

**Carrizo Plain Ecosystem Project
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Summary

Understanding relationships among giant kangaroo rats (GKR), plant dynamics, and cattle grazing is necessary to optimize conservation of upland species in the Carrizo National Monument. We completed the fifth year of the Carrizo Plain Ecosystem Project (CPEP), a long-term study to quantify these relationships using replicated cattle and GKR exclosures. 2011 marked the second consecutive year of high precipitation and abundance was significantly higher for all focal wildlife species, setting new records for the study. We also observed a sharp decline in native plant cover and a concurrent rise in exotic cover. Our ability to identify effects of cattle grazing on the dynamics of GKR and other species was improved by another year of data and patterns continue to emerge. Grazing had a significant positive effect on invertebrates and although results were not significant, there was a slight positive effect on GKR densities, and a slight negative effect on SJAS densities. GKR had a slight negative effect on overall native plant cover. However, bunchgrasses were positively affected by GKR presence and exotic grasses were negatively affected, suggesting that GKR foraging may limit the dominance of exotics they prefer to eat, such as large-seeded grasses. This was the first year that data was recorded on gopher (*Thomomys bottae*) activity on the Plain and results clearly indicate a preference for areas where GKR are absent. Beetle and arachnid abundance was higher where GKR were present. While 2010 and 2011 both had higher than normal levels of precipitation, the fact that we recorded significant differences in interactions among animals and plants between these years underlines the importance of this study and the need for further data collection in both wet and dry years.

Prepared by Rachel Endicott, 2011

Background

The Carrizo Plain National Monument, located in the southern San Joaquin Valley of California, is the largest (810 km²) of the few remaining San Joaquin grassland ecosystem remnants and is a “hotspot” of species endangerment (Dunn et al. 1997). The federally endangered giant kangaroo rat (*Dipodomys ingens*, hereafter “GKR”) is a keystone species in this system; it modifies the soil extensively with burrow systems and is important prey for many predators, such as the federally endangered San Joaquin kit fox (*Vulpes macrotis mutica*). Managing for endangered species conservation is a mandate of the monument (B. Stafford, pers. comm.), and this is a particularly challenging task because endangered species occur at every trophic level in the Carrizo Plain. Additionally, the Carrizo Plain is now dominated by annual grasses from Europe. Thus, sound management in the Carrizo Plain requires an understanding of the interactions between the many endangered and exotic species that occur there.

Previous research in the Carrizo by D. Williams provided basic demographic and life history information for GKR and compared a population in a grazed area to one in an ungrazed area. Additionally, monitoring data for a variety of species (including GKR) in relation to grazing was carried out for nine years and is currently being analyzed by Dr. C. Christian. These studies and others have provided conflicting evidence as to the effect of grazing on upland species and their habitats. Additionally, they cannot establish causal relationships between invasive plant dynamics and factors such as GKR abundance because they were observational rather than experimental.

In 2007, we initiated the Carrizo Plain Ecosystem Project (CPEP) to examine the relationships between cattle, GKR, plants, and other species in the Carrizo Plain using replicated exclosures (Prugh 2007). We gathered baseline data on the flora and fauna on our experimental plots, and we constructed 10 cattle exclosures in the annually-grazed Center Well pasture and 20 kangaroo rat exclosures in the Center Well and Swain (ungrazed) pastures. In 2011, we continued monitoring the flora and fauna on these plots, and three graduate student research projects initiated in 2010 completed the majority of data collection.

Long-term project goals

1. To determine how giant kangaroo rats affect the distribution and abundance of native and invasive plants in the Carrizo Plain National Monument
2. To determine how livestock grazing directly and indirectly affects native species in the Carrizo Plain, especially giant kangaroo rats and plants.
3. To assess the potential impacts of climate change on the distribution, abundance, dynamics and interactions of native and invasive species in the Carrizo Plain National Monument.

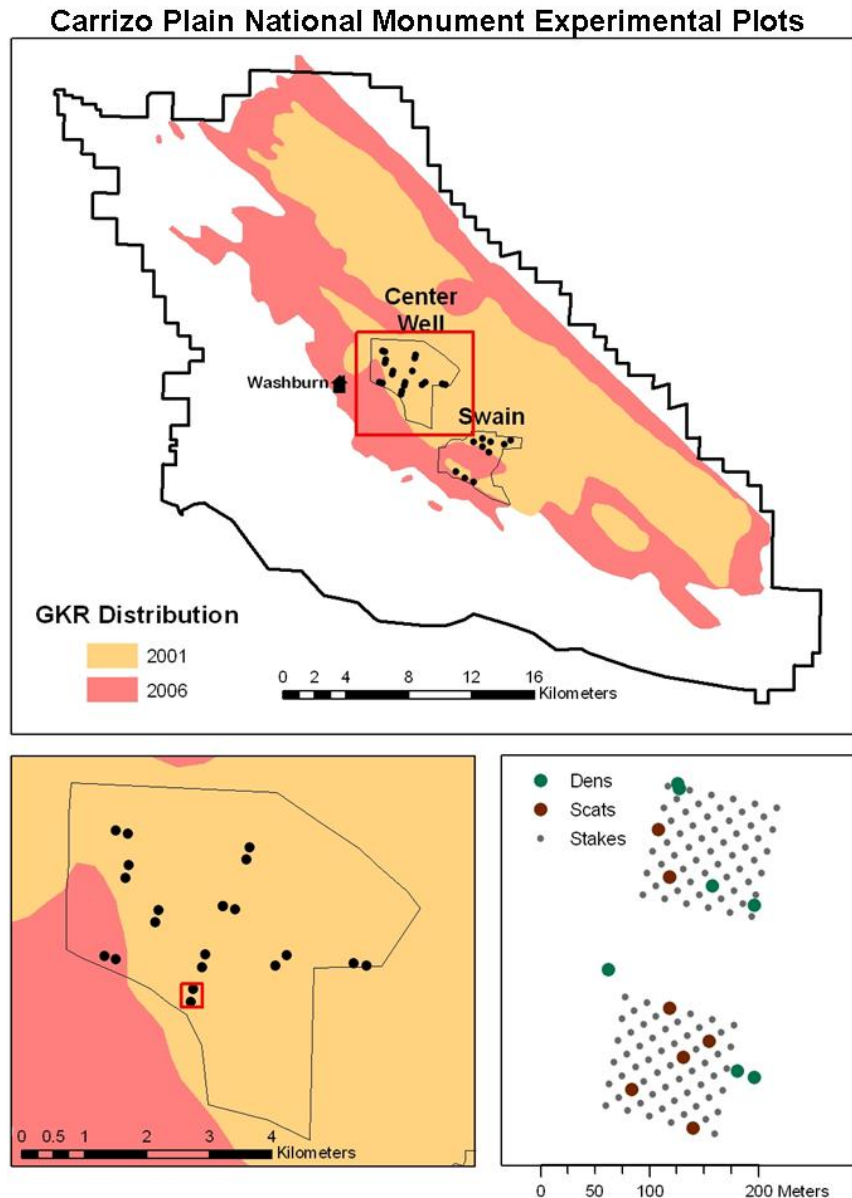


Figure 1. Map of study sites in the Carrizo Plain National Monument. Details are shown for the Center Well pasture and site CW 7. Kit fox dens and scats, as well as trap stakes, are shown for site 7.

Methods

Experimental design

We are using the Before-After-Control-Impact design with Paired sampling (BACIP; Osenberg et al. 1994) to determine the effect of GKR and cattle removal treatments on plant biomass and composition. BACIP is a powerful statistical framework that requires baseline surveys to control for pre-existing differences between control

and treatment sites. To determine the effect of GKR on plants, we are using a randomized block split-plot design with three fully-crossed factorial treatments: pasture, GKR presence, and soil disturbance (Figure 2). The effect of cattle on GKR, plants, and other species is added as a partial fourth treatment (Figure 2). Because there is no cattle grazing in the Swain pasture and because it is not feasible to exclude GKR while allowing access to cattle, we were not able to add livestock presence as a fully factorial treatment. Thus, we have used structural equation modeling to estimate the strength of interactions and indirect effects of cattle (Wootton 1994).

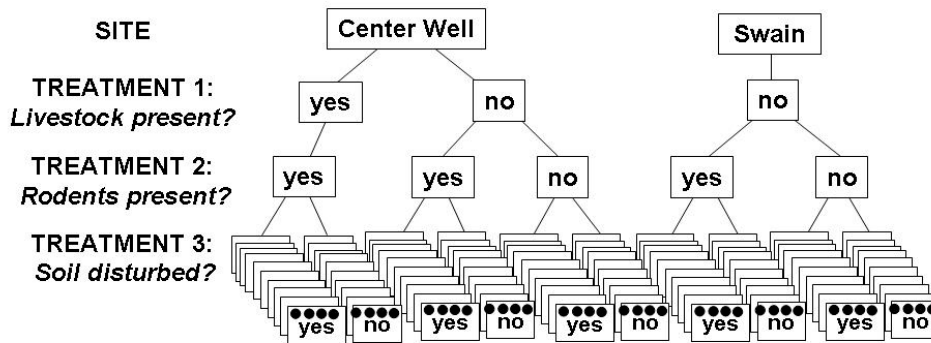


Figure 2. Experimental design of the project. There are ten blocks of each treatment combination and four nested vegetation plots (filled circles) within each block.

Exclosures

We constructed 20 20x20-m GKR exclosures, 10 in Center Well and 10 in Swain. Exclosures were placed in the center of each randomly chosen sub-block. Cattle exclosures were constructed around each GKR exclosure in Center Well. Cattle exclosures are 140x140-m (1.96 ha), large enough to have a population of roughly 20-100 GKR occurring within each exclosure. Paired 1.96-ha control plots are located 60 m from each cattle exclosure in Center Well in a random compass direction. Plants were sampled in each GKR exclosure, in a paired 400-m² area 20 m away from the GKR exclosure, and in Center Well, at the center of each paired control plot (Figure 3).

