Effects of grazing on upland vegetation at Jepson Prairie Preserve, Solano County, CA

Second year (2006) results

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EXECUTIVE SUMMARY

The purpose of this study is to test whether the current sheep grazing regimes at Jepson Prairie Preserve 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. 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. This progress report presents results from the second year of this three year study.

Eight plot locations were established in each of three adjacent fields. Each field was grazed with a different prescribed grazing regime. The amount of forage removed over the season for each plot location was determined by measuring forage height in adjacent grazed and nongrazed plots. First-year data showed that adjacent high and low plots within fields were grazed at different intensities by sheep. This effect was also observed during the second year of the study. Weed-dominated high plots were grazed preferentially when the low-lying native-dominated areas were flooded. As the season progressed and the exotic grasses began to dry out and set seed in the high plots, sheep preferentially grazed the native-dominated low plots.

The amount of forage removed from each grazed plot over the season was incorporated into a grazing profile variable. Grazing profiles varied among plots within fields that had the same topographic position (high or low). Some plots in different fields were more similar with respect to their grazing profiles than were plots within the same field.

A baseline assessment of native and exotic cover and species diversity was conducted in late April 2004 prior to the start of the experiment. Cover was reassessed again in April 2005 and 2006. Cover of native and exotic species in high plots was not significantly affected by different grazing profiles and did not differ between grazed and nongrazed plots overall. However, compared to the 2004 baseline assessment, native cover was significantly reduced and exotic cover increased in low plots that had not been grazed for two years. As was seen in 2005, low plots that were grazed heavily during the peak spring bloom period (late March and April) in 2006 had reduced native cover and increased exotic cover. However, plots that were grazed heavily during bloom in 2005 but only lightly during bloom in April 2006 rebounded to near 2004 cover levels. Within-season grazing profiles were better predictors of vegetation outcomes in low plots than were grazing profiles that included grazing that occurred in the previous year.

After one growing season, high and low plots excluded from grazing had substantially more residual dry matter (RDM) in August than did plots that were grazed. This difference continued in 2006, but the difference between the grazed and nongrazed plots was not statistically greater in 2006 than in 2005. Mulch levels were also greater in grazed plots overall than in nongrazed.

Overall, the study to date has demonstrated substantial effects associated with cessation of grazing. All the grazing prescriptions tested, including very low intensity regimes, showed substantial differences in weedy cover in low plots, and thatch accumulation in high and low plots, compared to nongrazed plots. However, none of the grazing treatments tested to date appear to constitute an improvement over the pre-experiment grazing regimes.

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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 ongoing 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, other 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 point(s) 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 (and other grazers) 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 (a) varying the timing and/or intensity of grazing impacts will differentially affect the competitive abilities of certain species and (b) this change in competitive advantage will alter the total cover achieved by various species. The purpose of this study is to determine 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 currently-used grazing regimes.

The study described here was initiated in 2004, at which time we established plots and collected baseline data on cover and other vegetation parameters. Experimental grazing treatments and associated data collection began in 2005. Baseline and first year (2005) results were presented in a report completed in January 2006 (Swiecki and Bernhardt, 2006). This report presents results through the end of the 2006 grazing year. One more year of data collection for the 2007 grazing season is currently planned. The study is funded by a grant from the California Bay Delta Authority and additional support from the Solano County Water Agency.

METHODS

Although the overall design of the experiment has been described previously (Swiecki and Bernhardt 2004), some of the 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.

The experiment was established in three adjacent fields, known as field 20East or east eucalyptus (EEuc); field 19East or east north section 24 (EN24); and field 18East 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 cluster location in each field. Subsequent candidate cluster 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 cluster areas in the fields. Upon reaching a candidate cluster location, we determined whether we could establish three plots (1 m^2 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 clusters in each field. The final distribution of the selected cluster locations is shown in Figure 1.

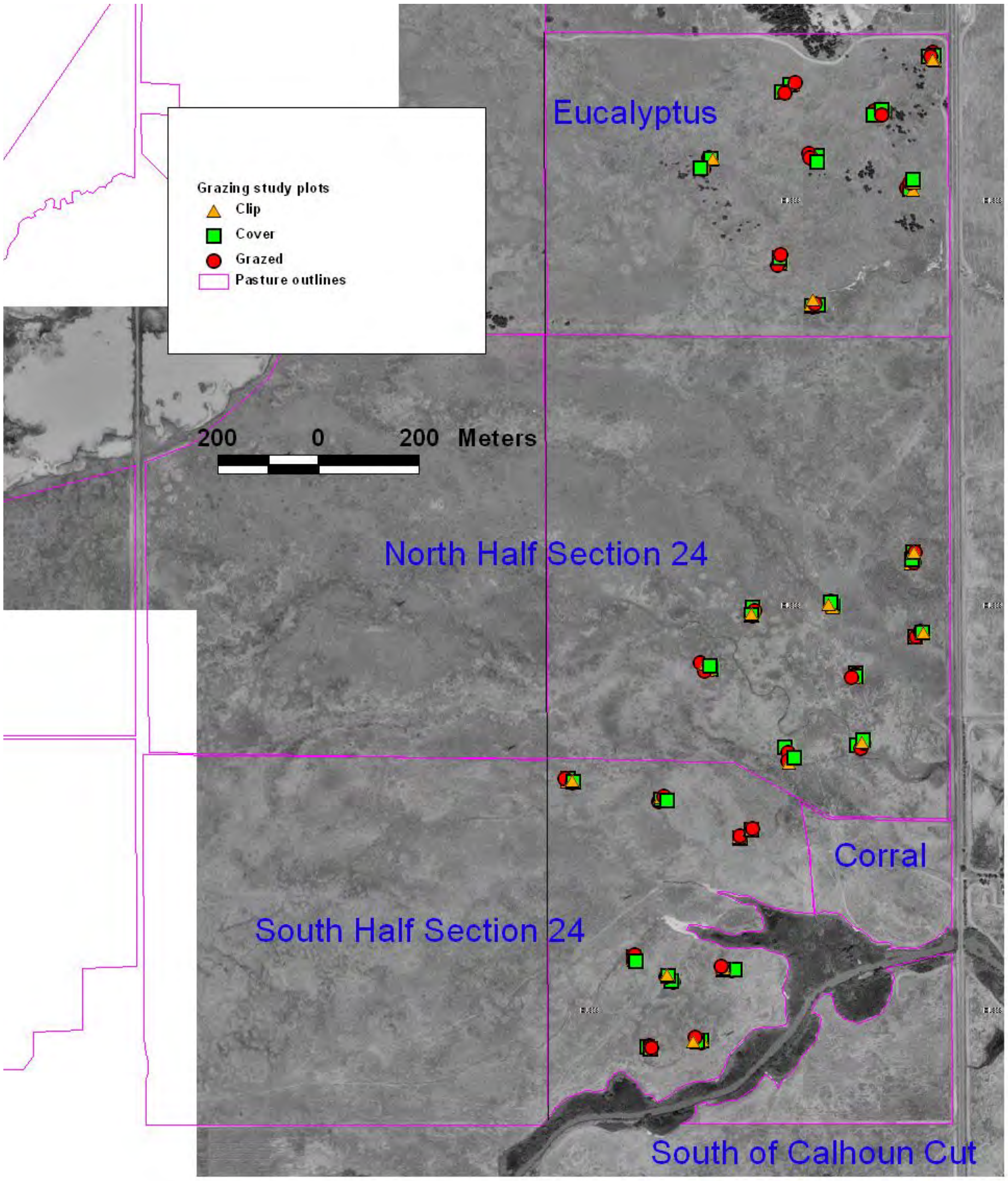

Figure 1. Plot cluster locations. The different symbols indicate different plot types (grazed, nongrazed cover, nongrazed clip) within the clusters.

The six plots in each cluster are in relatively close proximity to each other to ensure that all plots within each cluster had the same potential grazing exposure. The separation between plots in a cluster ranges from less than a meter (e.g., between adjacent high or low plots) to about 28 m (maximum distance between high and low plots in a single cluster). Given the size of the flocks used on these fields (about 140 to 560 head in 2005) and the fact that sheep tend to be somewhat attracted to the exclosures, plots within a given cluster had the same potential exposure to the flock as it moved around the field.

Plot setup

Within each cluster, each set of three plots (high or low) was matched to the degree possible for vegetation characteristics, including plant height, species composition, and cover. The three plot types designated in low (swale/pool) and high (upland) halves of each cluster were:

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

Nongrazed cover plot: excluded from grazing by fencing; used to measure cover and composition changes and thatch accumulation in the absence of grazing. This treatment is effectively a multiyear nongrazed control. The exclosures for cover plots are 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 clip plot: excluded from grazing by fencing; used as reference plot to estimate the amount of forage removal occurring each month in the matched grazed plot. Forage in this plot was manually clipped as needed at each observation date to maintain average forage height within 5 cm of the average forage 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 could be established, plots 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 clip plots treatments so that grazing impacts on overall vegetation height could be estimated 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 meter square point frame that is used to collect cover data fit directly over the carriage bolts, so the frame can 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 cluster 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 cover plots and the nongrazed clip plots. Exclosures are 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 is secured to the posts with plastic cable ties, which are readily removed when removal of the cage is necessary.

Grazing

The initial grazing plan developed by SLT and members of the Jepson Management Committee (JMC) was not fully implemented in 2005 (Swiecki and Bernhardt 2006). For the 2006 grazing year, the JMC decided to replicate the grazing that occurred in 2005, with one exception. Field

20E was grazed at only 17 AUM in 2005, and only in January and February, instead of the 75 AUM season long grazing called for in the plan. For 2006, grazing also occurred in March and was increased to 30 AUM. The grazing plan for 2006 is shown in *table 1*.

Table 1. Grazing plan for the 2005-2006 grazing season. The plan called for replicating the grazing that occurred in the 2005 grazing season, with the addition of 10 additional AUM before March 15 in 20E.

Field		**Jan-06**	**Feb-06**	**Mar-06**	**Apr-06**	**May-06**	**Jun-06**
18E	Grazing dates	-	21-27	2-7	-	16-30	9-19
	# of Head		216	216		547	202
	AUM		8.40	10.27		36.59	12.34
19E	Grazing dates	2-12	17-20	14-18	7-18, 20-30	1-13	-
	# of Head	142	216	365	345, 467	467	
	AUM	8.68	4.80	10.00	48.94	33.73	
20E	Grazing dates	12-24	11-16	before March 15	-	-	-
	# of Head	141	249				
	AUM	9.40	8.30	10.00			

Data collection

Grazing impact measurements

To estimate grazing impacts over the growing season in grazed plots, forage height measurements were made in both grazed and nongrazed clip plots over the following dates in 2006: 4-6 January, 14-16 February, 16-18 March, 25 April-2 May, and 8-11 August. All plots were photographed at each observation interval. At each observation period, 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*).

Average standing forage 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 lifted about 30 cm above the maximum forage height and allowed to drop freely; a second measurement was then made on the forage 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 forage biomass than does average forage height.

Figure 2. Falling plate meter in grazed plot.

If the average forage height in the nongrazed clip plot exceeded that of the paired grazed plot by 5 cm or more, forage in the nongrazed clip plot was mowed to match the height of the grazed plot. We used a battery-operated string trimmer to mow the clip plot. 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, the forage height in the clip plot was remeasured as noted 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 and between 25 April and 2 May 2006.

For the nongrazed cover 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, thatch (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 or other exotic grasses. Cover was assessed on a first hit basis, so total cover for the plot sums to 100%.

In addition, for all plots, we noted all plants 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 forage height and compressed forage height were also measured in all plots at this time, using the falling plate meter as described above.

Summer assessments

In August 2004, 2005, and 2006, after grazing for the season was complete and all spring annual vegetation was completely dry, we revisited each plot and noted the presence and cover of summer annuals that were not visible in April. All plots were photographed.

In 2004 and 2005, we estimated residual dry matter (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, the falling plate meter was used in 2005 and 2006 to measure average forage height and compressed forage height at five points in each plot as described above. Thatch height was also measured at five points in each plot using a measuring tape.

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

The 2005 data showed that RDM was significantly ($p<0.0001$) correlated with the falling plate reading, August grass height, April bare cover and 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 predict 2006 RDM. The calculated RDMs for a sample of the plots were checked against photo standards with known RDMs developed in 2004.

Data analysis

Calculation of grazing impact — For the first reading in January, the difference between forage heights in the grazed and nongrazed clip plots was used directly to calculate the grazing impact to that point (Equation 1). Grazing impacts were expressed as the percent of the potential forage 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 clip plots were mowed at the start of a time interval, forage height after mowing was used as the initial (t_1) nongrazed forage height.

$$\textit{grazing impact}_{t_1 \rightarrow t_2} = \frac{(t_2\,height_{nongrazed} - t_1\,height_{nongrazed}) - (t_2\,height_{grazed} - t_1\,height_{grazed})}{(t_2\,height_{nongrazed})} \times 100$$

(Equation 2)

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

Construction of grazing profiles — Grazing impacts from each time interval for each grazed plot constituted the grazing impact for that plot. We used hierarchical clustering to group plots with similar grazing profiles. Because high and low plots differ substantially in many ways, hierarchical clustering 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 $p \leq 0.05$. Effects of year and grazing variables were tested using repeated measures analysis of variance. 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 analysis were used for specific comparisons between paired observations.

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 unpaired. 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.

Outcomes of this test (significant increase, no change, significant decrease) were placed into contingency tables by grazing profile and subjected to contingency table analysis. Because many of the individual cells in the resulting contingency tables had low cell counts, the confidence levels calculated through standard chi square tests are not considered to be reliable. To compensate for the small sample size, we used a program (Exact Test version 1.0.0.2; 10, EDNData, http://www.exact-test.com/) that utilizes Monte Carlo simulation to estimate the exact P level for several tests of independence in the contingency table. We report the probability for the Monte Carlo estimate of the Fisher's exact test criterion, although the significance level of this test was usually very close to that of the Monte Carlo estimate for the likelihood ratio test. Monte Carlo estimates were based on 1×10^6 iterations.

RESULTS

Overall grazing regimes

Although the grazing plan for 2006 was intended to replicate the grazing pattern that occurred in 2005, the 2006 grazing regimes differed substantially from the plan in two of the three fields (*fig. 3, 4*). Field 20E was grazed according to the 2006 prescription (*fig. 3*); the grazing pattern from 2005 was roughly replicated and additional grazing was added in early March as called for in the plan. In 19E, 2006 grazing was very low in the critical month of April compared to levels in 2005. In 18E, the grazing pressures for May and June 2006 were reverse of what they had been in 2005. Overall, grazing pressure was lower in fields 19E and 20E in 2006 than had been achieved in 2005 (*table 2*). Grazing that occurred prior to the start of the study in 2003 and 2004 is shown in Table 2 for comparison.

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 our field observations made during evaluations. For example, parts of fields 18E and 19E were grazed in early January because gates connecting these fields to another had been left open, but this grazing does not appear in the grazing record. We had also observed sheep on pastures during some evaluation dates that were not reflected in the grazing records. In such cases, we have adjusted the grazing periods to reflect our field observations. Although we believe the grazing records are generally accurate, it is possible that the grazing records do not include all of the periods when sheep were present on the fields.

