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 Plain National Monument. We completed the sixth year of the Carrizo Plain Ecosystem Project (CPEP), a long-term study to quantify these relationships using replicated cattle and GKR exclosures. 2012 was a much drier year than the two previous wet years, and precipitation levels were similar to those seen in the dry years of 2007-2009. 2011 had the highest rainfall recorded for the study and abundance was significantly higher for all focal wildlife species, setting new records for the study. In 2012, a variety of results were seen. GKR densities were still high in the spring but by the summer trapping session numbers had dropped to the lowest recorded. Blunt-nosed leopard lizard numbers were also similar to 2011, and *Uta* lizards showed an increase over 2011, although numbers were still lower than seen in previous dry years. San Joaquin antelope squirrel (SJAS) densities dropped to levels seen in the previous dry years while invertebrate biomass was the highest yet recorded. Native plant cover and richness was the lowest yet recorded. Vegetation biomass gave unusual results this year with higher biomass in the fall rather than in the spring. Although no cattle were grazed this year due to low forage, differences were seen between grazed and ungrazed plots for species including GKR and SJAS, indicating that grazing effects may continue after cattle have been removed. GKR exclosures had significant effects on invertebrates in 2012 with overall biomass, as well as beetle and orthopteran abundance all higher where GKR were present. In Center Well pasture, GKR had a negative effect on native plants while in Swain natives were more prevalent where GKR were excluded. As seen in previous years, 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. Gopher activity continued to be high and was again more common in areas without GKR.

Prepared by Rachel Endicott, 2012

Background

The Carrizo Plain National Monument, located in the southern San Joaquin Valley of California, is the largest (810 km^2) 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 2012, 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 and a fourth project was initiated.

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.