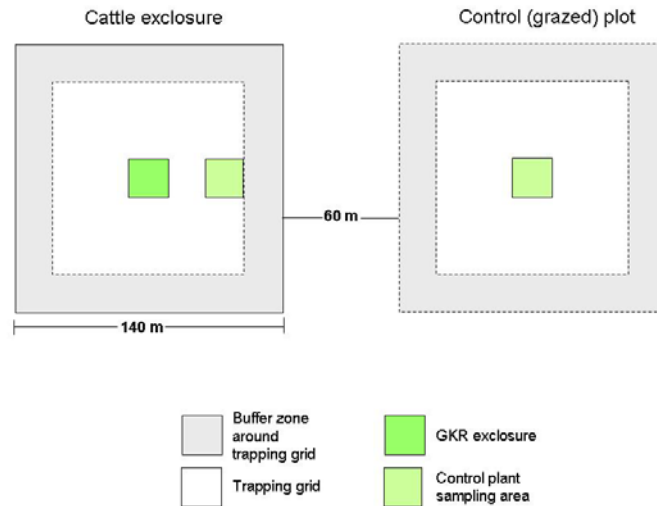


Figure 3. Nested enclosure design to separate livestock and GKR effects on plants, with paired control plot. A buffer zone around each GKR trapping grid ensured that the surveyed population was comprised of individuals living within the plot. This shows the design in Center Well; in Swain each plot is identical to the cattle enclosure but does not have cattle fencing.

Plant and soil sampling

We established 8 1-m² permanent plant sampling quadrats in each of the 50 400-m² plant sampling areas, for a total of 400 quadrats. Half of the quadrats were placed on GKR precincts and half were placed off precincts. The pinframe sampling method was used to determine plant cover and composition in each 1-m² plot, in which all species intercepted by 81 crossing points were recorded (Figure 4; Kimball and Schiffman 2003, Seabloom et al. 2003). Species occurring in the plot but not in the crosshairs were also noted. Biomass samples were obtained from 1/16-m² plots adjacent to each 1-m² plot to estimate biomass in April, July, and November (peak, post-grazing, and minimum biomass). Clip plots are surveyed in a different location each sampling session. Plant height was also measured prior to clipping.



Figure 4. Plant sampling plot in a non-precinct area, showing the 1-m² point frame and the 1/16-m² clip plot.

GKR surveys

Mark-recapture surveys were conducted on each plot to estimate GKR abundance. Extra-long Sherman traps were placed every 20 meters, with each line offset such that traps were arranged in a checkerboard (Figure 5; $n = 60$ traps per plot, diagonal trap distance = 14.1 m). Traps were baited with parakeet seed (microwaved to prevent germination) and paper towel, and they were set at dusk and checked approximately 3 hours later. Sessions lasted for 3 nights on each grid in April and August. All captured animals were marked with an ear and PIT tag, weighed, sexed, and released. Trapping occurred from April 4-May 13, 2011 (28 trap nights) and August 1-25, 2011 (18 trap nights).

To obtain mark-recapture estimates, we used the program R (R Development Core Team 2010) package RMark. We obtained population estimates for each trapping session as well as apparent survival estimates for the period between sessions using the robust design model (Pollock 1982). Death cannot be distinguished from dispersal in this model, so the “survival” rate obtained is referred to as “apparent survival.”

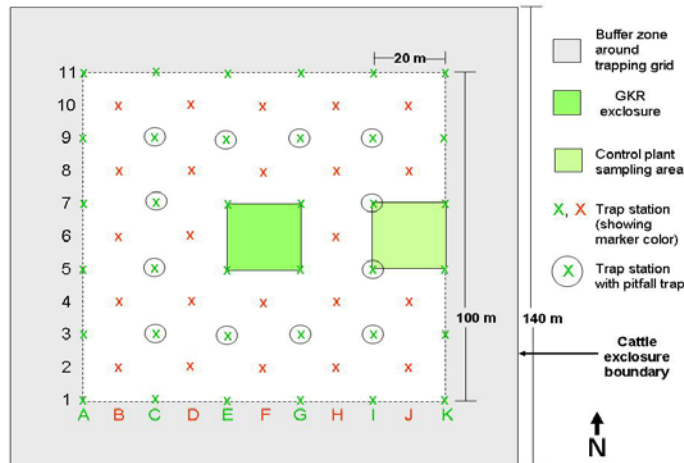


Figure 5. Detailed diagram of a cattle enclosure. Trap stations show trap locations for GKR mark-recapture surveys. Colors correspond to the spray-painted color on the stake marking the location. Letters and numbers identify the grid stakes (A1, B2, etc.).

Graduate student projects

Three graduate student projects focusing on GKR were initiated in 2010 and continued in 2011:

- 1) Doctoral student Tim Bean, UC Berkeley (supervisor: Justin Brashares)
Tim completed his masters project modeling the distribution of GKR in 2009, and his doctoral research builds from this project. He is conducting mark-recapture surveys of GKR at sites across the Carrizo Plain and combining this data with remote sensing and habitat variables to develop a habitat suitability model for GKR.
- 2) Masters student Chris Gurney, UC Berkeley (supervisor: Justin Brashares)
Chris is studying the effect of GKR foraging behavior and soil disturbance on native plant restoration in the Carrizo Plain. Using our exclosures, he conducted an experiment seeding small plots with four native species, two of which were preferred by GKR in diet trials and two of which were avoided. He seeded plots in and out of the GKR exclosures and with and without soil disturbance to see how these factors affect the success of seeding efforts. He also mapped out surface pit caches and haypiles and is monitoring these sites to determine how seed caching affects plant composition.
- 3) Masters student Steve Etter, CSU Northridge (supervisor: Tim Karels)
Steve is studying adult GKR survival. He radio-collared 63 adult and 2 juvenile GKR and monitored individuals daily to determine causes and rates of mortality. Individuals were collared on our plots in Swain, and sites with high or low GKR density were chosen in order to determine how density affects survival.

SJAS surveys

San Joaquin antelope squirrel (*Ammospermophilus nelsoni*, hereafter “SJAS”) abundance was determined on each plot using mark-recapture surveys. Tomahawk traps were placed every 40 m in checkerboard spacing, for a total of 18 traps per plot. Traps were baited with oats, set at dawn, and checked every two hours until noon or temperatures rose over 90° F. All captured animals were PIT-tagged, weighed, and sexed. Trapping occurred from May 21–June 14, 2011. The RMark package was used to obtain density estimates on each plot each year.

Bird surveys

Point counts were conducted four times on each plot from March 27–April 26, 2011. Concentric rings were demarcated with flags from the center of each 1.96-ha plot, marking 10 m, 25 m, 45 m, and 70 m. Point counts lasted 10 minutes and all birds seen and heard during this time were identified and recorded, along with the time heard/seen and which ring the bird(s) occurred in. Birds detected off plot or flying over the plot were recorded separately. We tried to avoid re-counting the same birds during counts on different plots. Plots were conducted from approximately 6–9 am and the order of plots visited was randomized.

Reptile surveys

Line transect surveys were used to estimate reptile abundance on each 1.96-ha plot. Three surveys were conducted on each plot from May 23–June 28, 2011. Seven 140-m long transects spaced 20 m apart were slowly walked by a single observer, and all reptiles detected within 10 m on either side of the transect were identified and recorded, along with the perpendicular distance from the transect line and age (hatchling or adult). Air temperature was recorded at the start of each survey and wind speed, and time of day were recorded at the start and end of each survey. We adopted temperature and wind cutoffs recommended in the blunt-nosed leopard lizard (BNLL) protocol.

Invertebrate surveys

Grasshoppers were counted during reptile surveys. Additionally, pitfall traps were placed on each plot between June 15–16, 2011 and collected 2 weeks later ($n = 8$ traps per plot, 240 total). Traps were made of standard plastic beer cups sunk into the ground such that the top of the cup was level with the ground (Figure 6A). Traps were covered with 10x10” pieces of aluminum flashing with an inch of space between the cover and ground (Figure 6B). Two cm of safe antifreeze (propylene glycol) was poured into each cup. A small piece of plastic aviary fencing ($\frac{3}{4}$ ” mesh) was placed just inside each cup to keep lizards out of the traps (Figure 8A). This probably filtered out larger insects as

well. Upon collection, the contents of each trap was rinsed and stored in 50-mL falcon tubes filled with ethanol. Samples were then sorted and all insects were counted and identified to order and morphotype. Each sample was weighed, and key insects (beetles, ants, and orthopterans) were also weighed separately.

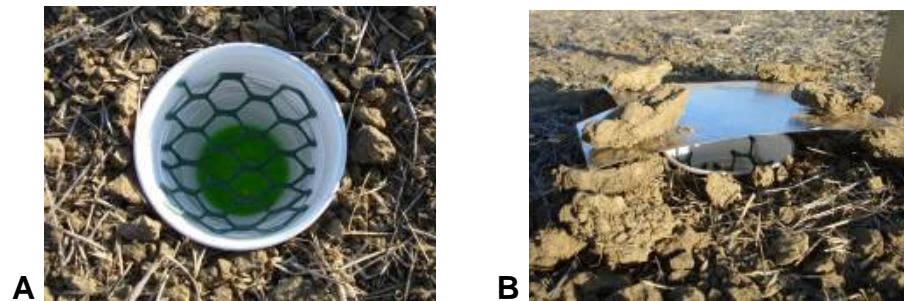


Figure 6. Pitfall trap viewed from above (A) and from the side with the aluminum cover (B).

Spotlight surveys

Ten spotlight routes along dirt roads in our study pastures ranging in length from 1.9-5.5 km (total distance = 35.4 km for all 10 routes) were surveyed in spring (May 16, 17 & 19, $n = 3$ surveys) and summer (July 24, 26 & 27, $n = 3$ surveys). We used 1-million candlepower spotlights aimed out either side of a slowly moving vehicle and animals were located by seeing eyeshine. Binoculars were used to aid identification. All predators and lagomorphs were identified and recorded, along with their distance from the transect (using a rangefinder), angle from the vehicle, and location along the transect line.