Table 2. 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**	**2003**	**2004**	**2005**	**2006**
18E	68	64	0.71	0.77	0.94	0.89
19E	106	86	0.40	0.27	0.6	0.49
20E	18	30	0.16	0.34	0.15	0.26

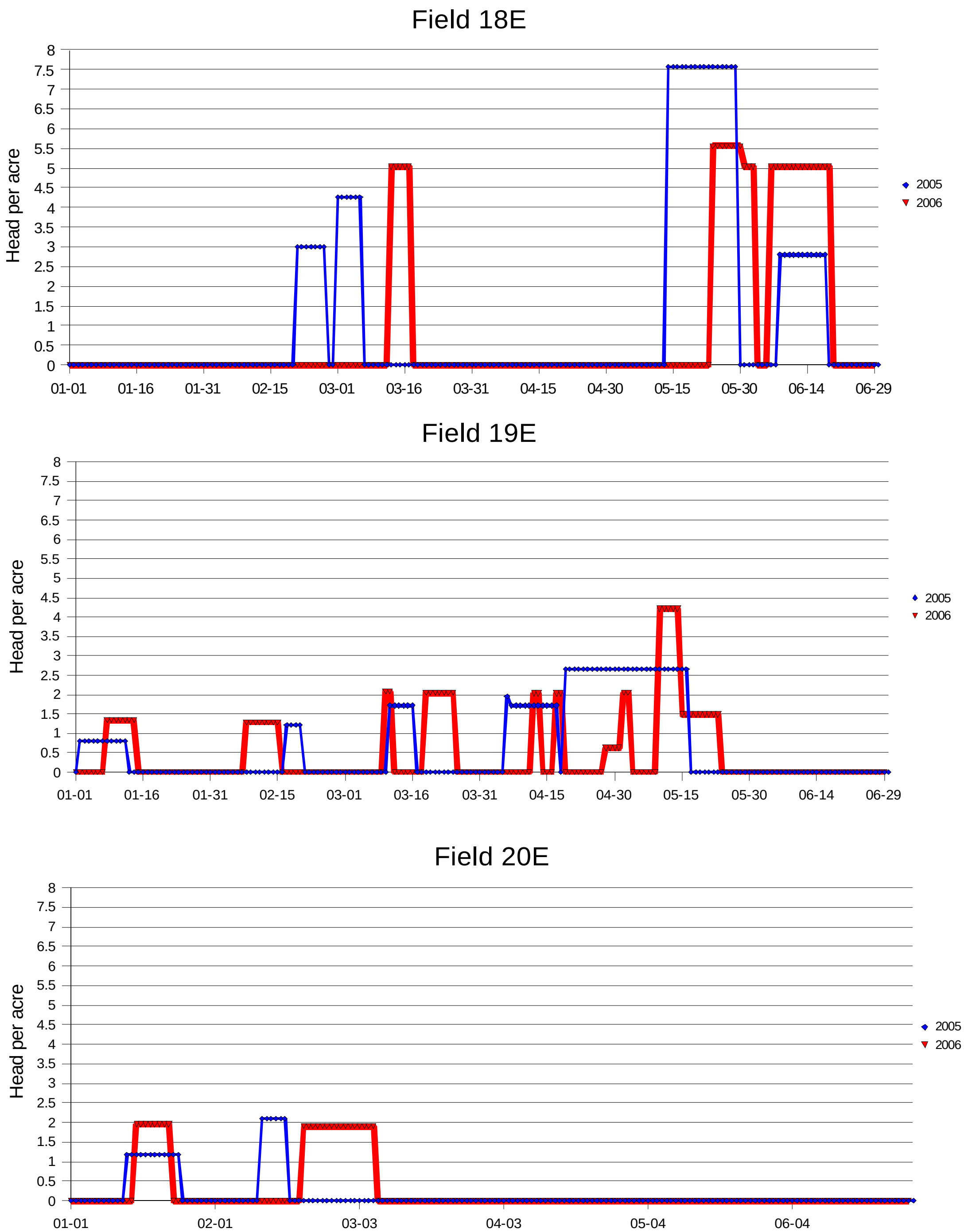

Figure 3. Periods of grazing and overall stocking levels in head per acre in the three study fields in the 2005 (thin blue line) and 2006 (thick red line) grazing seasons.

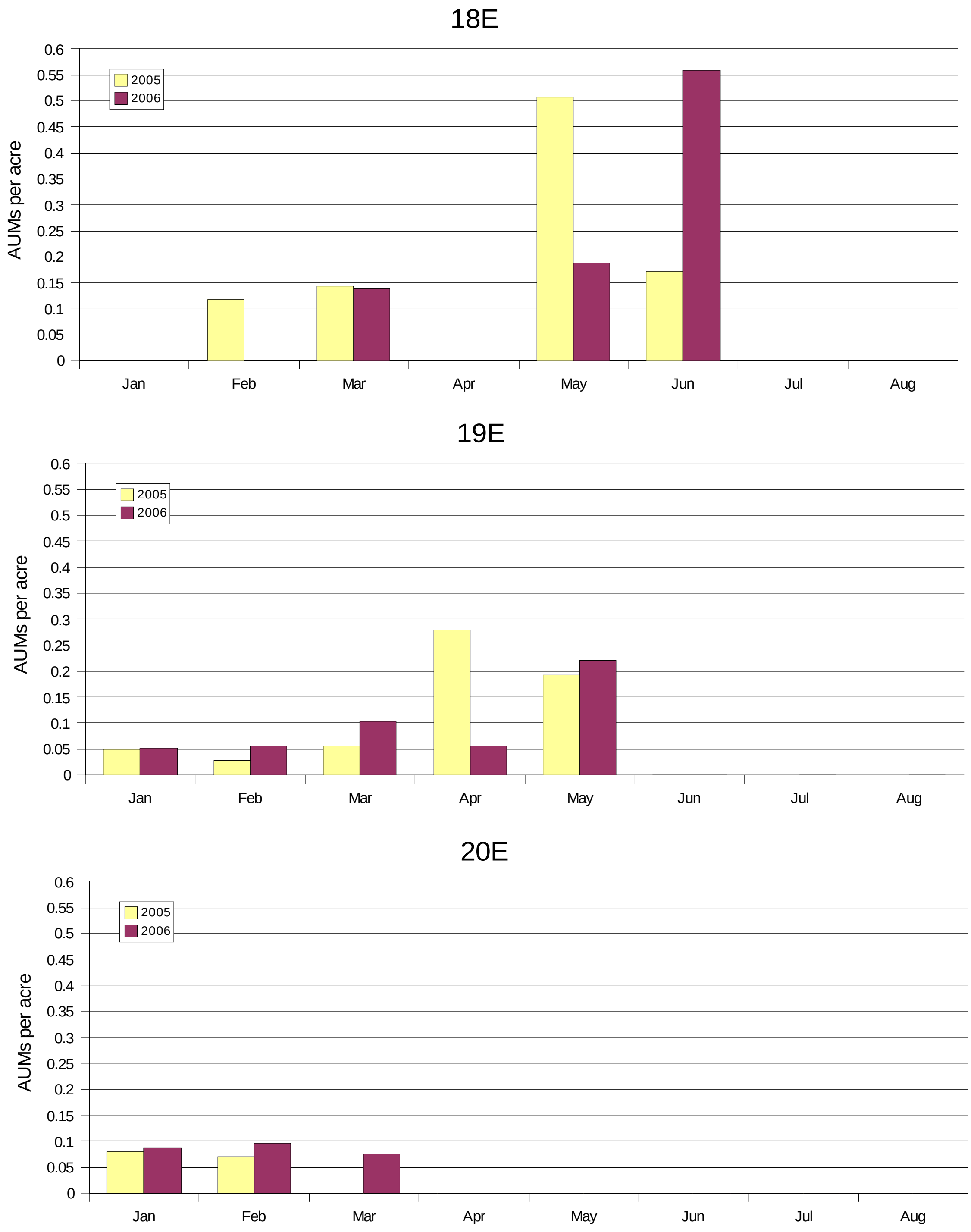

Figure 4. AUM per acre by month in 2005 and 2006 in the three study fields.

Comparison of vegetation height growth by year - 2005 vs. 2006

Although rainfall totals in the 2004-2005 and 2005-2006 seasons were similar, the two years showed very different rainfall patterns (*fig. 5*). Whereas the 2004-2005 season had substantial amounts of early rainfall, the first substantial rains in 2005-2006 were in late December 2005 (*fig. 5*). As a result, forage growth got off to a slower start in 2006 relative to 2005. The delay in vegetative growth can be seen from the cumulative height growth curves for each growing season (*fig. 6*). Furthermore, the cumulative growth of forage in 2006 was significantly less than that of 2005 (*table 3*). These observations are consistent with those of Murphy (1970), who showed that early rainfall sufficient to spur seed germination (about 1.25-2.5 cm) while temperatures are still warm was correlated with increased forage yields in California annual grasslands.

Cumulative forage growth varied significantly by field and the position of the plots (*table 3*). Plots in low positions grew significantly less than plots in high positions in both years. Because the magnitude of this difference was similar in both years the interaction between year and plot position was not significant (*table 3*). However, a significant field by year interaction was detected (*table 3*). For 18E and 19E, cumulative growth was significantly lower in 2006 than in 2005, but 20E showed no significant change between 2005 and 2006.

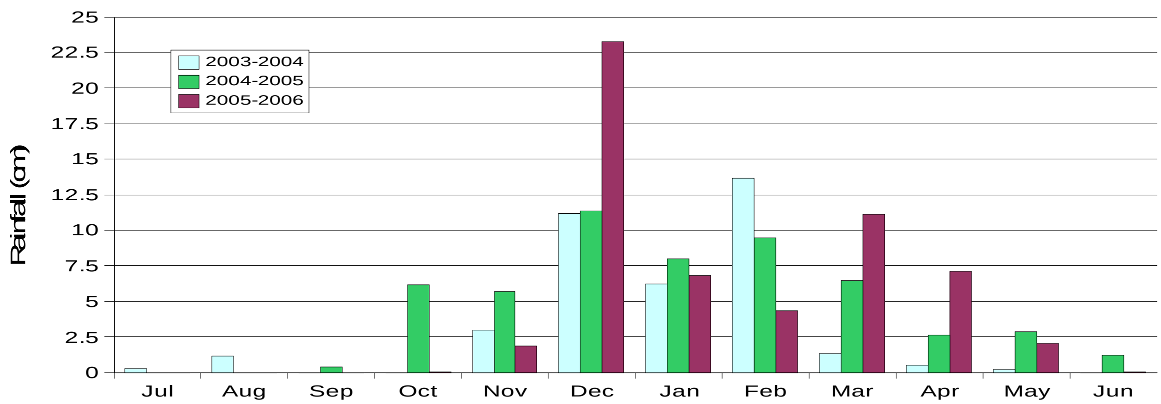

Figure 5. Rainfall measured at the CIMIS station 122 (Hastings Tract), located about 2.4 km northwest of the study area.

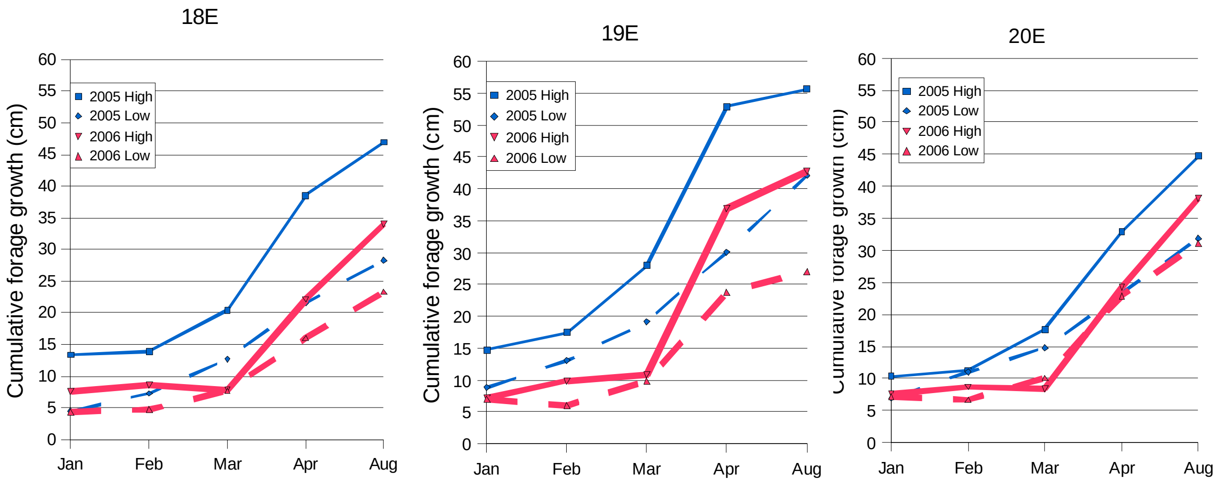

Figure 6. Cumulative height growth of vegetation in high (solid lines) and low (dashed lines) in the nongrazed mowed plots in 2005 (thin blue lines) and 2006 (thick red lines). Cumulative height growth was calculated by summing the growth increments for each interval. Note that many low plots had standing water in the January and March 2006 readings but were dry in Feb 2006. Differences in height measurements made under dry and submerged conditions are largely responsible for the slightly negative growth increments seen in some plots in February and March 2006.

Table 3. Summary of repeated-measures analysis of variance for total cumulative growth of mowed plots in 2005 and 2006 by plot position (high, low) and field (18E, 19E, 20E).

Source	**df**	**F ratio**	**Probability**
Between plots			
Position (high, low)	1	59.1880	<.0001
Field	1	10.5379	0.0002
Position × Field	1	1.1878	0.3149
Within plots			
Year	1	40.6219	<.0001
Year × Position	1	2.7631	0.1039
Year × Field	1	3.3286	0.0455
Year × Position × Field	1	1.4641	0.2428

In 2005, the largest increase in forage height occurred between the March and April evaluations (*fig 7*). This pattern was also seen in 2006, except among mowed plots in 20E, which had equally large height increases in the March-April and April-August intervals (*fig. 7*). Large increase in forage height was primarily associated with the growth of exotic grasses, especially in the high plots.

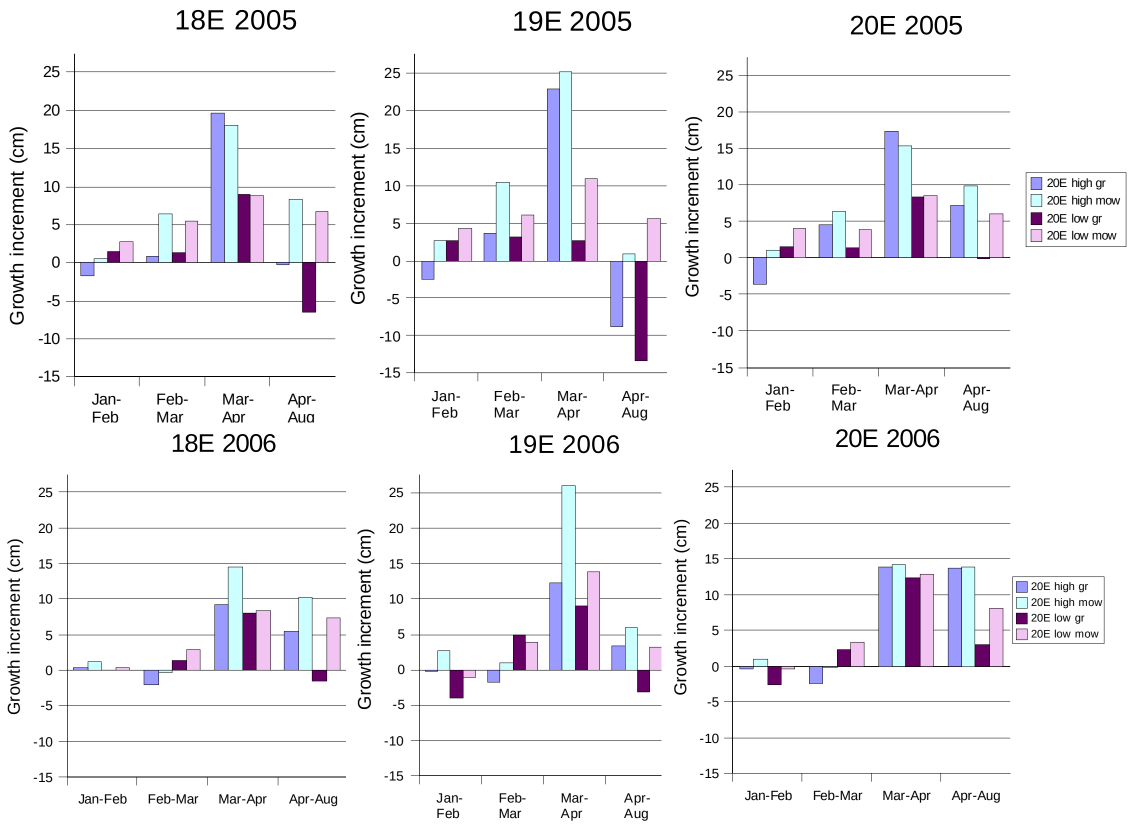

Figure 7. Growth increment in high (blue shades) and low (purple shades) grazed (dark colors), and mowed (light colors) plots in from left to right, 18E, 19E and 20E. Negative growth increments resulted when vegetation was shorter at the end of the interval than at the beginning.

