 15. Study hypotheses listed in the original study design, summary of study results that address the hypotheses, and conclusions indicating whether study data support the hypotheses.

Hypothesis	Results pertaining to hypothesis	Conclusion
1. Changes in the initial and final vegetation states for a given growing season will vary with the seasonal grazing profile.	**High and low plots** - plant height and biomass varied by grazing profile - no effect of grazing profile on species richness **High plots** - no effect of grazing profiles on native plant cover. **Low plots** - change in native plant cover was affected by grazing profiles; increased grazing intensity associated with lower native plant cover.	Within range of grazing profiles tested, only some vegetation outcomes were influenced by grazing profiles.

Hypothesis	Results pertaining to hypothesis	Conclusion
2. Grazing profile variables that include a temporal element (timing of grazing impact) will be better predictors of vegetation change outcomes than variables that only measure total biomass removal.	All grazing variables include a temporal element to some degree: total biomass removal was confounded with time because most plant biomass is produced late in the growing season. **High and low plots** – biomass and plant height measurements generally show influence of temporal variables. April height varied by grazing profile. August RDM was affected mainly by late (April-August) grazing. **Low plots** – timing of grazing impacts influenced change in native cover; grazing during peak spring bloom showed strongest negative impact on native cover change.	All grazing variables tested were influenced by the timing of grazing, so even variables measuring total biomass removal include some temporal information. Grazing variables that include explicit temporal information were better explanatory variables for most vegetation outcomes. Vegetation outcomes affected by grazing were influenced by both the intensity and timing of grazing impacts.
3. Weed-dominated (high) and native-dominated (low) experimental units will show different responses to grazing variables.	**High plots** – only vegetation height, RDM and mulch height were affected by grazing profiles. Complete cessation of grazing for 3 years resulted in slight decrease in native cover and a small reduction in native species richness. **Low plots** - vegetation height, RDM, mulch height and native cover were affected by grazing profiles. Complete cessation of grazing resulted in large reduction in native cover by second year, and a large reduction in native species richness by the third year.	High and low plots showed clear differences in their response to grazing. Native cover in weed-dominated high plots showed little response to widely differing grazing intensities. Native cover in native-dominated low plots showed adverse effects due to both high grazing impacts and prolonged cessation of grazing.
4. Different grazing profiles are likely to occur between weed- and native-dominated (high and low) experimental units within plot sets.	Grazing impacts on adjacent high and low plots differed substantially in response to various conditions: - low plots had reduced grazing impacts relative to high plots if grazing occurred while low plots were inundated; - early in the season, high plots with high amounts of residual dry matter were grazed less than adjacent low plots; - low plots were grazed preferentially late in the growing season due to reduced palatability of flowering and senescent grasses in high plots.	In general, grazing impacts on high and low areas are quite different. Weather conditions, inundation, and plant phenology strongly influence the magnitude of this difference.

Hypothesis	Results pertaining to hypothesis	Conclusion
5. Thatch /mulch accumulation/ removal will vary with grazing profiles.	**High and low plots** – both mulch height and August RDM were significantly affected by late season (May-June) grazing: - cessation of grazing led to progressive increases in mulch height, which were initially evident after 1 year; -RDM in nongrazed plots was significantly greater than in grazed plots; the effect was significant from the first year that grazing was stopped.	Different grazing profiles differed somewhat with respect to mulch accumulation, but as expected, cessation of grazing led to substantially higher levels of mulch accumulation
6. Compared with nongrazed units, grazed units will have lower weedy cover and increased native species cover.	**High and low plots** – in 2007, grazed plots had more exotic species than nongrazed plots. In both 2006 and 2007, grazed plots also had more native species than nongrazed plots. **High plots** – native cover in nongrazed plots did not differ from grazed plots until 2007, after 3 years of exclosure, and differences were still small. Exotic cover did not differ between grazed and nongrazed plots. **Low plots** – nongrazed plots showed decreased native cover and increased exotic cover compared to grazed plots starting in 2006, after 2 years of exclosure.	Nongrazed low plots generally develop greater weedy cover and less native cover if left ungrazed for multiple consecutive years. High plots may or may not show a decline in native cover without grazing because native cover is often very low or lacking even in the presence of grazing.

High versus low topographic positions

A key issue that affects the management of Jepson Prairie's grazed grasslands is the profound difference that exists between the high and low microtopographic units that are interdigitated within pastures. These units support different species associations in large part because of their differing soils and hydrologic regimes. As shown in this study, sheep grazed adjacent high and low microtopographic positions differently at various times during the season.