Kit fox activity and diet

In 2010, kit fox dens found on plots or opportunistically while walking to plots were geo-referenced. In 2011, we continued to collect scats deposited on our traps as kit foxes often marked our traps with urine and feces. We collected 109 kit fox scats. We also recorded all sightings of kit foxes.

Cattle grazing intensity

We counted cow patties on our control plots shortly after the cows were removed.

Results and Discussion

Plants

General plant composition

Plant species richness in our study area was similar to richness in 2008-2010, but plant cover changed dramatically this year (Table 1). Native plant cover declined sharply in both Center Well and Swain pastures and exotic cover in both pastures was the highest ever recorded for this study. Cover was also much less evenly distributed this year than it was in 2010.

2011 saw a steep increase in *Poaceae* cover, and GKR exclosures had the highest incidence of *Poaceae* species (Figure 7 and Figure 8). The dominant grass in Center Well was *Schismus arabicus* while *Bromus madritensis* dominated in Swain. In GKR exclosures, *Bromus* was the most common grass, while in areas with GKR, *Schismus* was the most common grass (Table 2).

In comparing all plots, the most common plant in Center Well was the exotic species *Erodium cicutarium*, followed by the native species *Vulpia microstachys* and the exotic *Schismus*. In 2010 three species dominated, two natives (*Vulpia microstachys* and *Lepidium nitidum*) and one exotic (*Erodium cicutarium*) but in 2011 the percent cover of *Erodium* was much higher (34.26%) than either *Vulpia* or *Schismus* (20.20% and 12.86%) (Table 2). On all plots in the Swain pasture, the exotic grass *Bromus* was the most common species (27.39%), followed by *Erodium* (15.14%) and *Vulpia* (11.79%).

Table1. Species richness and relative percent plant cover in the Center Well and Swain pastures, 2007–2011.

Metric	Type	Center Well					Swain				
		2007	2008	2009	2010	2011	2007	2008	2009	2010	2011
Species richness	native	18	29	29	31	28	15	43	40	45	39
	exotic	8	7	6	7	9	7	10	8	6	7
	total	26	36	35	38	37	22	53	48	51	46
Plant cover (%)	native	23	28	42	67	35	17	20	41	57	32
	exotic	17	37	28	25	49	32	33	32	34	44
	total	40	65	70	92	84	50	52	73	90	76

Table 2. Relative % cover of plant species in the Center Well and Swain pastures in 2011 ($n = 400$ plots), and without GKR (“No GKR”, inside GKR exclosures, $n = 160$ plots) and with GKR (“GKR”, outside GKR exclosures, $n = 240$ plots).

Species	Type	Center Well	Swain	No GKR	GKR
<i>Erodium cicutarium</i>	invasive	34.26	15.14	18.60	32.82
<i>Vulpia microstachys</i>	native	20.20	11.79	23.91	12.25
<i>Schismus arabicus</i>	invasive	12.86	9.46	3.46	17.17
<i>Trifolium gracilentum</i>	native	9.29	2.25	4.08	8.38
<i>Hordeum murinum</i>	invasive	5.68	5.30	8.76	3.31
<i>Bromus madritensis</i>	invasive	3.45	27.39	20.86	6.76
<i>Lasthenia minor</i>	native	2.78	0.24	0.20	2.94
<i>Vulpia myuros</i>	invasive	2.26	0.68	2.32	1.20
<i>Amsinckia tessellata</i>	native	2.16	2.29	1.61	2.63
<i>Microseris douglasii</i>	native	1.99	0.10	1.76	0.94
<i>Lotus wrangelianus</i>	native	1.83	2.71	2.26	2.09
<i>Microseris elegans</i>	native	0.77	1.04	0.48	1.15
<i>Astragalus oxyphysus</i>	native	0.70	1.49	1.58	0.60
<i>Eriogonum gracillimum</i>	native	0.47	1.15	0.89	0.61
<i>Lepidium nitidum</i>	native	0.42	0.22	0.10	0.51
<i>Pectocarya penicillata</i>	native	0.23	1.26	0.30	0.84
<i>Dichelostemma capitatum</i>	native	0.20	0.30	0.37	0.15
<i>Capsella bursa-pastoris</i>	invasive	0.17	--	--	0.18
<i>Astragalus lentiginosus</i>	native	0.09	2.07	1.62	0.30
<i>Amsinckia menziesii</i>	native	0.03	--	--	0.03
<i>Calandrinia ciliata</i>	native	0.03	<0.01	0.01	0.03
<i>Lupinus microcarpus</i>	native	0.03	0.19	0.19	0.03
<i>Phlox gracilis</i>	native	0.03	--	0.02	0.02
<i>Poa secunda</i>	native	0.02	4.78	1.65	1.94
<i>Hollisteria lanata</i>	native	0.01	1.59	0.36	0.78
<i>Tropidocarpum gracile</i>	native	0.01	0.09	0.02	0.06

Table 2 Continued.

Species	Type	Center Well	Swain	No GKR	GKR
<i>Guillenia lasiophylla</i>	native	0.01	<0.01	--	0.01
<i>Trichostema lanceolatum</i>	native	0.01	0.02	0.02	0.01
<i>Allium sp.</i>	native	<0.01	0.03	--	0.02
<i>Astragalus didymocarpus</i>	native	<0.01	0.02	0.01	0.01
<i>Herniaria hirsuta</i>	invasive	<0.01	0.16	0.02	0.09
<i>Lactuca serriola</i>	invasive	<0.01	0.02	--	0.01
<i>Lasthenia californica</i>	native	<0.01	3.22	1.62	0.94
<i>Malacothrix coulteri</i>	native	<0.01	<0.01	--	--
<i>Stellaria media</i>	invasive	<0.01	--	--	--
<i>Trifolium albopurpureum</i>	native	<0.01	--	--	--
<i>Uropappus lindleyi</i>	native	<0.01	0.09	0.03	0.04
<i>Camissonia campestris</i>	native	--	<0.01	--	--
<i>Camissonia palmeri</i>	native	--	0.07	0.01	0.04
<i>Castilleja exserta</i>	native	--	0.01	0.01	--
<i>Castilleja lineariloba</i>	native	--	0.01	--	0.01
<i>Chaenactis glabriuscula</i>	native	--	1.11	0.63	0.28
<i>Chamaesyce ocellata</i>	native	--	<0.01	--	--
<i>Chorizanthe uniaristata</i>	native	--	1.22	0.52	0.42
<i>Eremocarpus setigerus</i>	native	--	<0.01	--	--
<i>Lastarriaea coriacea</i>	native	--	0.95	0.73	0.10
<i>Lepidium dictyotum</i>	native	--	0.02	0.01	0.01
<i>Linanthus bicolor</i>	native	--	<0.01	--	--
<i>Linanthus liniflorus</i>	native	--	0.91	0.61	0.16
<i>Lomatium utriculatum</i>	native	--	<0.01	--	--
<i>Plagiobothrys canescens</i>	native	--	0.10	--	0.06
<i>Plantago erecta</i>	native	--	0.52	0.37	0.08

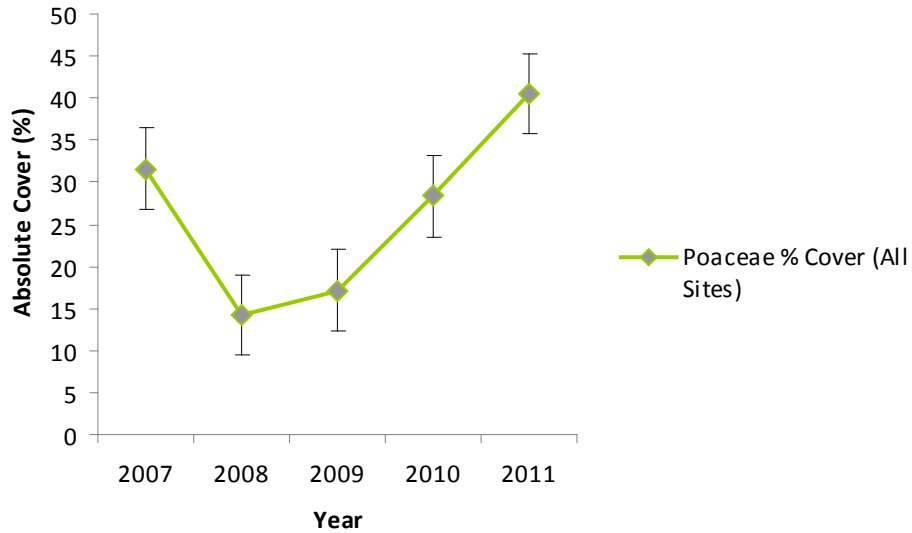


Figure 7. Absolute percent cover of all *Poaceae* species over time. Means and standard error bars are shown.

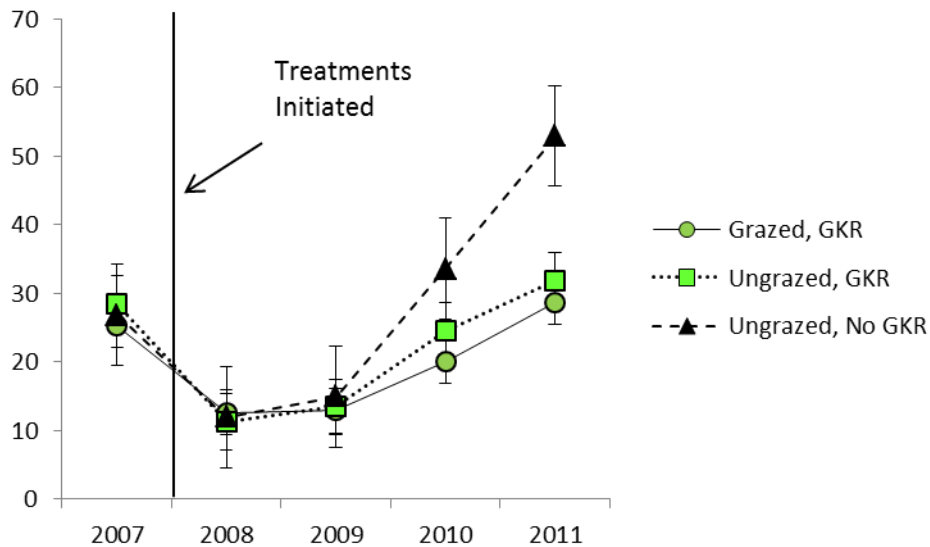


Figure 8. *Poaceae* cover in experimental plots within the Center Well pasture. Three treatments were initiated prior to the spring of 2008: kangaroo rat exclusions (ungrazed, no GKR), cattle exclusions (ungrazed, GKR), and control plots (grazed, GKR). Means and standard error bars are shown ($n = 10$ replicates per treatment).