Grazing impacts on vegetation height growth by field

In our previous report (Swiecki and Bernhardt 2006), we presented data showing because sheep avoided flooded areas, most low plots showed little or no grazing impact if grazing occurred when the plots were likely to be inundated. We conducted a similar analysis of the 2006 grazing season data to see whether this patterns was again evident. Figure 8 summarizes the relationship between rainfall, grazing period, and water depth in the low plots.

Although the latter half of December 2005 was very wet, little additional rain fell over the following six weeks. As a result, although most low plots contained substantial amounts of standing water in January 2006 (*fig. 8*, cover photo), the shallow pools and swales where the low plots were located were dry by the time of the February evaluations. These low areas were again inundated to varying degrees from the end of February 2006 through mid-April due to the frequent rains that occurred during this period. By the time of the spring evaluations in late April, all of the low plots were again dry. In fields in which grazing occurred while low plots were flooded, grazing impacts on low plots were reduced. Consequently, high plots were grazed more heavily than low position plots during these periods (*fig. 8*), as was seen in 2005 (Swiecki and Bernhardt 2006). Furthermore, results from both 2005 and 2006 also indicated that sheep grazing impacts were generally greater in the low plots than in the high plots if grazing occurred when low plots were free of standing water.

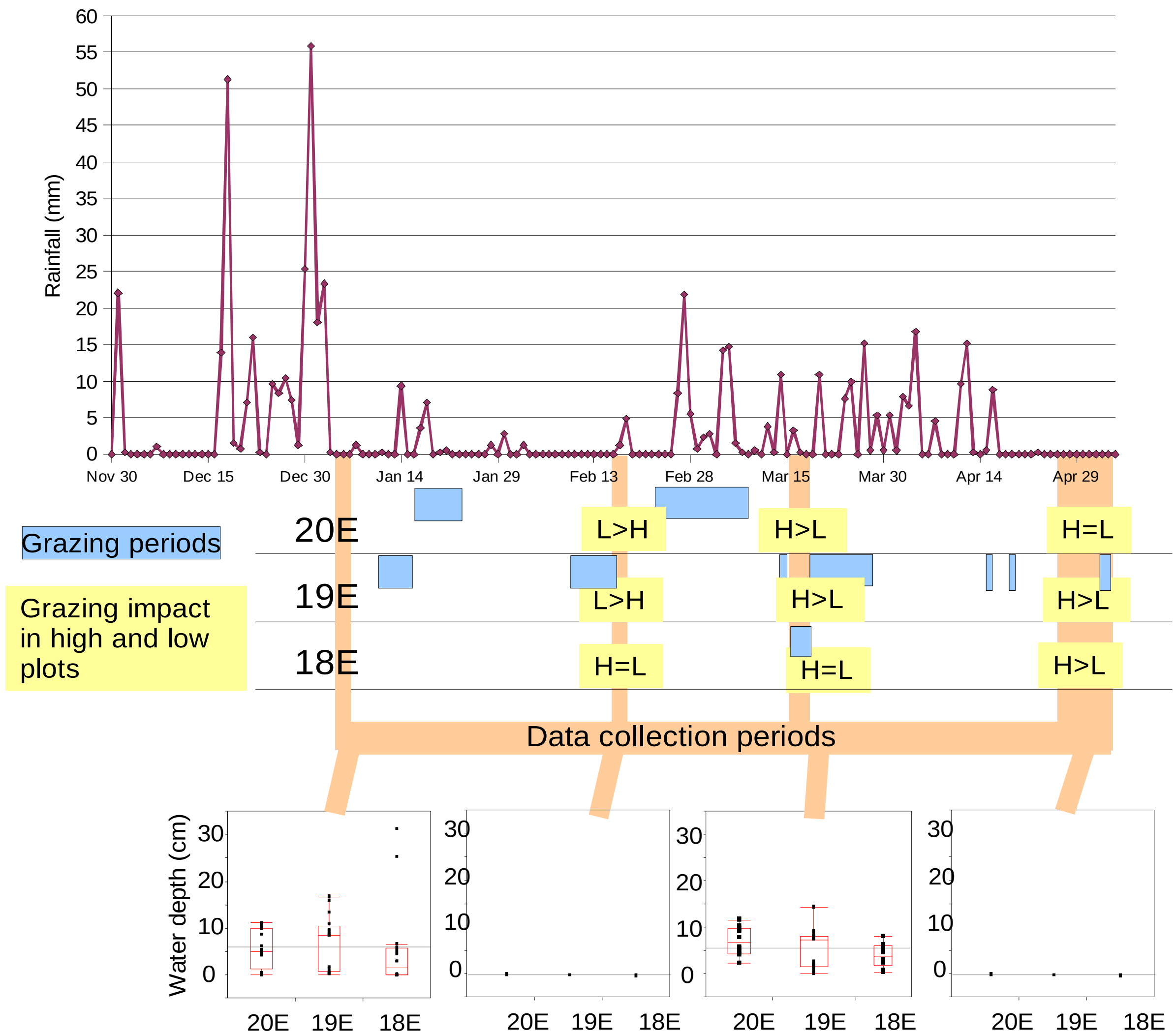

Figure 8. Temporal relationships between rainfall (top graph); grazing periods, and relative grazing impacts in high (H) and low (L) plots in fields 20E, 19E, and 18E (middle); and water depth (bottom) measured in low plots at evaluation dates in January, February, March and April 2006. Rainfall data are from CIMIS station 122 (Hastings Tract) located about 2.4 km northwest of the study area. 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: H>L greater impact in high plots than paired low plots; H=L similar level of impact in paired high and low plots : L>H greater impact in low plots than paired high plots. Box plots for water depth readings in the low plots at the four evaluation dates show actual depths (points), median (line within box) and the first and third quartiles (outer edges of boxes). Lines beyond boxes extend to furthest data point that falls within 1.5× the interquartile range. The overall mean for each evaluation date is shown by the horizontal line in each graph.

Figures 9, 10, and 11 illustrate patterns of vegetation growth among grazed and nongrazed plots and grazing impacts, presented as percent forage removal. In fields 18E and 19E, high plots showed the greatest grazing impacts in the April readings; grazing prior to the April readings occurred during periods when the low plots were mostly flooded (*fig. 8*). Late grazing in May and June in fields 19E and 20E, when low plots were dry, was associated with higher grazing impacts to low plots than to high plots (*fig. 7, 8, 9,10).*

Field 20E was grazed similarly in 2005 and 2006, and the pattern of vegetation removal was similar in both years. Low plots were inundated during the March grazing period (*fig. 8*), leading to greater grazing impact in high plots than in low plots in the March reading (*fig. 11*). Field 20E, which was not grazed after March, also showed a greater grazing impact on low plots than on high plots during the April-August measurement interval. This was due to greater forage growth in the mowed plots than in the grazed plots, rather than to actual forage removal in the grazed plots during the measurement interval (*fig. 7*). This suggests that the grazing impacts made between January and March continued to suppress forage growth throughout the rest of the growing season. Soil compaction and trampling of vegetation, which occurred in the grazed plots but not the mowed plots, is the most likely cause of the growth suppression that occurred in the absence of continued grazing.

In fields 18E and 19E, grazing in May and June was associated with reduced vegetation height in the low plots (*fig. 7, 9, 10*), although reductions were not as great as those achieved in 2005. This may be due to the different combinations of herd size and days of grazing, or the difference in the vegetation itself which differed with respect to overall productivity (*fig. 6*) and phenology between 2005 and 2006.

In 2005, the end-of-season forage heights in the nongrazed cover plots were similar to the calculated cumulative growth of mowed plots. The same pattern was seen in 2006, with the exception of the mowed and nongrazed cover low plots in 19E (*fig. 10*, compare thin and thick solid purple lines). In this field, the nongrazed cover plots grew significantly more than the mowed plots. We did not identify any specific factor that clearly accounts for the growth differential between the nongrazed cover plots and mowed plots in this field.

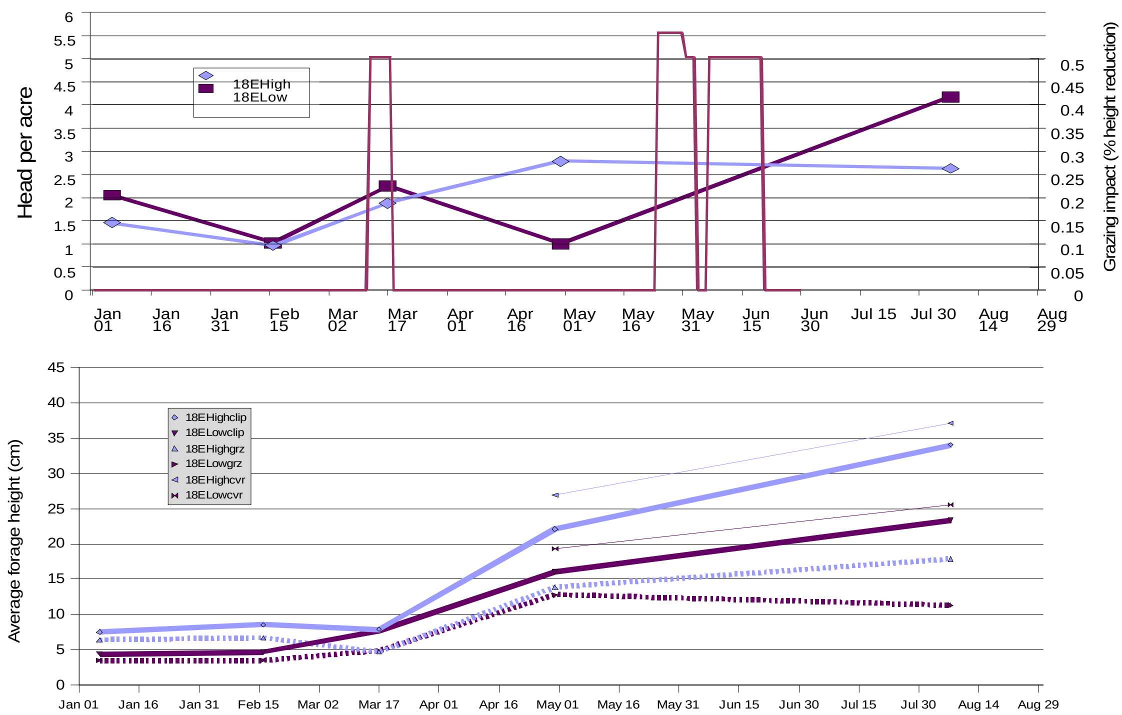

Figure 9. Field 18E. Top graph: Grazing pattern and grazing impact, as percent height reduction in grazed plots compared to non-grazed mowed plots. Blue line with diamonds represents high plots, burgundy lines with squares represent low plots. Lower graph, forage height of grazed and nongrazed cover plots and cumulative growth of nongrazed mowed plots. off-on data for 18E. Blue lines high plots, purple lines low plots, dashed lines grazed plots, solid thick line nongrazed mowed plots, thin solid lines are heights of the nongrazed cover plots. The actual day of sheep removal from this field in March is uncertain.

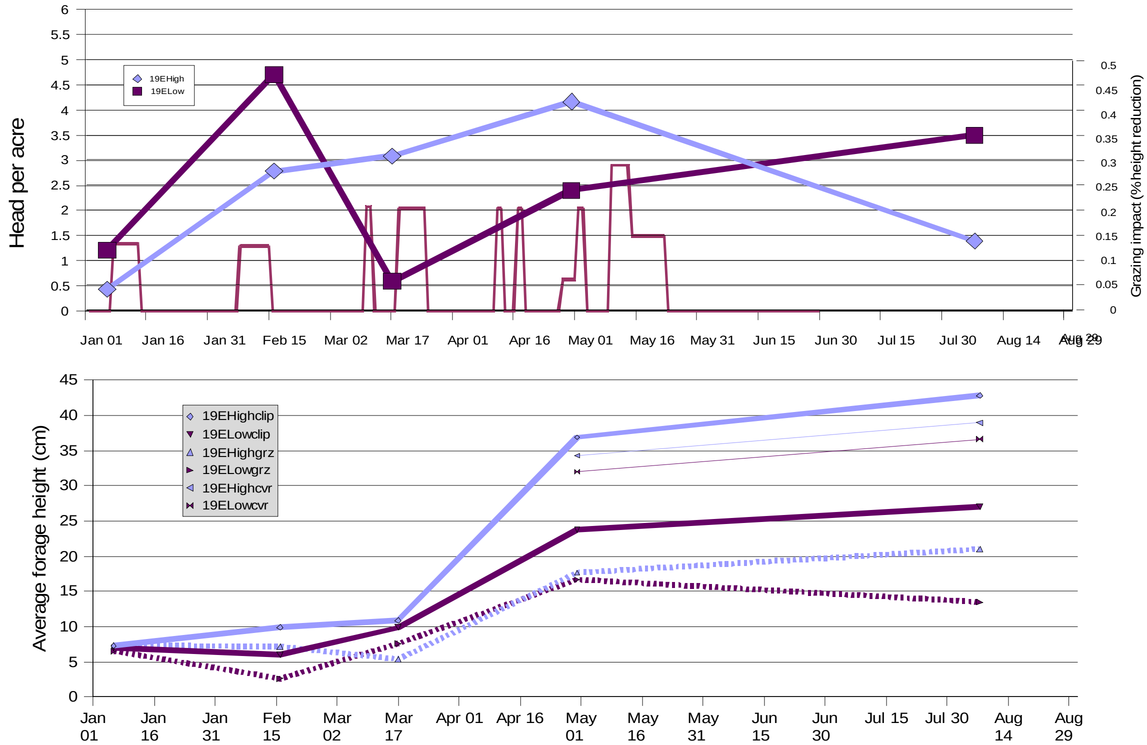

Figure 10. Field 19E. Legends as for figure 9.

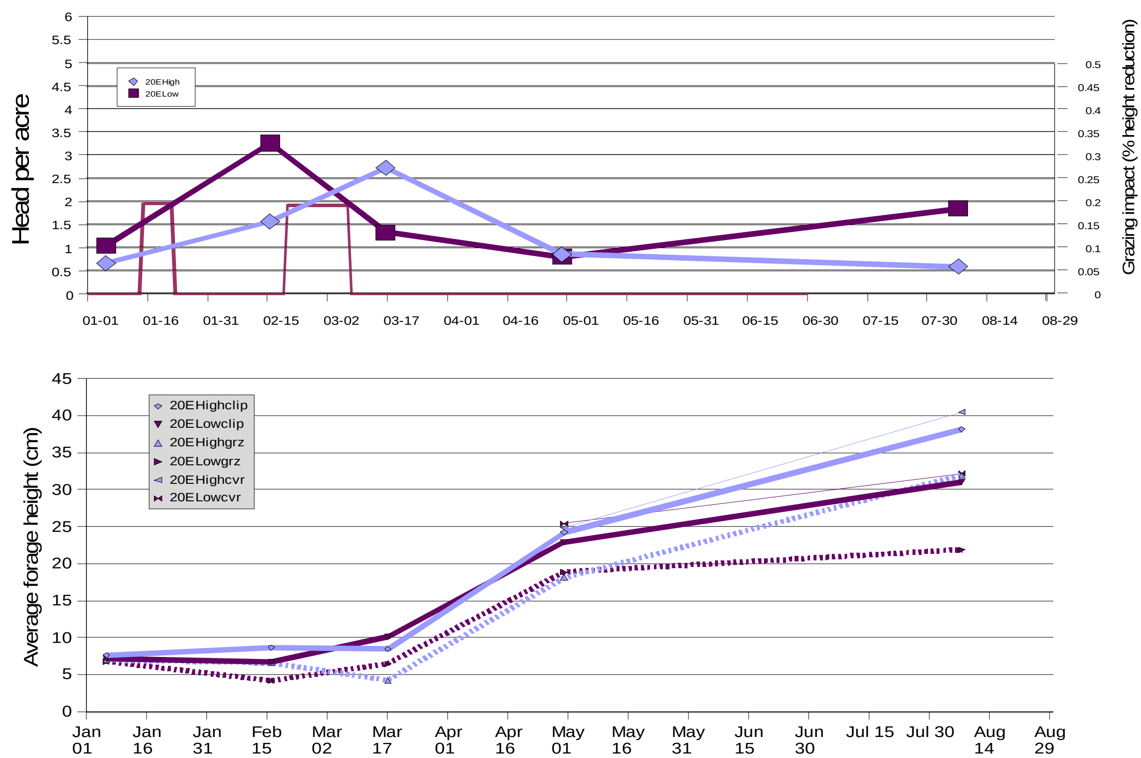

Figure 11. Field 20E. Legends as for figure 9.