In 2005 and 2006, low plots were flooded for extended periods early in the growing season. In fields that were grazed during these periods, sheep grazing in the low plots was curtailed, resulting in higher relative vegetation utilization in high plots. However, in the absence of inundation, early season grazing impacts in high and low plots were either similar or greater in low plots. In 2007, low plots remained dry due to low rainfall throughout most of the spring, and early season vegetation utilization in low plots was greater than that in high plots (*fig. 10*). The same effect was seen in dry periods during 2006. Although the vegetation in high and low plots may be similarly palatable early in the season, high plots often have more previous-year plant residues present than do the low plots (*fig. 16*), which may deter sheep from grazing the high plots as strongly.

Later in the season, relative utilization of the vegetation in the high plots declines because exotic grasses that are common on the high plots, such as ripgut brome and medusahead, begin to

flower and senesce and become less palatable. Thus, across the entire grazing season, overall grazing impacts to the low positions will tend to be greater than impacts to the high positions unless sheep are only present on fields during periods of maximum inundation,

Due to the predominance of fast-growing exotic grasses in high plots, total vegetation height in the high plots generally exceeded that of the low plots by January (*fig. 4*) and typically remained higher for the duration of the season. Data from this study indicate that under sheep grazing regimes similar to the ones used in this study, vegetation in the high positions will normally be taller than that in the low positions over the growing season.

All of the grazing regimes we tested had more impact on native cover in low plots than in high plots (*table 16,* Swiecki and Bernhardt 2006, 2007), with greater January-April grazing intensities being associated with more negative impacts to native cover in low plots. It is not clear that any practical sheep grazing regime could be implemented at Jepson Prairie that would result in greater impacts on vegetation in the high areas than in the low areas over the entire growing season.

Influence of environmental conditions

Changes in the initial and final vegetation states in Jepson Prairie grasslands each year depend strongly on weather variables. Virtually every vegetation variable we tested showed significant differences attributable to year (*table 16*) that were directly related to total rainfall, periods of inundation in the low plots, and/or temperature. Most of the vegetation changes related to weather were apparent across the range of grazing intensities tested, including nongrazed plots, and affected both high and low plots. Overall, the magnitude of weather-related changes in vegetation exceeded that produced by altering grazing treatments. Only cessation of grazing for 2-3 years produced effects on vegetation that were on par with those associated with year to year weather differences seen over the three years of the study.

Although weather conditions varied across the three years of the study, the level of climate variation represented in this time span is only a fraction of that historically represented at the site or possible under future altered climate conditions. Because weather effects exert such a strong influence on vegetation outcomes and only a relatively narrow range of weather conditions can be represented in a small sample of years, three years constitutes a bare minimum duration for a meaningful grazing study. Five years is a more reasonable minimum duration for grazing management studies. Longer study periods provide both a greater variety of weather conditions and allow better estimates of the strength of grazing-related factors across these various conditions. Our results clearly support the concept that weather-related effects can exceed and potentially mask (Jackson and Bartolome 2002) or even reverse the effect of grazing or other management inputs in any given year. In this study, the number of exotic species in low positions plots was greater in grazed than in nongrazed plots in 2007, a dry year, reversing the effect seen in 2006, a wet year.

Because plant cover variables can be significantly affected by weather, the study was designed to minimize the chances that random fluctuations in plant cover would be erroneously attributed to grazing variables. The use of paired grazed plots and nongrazed controls allowed us to more

readily identify trends that were unrelated to the grazing impacts and account for these in the models.

Table 16. Summary of statistically significant effects on vegetation outcomes in multiple year analyses.

	High plots			Low plots		
	Weather	Grazed/ nongrazed	Grazing variables	Weather	Grazed/ nongrazed	Grazing variables
Biomass, RDM and mulch						
- April vegetation height	✓	--	Jan-Apr (-), mult profiles	✓	--	Jan-Apr (-), mult profiles
- August RDM	✓	grazed↓	Apr-Aug (-)	✓	grazed↓	Apr-Aug (-)
- Mulch height	✓	grazed↓	Apr-Aug (-)	✓	grazed↓	Apr-Aug (-)
- Mulch cover	✓	grazed↓	--	✓	grazed↓	--
Native cover / richness						
- All native cover	✓	grazed↑	ns	✓	grazed↑	Jan-Apr (-), Mar-Apr (-), mult profiles
- native spp count	✓	grazed↑	ns	✓	grazed↑	ns
Weedy cover / richness						
- medusahead cover	✓	ns	--	✓	ns	--
- all exotic cover	✓	ns	--	✓	grazed↓	--
- exotic species count	✓	ns	--	✓	ns	--