Grazing intensity

Approximately 1,112 cows and calves were turned out in Center Well from March 14–August 5, 2011, for a total of 881 animal use months. Grazing intensity appears to be down from 2010 (Table 3) and there was a low correlation in 2011 between grazing intensity and plant biomass (Figure 9, $r = 0.2$), however cow patties may have been undercounted. In previous years cattle were removed from Center Well by July but this year cows remained on site through August and older cow patties may not have been recognized as from the current year. Cows were often observed on control sites and there were numerous problems with cows destroying and moving traps, indicating a high cow presence on plots this year. The correlation for all years is stronger ($r = 0.64$) indicating that overall there is a correlation between grazing intensity and plant biomass.

Table 3. Average counts of cows seen (2008-2010) on control (grazed) plots in the Center Well pasture ($n = 29$ surveys), and the total number of cowpats found on each plot (2008-2011).

Plot	2008		2009		2010		2011
	N cows	N patties	N cows	N patties	N cows	N patties	N patties
C1	3.17	459	0	24	1.31	418	253
C2	0.83	216	0.25	25	0.38	402	191
C3	1.30	155	0.13	35	1.48	219	234
C4	2.09	166	0.13	32	1.86	273	307
C5	0	4	0	11	0	129	58
C6	1.70	162	0	12	4.21	439	223
C7	0	132	0	3	0.59	238	147
C8	0.13	143	0	40	0.28	213	143
C9	0.17	125	0	16	0.10	303	132
C10	0.26	86	0	2	0.38	289	185

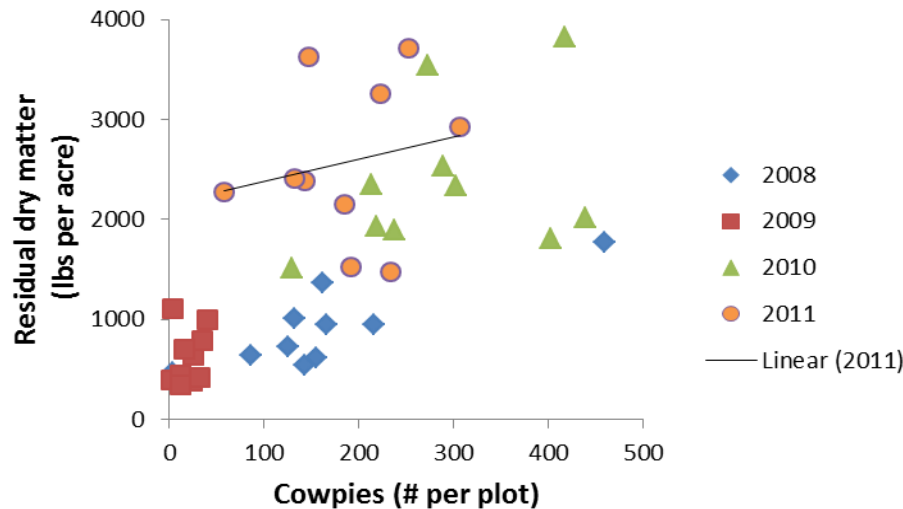


Figure 9. Relationship between grazing intensity (as measured by the number of cowpies) and plant biomass (residual dry matter) on plots in the Center Well pasture, 2008-2011. Plant biomass was measured in April each year.

Effect of cattle and kangaroo rat exclusion

Biomass removal by cattle and GKR.

We calculated the biomass removed by cattle as follows: the biomass measured on plots exposed to grazing was subtracted from the biomass measured on paired plots within cattle exclosures ($n = 10$ replicate pairs in Center Well). Similarly, we calculated the biomass removed by GKR by subtracting the biomass measured within cattle exclosures (which were exposed to GKR but not cattle) from the biomass measured within GKR exclosures in Center Well. Biomass was measured in April (peak), July (post-grazing), and November (minimum).

The peak residual dry matter (RDM) prior to grazing by cattle was approximately 2,600 pounds per acre in 2011 (Table 4), similar to the amount in 2010 (2,900 lbs per acre) and far higher than levels in 2008 and 2009. Cattle grazing reduced plant biomass by nearly 500 lbs/acre and GKR foraging by over 1000 lbs/acre (Figure 10). Biomass removal from grazing remained relatively steady throughout the year, possibly due to the prevalence of grasses well into the summer months and the longer than usual grazing period. Removal by GKR was higher in July than in April or November possibly due to the prevalence of grasses and to the drop in GKR densities seen between April and August (Figure 10, Figure 11). Similar to 2010, the cattle grazing effect was still apparent in November in 2011 (Table 4, Figure 10). Without grazing by GKR or cattle, RDM levels were reduced to a minimum of approximately 2,206 lbs/acre by factors such as insect herbivory, wind, and foraging by squirrels (Table 4).

Table 4. Average (\pm standard error) plant biomass measured in pounds per acre on 10 replicate sites in the Center Well pasture, 2011. Each site consisted of a control plot grazed by cattle (“GKR and cattle” treatment), a cattle enclosure (“GKR only” treatment), and a GKR enclosure (“no GKR or cattle” treatment).

Treatment	April	July	November
GKR and cattle	2573 \pm 250	2414 \pm 326	714 \pm 76
GKR only	3096 \pm 416	2875 \pm 361	1205 \pm 220
No GKR or cattle	4213 \pm 461	4431 \pm 413	2206 \pm 254

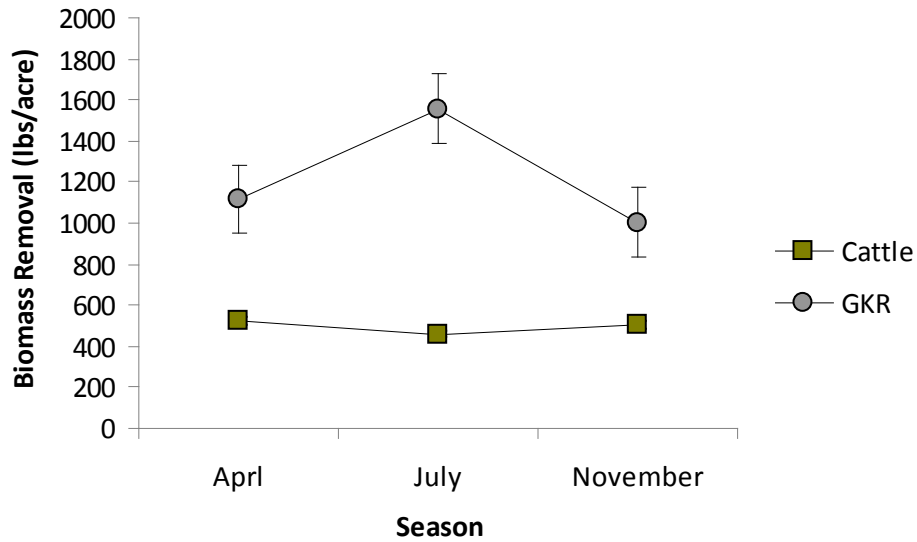


Figure 10. Biomass removal in Center Well pasture by cattle and GKR in 2011, measured as the difference in biomass among cattle and GKR enclosure treatments.



Figure 11. Photograph of the kangaroo rat enclosure at Center Well 9 in April 2011.

Native and exotic plant cover

In 2010, native percent cover in Center Well was 67% and in Swain 57%, but in 2011 those numbers dropped to 35% in Center Well and 32% in Swain. Neither grazing nor GKR exclusion had a significant effect on native cover. Native plant cover in Center Well was higher where GKR were excluded, but results were not significant (Figure 12; $t = 1.6338$, $P = 0.14$).

In plots without GKR, *Vulpia microstachys*, *Bromus madritensis* and *Erodium cicutarium* were the most common species while in plots with GKR, *Erodium* dominated (32.82%) followed by *Schismus arabicus* (17.17%) and *Vulpia* (12.25%). In 2010, *Vulpia*, *Lepidium* and *Erodium* were the most common where GKR were excluded while *Erodium* dominated, but not as strongly (18.25%), followed by *Lepidium* (13.01%), *Vulpia* (12.83%) and *Trifolium gracilentum* (11.97%).

The increased native cover in GKR enclosures was mainly due to higher cover of *Vulpia microstachys*, as well as a variety of relatively rare species, such as *Lotus wrangelianus*, *Chaenactis glabriuscula*, *Linanthus liniflorus*, *Lastarriaea coriacea*, and *Lupinus microcarpus* (Table 2). However, exotic species *Bromus* and *Hordeum murinum* were more common where GKR were excluded and some native species, such as *Poa secunda* and *Amsinckia tessellata* were more common where GKR were present (Table 2).

Erodium was the most common species in both grazed (38.73%) and ungrazed (24.13%) areas. Following *Erodium* in frequency in grazed areas were *Schismus* (20.24%) and three native species, *Trifolium* (12.31%), *Vulpia microstachys* (10.85%) and *Lasthenia minor* (4.64%). In ungrazed areas *Vulpia* was the second most common

species (18.53%), followed by *Bromus* (15.55%), *Schismus* (9.44%), *Hordeum* (6.22%) and *Trifolium gracilentum* (5.22%).