Comparison of vegetation growth in grazed plots and nongrazed cover plots

In both 2005 and 2006, overall vegetation height in August was significantly lower in grazed plots than in nongrazed cover plots (*fig. 12*). In all three fields, with the exception of high position plots in 20E in 2006, grazed plots showed significant reductions in vegetation height relative to the nongrazed cover plots (*table 4*). Even in the most lightly grazed field, (20E, grazed at 0.26 AUM/acre in 2006), 2005 and 2006 vegetation height reductions were significant in low plots (*table 4*). Although the reduction in vegetation height in the 20E high plots was greater in 2006 than in 2005, the significance level of the 2006 height reduction was lower (p=0.0518) due to the higher overall variance.

Overall trends in height growth differed between high and low plots. In high plots average August vegetation height was greater in 2005 than 2006 for both grazed and nongrazed cover plots. In contrast, neither grazed nor cover low plots showed a significant decrease in August height in 2006 compared to 2005.

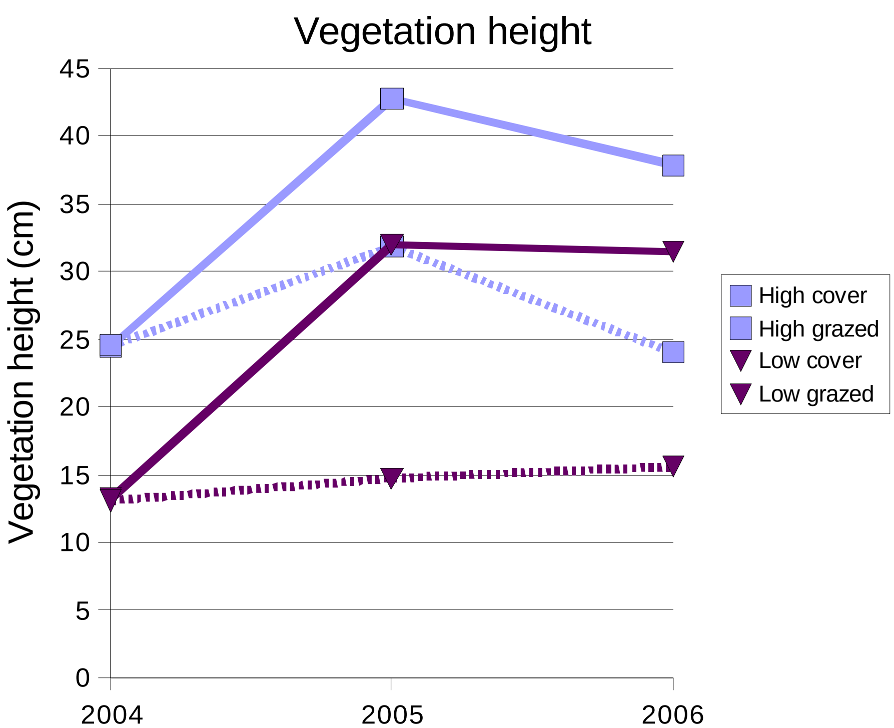

Figure 12. Overall average height of vegetation in grazed (dotted lines) and nongrazed cover plots (solid lines) in August of each year. All plots were grazed in 2004 before the experiment was started.

Table 4. Percent reduction in forage height in August between grazed plots and the nongrazed cover plots. * indicates the difference between paired grazed and nongrazed plots is significant.

Position	Field	% reduction 05	% reduction 06
High	18E	32*	46*
High	19E	30*	46*
High	20E	14*	18
Low	18E	62*	56*
Low	19E	64*	63*
Low	20E	34*	32*

2006 grazing profiles

As noted in the introduction, grazing impacts are nonuniform within fields. Because sheep move as flocks and are given access to the fields in fairly short pulses (generally less than 2 weeks), different plot clusters within a given field have the potential to be subjected to different grazing intensities over time. In order to examine the effects of grazing on various vegetation outcomes, it is first necessary to determine the actual grazing impacts that each grazed plot has been exposed to over the grazing season.

To accomplish this, we quantified grazing impacts for each grazed plot directly by comparing forage height in the grazed plot with that of a paired nearby nongrazed plot in the same microtopographic position (high or low). Grazing impacts for the months of January through April and for the April-August interval were calculated by comparing changes in vegetation height between the grazed and nongrazed plots over each time interval. Nongrazed plots were mowed if necessary after each evaluation to match the new height of the paired grazed plot.

To examine the combined effect of grazing over the entire season, the monthly impacts were aggregated to construct grazing profiles, i.e. sequences of grazing impacts over time. Grazing profiles have the potential to differ between every plot due to a wide range of variable that affect the amount of biomass removed at different time periods (random movements of the flock, presence of standing water in the plot, the growth stage and composition of the vegetation at the time that sheep are present, and so on).

To further aggregate grazing profiles into groups that could be used to examine the relationships between grazing profile and 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 data (Swiecki and Bernhardt 2006).

Figure 13 shows the clustering dendrograms and the grazing profile clusters that were used for subsequent analyses. Four overall grazing profiles were defined for high plots and five were defined for the low plots based on clustering. Average grazing impact by month for each profile is shown in Figure 14. Profiles that resembled those developed for the 2005 grazing season were given the same letter names used in 2005. In the low plots, grazing profiles A, C, and D were similar to profiles assigned these letters in the 2005 analysis, whereas the 2005 profile B and the 2006 profiles E and F and did not appear in both years. None of the 2006 grazing profiles for the high plots matched those from 2005, so the 2006 profiles were assigned new designations (6-9).

Table 5 shows the correspondence between grazing profiles in high and low plots within plot clusters. All of the high position grazing profiles were associated with multiple low profiles. Four of the five low profiles were associated with multiple high profiles. Only low profile F occurred exclusively with high profile 9.

Although some of the grazing profiles in high and low plots had similar overall patterns, most of these patterns did not co-occur within clusters. Profiles F and 8 which show similar patterns occurred on high and low plots in different fields (*table 5*). Profiles A and 7, which are also very similar, co-occur in only one of three plot clusters (*table 5*). The general lack of concurrence between grazing profiles in adjacent high and low plots provides further evidence that selective grazing by sheep over the growing season gives rise to different grazing impacts on weed dominated and native dominated patches of vegetation within fields.

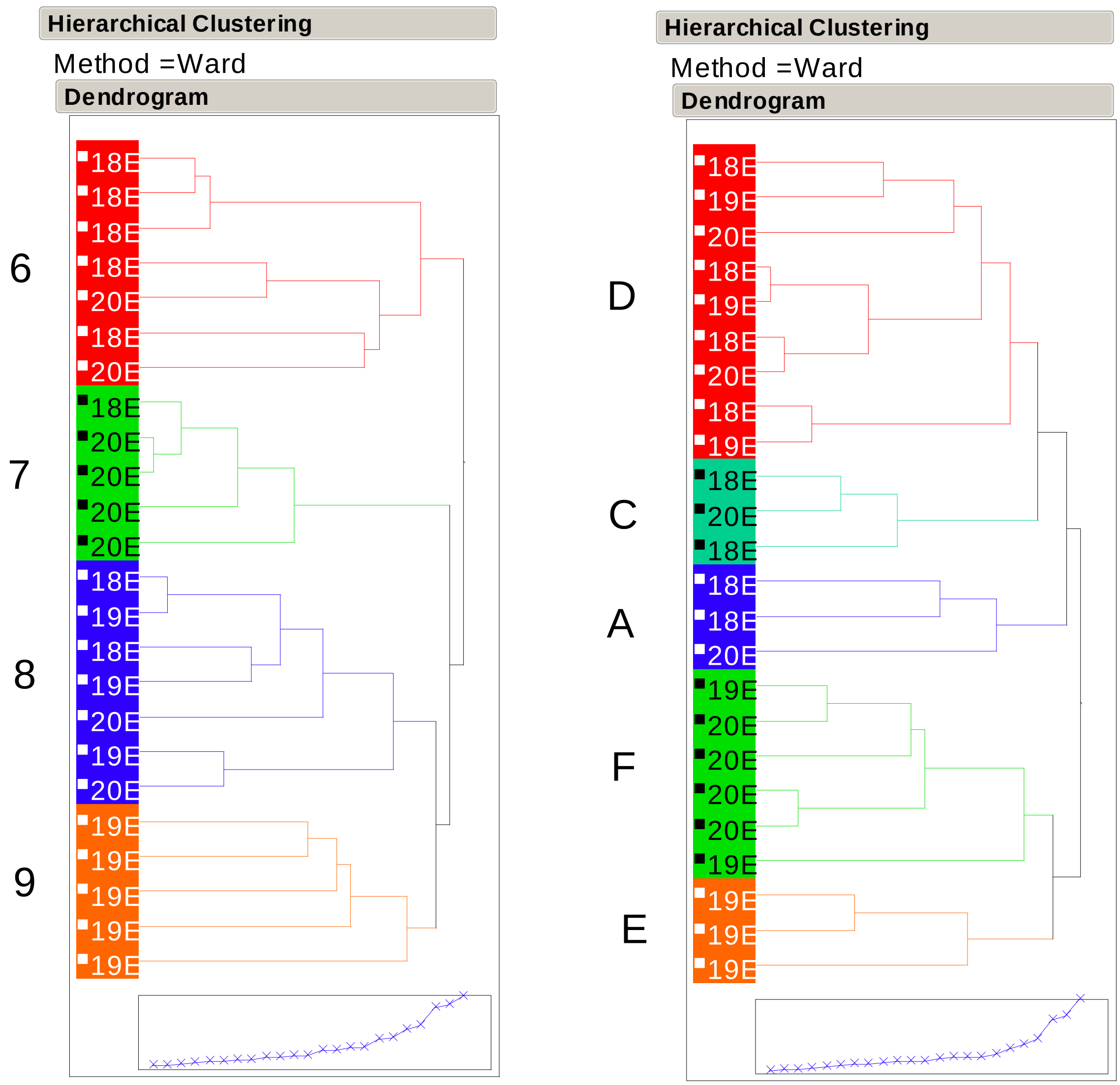

Figure 13. Hierarchical clustering diagrams of grazing impacts for high (left dendrogram) and low (right dendrogram) plots. Plots are identified by field numbers. Within high and low plots, hierarchical clusters are marked by colors.

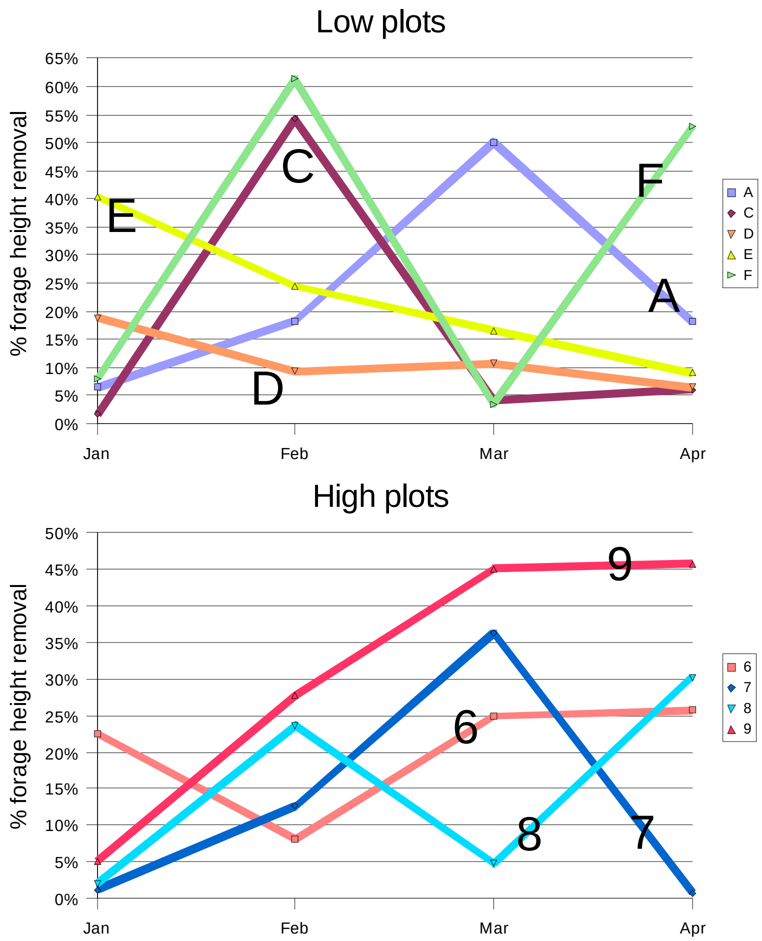

Figure 14. Average percent forage removed by month for each grazing profile, developed by heirarchical clustering, for low and high plots.

Table 5. Co-occurrence within plot clusters of low and high grazing profiles. Table cells show the number of clusters in which each combination of high and low grazing profiles occurred. Each of the 24 plot clusters has one grazed plot in the high and one in the low topographic position..

	Low grazing profile					
High grazing profile	**A**	**C**	**D**	**E**	**F**	**Total plot clusters**
6	2	1	3	1	0	7
7	1	1	2	1	0	5
8	0	3	3	1	0	7
9	0	1	1	0	3	5
Total plot clusters	3	6	9	3	3	24

2006 grazing profiles and vegetation outcomes

We used several approaches to look at the relationship between grazing profiles and various vegetation outcomes. The results of the various analyses were generally in agreement.

One of the hypotheses being tested in this study is whether changes between the initial and final vegetation states for a given growing season are affected by the seasonal grazing profile. To address this question, it is necessary to determine whether vegetation parameters of interest have changed between 2005 and 2006 and whether observed changes are significantly related to grazing profiles.

Contingency table analysis

As a relatively conservative test of this hypothesis, we used Newcombe's (1998) adaptation of the Wilson (1927) test to calculate the confidence interval for the difference between the cover percentages for either native or exotic cover in different years. The Wilson test is used to show whether the observed cover values in the two years were significantly different, given the sample size used in the point frame (100 points). We interpreted a significant value in the difference of proportions test as indicating that a plot showed a significant change in a given cover variable, i.e., that there was a measurable change in the vegetation state. In essence, this procedure compares estimates of cover obtained through dot-grid counts in different years and produces a discrete ordinal outcome (significant increase, no change, significant decrease). Figure 15 shows the percentages of plots in the nongrazed cover treatment and the various grazing profiles that showed a significant increase, significant decrease, or no change in either overall native cover or exotic cover.