-- = not tested; ns=no significant effect
✓ = significant effect of year
grazed↓= significant effect, grazed lower (↓) or higher (↑) than nongrazed;
Jan-Apr (-) = Jan-Apr grazing impact significant, effect direction negative.
Mar- Apr (-) = Mar-Apr grazing impact significant, effect direction negative.
Apr-Aug (-) = Apr-Aug grazing impact significant, effect direction negative.
mult profiles = multiple year grazing profiles based on Jan-Apr grazing impacts in one year but using patterns from all
    3 years of study;
* model based on 2006 and 2007 data only

Differences in vegetation outcomes within grazed plots

Grazed plots of a given microtopographic position (high or low) showed differing grazing impact profiles within and between fields, with season-long grazing intensities ranging from 0 to 90% residual dry matter removal. The timing of grazing impacts also varied substantially among these plots. These findings support one of the underlying assumptions of the study design, that fields experience a non-uniform mosaic of grazing impacts.

Different grazing profiles and grazing impact variables were associated with significant effects on vegetation height and biomass, August RDM, and mulch depth (*table 16*). However, for the most part, differences in biomass removal between grazed plots did not translate into differences in native or exotic plant cover. Effects of differential grazing impacts on plant cover were only seen in the low plots. For all significant grazing profile and intensity variables, higher levels of

grazing during January-April in the low plots were associated with reductions in native cover. In contrast, in high plots, varying levels of grazing did not significantly alter native cover levels. The lack of effect on native plant cover in high plots was not simply due to insufficient grazing pressure. In the high plots with the greatest grazing impacts, both vegetation height and RDM levels were similar to those seen in some of the low plots, but this level of reduction in plant biomass did not elicit a significant change in the composition of the vegetation. Within the range of grazing impacts observed, higher grazing intensity did not increase native cover or richness or reduce exotic cover in either high or low plots.

In a study on upland grasslands, grazing treatments varying in intensity and duration did not affect native cover or native species richness in nonburned plots (Marty 2002), similar to what we observed in high plots. In a different study on cattle-grazed vernal pool habitats, Marty (2005) observed some significant differences in relative native cover and absolute exotic cover between plots in upland and pool edge sites, but not within pools. Actual levels of grazing impact in the different grazing regimes were not reported.

Differences in vegetation outcomes in grazed vs. nongrazed plots

Within the first season that exclosed plots were released from grazing pressure, vegetation height (*fig. 24, 25*) and RDM (*fig. 26*) in the nongrazed plots increased significantly above levels in the grazed plots. Both high and low plots showed similarly large differences between grazed and nongrazed plots with respect to vegetation height and RDM.

In high position plots, large differences in plant biomass did not give rise to correspondingly large changes in native cover or species richness. For example, in both 2006 and 2007, August RDM in the grazed high plots was less than that in the nongrazed low plots (*fig. 26*), yet both native species cover (*fig. 28*) and richness (*fig. 36*) were higher in the nongrazed low plots than in the grazed high plots. Beginning in the first year after grazing cessation, RDM in grazed plots was 30 to 50 percent less than that in the nongrazed plots. Over the same period, exotic cover in the grazed plots did not differ from that in nongrazed plots (*fig. 28*). Native cover in grazed plots was elevated slightly above that seen in nongrazed plots in 2007, but this difference was primarily due to higher saltgrass cover in the grazed plots. Native species richness, though very low overall, averaged one native species more per plot in grazed than nongrazed plots in 2006 and 2007.

Exotic grasses remained the dominant cover in high plots when subjected to varying levels of grazing as well as when plots were left ungrazed for three years. Many of the exotic grasses are both highly competitive and not preferred by sheep, especially later in the season. Furthermore, we did not observe any native species in the high areas are that were both especially competitive and avoided by sheep. Hence, it seems unlikely that higher levels of grazing than those tested are likely to result in the displacement of exotic cover by native species in high sites similar to those included in the study. The slight differences in native species richness and cover seen between grazed and nongrazed high plots show that grazing provides some benefit to native species in these sites. However, this slight benefit may be near the maximum effect that can be expected given the dominance of exotic vegetation on the high areas.

Low plots showed much more substantial decreases in native cover and richness due to the cessation of grazing, but the appearance of these effects lagged behind biomass-related changes by at least a year. Significant differences in native and exotic cover and native species richness first developed in 2006 and persisted into 2007 (*fig. 28, 36*). Three years after grazing ceased in low position plots, both native cover (*fig. 28*) and native species richness (*fig. 36*) were significantly lower in nongrazed plots than in grazed plots.