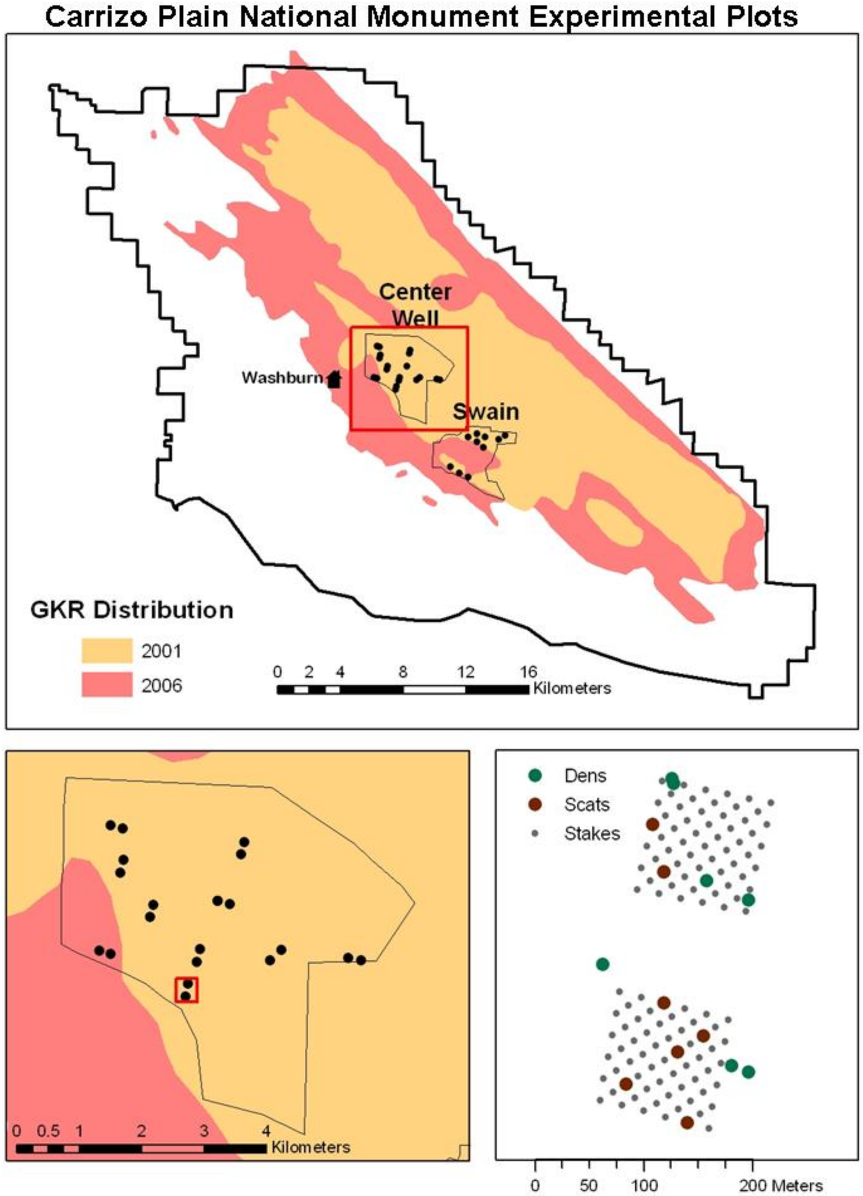

Figure 1. Map of study sites in the Carrizo Plain National Monument. Details are shown for the Center Well pasture and site CW 7. Kit fox dens and scats, as well as trap stakes, are shown for site 7.

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).

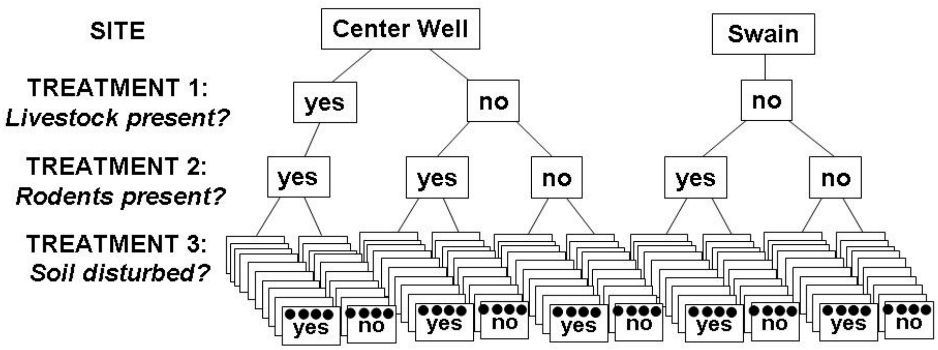

Figure 2. Experimental design of the project. There are ten blocks of each treatment combination and four nested vegetation plots (filled circles) within each block.

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-m^2 area 20 m away from the GKR exclosure, and in Center Well, at the center of each paired control plot (Figure 3).

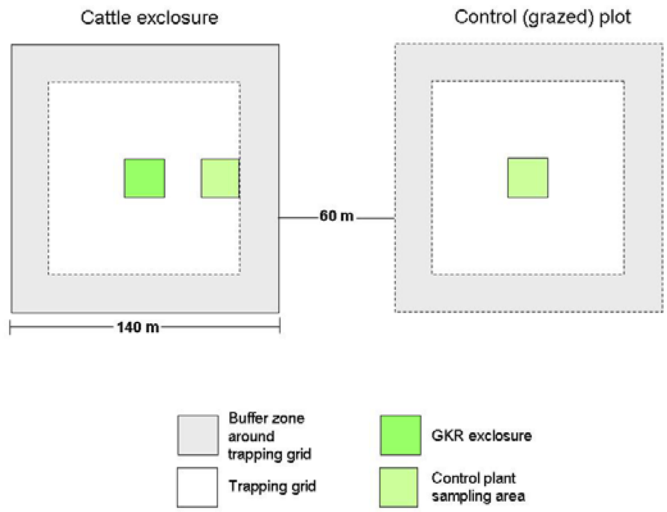

Figure 3. Nested exclosure design to separate livestock and GKR effects on plants, with paired control plot. A buffer zone around each GKR trapping grid ensured that the surveyed population was comprised of individuals living within the plot. This shows the design in Center Well; in Swain each plot is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

Plant and soil sampling

We established 8 1-m^2 permanent plant sampling quadrats in each of the 50 400-m^2 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-m^2 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-m^2 plots adjacent to each 1-m^2 plot to estimate biomass in April and September (expected peak and minimum biomass). Since cattles were not grazed this year the July, post-grazing biomass samples were not collected. Clip plots are surveyed in a different location each sampling session. Plant height was also measured prior to clipping.