The overall tests for independence (Fisher's test) for the high plot contingency tables were nonsignificant, indicating that overall changes (2005-2006) in native and exotic species cover were not significantly affected by any of the grazing profiles. In addition, these vegetation outcomes did not differ significantly between grazed and nongrazed plots. This latter effect was confirmed in analyses of 2x3 contingency tables comparing the cover outcomes (increase, no change, decrease) in the nongrazed cover plots to the aggregate of all grazed plots. These results suggest that the 2006 grazing did not significantly influence overall native or exotic cover in the high plots.

In contrast, low plot contingency tables showed significant differences among the outcomes in the tables for native cover (Fisher's test estimated $p=0.03$) and exotic cover (approximate Fisher's test estimated $p=0.001$) that included the nongrazed cover plots and all grazing profiles (Figure 15). However, 2x3 tables comparing all grazed plots to the nongrazed cover plots were not significant at the 5% level (Fisher's test estimated $p=0.10$ for native cover, $p=0.06$ for exotic cover). We also constructed contingency tables that omitted the nongrazed plots and compared only different grazing profiles in the low grazed plots. These analyses indicated that 2005-2006 changes in exotic cover were significantly influenced by grazing profile (Fisher's test estimated $p=0.006$), but changes in native cover were not (Fisher's test estimated $p=0.11$).

In aggregate, these tests suggest that changes (2005-2006) in exotic plant cover in the low plots were significantly associated with the 2006 grazing profiles but native plant cover changes were only weakly associated with grazing. Among grazed plots, only those grazed under profiles C and D showed decreases in exotic cover or increases in native cover between 2005 and 2006. Plots in these grazing profiles had relatively low grazing impacts overall and were not grazed near the peak period of plant growth between March and April (*fig. 14*). Although most nongrazed plots showed undesirable changes in cover from 2005 to 2006 (reduced native cover, increased exotic cover), these changes were not seen in all nongrazed plots.

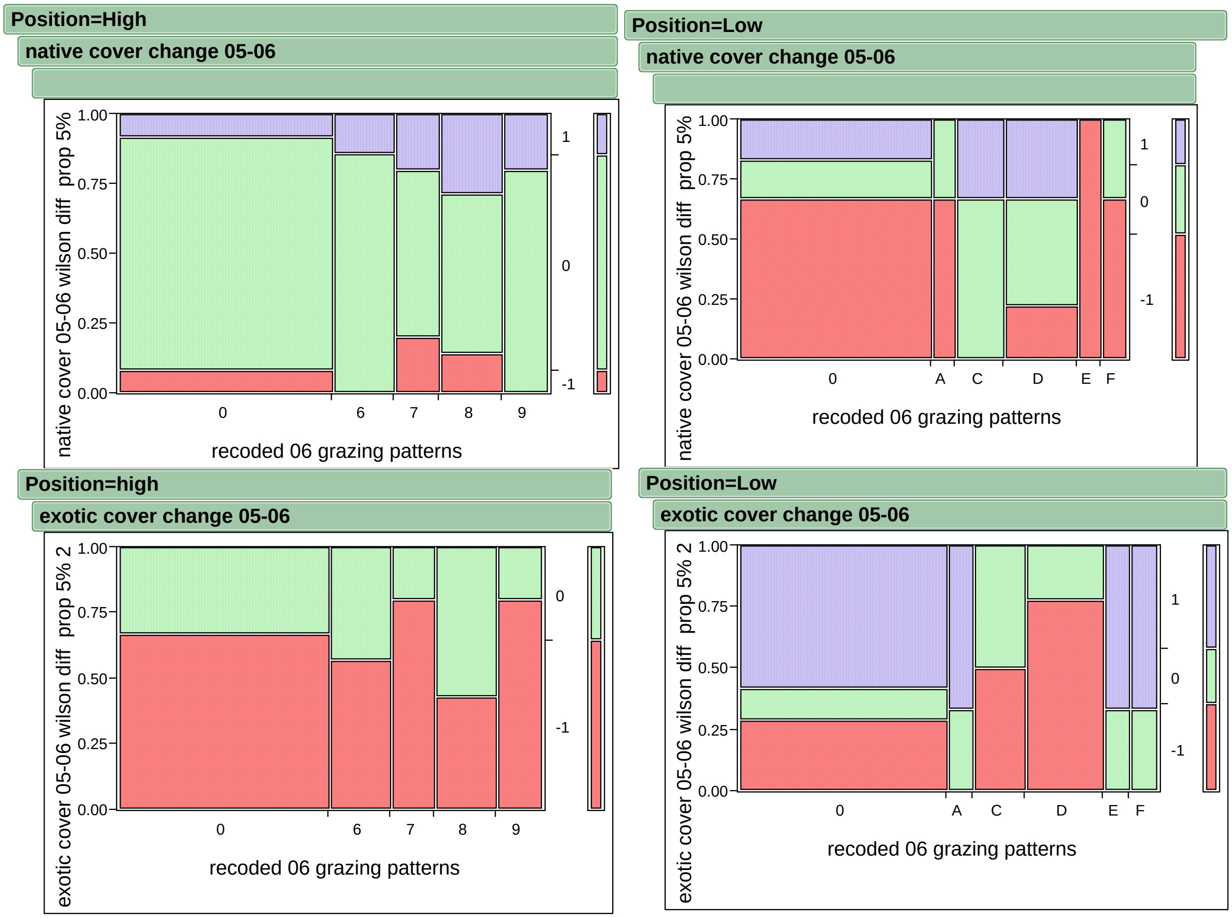

Figure 15. Proportions of high and low plots showing a decrease (-1, red bars), no change (0, green bars), or increase (1, blue bars) from 2005 to 2006 in the nongrazed (grazing pattern 0 on x axis) plots and plots with various grazing profiles (see Figure 14).

Repeated measures analysis of variance

The foregoing analysis is relatively conservative (i.e., tending to have lower Type I error) in that it does not consider the magnitude of the changes in cover, only whether a change is significant. We also conducted repeated measures analysis of the transformed cover percentages, an analysis that does consider the magnitude of observed changes. Overall, this method is less conservative (i.e., tending to have lower Type II error), and is more likely to be affected by high outliers.

Table 6 summarizes the results of the repeated measures analysis of variance. As seen in the foregoing analyses, native and exotic cover in the high plots were not significantly affected by the grazing regimes, including a complete lack of grazing (nongrazed cover plots). Exotic cover declined overall between the spring assessments in 2005 and 2006 (significant effect of year).

Much of the reduction in exotic cover in the high plots from 2005 to 2006 was associated with reduced cover of medusahead in 2006. Low plots also showed a significant decline in medusahead cover from 2005 to 2006 (*table 6*), although the significance of this effect is strongly influenced by one plot in 19E that had 12% medusahead cover in 2005, well beyond the 2005 mean medusahead cover (0.56%) in low plots overall.

We believe that the measured decrease in medusahead cover is largely an artifact associated with the delayed maturity of vegetation in 2006 relative to 2005. Most medusahead plants were headed out by the time of the 2005 spring evaluations, but this was not the case in April 2006. Comparisons of plot photos taken in the 2006 spring evaluations (late April-early May) to the those taken during the August evaluations showed high medusahead cover in some plots that had no mature medusahead in spring. In addition, a comparison of individual plot photos from August 2005 and August 2006 failed to show any obvious decrease in medusahead cover overall.

Repeated measures analysis showed no significant effect of year on native and exotic cover in low plots from 2005 to 2006, but effects of grazing profiles were significant over time (*table 6*). Similar to the pattern seen in the contingency table analyses, grazing profiles C and D showed strong increases in average native cover and strong reductions in average exotic cover from 2005 to 2006. The remaining grazing profiles (A,E,F) and the nongrazed cover plots showed decreased native cover and increased exotic cover over this same interval.

Table 6. Probability levels of F tests for repeated measures analyses for native and exotic cover in 2005 and 2006 by plot position (high/low), and grazing profile (see *fig. 14*). Nongrazed cover plots are included as a single grazing profile (profile 0). Factors significant at p≤0.05 are shown in boldface. Cover percents were transformed before analysis.

	Between plots	**Within plots**	
Source:	**Grazing profile**	**Year**	**Year × Grazing profile**
High plots df:	4	1	4
All native species cover	0.1014	0.0588	0.9319
All exotic species cover	0.0822	**<0.0001**	0.5599
Medusahead cover	0.5534	**<0.0001**	0.5369
Low plots df:	5	1	5
All native species cover	**0.0037**	0.0521	**0.0284**
All exotic species cover	**0.0010**	0.8211	**0.0053**
Medusahead cover	0.1403	**0.0012**	**0.0010**

Grazing profiles vs total seasonal forage removal

One of the hypotheses for this study was that grazing predictors that include a temporal element (timing of grazing impact) will be superior to predicators based only on total biomass removal. Total percent height removal (January-April 2006) was a significant predictor of change only for exotic cover in low plots in repeated measures analysis of variance (time x total height removal interaction p=0.017). Overall, greater total levels of height removal due to grazing in 2006 were associated with increased exotic cover (*fig. q*). When both grazing profile and total height removal were included in the same model for change in exotic cover, only grazing profile was significant. These results suggest that grazing profiles, which address both the amount and timing of biomass removal are better predictors of vegetation change than measures of seasonal biomass removal alone. For 2006, greater biomass removal was associated with decreases in native cover and increases in exotic cover.

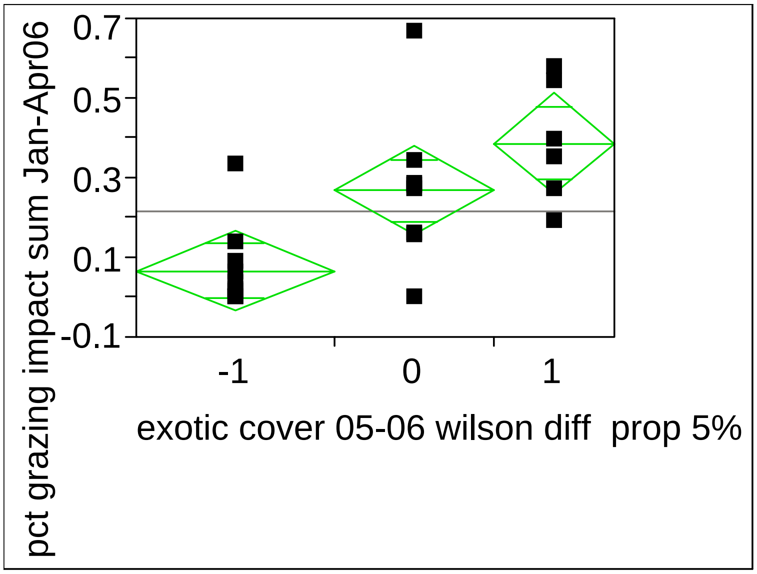

Figure 16. Average total height removal due to grazing in 2006 for plots that showed significant decreases (-1), increases (1), or no significant change (0) in exotic plant cover from spring 2005 to spring 2006.

Grazing profiles including late season grazing from the previous year

To test whether late season grazing occurring after spring evaluations in 2005 had a carryover effect on 2006 vegetation outcomes, we created grazing profiles that included May-June 2005 grazing impacts as well as the January through April 2006 grazing impacts for the low plots only (*fig. 17*). May-June grazing impact was measured in the summer assessments that took place in August 2005. As shown in *table 7*, three of the May 2005-April 2006 grazing profiles (2, 3, 4) are constituted exclusively of plots from a single January-April grazing profile. However, only 2005-2006 profile 2 and 2006 profile F represent the identical set of plots (*table 7*).

Repeated measures analyses of native and exotic cover for 2005 and 2006 showed no significant effects of time or time x grazing profile interaction using the May 2005-April 2006 grazing profiles. The nongrazed cover plots were included as a grazing treatment as in the above analysis, but omitting these plot from the analysis doe not change the results. Because including May-June 2005 grazing impacts in the grazing profiles renders this variable a nonsignificant predictor of cover change, we conclude that the grazing that occurred in May and June 2005 had no substantive impact on the plant cover in the following season.

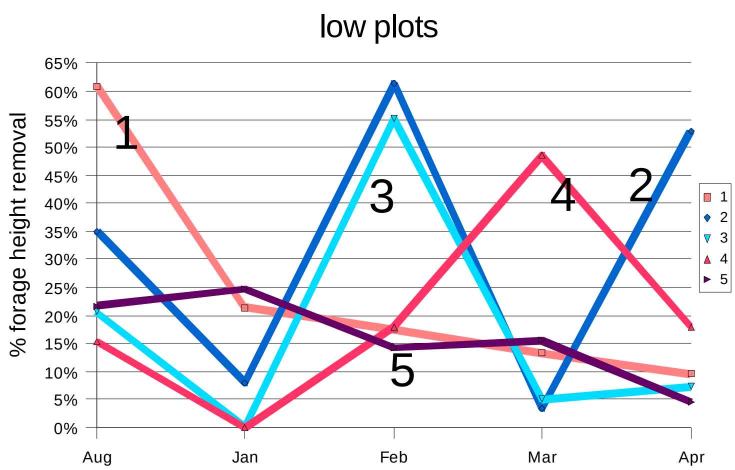

Figure 17. Average percent forage removal for grazing profiles created by hierarchical clustering of grazing impacts occurring in low plots from May 2005-April 2006.

Table 7. Cross-tabulation showing the correspondence between low grazing profiles based on January-April 2006 grazing impacts (letters, see *fig 14*, top) and low grazing profiles based on May 2005-April 2006 grazing impacts (numbers, see *fig. 14*). Cells contain counts of the number of plots with each grazing pattern combination.

		May 2005-April 2006 grazing profiles					
	Count	**1**	**2**	**3**	**4**	**5**	Totals
January-April 2006 grazing profiles	**A**	1	0	0	2	0	3
	C	1	0	5	0	0	6
	D	5	0	0	0	4	9
	E	1	0	0	0	2	3
	F	0	3	0	0	0	3
	Totals	8	3	5	2	6	24

Vegetation changes from 2004 to 2006

Contingency table analysis

We performed contingency table analyses as described above to determine whether changes in native or exotic cover occurring between 2004 and 2006 were associated with the presence or absence of grazing overall. Overall, 79% of the high plots showed no significant change in native cover between 2004 and 2006. Half of the high plots also showed no significant change in exotic cover between 2004 and 2006; 40% showed a significant decrease in exotic cover. These trends were almost identical among grazed and nongrazed cover plots and tests of independence for tables of grazing (grazed/nongrazed) and change in native or exotic cover (increase/no change/decrease) were nonsignificant.

In low plots, change in native and exotic cover between 2004 and 2006 (*fig. 18*) were significantly associated with the presence of grazing (Fisher's test approximate p=0.013 for native cover, p=0.003 for exotic cover). Among nongrazed low plots, 75% showed a significant increase in exotic cover and 71% showed a corresponding decrease in native cover. In contrast, between 2004 and 2006, 40% of the grazed low plots showed increased exotic cover and 33% showed a decrease in native cover.