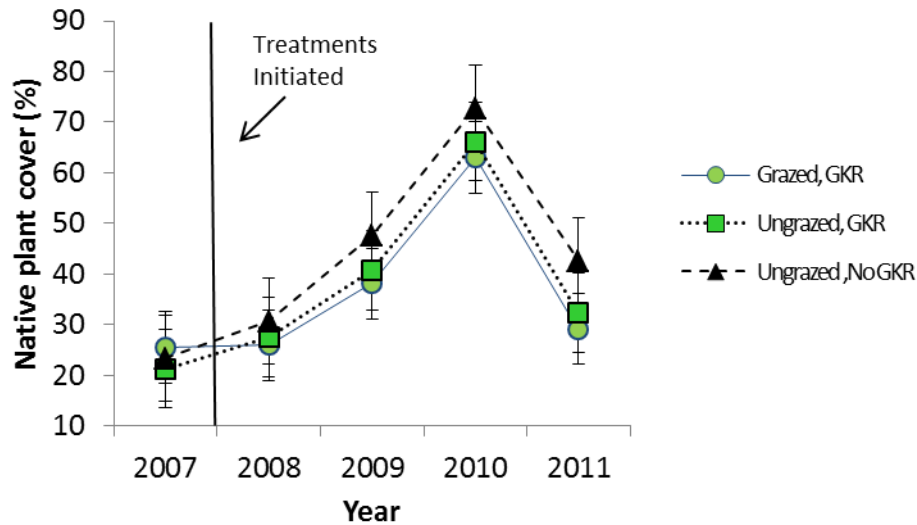


Figure 12. Native plant cover in experimental plots within the Center Well pasture. Three treatments were initiated prior to the spring of 2008: kangaroo rat exclusions (ungrazed, no GKR), cattle exclusions (ungrazed, GKR), and control plots (grazed, GKR). Means and standard error bars are shown ($n = 10$ replicates per treatment).

Soil disturbance by GKR promoted exotic grasses, especially in the Swain pasture ($t = 9.75$, $P < .001$). Results from the Swain pasture indicate that GKR foraging controls exotic grasses and promotes native bunchgrass, thus counteracting the effects of their soil disturbance (Figure 13). For example, *Poa secunda* was more abundant in areas where GKR were present despite the fact that it was less abundant on GKR precincts, where soil disturbance was high (Figure 13A). *Bromus m. rubens* showed the opposite pattern, in which it was more than three times as abundant in areas without GKR and more than twice as abundant on GKR precincts (Figure 13B). Thus, red brome and other exotic grasses may outcompete *Poa* in the absence of GKR, whereas the presence of GKR likely reduces exotic grass dominance via preferential seed predation.

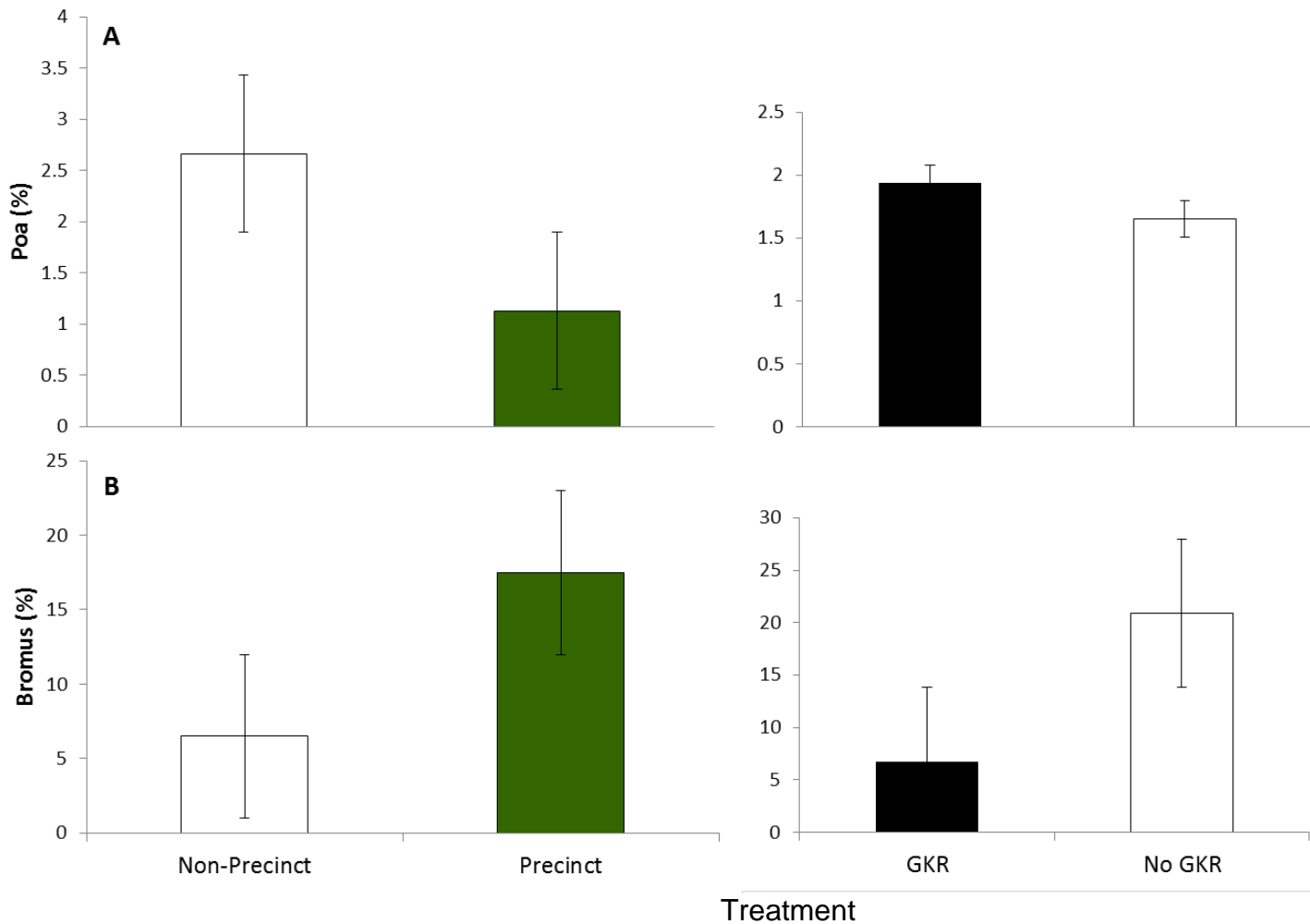


Figure 13. Cover of (A) *Poa secunda* and (B) *Bromus madritensis rubens* in the Swain pasture, 2011. Averages and standard errors are shown for plots in and out of GKR exclosures (No GKR/GKR), and on and off GKR precincts.

Gopher Activity

2010 was the first year with gopher (*Thomomys bottae*) activity in multiple GKR exclosures and trapping was initiated. In 2011 gopher activity dramatically increased and was present on all sites in Swain (Table 5). Gopher activity was significantly more common in areas where GKR were excluded (Figure 14; $t = -3.67$, $P < .005$). Gopher activity was more common overall in Swain pasture, and in gopher activity was more common in areas where GKR were excluded in both pastures.

Table 5. Percent of sites showing gopher activity.

Sites with Gopher Activity				
Center Well			Swain	
Ungrazed, No GKR	Ungrazed, GKR	Grazed, GKR	Ungrazed, No GKR	Ungrazed, GKR
60%	20%	10%	100%	90%

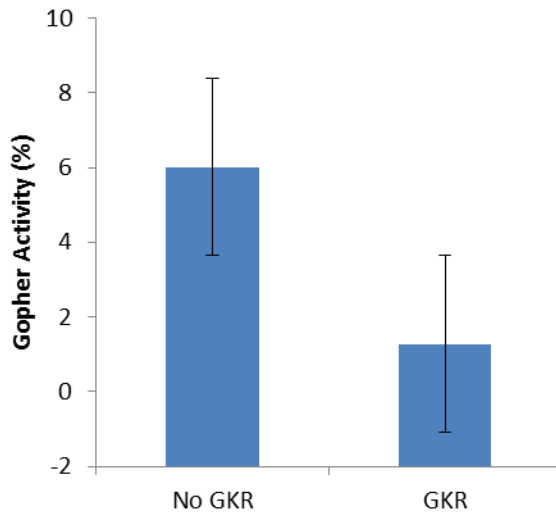


Figure 14. Percent cover of gopher activity with and without GKR. Standard error bars are shown.

GKR abundance

A total of 2,992 individual kangaroo rats were captured in 2011; 1,394 of which had not been previously marked. Eight of these kangaroo rats were *Dipodomys nitratooides*, and the other 2,984 individuals were *Dipodomys ingens*. Including recaptures, a total of 5,736 giant kangaroo rat captures occurred. Total trap effort was 10,860 traps*nights. Each trap had a 60% chance of catching a GKR on average, which is the highest trap rate yet for the study. Mark-recapture estimates of GKR abundance were less varied among sites this year with 24-74 GKR per plot (Table 6). Overall, the estimates indicate that populations are currently stable at moderate-high densities. GKR abundance increased this year on all plots, with both grazed and ungrazed plots in Center Well showing a dramatic increase. This is the first year that the Center Well sites showed an increase since August 2008. Last year Swain populations exceeded those in Center Well but this year populations were more similar (Table 6). Apparent survival rates varied among sites, ranging from 0.61-0.83 (Table 6).

2011 was the second consecutive year with above average rainfall, and we continued to see signs that grazing under these conditions may benefit GKR. GKR

densities tended to be higher in grazed plots in Center Well compared with ungrazed plots in cattle enclosures, however differences were not highly significant (Figure 15; paired t-test, $t = 1.81$, $n = 10$, $P = 0.10$). Densities on Center Well tended to be higher in grazed plots in comparison with Swain pasture ($t = -1.70$, $P = 0.12$) and differences were not significant between Swain pasture and ungrazed plots ($t = -0.31$, $P = 0.77$).

The increase in density may have been caused by adult immigration, because survival and reproduction did not differ among grazed and ungrazed plots in Center Well (reproduction paired $t_9 = 0.80$, $P = 0.44$). While summer apparent survival in Center Well was higher than in 2010, it was still lower than in the previous years and while overwinter apparent survival in 2011 was the highest yet recorded, the difference between apparent survival in spring and summer was the lowest ever recorded (Figure 16).