These changes were related to increased growth of exotic grasses in the low nongrazed plots (*fig. 29*). In both 2006 and 2007, exotic grass cover in nongrazed plots was substantially higher than in grazed plots. Most of the increase in exotic grass cover in nongrazed low plots was due to annual ryegrass, which grew quite rampantly in many plots when it was not checked by grazing. Annual ryegrass, a facultative wetland species, was the exotic species that seemed to be the best adapted to growing in the low position plots. In comparison, after three years, medusahead remained at a low percent cover in low position plots, and did not differ significantly in cover between grazed and nongrazed plots (*fig. 33*). Also, exotic forb cover did not differ between low grazed and nongrazed plots until 2007, when grazed plots showed an increase in exotic forb cover (primarily *Erodium* spp.; *fig. 24, 32*). Although sheep graze both grasses and forbs, the primary beneficial effect of sheep grazing that we observed in this system was suppression of annual ryegrass.

Comparisons between grazed and nongrazed low plots showed that cessation of grazing resulted in negative effects on native cover and native species richness by the second year that plots were excluded from grazing. However, among grazed plots, higher grazing intensities in January-April had negative effects on April native cover (*fig. 18, 19*). Taken together, these results suggest that while grazing suppresses annual ryegrass and promotes native cover, the amount of grazing needed to provide this effect is relatively low. Not only did plots with low grazing impacts have more native cover than plots with higher impacts, but negative impacts on native cover and species richness associated with cessation of grazing were not seen until the second nongrazed year. This suggests that low areas can periodically be left ungrazed for a year without a strong negative effect on native cover or richness.

With the exception of annual ryegrass, exotic species in the plots at Jepson Prairie are not as well adapted to the spring flooding that occurs in the low areas as are the native vernal pool species. *Lepidium latifolium*, another pool-adapted invasive exotic, was not present in any of our plots. While native species may tolerate sporadic grazing such as that imposed by the original native herbivores, they do not show any particular adaptation to prolonged grazing and showed reduced cover as grazing impact increased. Hence, periodic inundation of low areas, rather than grazing, provides the primary selective force to maintain native species dominance in these areas.

Under relatively light and/or sporadic grazing, adverse impacts to most native species are minimal but annual ryegrass is suppressed, which further augments the competitive advantage of the native species. However, in a dry year such as 2007, the lack of flooding improves the competitive abilities of exotic species and disfavors the native species. If fields are grazed when low areas are not inundated, the native species tend to be more strongly impacted than is the grazing-tolerant annual ryegrass, leading to reduced native cover and increased exotic cover. Also, low grazed plots showed a sharp increase in exotic species richness between 2006 and

2007, whereas nongrazed plots, which generally had more thatch on the soil surface, showed a smaller increase in exotic species richness (*fig. 36*). Grazing reduces thatch and exposes bare mineral soil, which can create more favorable seedbed conditions for germination of annuals that are favored by soil disturbance, as is the case for many exotic annuals.

Several studies cited in Barry (1998) have also shown that cessation of grazing is associated with a decrease in native species cover and/or richness in California grasslands. Marty (2005) noted higher cover of exotic annual grasses and lower relative cover and richness of native species in vernal pools excluded from grazing for three years compared to cattle grazed pools. Similarly, nongrazed plots on serpentine soils had lower native species richness than grazed plots (Harrison et al 2003). In a situation analogous to that seen in the low plots, native species have a competitive advantage over exotic species on serpentine soils. On nonserpentine soils, which are analogous to our high plots, grazed plots showed reduced native species richness compared to nongrazed plots (Harrison et al 2003). However, in our study, high grazed plots had slightly higher native species richness than nongrazed high plots. In the first two years of her study, Harrison (1999) did not detect a difference in native species richness between grazed and nongrazed areas on either serpentine and nonserpentine areas. This suggests that other factors, including a fire that affected a portion of the plots after the 1999 study and/or variation associated weather conditions, may accentuate or dampen out effects of grazing, as was seen in our study.

Grazing plan goals stated in the RFP

The original RFP indicated several overall goals of the grazing program at Jepson Prairie. Relative to residue management, the RFP set a goal of reducing mulch by 30% over 10 years. In 2007, grazing had the effect of reducing RDM by 63% in the high areas and 77% in the low areas relative to the nongrazed controls. These reductions exceed the goals given in the original study RFP. The difference achieved in 2007 was the largest difference seen over the three years in which the grazing study was conducted, but even the first year after grazing ceased, RDM in the grazed plots averaged 50% of that in the nongrazed plots.