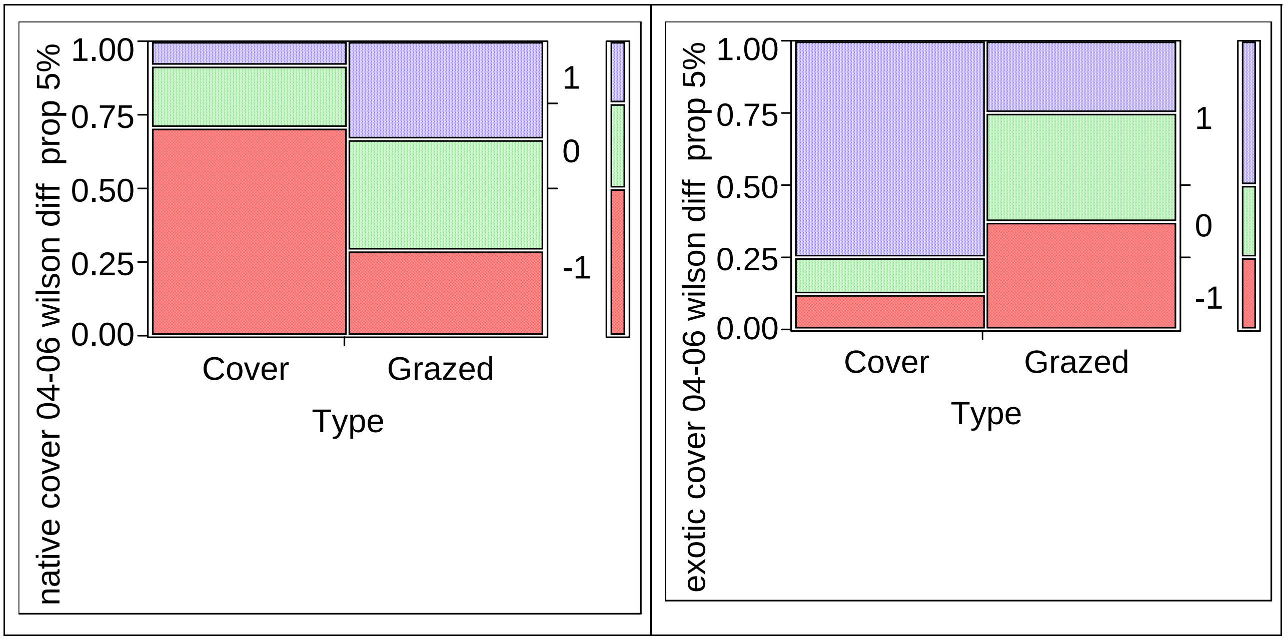

Figure 18. Proportions of low plots showing a decrease (-1, red bars), no change (0, green bars), or increase (1, blue bars) in native (left) and exotic cover (right) from 2004 to 2006 by overall grazing status (nongrazed cover vs. all grazed plots). N=48 plots.

Repeated measures analysis of variance

The same overall trends are apparent from repeated measures analysis of variance of 2004 and 2006 levels of native and exotic cover (*fig. 19, table 8*). The analyses show that high and low plots responded differently over time with respect to the influence of grazing. Native and exotic cover in the high plots were not significantly affected by grazing overall. However, repeated measures analyses on the high plots only show that observed changes in native (p=0.0192) and exotic cover (p=0.0005) between 2004 and 2006 were significant. In contrast, in low plots, only nongrazed plots showed a significant increase in exotic cover and a significant decrease in native cover between 2004 and 2006 (*fig. 19*; repeated measures on low plots only time x grazing interaction: p=0.0003 for native cover, p<0.0001 for exotic cover). Overall levels of native and exotic cover in grazed plots in 2004 and 2006 are shown in figure 20.

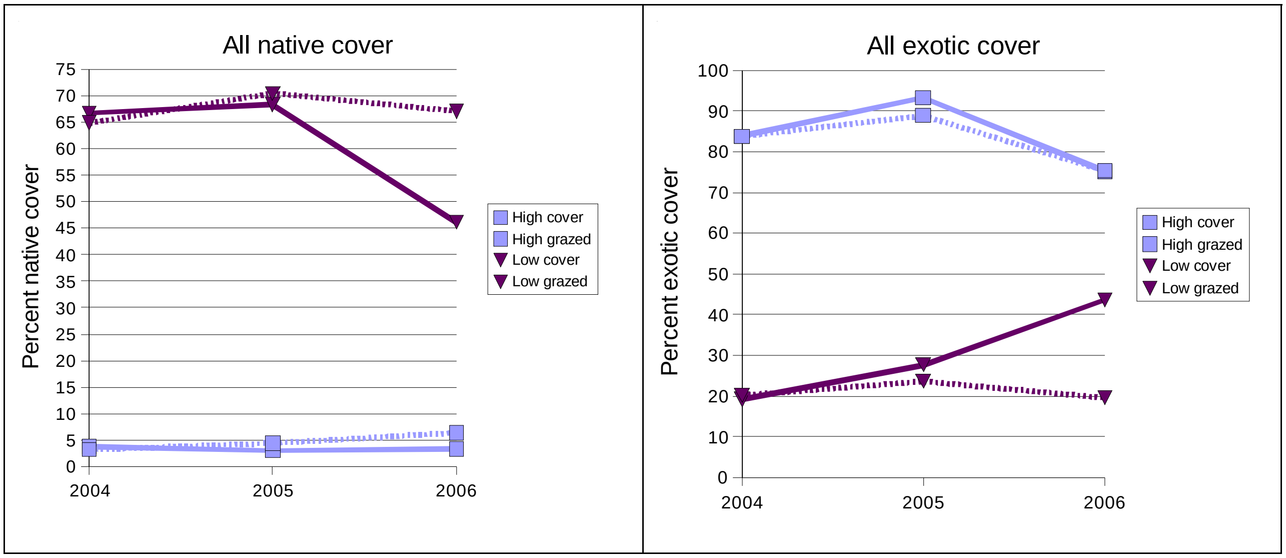

Fig 19. Average percentages of native (left) and exotic cover (right) measured in during spring evaluations in 2004-2006 in grazed (dashed lines) and nongrazed cover (solid lines) plots for high (blue) and low (burgundy) plot positions.

Table 8. Probability levels of F tests for repeated measures analyses for vegetation outcomes for 2004 and 2006 by plot position (high/low), and plot type (grazed, nongrazed). Factors significant at p≤0.05 are shown in boldface; p levels >0.1 are shown listed as ns. Cover percents and count data were transformed before analysis.

	Between plots			***Within plots***			
Source:	**Position**	**Type**	**Position X Type**	**Year**	**Year × Position**	**Year × Type**	**Year × Position × Type**
Cover:							
All native species	**<0.0001**	ns	ns	ns	**0.0019**	**0.0001**	**0.0077**
Native grasses	**<0.0001**	ns	ns	**<0.0001**	**<0.0001**	ns	ns
Native forbs	**<0.0001**	**0.0260**	ns	**<0.0001**	**<0.0001**	**0.0017**	**0.0441**
All exotic species	**<0.0001**	.0696	.0576	ns	**0.0001**	**0.0003**	**0.0002**
Exotic forbs	**<0.0001**	ns	ns	ns	ns	ns	0.0656
Exotic grasses	**<0.0001**	**0.0486**	0.0803	**ns**	**0.0001**	**0.0001**	**0.0023**
Medusahead	**<0.0001**	**ns**	**ns**	**<0.0001**	**<0.0001**	ns	ns
Count of species present:							
All native species	**<0.0001**	ns	ns	**<0.0001**	ns	**0.0200**	ns
Native grass species	**<0.0001**	ns	ns	**0.0089**	**0.0011**	ns	ns
Native forb species	**<0.0001**	ns	ns	**<0.0001**	**0.0020**	**0.0212**	ns
All exotic species	**<0.0001**	**0.0465**	0.0740	**0.0057**	**0.0001**	0.0546	**0.0214**
Exotic forb species	**<0.0001**	ns	ns	ns	ns	ns	ns
Exotic grass species	**<0.0001**	**0.0046**	0.0811	**<0.0001**	**0.0002**	**0.0537**	ns

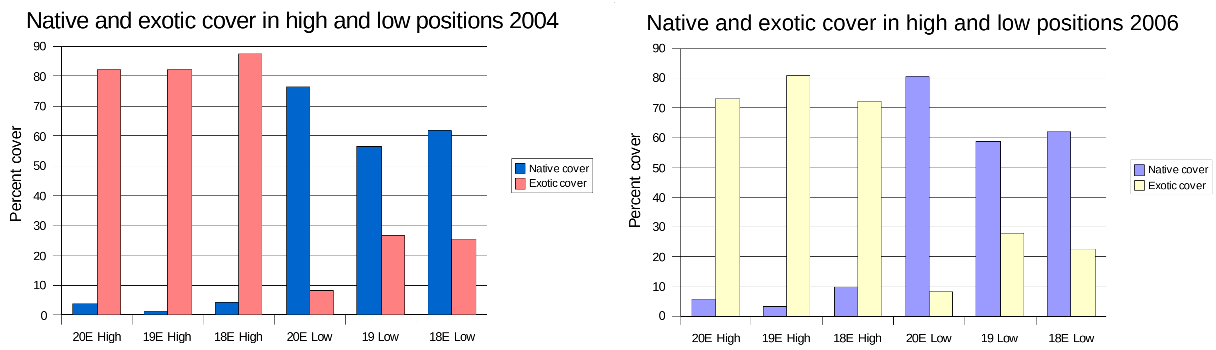

Figure 20. Average native and exotic cover in grazed plots in 2004 and 2006 by field.

We also tested whether various other vegetation variables had changed between 2004 and 2006 due to the removal of grazing in the nongrazed cover plots (*table 8, fig. 21*). Several of these vegetation variables changed significantly between 2004 and 2006. Of these, the overall increase in exotic grass cover from 2004 to 2006 in the low plots shows a significant linear trend over this interval (MANOVA $p<0.0001$). This result agrees with our field observations that annual ryegrass has become much more common in the nongrazed low plots over the past two years. However, other changes over the 2004 to 2006 interval appear to be associated specifically with the 2006 growing season and are not the result of an obvious directional trend across both years. For example, low plots showed a significant increase in native grass cover at the expense of native forb cover between 2005 and 2006 but no significant change was seen between 2004 and 2005; the linear trend across both growing seasons was nonsignificant. The change in 2005-2006 native forb cover, but not native grass cover was also significantly affected by the presence of grazing (repeated measures on low plots only, time x grazing interaction $p=0.0206$).

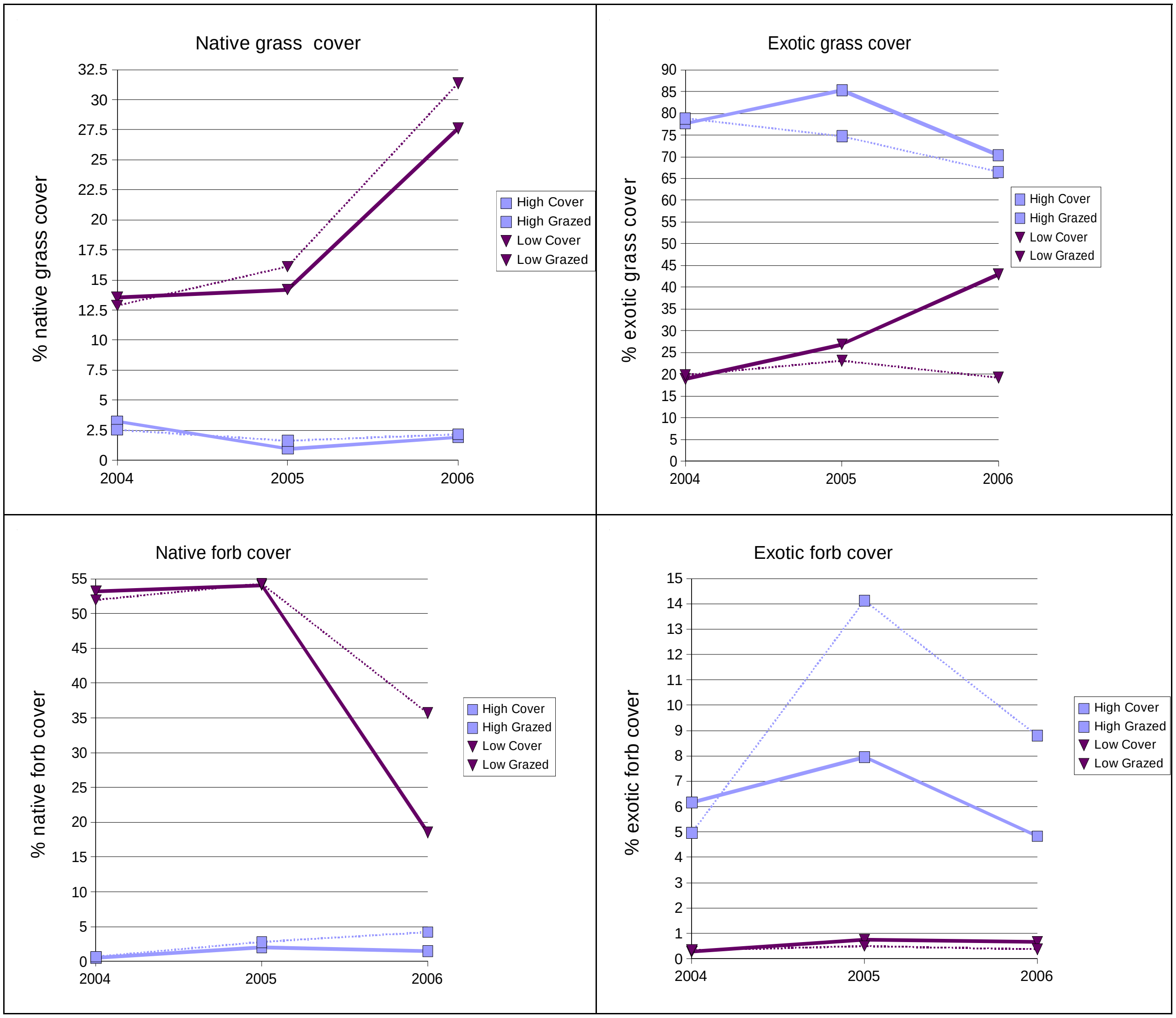

Figure 21. Average cover percentages for native grasses (upper left), native forbs (lower left), exotic grasses (upper right) and exotic forbs (lower right) measured in during spring evaluations in 2004-2006 in grazed (dashed lines) and nongrazed cover (solid lines) plots for high (blue) and low (burgundy) plot positions. Note differences of scale on y axis.

As shown in Figure 22, much of the increase in native grass cover was due a strong increase in the cover of *Pleuropogon californicus*. Long periods of inundation both early and later in the season provided conditions favorable for the growth of this species, which can form dense stands that inhibit the growth of small forbs.

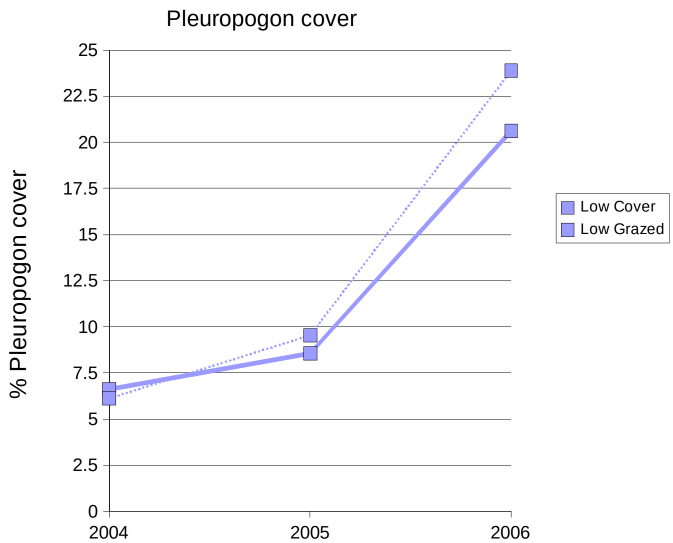

Figure 22. Changes in *Pleuropogon* in low plots. The dashed line represents the grazed plots and the solid line the nongrazed cover plots.

Medusahead is the only exotic grass identified by species in the cover ratings. It contributes to the exotic grass cover rating (exotic grass cover= medusahead cover plus unidentified grass cover) and can also be examined as a separate cover variable. Spring medusahead cover in the high plots has declined significantly between 2004 and 2006 (*fig. 22*). As noted above, most of this effect is due to the large drop between 2005 and 2006, although the overall decline from 2004 to 2005 was also significant. The reduction in medusahead cover was significantly greater in the high plots compared to the low plots, but was not significantly affected by grazing.