Reproduction was very low in 2011 compared with previous years (Table 7; 0.04 juveniles per adult, compared with 0.4 in 2008 and 2009 and 0.3 in 2010) and may account for the low summer survival.

The seasonal genital lesions that appear in August trapping sessions, which are likely chiggers (trombiculid mites), were even higher in 2011 (74%) than in 2010 (66%), but both of these wet years were much higher than the dry years of 2008 and 2009 when rates were 16-17%. The higher precipitation levels in 2010 and 2011 may have contributed to the rise in affected rates. It is unknown whether the lesions have any impacts on GKR demographics.

GKR estimates on each plot were not strongly correlated among surveys in 2010 and 2011 ($r = 0.36-0.41$) which differs from previous years (2009-2010, $r = 0.66-0.71$, 2008-2009, $r = 0.70-0.89$). This low correlation among surveys may be related to unusually high densities at sites that have not previously recorded high numbers (For example, Swain Pasture, Figure 17).

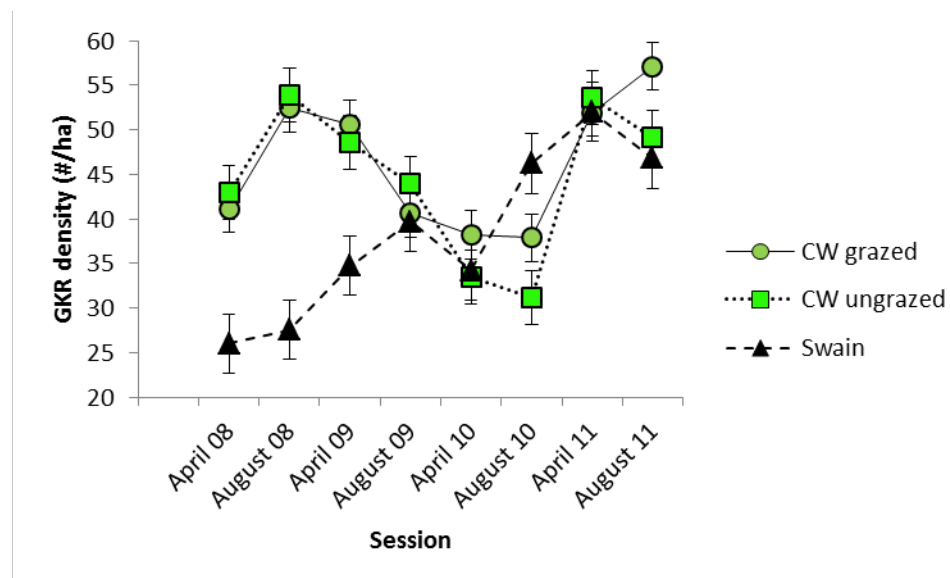


Figure 15. Average GKR population estimates in Center Well grazed plots, Center Well ungrazed plots, and Swain ungrazed plots, during each trapping session.

Table 6. GKR population size and apparent survival estimates in 2011. Apparent survival is the proportion of GKR remaining on each site between trapping periods. Population sizes are estimated numbers of GKR on each 1.96-ha plot (1-ha trapping grid plus 20-m buffer zone) during April and August trapping sessions. Standard errors (SE) are shown for each estimate.

Pasture	Grazing treatment	Plot	April estimate	April SE	August estimate	August SE	Apparent Survival	Survival SE
Center Well	Grazed	C1	54	1.66	57	2.40	0.66	0.07
Center Well	Grazed	C10	73	1.17	73	1.88	0.66	0.03
Center Well	Grazed	C2	54	1.16	69	1.22	0.69	0.07
Center Well	Grazed	C3	54	1.11	61	1.65	0.70	0.06
Center Well	Grazed	C4	40	0.77	63	1.35	0.73	0.03
Center Well	Grazed	C5	56	0.61	31	1.02	0.64	0.03
Center Well	Grazed	C6	40	0.72	32	1.26	0.58	0.05
Center Well	Grazed	C7	47	1.19	55	1.72	0.83	0.07
Center Well	Grazed	C8	52	1.02	68	1.69	0.68	0.03
Center Well	Grazed	C9	48	0.77	62	1.31	0.67	0.03
Center Well	Ungrazed	E1	41	1.10	20	1.49	0.61	0.08
Center Well	Ungrazed	E10	63	0.96	72	1.59	0.65	0.03
Center Well	Ungrazed	E2	55	1.88	52	1.93	0.67	0.07
Center Well	Ungrazed	E3	54	0.91	48	1.34	0.66	0.07
Center Well	Ungrazed	E4	46	0.83	60	1.42	0.71	0.03
Center Well	Ungrazed	E5	52	0.55	42	0.94	0.66	0.03
Center Well	Ungrazed	E6	50	0.65	35	1.13	0.65	0.05
Center Well	Ungrazed	E7	52	1.74	55	2.43	0.82	0.08
Center Well	Ungrazed	E8	58	1.08	64	1.76	0.66	0.03
Center Well	Ungrazed	E9	44	0.54	43	0.94	0.65	0.03
Swain	Ungrazed	S1	57	0.69	71	1.19	0.71	0.03
Swain	Ungrazed	S10	52	0.69	43	1.19	0.80	0.03
Swain	Ungrazed	S2	73	0.61	51	1.05	0.70	0.03
Swain	Ungrazed	S3	56	0.84	60	1.41	0.70	0.03
Swain	Ungrazed	S4	56	0.71	54	1.21	0.68	0.03
Swain	Ungrazed	S5	51	0.79	35	1.34	0.62	0.05
Swain	Ungrazed	S6	50	0.87	38	0.84	0.70	0.07
Swain	Ungrazed	S7	58	1.31	58	1.32	0.81	0.05
Swain	Ungrazed	S8	31	0.39	24	0.70	0.57	0.05
Swain	Ungrazed	S9	35	0.35	33	0.64	0.65	0.04

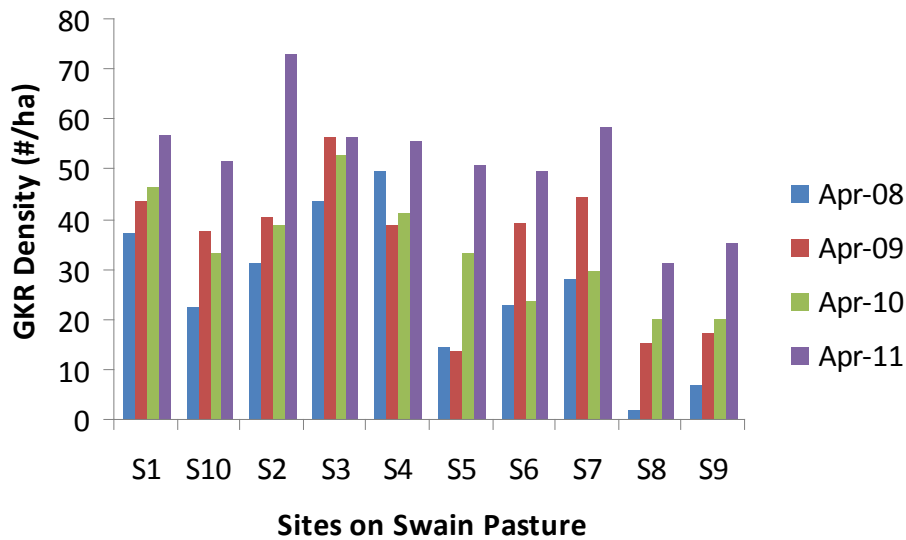


Figure 17. GKR density estimates on Swain Pasture sites for April captures 2008-2011.

SJAS abundance

SJAS density increased dramatically in 2011, in particular density in Swain pasture was nearly twice as high as that seen in 2010 (Figure 18). In 2010, cattle grazing had a strong negative effect on San Joaquin antelope squirrels. In 2011 this trend continued but it was not as widespread or as significant. SJAS populations were far higher in Swain than in Center Well and Center Well ungrazed plots showed only a slightly higher density of SJAS than grazed plots. SJAS densities continued to increase in Swain but were actually lower on ungrazed Center Well plots than they were in 2010 (Figure 18A).

A total of 330 individual antelope squirrels were captured and a total of 1,194 captures (including recaptures) occurred. As in previous years, the sex ratio was male-biased (Table 7, 0.86 females per male). Reproduction was lower than in 2010 (Table 7, 0.88 juveniles per adult in 2011, compared with 1.1 per adult in 2010) but higher than in previous years.

The higher densities on ungrazed plots in Center Well were due to increased reproduction rather than differences in survival (Figure 19), whereas the higher densities in Swain were due to higher survival (Figure 19). As with GKR, SJAS estimates on each plot were not correlated between 2010 and 2011 ($r = 0.45$, $n = 30$ plots, $P < 0.01$), and this may also have been due to the higher than normal densities of SJAS (Figure 20).