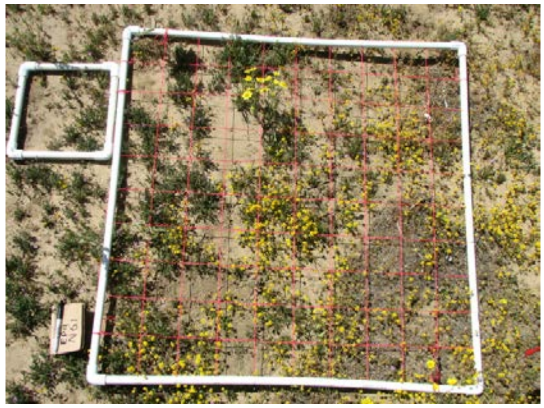

Figure 4. Plant sampling plot in a non-precinct area, showing the 1-m^2 point frame and the 1/16-m^2 clip plot.

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, a head measurement taken and released. Trapping occurred from April 9-May 3, 2012 (16 trap nights) and August 5-29, 2012 (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."

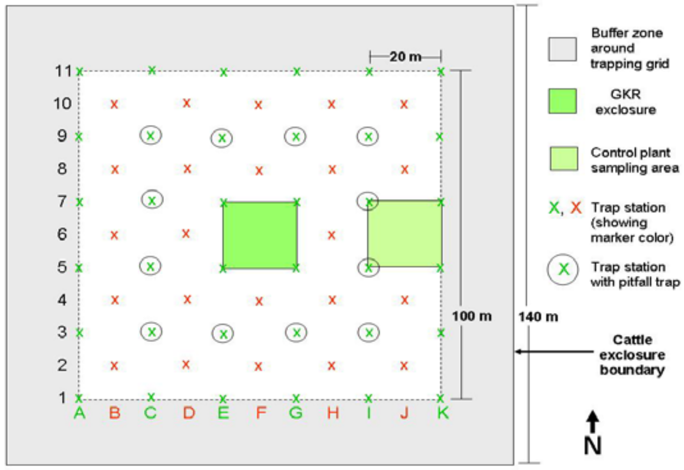

Figure 5. Detailed diagram of a cattle exclosure. Trap stations show trap locations for GKR mark-recapture surveys. Colors correspond to the spray-painted color on the stake marking the location. Letters and numbers identify the grid stakes (A1, B2, etc.).

Graduate student projects

A new graduate student project was initiated in 2012:

1) Masters student Camdilla Wirth, CSU Northridge (Supervisor: Tim Karels)
Camdilla will investigate a possible intraguild predator interaction between a mammal, the San Joaquin Antelope squirrel (*Ammospermophilus nelsoni*), and a reptile, the common side-blotched lizard (*Uta stansburiana*). The project also seeks to explain potential mechanisms for coexistence: exclusive prey resources for both the squirrels and lizards, high squirrel preference for exclusive prey, and spatial refuge for lizards.

Additionally, three graduate student projects which began in 2010 were completed in 2012:

2) Doctoral student Tim Bean, UC Berkeley (supervisor: Justin Brashares)
Tim completed his doctoral project modeling the distribution of GKR in 2012. He conducted mark-recapture surveys of GKR at sites across the Carrizo Plain and combined this data with remote sensing and habitat variables to develop a habitat suitability model for GKR.

3) Masters student Chris Gurney, UC Berkeley (supervisor: Justin Brashares)
Chris studied 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. He completed his masters project this year.

4) Masters student Steve Etter, CSU Northridge (supervisor: Tim Karels)
Steve studied adult GKR survival. He radio-collared 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. He is expected to complete his masters project by the end of this year.

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 19, 2012. The RMark package was used to obtain density estimates on each plot each year.

Bird surveys

Point counts were conducted three times on each plot from March 27–April 14, 2012 (in previous years four repetitions were conducted). 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 in which ring the bird(s) occurred. 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 15, 2012. 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 6-7, 2012 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 (¾” mesh) was placed just inside each cup to keep lizards out of the traps (Figure 6A). 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.

A 

B 

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 16-19, 2012, *n* = 3 surveys) and summer (July 30-31, August 1-2, 2012, *n* = 4 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 2012, we continued to collect scats deposited on our traps as kit foxes often marked our traps with urine and feces. We collected 92 kit fox scats. We also recorded all sightings of kit foxes.