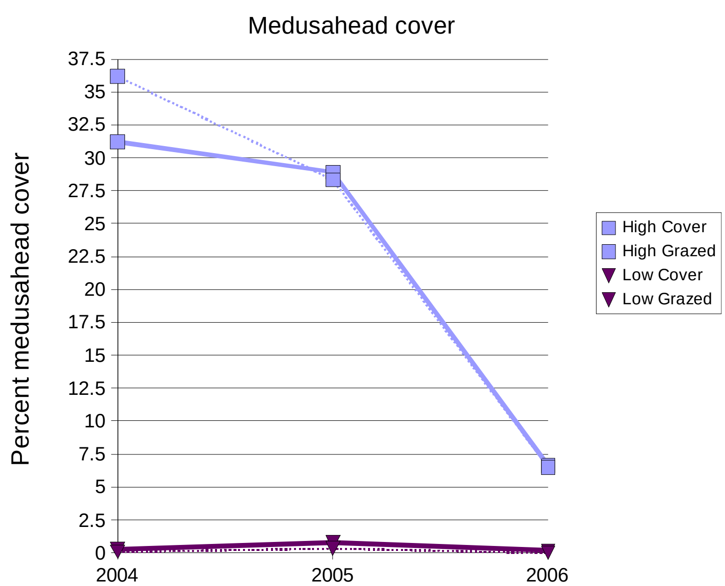

Figure 22. Medusahead cover in high and low plots. Nongrazed plots are represented by solid lines, grazed plots by dotted lines.

Since 2004, the number of native species per plot has increased significantly overall (*table 8, fig. 23*). The significant year x type interaction is related to the fact that the number of native species increased significantly in the grazed plots, but not in the nongrazed cover plots. Low plots showed a more highly significant increase in native species count from 2004 to 2006 (matched pair p=0.0195) than the high plots (matched pair p=0.0887). The absolute change in the number of native species in grazed plots has been small, and could be affected by the fact that 2005 and 2006 were relatively wet years. Nonetheless, results suggest that after two years native species diversity may have been adversely affected by cessation the of grazing in the nongrazed cover plots. The number of exotic species has decreased since 2004 in the low grazed plots only (*fig. 23*).

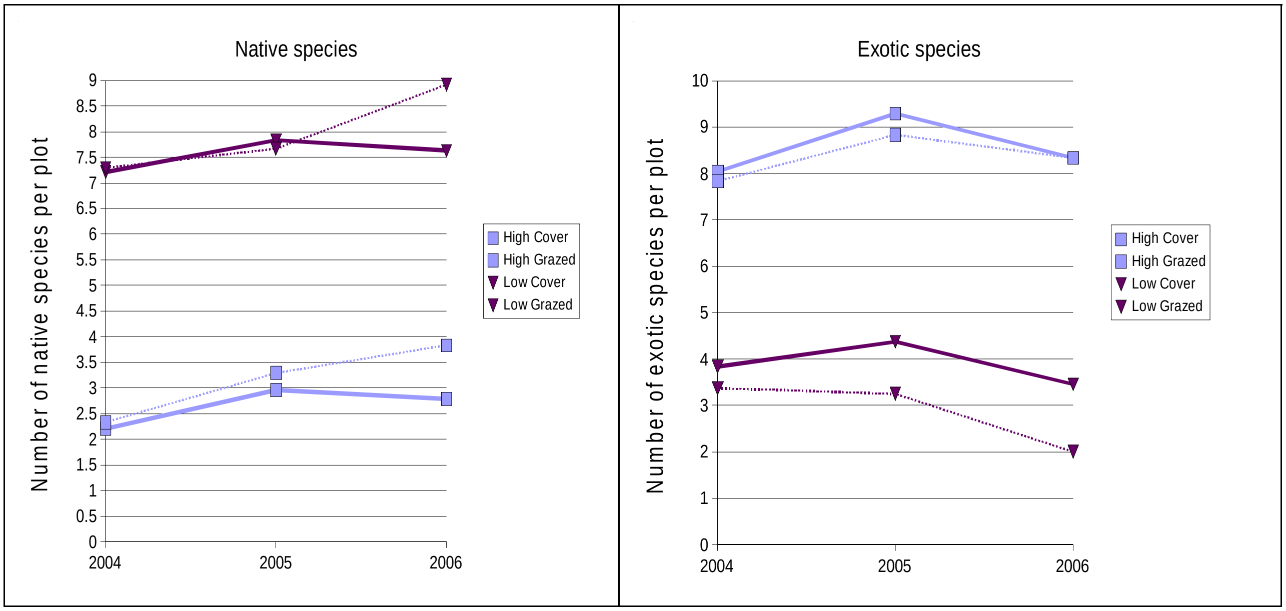

Figure 23. Changes in the number of native or exotic species for grazed and nongrazed plots.

Two-year grazing profiles

To determine whether changes in vegetation outcomes from 2004 to 2006 could be related to specific grazing patterns, it was necessary to develop grazing profiles that extended from the beginning of the 2005 grazing season through April 2006. Because only low plots had shown substantial changes in most vegetation outcomes over this period, this analysis was restricted to the low plots. We used hierarchical clustering as before and developed five two year grazing profiles for low plots. Three of these profiles occurred in only a single field; the others were represented in two or three fields.

These two year profiles were not significant predictors of changes in either native or exotic cover from 2004 to 2006 in either contingency table analyses or repeated measures analyses. The poor performance of the two year profiles is consistent with the lack of advantage in including May-June 2005 grazing impacts when developing 2006 grazing profiles. We believe that these data indicate that current season grazing and weather conditions exert the strongest influences on the vegetation outcomes recorded in spring. Carryover effects from the preceding season were minor or insignificant at least within the small range of grazing histories represented in this study.

This effect is illustrated by a comparison of native and exotic cover levels from 2004 through 2006 in low plots that were grouped in 2005 grazing profile B. This profile was characterized by high grazing impacts during the peak bloom period for native annuals and showed a significant decrease in native cover in 2005 (Swiecki and Bernhardt 2006). As shown in *figure s*, these plots were distributed among three different grazing profiles in 2006. Those grazed heavily during bloom in 2006 (profile F) showed an additional strong decrease in native cover and an increase in exotic cover. Plots that were grazed more lightly in 2006 (profiles C and D) showed recovery of native cover to 2004 levels and decreases in exotic cover to extremely low levels (*fig. 24*).

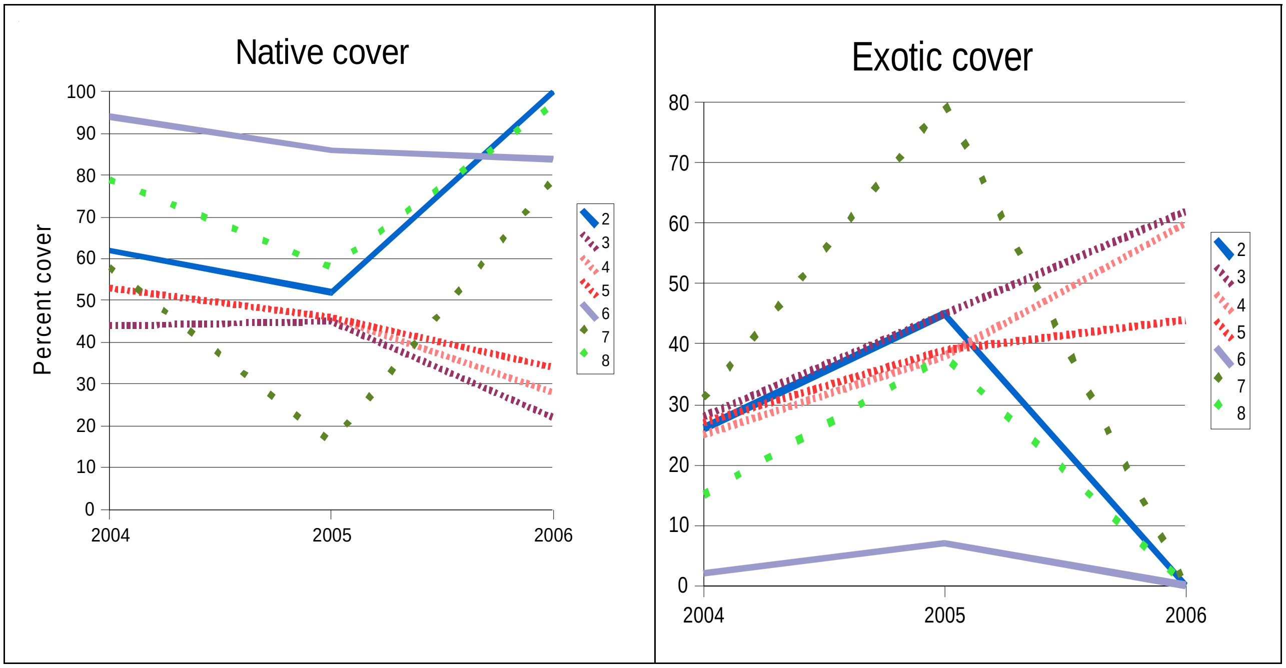

Figure 24. Changes in native and exotic cover for low grazed plots in 2005 grazing profile B. Different grazing profiles in 2006 are shown by different line types:
finely dashed lines = 2006 profile F (plot clusters 3,4,5),
solid lines = 2006 profile C (plot clusters 2 and 6),
dotted lines = 2006 profile D (plot clusters 7 and 8).

Changes in residual dry matter from 2004 to 2006

We used repeated measures analysis of variance of August residual dry matter (RDM) by plot position (high vs. low) and plot type (grazed vs. nongrazed) to determine whether season-end RDM had changed from 2005 to 2006 (*table 9, 10*). This overall analysis showed that RDM was significantly higher in nongrazed plots than in grazed plots and was higher for plots in high positions compared with those in low positions. In addition, 2006 RDM levels were lower overall than in 2005, which was primarily due to the significant decrease in RDM in high plots between 2005 and 2006 (*fig. 25*).

Table 9. Summary of repeated-measures analysis of variance for end-of-season (August) residual dry matter in 2005 and 2006 by plot position (high, low) and plot type (grazed, nongrazed).

Source	df	F ratio	Probability
Between plots			
Position (high, low)	1	1.2351	<.0001
Type (grazed, nongrazed)	1	1.1072	<.0001
Position × Type	1	1.1779	0.2806
Within plots			
Year	1	25.1220	<.0001
Year × Position	1	16.9323	<.0001
Year × Type (grazed, nongrazed)	1	0.000036	0.9542
Year × Position × Type	1	1.6395	0.2036

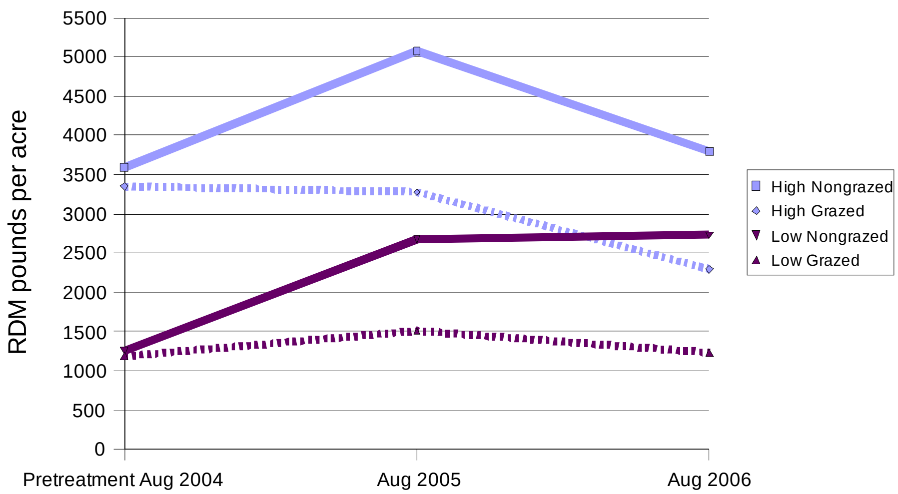

Figure 25. Pre-treatment and post-treatment residual dry matter (RDM) measured in August 2004, 2005 and 2006. For both plot positions (low and high), nongrazed control plots showed a significant increase in RDM levels between the 2004 pretreatment baseline and the 2005 reading after one year of differential grazing. Dashed lines represent the averages from grazed plots.

Table 10. Average percent reduction in RDM of grazed plots compared to nongrazed cover plots in 2005 and 2006 and average lbs/acre of forage removed through grazing (calculated from the difference between the RDM of paired grazed and nongrazed plots). Significant differences between paired grazed and nongrazed plots in matched pairs t-tests (1 tailed) are denoted by asterisks.

Position	Field	% reduction 2005	lbs/acre removed 2005	% reduction 2006	lbs/acre removed 2006
High	18E	40*	2234	47*	1671
High	19E	33*	1722	52*	2040
High	20E	33*	1449	24	862
Low	18E	48*	737	60*	1232
Low	19E	50*	1688	66*	2140
Low	20E	30*	1066	44*	1022

In addition to RDM measurements, we used two other methods to assess mulch (or thatch) levels in nongrazed cover and grazed plots. Figure 25 shows mulch height measured each year in the nongrazed cover and grazed plots in each field. Mulch height was defined as the depth of residual dry matter carried over from previous seasons, as opposed to dead material that had accumulated in the current season. With a few exceptions, mulch height generally increased over time in the nongrazed cover plots, and decreased over time in the grazed plots (*fig. 26*). The overall mulch height in 2006 was significantly less in grazed plots than in the nongrazed cover plots. Mulch height in 2006 was not correlated with the grazing profiles.

Among grazed plots, regression analysis of the 2004 through 2006 grazing seasons indicated that field-level grazing intensity (AUM/acre) was not significantly correlated with mulch height in either high or low plots.

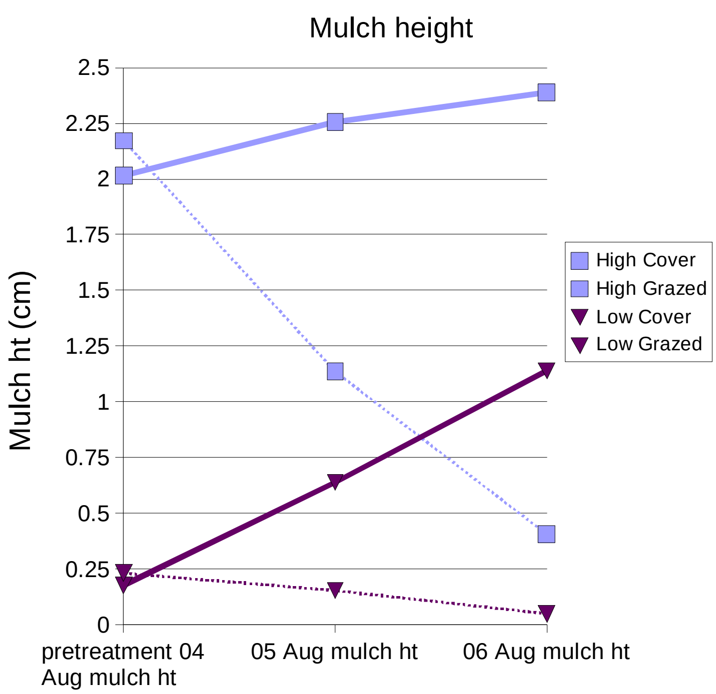

Figure 26. Changes in mulch (thatch) height in grazed and nongrazed cover plots measured in August each year. Grazed and nongrazed cover plots were grazed in 2004 before the experiment was started.

Mulch cover and bare cover were also assessed in April 2004, 2005, and 2006 in conjunction with assessments of native and exotic cover in the plots. The repeated measures analysis of variance for mulch cover in 2004 and 2006 (*table 11*) shows no overall change in mulch cover over time, but significant interactions between time and plot position, and time and plot type. No significant increase in mulch cover in nongrazed plots compared to grazed plots was observed in the first year after grazing was discontinued. In the second year, the difference in mulch cover between the grazed and nongrazed cover plots was significant (*table 11, fig. 27*).

Table 11. Probability levels of F tests for repeated measures analyses for cover of mulch and bare soil within plots for 2004 and 2006 by plot position (high/low), and plot type (grazed, nongrazed). Factors significant at p≤0.05 are shown in boldface. Cover percents and count data were transformed before analysis.