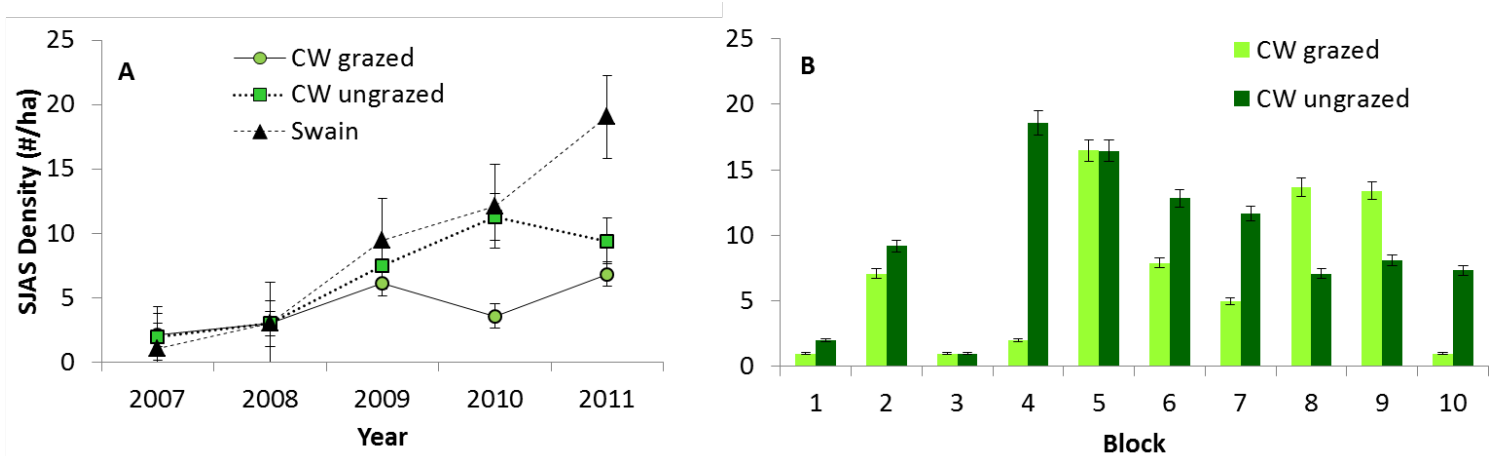


Figure 18. Estimates of San Joaquin antelope squirrel density. (A) Average annual density (\pm standard error) in Center Well grazed plots, Center Well ungrazed plots, and Swain ungrazed plots. (B) Density in 2011 on each replicate site (block) in Center Well, with 95% confidence intervals.

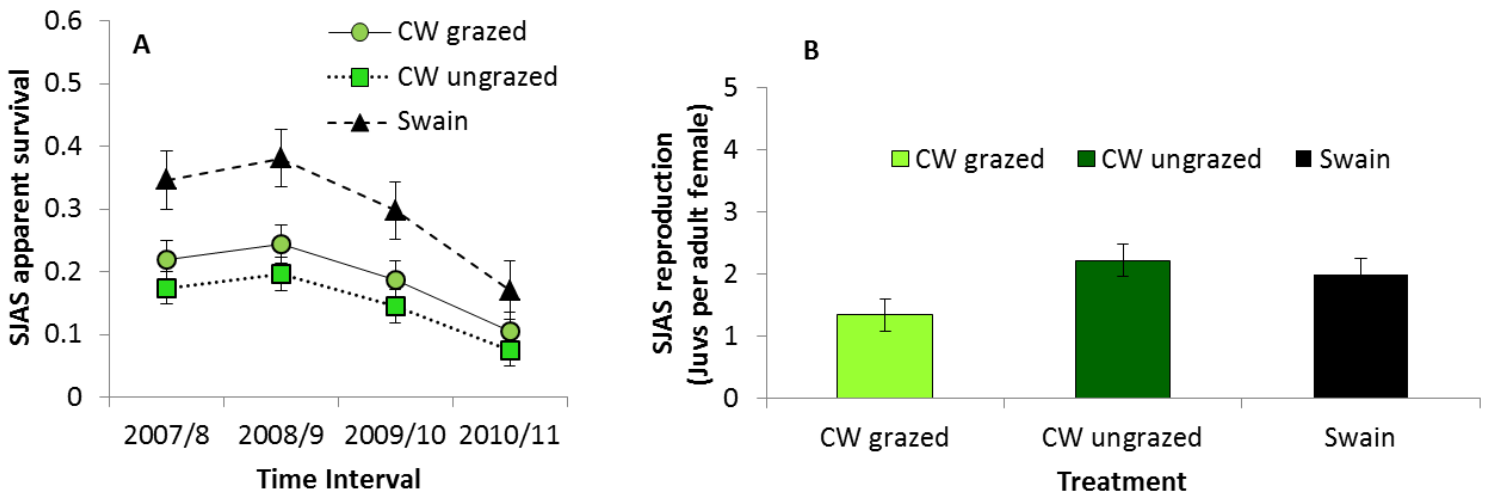


Figure 19. (A) Apparent survival of San Joaquin antelope squirrels on Center Well grazed plots, Center Well ungrazed plots, and Swain ungrazed plots, 2007-2011. (B) SJAS reproduction in 2011 in the three treatments. Standard error bars are shown.

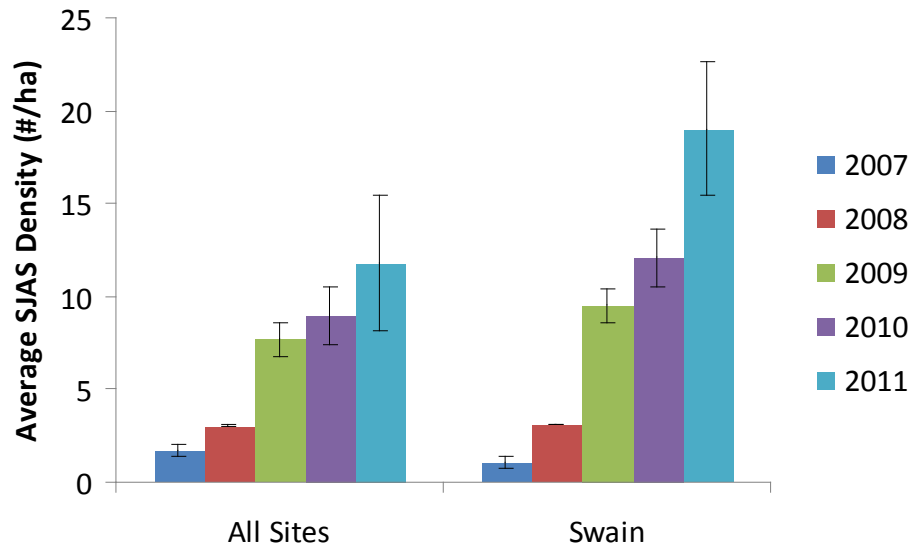


Figure 20. Average density of SJAS on all sites and in Swain pasture from 2007-2011. Standard error bars are shown.

Bird abundance

Bird abundance on our plots in 2011 was more than twice as high as the previous record abundance in 2007 for this study. A total of 2,367 individuals from 20 bird species were detected during point counts, 1,347 of which were either on or flying over our plots. As in previous years the most common birds found on plots were horned larks; however numbers of savannah sparrows, western meadowlarks, ravens and white-crowned sparrows increased from previous years. Several species were documented for the first time on plots in 2011: California quail, western kingbirds, California thrasher, Lawrence’s goldfinch, short-eared owl and Lincoln’s sparrow (Table 8).

Table 8. Total counts of birds detected on or flying over plots, 2007-2011.

Common Name	Scientific Name	2007	2008	2009	2010	2011
Horned Lark	<i>Eremophila alpestris</i>	545	61	203	158	543
Savannah Sparrow	<i>Passerculus sandwichensis</i>	0	1	3	41	504
Western Meadowlark	<i>Sturnella neglecta</i>	11	3	33	8	132
Common Raven	<i>Corvus corax</i>	16	43	55	45	101
White-crowned Sparrow	<i>Zonotrichia leucophrys</i>	0	0	0	1	20
Unidentified Sparrow	<i>Emberizidae (gen, sp)</i>	0	0	0	1	18
California Quail	<i>Callipepla californica</i>	0	0	0	0	5
Lark Sparrow	<i>Chondestes grammacus</i>	0	2	0	0	5
Violet-green Swallow	<i>Tachycineta thalassina</i>	0	0	10	1	4
Lawrence's Goldfinch	<i>Carduelis lawrencei</i>	0	0	0	0	3
Western Kingbird	<i>Tyrannus verticalis</i>	0	0	0	0	3
Mourning Dove	<i>Zenaida macroura</i>	0	0	1	0	2
Red-tailed Hawk	<i>Buteo jamaicensis</i>	0	5	1	1	1
Unidentified Hawk	<i>Accipitridae (gen, sp)</i>	0	0	0	1	1
Northern Mockingbird	<i>Mimus polyglottos</i>	0	0	1	0	1
Ferruginous Hawk	<i>Buteo regalis</i>	0	0	1	0	1
Lincoln's Sparrow	<i>Melospiza lincolnii</i>	0	0	0	0	1
California Thrasher	<i>Toxostoma redivivum</i>	0	0	0	0	1
Short-eared Owl	<i>Asio flammeus</i>	0	0	0	0	1
American Pipit	<i>Anthus rubescens</i>	0	0	0	39	0
Prairie Falcon	<i>Falco mexicanus</i>	0	0	0	2	0
Northern Harrier	<i>Circus cyaneus</i>	0	0	0	1	0
Greater Roadrunner	<i>Geococcyx californianus</i>	0	0	0	0	0
Loggerhead Shrike	<i>Lanius ludovicianus</i>	0	2	0	0	0
Common Nighthawk	<i>Nyctidromus albicollis</i>	0	0	0	0	0
House Finch	<i>Carpodacus mexicanus</i>	0	0	0	0	0
Unidentified Swallow	<i>Hirundidae (gen, sp)</i>	0	0	0	0	0
Unidentified Thrush	<i>Turdidae (gen, sp)</i>	0	0	0	0	0
White-tailed Kite	<i>Elanus leucurus</i>	0	0	0	0	0
Red-winged Blackbird	<i>Agelaius phoeniceus</i>	0	0	0	18	0
Long-billed Curlew	<i>Numenius americanus</i>	0	0	0	5	0
Cliff Swallow	<i>Petrochelidon pyrrhonota</i>	0	0	0	3	0
Chipping Sparrow	<i>Spizella passerina</i>	0	0	1	0	0
Dusky Flycatcher	<i>Empidonax oberholseri</i>	0	0	6	0	0
American Kestrel	<i>Falco sparverius</i>	0	0	2	0	0
Mountain Plover	<i>Charadrius montanus</i>	0	0	1	0	0
Sage Sparrow	<i>Amphispiza belli</i>	0	0	1	0	0
Brewer's Blackbird	<i>Euphagus cyanocephalus</i>	3	0	0	0	0
Unidentified Bird	<i>Aves (gen, sp)</i>	0	0	0	0	0

Table 8 Continued.