The second goal of the grazing program was to promote an increase in cover of representative upland vegetation by 20% over a 10 year period. The small absolute difference seen in native species cover between grazed (4.6%) and nongrazed plots (1.5%) in 2007 actually exceeded the 20% criterion when expressed as a relative increase. However, key upland native species such as *Nasella pulchra* have not shown differences in cover between the nongrazed and grazed plots (*fig. 30*). Recent reports (Dyer 2003, Marty and others 2005) indicate that responses of *N. pulchra* to grazing are complex and may not be apparent in short-lived experiments such as this one. Although grazing can benefit *N. pulchra* by removing competition from exotic grasses (Dyer 2003, Marty and others 2005), browsing can also reduce height and reproduction of mature bunchgrasses (Marty and others 2005). *N. pulchra* was observed to be preferred when grazing occurred in summer and there was no other green forage (Dyer 2003).

In 2007 the largest contributor to native cover in the high plots was saltgrass, in the two previous years with higher rainfall, *Juncus bufonis* and native clovers contributed to native cover in high plots. Although year to year variability due to weather tends to complicate the picture, it appears that native species richness was slightly greater in grazed high plots than in plots left nongrazed

for several years. However, species that are highly suppressed or eliminated by grazing, such as soaproot (*Chlorogalum pomeridianum*) were generally lacking in the area prior to the start of the study, so long-term effects on native species richness in high areas cannot be inferred from this relatively short study.

The third goal of the RFP was to reduce target weed abundance and cover by 30% over a period of 10 years. Target weeds listed in the RFP included yellow star thistle, purple star thistle, medusahead grass, and barbed goat grass. Only medusahead grass was common enough in the three fields included in the study to be included in the plots, but cover of this species was not affected by grazing in either the high or low plots.

Recommendations for grazing regimes at Jepson Prairie

This study confirms previous work showing that cessation of grazing results in a loss of native cover and richness, primarily in low microtopographic areas subject to periodic flooding. However, within the range of grazing regimes tested, no particular grazing regime was clearly superior. Increasing grazing intensity was generally associated with negative impacts on native cover in the low areas, especially when it occurred when the low areas were not flooded or when native annuals were near peak bloom. Plant cover and richness in the high areas were not substantially affected by levels of grazing that reduced August RDM by 63% on average compared to nongrazed plots. It is therefore likely that increasing grazing pressure beyond levels seen in the study could increase adverse impacts to native cover in low areas without providing substantial improvement to native cover in the high areas.

Taken together, these observations indicate that (1) grazing practices similar to what have been used on the Preserve are providing a large benefit relative to maintaining native cover and richness in playas, pools and swales and (2) it may not be possible to further improve native cover and richness by varying sheep grazing regimes. It also appears that relatively low levels of grazing may be adequate to provide near maximal benefits that can be obtained by grazing.

Since most of the benefits provided by sheep grazing appear to be attainable at relatively low grazing intensities, the primary issue to consider in grazing management at the preserve may be to minimize negative impacts. This suggests the following guidelines for the grazing program:

1. Fields that have not been burned in the previous year should normally be grazed to some extent; however, an interruption of grazing for a single season can be imposed if necessary for some other reasons, without long term adverse effects.
Note the following data gaps relative to this guideline:
- our data do not provide information on impacts of grazing in the year after a burn;
- we have shown no significant changes in native cover after a single season of rest from grazing, but do not know how often a rest year can be imposed without impacting native cover.

2. Minimize grazing impacts to any given field during the peak bloom period, which may range from late March through late April depending on the year. Avoid grazing that reduces April vegetation height in low positions below 4 to 6 inches.

3. In dry years, avoid long grazing periods and heavy grazing impacts in individual fields if pools and swales are dry.

4. Maximum grazing impacts (duration and stocking) are best applied during periods when pools and swales are likely to be flooded and will therefore be avoided by sheep.

5. Stocking levels within the range of those used in this study (0.15-0.95 AUM per acre) should be acceptable, with the general consideration that heavier stocking can be used in more productive years, lighter stocking should be used in less productive years. Our data do not indicate that higher grazing impacts have an advantage over lower impacts with respect to favoring native cover and richness. Hence, any use of higher grazing intensities over the long term should be done in conjunction with sufficient multi-year monitoring to ensure that native species are not adversely impacted.

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