	Between plots			***Within plots***			
Source:	**Position**	**Type**	**Position X Type**	**Year**	**Year × Position**	**Year × Type**	**Year × Position × Type**
Mulch	**<0.0001**	0.0966	ns	ns	**0.0003**	**0.0089**	ns
Bare	**<0.0001**	**<0.0001**	ns	**<0.0001**	ns	**0.0085**	ns

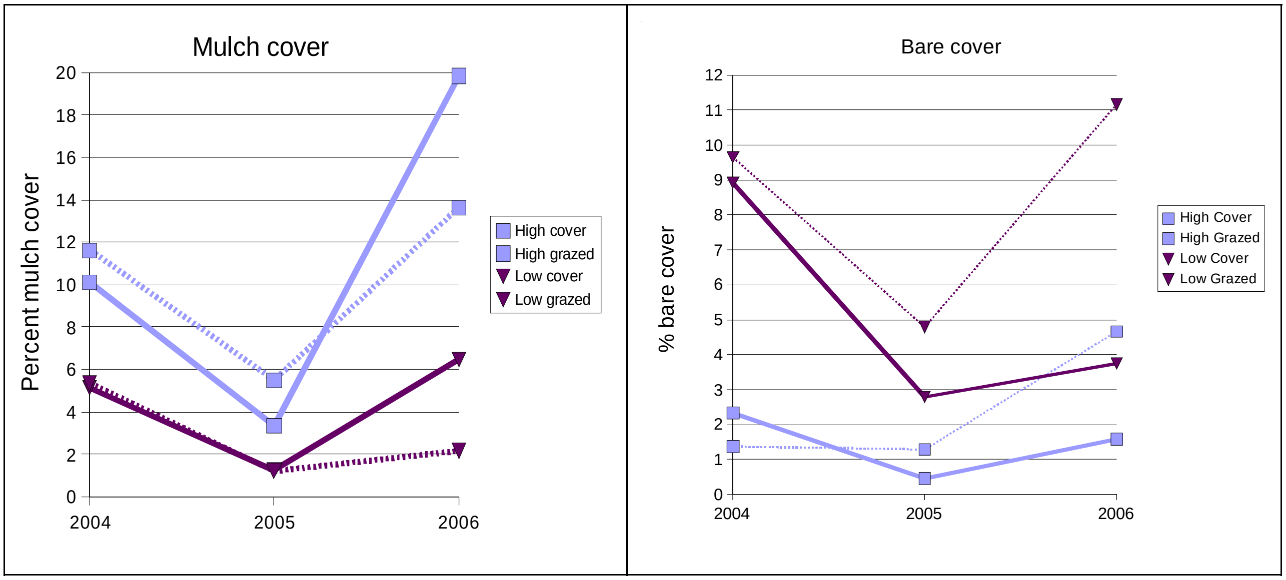

Fig 27. Average cover percentages of mulch (left) and bare soil (right) measured in during spring evaluations in 2004-2006 in grazed (dashed lines) and nongrazed cover (solid lines) plots for high (blue) and low (burgundy) plot positions.

The percentage of bare soil increased in the grazed plots relative to the nongrazed cover plots between 2005 and 2006 (*fig. 27*). Bare soil cover is much greater in the grazed plots than in the nongrazed plots and the differences are significant overall for both the high and low plots (*Table 11*). Gopher activity appears to be a large contributor to the increase in bare soil cover. In establishing the plots in 2004, we generally avoided spots with substantial amounts of gopher activity. As gophers have moved into many of the plots over time, the amount of bare soil associated with gopher activity has increased, dramatically in some cases (*fig. 28*). We have not collected data to determine whether gopher activity differs substantially between grazed and nongrazed treatments. However, because vegetation growth is greater overall in nongrazed plots compared to grazed plots, first-hit point counts are more likely to intercept vegetation in nongrazed plots that in grazed plots even if both have similar levels of gopher-excavated soil.

Figure 28 (previous page). Examples of plots with substantial gopher activity. Low nongrazed cover plot photographed in August 2006 (top), and low grazed plot photographed in February 2006 (bottom). .

One possible explanation for the decrease in mulch heights in the grazed plots as a group is that in these grazed plots, the combined action of trampling by sheep and soil movement by gophers tends to bury mulch, removing it from the soil surface. In the nongrazed cover plots, mulch is not broken up and flattened by trampling. Gopher activity may be is less effective at burying this old plant material in nongrazed plots because it is generally not compressed against the soil surface.

One of the goals of the original RFP for this project (12/18/03) was to reduce cover of thatch by 30% over a period of 10 years in grazed plots compared to the nongrazed control. The percent RDM reductions occurring under even the lightest grazing regime in this study are within this range for the low plots and approaching this range in the high plots (Table 6). Taken together, these three measures of thatch removal show that all of the grazing regimes are effective in reducing thatch, and that the light grazing regime in E20 is the least effective among the three treatments. Beyond that, there is no significant correlation between any of the mulch related outcome variables and the variables related to grazing intensity.

DISCUSSION

Grazed vs nongrazed plots

The experiment has so far demonstrated that nongrazed plots have experienced substantial changes in several metrics of residual dry matter by two years after the cessation of grazing. Compared with nongrazed cover plots, grazed plots have shown lower vegetation height and RDM, and reductions in mulch cover and depth. Most of these effects were seen within the first year after grazing ceased. It should also be noted that differences have been seen in all fields, including 20E, which was grazed very lightly in 2005 and lightly in 2006.

Although changes in measures of plant biomass were statistically significant after one season, significant effects on native cover and diversity did not appear until the second year after grazing cessation. Furthermore, significant changes in vegetative cover associated with grazing cessation have only occurred in plots in native-dominated low plots. The high plots, which are dominated by exotic grasses and have very low native cover have not yet shown significant differences in native or exotic cover between grazed and nongrazed plots.

The observed overall differences between grazed and nongrazed plots are related to three overall goals of the Jepson grazing program cited in the RFP (12/18/2003) in *Table 12* below. Compared with cover plots left ungrazed for two years, grazed plots overall have lower thatch, and low plots show a more desirable balance between native and exotic species. The overall implication is that even the lightest grazing regimes currently in use provide clear benefits in these categories relative to a nongrazed condition.

Table 12. Summary of statistically significant vegetation changes since 2004 in nongrazed cover plots compared to grazed plots. + = statistically significant change, — = no change.

	High plots	Low plots
Increased thatch in nongrazed		
-August vegetation height	+	+
-RDM	+	+
-Mulch height	+	+
-Mulch cover	+	+
Decreased natives in nongrazed		
-All native cover	—	+
-native spp count	—	+
Increased weeds in nongrazed		
-medusahead cover	—	—
-all exotic cover	—	+
-exotic species count	—	+

Differences between grazing profiles

Although there are clear differences between grazed and nongrazed plots overall, differences between grazing profiles have been more modest. As expected based on the overall grazed/ nongrazed analyses, only low plots showed any significant changes in vegetation outcomes that were related to grazing profiles. Furthermore, within-year grazing profiles were better predictors of spring vegetation outcomes than profiles that included grazing impacts from the previous season. This suggests that, at least for the range of grazing intensities included in this study, year-to-year carryover effects have been minimal and/or are overshadowed by current season grazing impacts.

Because native cover was already high in the low plots at the start of the study, most of the potential to observe change was in the negative direction. Based on the results from both seasons, the strongest single effect seen was the negative effect on native cover associated with grazing during the peak bloom period for native spring forbs. This effect was more pronounced in 2005 (Swiecki and Bernhardt 2006) when the field–level grazing regime was more intensive during this period. Nonetheless, those plots with the most intensive grazing during March-April 2006 (profile F) showed undesirable changes in native and exotic cover in 2006 (*fig. 24*).

Both of the grazing profiles that were associated with more desirable vegetation states in 2006 (C, D) had little or no grazing during the peak bloom period, and one (D) had very little grazing impact at all during 2006. Within the range of grazing intensities tested, the study provides no clear evidence that higher grazing intensity is associated with improved vegetation outcomes. Furthermore, even though the field-level grazing treatments vary almost threefold in grazing intensity (as measured by AUM/acre), we have not seen any significant correlation between AUM/acre and any of the vegetation outcome variables tested for either high or low plots. Because the overall grazing intensities used are relatively low, it is not possible to extrapolate the results of this study to predict the outcome of much higher grazing intensities. Nonetheless, there is no reason to believe that higher grazing intensities during peak bloom would have any less detrimental effects on pool/swale vegetation. Hence, avoiding or minimizing grazing impacts during this period should be incorporated in any planned grazing regime.

Results from 2006 also confirm the general relationship between pool/swale inundation and relative grazing impacts seen in 2005 (Swiecki and Bernhardt 2006). Because sheep avoid grazing in flooded areas, grazing during periods when pools are filled increases grazing intensity within the high plots relative to the low plots. This also seems to be the only condition observed to date under which high plots are grazed more heavily than low plots, although grazing intensity in both positions can be nearly equal early in the season. Because many of the pools and swales are filled for limited periods of time that cannot be predicted in advance of rainfall, there is not much potential to use this particular phenomenon to establish a schedule for an improved grazing regime. Nonetheless, this information could be integrated into a more adaptive and opportunistic grazing prescription that uses vegetation parameters (height, phenology) and inundation to adjust stocking levels and timing. When pools and swales are flooded, stocking rates could be increased to provide more intensive vegetation utilization on the high areas. Actual stocking rates and durations would have to be adjusted based on field conditions, which will vary from year to year.

By focusing on grazing profiles (measured grazing impacts over time) rather than the field-level grazing regimes (duration and density of sheep stocking), we are attempting to determine which components of the grazing regimes are responsible for changes in vegetation. This approach has shown that sheep grazed high and low position vegetation differently as the season progressed and that prolonged grazing during spring bloom has a negative impact on vegetation outcomes in low positions. These appear to be among the underlying factors that determine whether a given field-level grazing regime will have a positive or negative effect on desired vegetation outcomes.

The amount of variation observed in grazing profiles within fields supports our original assumption that specific field-level grazing regimes typically do not result in uniform levels of forage removal within a field. Given that most of the grazing profiles were not associated with significant changes in vegetation outcomes, our results to date indicate that it may be possible to maintain the current levels of native cover with a range of grazing regimes. However, driving the vegetation to a substantially different state (e.g., high native cover in the high microtopographic positions) may require substantially different grazing profiles than those represented in the study to date.

Summary of hypothesis and second year results

Hypothesis 1. Changes in the initial and final vegetation states for a given growing season will vary with the seasonal grazing profile.

First and second year data support this hypothesis, but only for low plots. The most notable effect we observed was that grazing during the spring bloom period decreased native cover relative to the prior year.

Hypothesis 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.

For low plots, grazing profiles were better predictors of native and exotic cover change than total of percent height removal (January-April), which supports this hypothesis. However, because only a relatively narrow range of grazing profiles was examined and cover changes in high plots were nonsignificant, data that support this hypothesis are limited.

Hypothesis 3. Weed-dominated and native-dominated experimental units will show different responses to grazing variables.

Data from both years support this hypothesis. Weed dominated plots (high plots) in general have changed less in response to cessation of grazing than have native-dominated plots (low plots), and only low plots have shown vegetation cover changes associated with grazing profiles.

Hypothesis 4. Different grazing profiles are likely to occur between weed- and native-dominated experimental units within plot clusters.

First and second year results support this hypothesis. Grazing profiles differed between weed-dominated high and native-dominated low plots. In addition, sheep grazed weed-dominated high plots more heavily when pools were filled by rainwater, and low plots more heavily when pools dried out.

Hypothesis 5. Thatch /mulch accumulation/removal will vary with grazing profiles.

There is definitely much more thatch in nongrazed units than in grazed units. Although there were significant differences in mulch height associated with grazing profiles in 2005, there were no significant correlations in 2006. Among the grazing levels in the experimental fields there is not a significant correlation between AUM/acre and thatch accumulation.

Hypothesis 6. Compared with nongrazed units, grazed units will have lower weedy cover and increased native species cover.

As discussed above and summarized in Table 12, results from the second year of the study support this hypothesis for low plots only. It is likely that the nongrazed cover plots have not yet stabilized and further changes in cover and diversity are likely to occur in the future.

Recommendations for 2007 grazing regimes

After two years, none of the grazing treatments have reduced exotic cover below levels that were present in grazed plots prior to the start of the study. In addition, the only grazing treatment that seems to have a negative effect on native cover in low plots is grazing during the April bloom period.

As we enter the third (and last based on current funding) year of the study, it is reasonable to reconsider the grazing regimes being used to determine whether alternative grazing regimes would provide more useful information. Three alternatives are discussed below.

Alternative	Pros	Cons	Notes
1. Maintain current prescriptions in all 3 fields	-Would increase confidence in current conclusions by repeating over an additional year/weather regime. -If 2007 regime is closer to target levels, better replication of the high April grazing impact could be achieved.	-None of the current regimes under study appears to represent an improvement over the existing standard regimes. - Appears unlikely that current regimes will significantly affect vegetation in high plots	Prescriptions would be the same as proposed for the 2006 season.
1a. Retain three current prescriptions, but shift fields	-Reduces the confounding between field and grazing regime.		Given that year-to-year carryover effects appear to be minimal, replication of effects in different fields would provide greater confidence.
2. Retain 2 existing regimes, add one higher intensity regime. Include shift in field for at least one retained regime. 20E: use current low intensity prescription 18E: use current 19E prescription (high April grazing intensity) 19E: use current 18E timing but increase AUM to that specified in the draft Management plan (Witham in preparation)	-Keeping one field with constant grazing response in the third year provides a means to account for differences due to weather. -Field shift reduces the confounding between field and grazing regime. -Test includes grazing level specified in management plan. -Higher intensity regime uses a sequence that has been tested at a lower intensity.	-Loss of replication in a third year of one grazing treatment -New grazing regime is tested for only a single year.	20E is probably the best choice for retention as a constant treatment, but other choices are possible. Another alternate configuration would be to drop the 19E grazing prescription and use the 18E regime, which would be replicated at two levels in a single year.
3. Retain one existing regime and duplicate one higher intensity regime in two fields. 20E: use current low intensity prescription 18E and 19E: use current 18E timing but increase AUM to that specified in the draft Management plan (Witham in preparation)	-Test includes grazing level specified in management plan. -Greater replication of the higher grazing intensity regime. -High intensity regime is tested against wider range of past grazing histories. -Keeping one field with constant grazing response in the third year provides a means to account for differences due to weather.	-Only one of the current regimes can be assessed for a third year. -New grazing regime is tested for only a single year.	20E is probably the best choice for retention as a constant treatment, but other choices are possible. The19E grazing prescription is dropped because it is the least likely to be an improvement over the current regimes

Currently there is a great deal of interest on the part of the Jepson Prairie Management Committee to increase grazing pressure at Jepson Prairie Preserve. The authors discussed these alternatives in a Dec 11 2006 conference call open to all JPMC members. Participating were Ben Wallace, SLT, Shorty Boucher, UC Natural Reserve System, and the authors. After much discussion and consideration of pros and cons for all the various alternatives, the variant of alternative 2 listed in the notes column was selected for the 2007 grazing year.

This alternative retains the low intensity, early grazing regime in field 20E for 2007. Maintaining the prescription in 20E gives us an opportunity to confirm the effects of light grazing seen in the past 2 years, and provides a standard by which to judge the magnitude of weather effects on vegetation outcomes. The prescription used in field 19E, which includes high intensity grazing during peak bloom, will be omitted. Data from the past two years indicates that this is likely to provide undesirable outcomes in low pool/swale vegetation. The overall grazing timing used in 18E (early and late grazing) will be imposed at two grazing intensities. Field 19E will be grazed according to the prescription (timing and overall stocking level) used on 18E in 2005 and 2006. Field 18E will have the same overall timing of grazing, but will be grazed at a higher stocking level; AUM will be increased substantially, to levels recommended in the management plan (Witham, 2006). Because field 18E is half the size of 19E, it should be the easier field to stock at a higher AUM/acre. The design also allows us to determine whether shifting the grazing regime in 18E to 19E will yield similar outcomes to those seen in 18E over the past two seasons.

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