Common Name	Scientific Name	2007	2008	2009	2010	2011
Golden Eagle	<i>Aquila chrysaetos</i>	0	1	0	0	0
Vesper Sparrow	<i>Pooecetes gramineus</i>	0	1	0	0	0
Unidentified Hummingbird	<i>Trochilidae (gen, sp)</i>	0	0	0	0	0
Grasshopper Sparrow	<i>Ammodramus savannarum</i>	0	0	0	0	0
Peregrine Falcon	<i>Falco peregrinus</i>	0	0	0	0	0
Total		572	117	308	299	1347

Reptile abundance

A total of 42 side-blotched lizards (*Uta stansburiana*) and 36 blunt-nosed leopard lizards (*Gambelia sila*) were seen during reptile surveys. No other reptile species were seen during surveys. All blunt-nosed leopard lizard (BNLL) sightings were geo-referenced. As in previous years, all BNLL sightings were in the Swain pasture. Sightings occurred on 7 of the 10 sites in Swain, indicating that BNLL are distributed throughout the pasture. BNLL abundance was the highest ever recorded for this study while *Uta* abundance was the lowest ever recorded (Figure 21, Table 9). The correlation between grazing and *Uta* densities is unclear: there was no relationship found this year and results have differed in previous years.

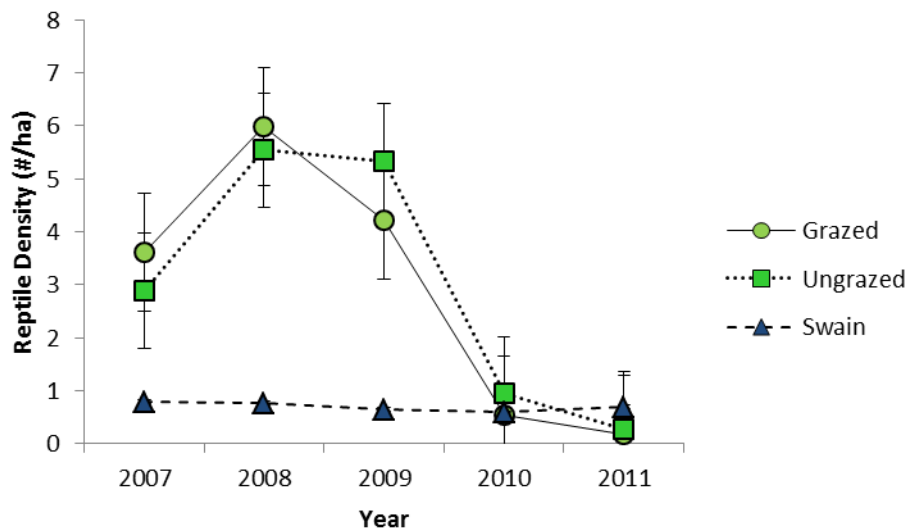


Figure 21. Estimates of reptile density each year from 3 replicate surveys on Center Well grazed plots, Center Well ungrazed plots, and Swain ungrazed plots. Standard error bars are shown.

Table 9. Totals of Blunt Nosed Leopard Lizards (*Gambelia sila*) and Side Blotch Lizards (*Uta stansburiana*) over time.

Species	2007	2008	2009	2010	2011
BNLL	4	7	19	18	36
UTA	419	675	631	114	42

Invertebrates

Both cattle and GKR exclosures had strong effects on the invertebrate community in 2011. Invertebrate richness was higher on grazed versus ungrazed plots and higher where GKR were present (Figure 22A; $t = 3.69$, $P = 0.005$ and $t = 3.96$, $P < 0.001$). Beetle and arachnid abundance were both higher where GKR were present (Figure 22B & 19C, $t = 5.01$, $P < 0.005$ and $t = 2.69$, $P < 0.01$). Beetle abundance was also higher on grazed plots (Figure 22B, $t = 2.90$, $P < 0.005$). This is the first year that cattle exclosures showed a significant impact on invertebrate richness.

Species associations

Table 10 shows the associations among the flora and fauna on our plots. Bird abundance was negatively correlated with bird diversity, possibly due to the occurrence of large, single species flocks. Bird abundance was positively correlated with plant biomass and height and negatively correlated with GKR densities. Many Carrizo birds nest on the ground and use plants for shading and protection and may therefore benefit from areas with lower densities of GKR and less clearing of vegetation. In contrast, plant biomass was negatively correlated with lizard and SJAS abundance, species which prefer more open areas. Lizards and SJAS were positively correlated with plant richness indicating that these species may benefit in some way from areas with a wider variety of plant species, perhaps plants which provide a food source to their prey or which have more open growth patterns. GKR and lizards were each negatively correlated with their primary food source, plant biomass and invert biomass, respectively.

Table 10. Matrix of correlation coefficients (r) among species counts on each of the 30 plots. Significant correlations ($P < 0.05$) are highlighted in bold. Richness is the number of species.

2011	<i>N squirrels</i>	<i>N GKR</i>	<i>GKR Survival</i>	<i>N Birds</i>	<i>Bird Diversity</i>	<i>N Lizards</i>	<i>Native Cover</i>	<i>Plant Biomass</i>	<i>Plant Height</i>	<i>Plant Richness</i>	<i>Invert Richness</i>
<i>N GKR</i>	-0.11										
<i>GKR Survival</i>	0.09	0.43									
<i>N Birds</i>	-0.15	-0.43	-0.31								
<i>Bird Diversity</i>	0.20	0.26	0.36	-0.77							
<i>N Lizards</i>	0.28	0.2	0.38	-0.16	0.21						
<i>Native Cover</i>	-0.12	0.2	0.32	0.01	0.03	0.13					
<i>Plant Biomass</i>	-0.3	-0.39	-0.24	0.41	-0.33	-0.41	-0.02				
<i>Plant Height</i>	-0.22	-0.59	-0.31	0.41	-0.24	-0.27	-0.03	0.83			
<i>Plant Richness</i>	0.46	0.09	0.25	-0.15	0.2	0.65	0.12	-0.41	-0.31		
<i>Invert Richness</i>	0.14	0.07	0.17	-0.08	0.08	-0.02	-0.04	-0.17	-0.03	0.07	
<i>Invert Biomass</i>	-0.36	0.07	0.28	0.28	-0.09	-0.36	0.07	0.34	0.08	-0.34	0.03

Conclusions and Future Directions

Rainfall during the 2011 growing season (October 2010-April 2011) was above average (40 cm), and 10 cm more than in 2010, the first wet year of the study (precipitation levels during 2007-2009 were 9-16 cm). Peak plant biomass was again high this year and the impacts of cattle grazing on wildlife continued to emerge. Beetle abundance was significantly higher on grazed plots and, although not statistically significant, GKR and arachnids ($P = 0.10$ and $P = 0.11$) tended to be more abundant on

plots that were grazed by cattle compared with paired plots in cattle exclosures. Beetles and other insects may have responded positively to the presence of cattle dung piles.

In 2010 cattle grazing had a strong negative effect on SJAS and lizard abundance, but this trend was not significant for SJAS in 2011 and disappeared for lizards. It may be that grazing has a slight negative effect on SJAS and lizard populations but that certain weather patterns or other species interactions outweigh these effects in some years. More data needs to be collected during wet years to understand what factors play into the positive and negative effects of grazing on these species.

Peak vegetation biomass was 2,573 lbs/acre in April, and this was reduced to a minimum of 714 lbs/acre by November in areas exposed to grazing by all species (Table 4). Our exclosures allow us to determine what proportion of this loss of vegetation was due to cattle, GKR, or other forces (wind, insects, etc.). GKR removed approximately 39% (at an average density of 51/ha) and cattle removed approximately 19% (with 881 animal use months).

Data on gopher activity was collected for the first time this year. The apparent selection of GKR exclosures by gophers indicates that GKR may be competitively dominant, or that gophers prefer the thick vegetation that occurs in exclosures. While there was a significant increase in gopher activity this year, the activity was highly localized and occurred on only a small number of vegetation plots (3.5%).

While both 2010 and 2011 were wet years, precipitation in 2010 was spread out more evenly over the rainy season while in 2011, 50% of precipitation occurred in December. These changes in the timing of precipitation may have influenced plant type such as the increase in exotic grasses this year. In addition, plant cover was less evenly distributed in 2011 and *Poaceae* cover was the highest ever recorded. These changes in grass cover may have contributed to differences in overall native cover and biomass removal. Further study in wet and dry years will serve to clarify these connections.

Some patterns remained similar to 2010 results. For example, invertebrates tended to do better where GKR were present. This continuing pattern may be due to provisioning of herbivorous insects by their clipping and seed caching behaviors.

Another continuing trend was the positive effect of soil disturbance on exotic grass cover and the contrasting reduction of these grasses by GKR foraging, thus restricting exotic grass distribution primarily to their disturbed mounds. Although GKR precincts may function as foci of invasion, once exotic grasses are present in an area, GKR may actually benefit native bunchgrasses by removing exotic grass seeds and preventing their spread. However, native species that GKR prefer to eat, such as *Lotus*, are more abundant in the absence of GKR, and native cover overall was higher where GKR were excluded.

In the 2012 field season, we will continue to monitor flora and fauna on our experimental plots. Prior to the field season, manuscripts will be prepared for peer-reviewed publication. Data collection is almost complete for the three graduate student projects and dissertation work is underway.

Products of the Carrizo Plain Ecosystem Project

- 22) Brashares, J., Prugh, L., Butterfield, S., Saslaw, L., Stafford, R., Allen-Diaz, B and J. Bartolome. Direct and indirect effects of rodents and cattle on invasive plants in a California grassland ecosystem. July 2011. USDA-AFRI Annual Conference. Washington, D.C.
- 21) Bean, W.T., Prugh, L., Brashares, J. and R. Stafford. An evaluation of monitoring methods for giant kangaroo rats at multiple scales," March, 2011. San Joaquin Valley Natural Communities Conference. Bakersfield, CA.
- 20) Prugh, LR and JS Brashares. 2011. Partitioning the effects of an ecosystem engineer: Kangaroo rats control community structure via multiple pathways. 96th Ecological Society of America Annual Meeting, Austin, TX (paper).
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