Cattle grazing intensity

Cattles were not grazed this year because there was not enough forage and therefore cattle patty counts were not conducted, however cattle patty counts were conducted in all previous years shortly after the cattles were removed.

Results and Discussion

Plants

General plant composition

Plant species richness in both Center Well and Swain dropped to the second lowest value in six years (Table 1). Exotic species richness has remained similar across all years (value range: 6-10) but native species richness dropped in both pastures. Native species richness was the second lowest recorded in both pastures, with a steeper decline in Center Well. The lowest species richness values occurred in 2007.

Percent cover was the lowest yet recorded for this study and was particularly striking after the previous two wet years which showed the highest percent cover of the study (Table 1). Both native and exotic plant cover declined in 2012, with native percent cover showing the most dramatic drop with less than 10% cover in both pastures.

Poaceae cover was the third lowest recorded, and not significantly different from 2009 levels. Poaceae cover was highest in GKR exclosures but the relationship was not as strong as in 2010 and 2011 (Figure 7). *Schismus arabicus* and *Bromus madritensis* remained the dominant grass species in Center Well and Swain, respectively. Similarly, *Bromus* was again the most common grass in GKR exclosures, 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 *Schismus arabicus*, followed by the native species *Vulpia microstachys* and the exotic *Hordeum murinum*. On all plots in the Swain pasture, the exotic *Erodium circutarium* was the most common species, followed by *Bromus* and *Schismus* (Table 2).

The plants dominating in Center Well for 2012, were more similar to those seen in 2011(*Erodium*, *Vulpia microstachys*, *Schismus*) than those seen in the dry years of 2007-2009 when neither *Schismus* nor *Hordeum* were highest for percent cover, although *Vulpia microstachys* was one of the top plants for percent cover in 2007-2009.

In Swain pasture, the plants dominating percent cover were more similar in 2012 to the other dry years, with *Bromus* and *Erodium* common in 2007 and *Schismus* and *Erodium* common in 2008 and 2009. *Bromus* and *Erodium* were also common in 2011 in Swain.

Table1. Species richness and relative percent plant cover in the Center Well and Swain pastures, 2007–2012.

Metric	Type	Center Well					
		2007	2008	2009	2010	2011	2012
Species richness	native	18	29	29	31	28	21
	exotic	8	7	6	7	9	7
	total	26	36	35	38	37	28
Plant cover (%)	native	23	28	42	67	35	5
	exotic	17	37	28	25	49	16
	total	40	65	70	92	84	21
		Swain					
		2007	2008	2009	2010	2011	2012
Species richness	native	15	43	40	45	39	34
	exotic	7	10	8	6	7	9
	total	22	53	48	51	46	43
Plant cover (%)	native	17	20	41	57	32	7
	exotic	32	33	32	34	44	25
	total	50	52	73	90	76	32

Table 2. Relative % cover of plant species in the Center Well and Swain pastures in 2012 (*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
Schismus arabicus	Invasive	29.60	13.90	6.15	34.54
Vulpia microstachys	Native	21.14	3.98	14.06	11.24
Hordeum murinum	Invasive	19.58	7.43	19.46	8.54
Erodium cicutarium	Invasive	17.26	28.59	22.22	23.56
Bromus madritensis	Invasive	8.36	24.90	25.85	9.12
Astragalus oxyphysus	Native	1.02	1.06	1.07	1.02
Vulpia myuros	Invasive	0.68	0.02	0.43	0.29
Trifolium gracilentum	Native	0.49	0.34	0.13	0.64
Unidentified		0.49	0.12	0.67	<0.01
Tropidocarpum gracile	Native	0.27	<0.01	0.05	0.20
Eriogonum gracillimum	Native	0.27	1.52	0.94	0.86
Lepidium nitidum	Native	0.27	0.10	<0.01	0.33
Poa secunda	Native	0.17	7.74	3.78	4.14
Pectocarya penicillata	Native	0.12	2.12	0.43	1.70
Dichelostemma capitatum	Native	0.10	0.14	0.05	0.18
Microseris elegans	Native	0.07	0.29	0.05	0.29
Amsinckia tessellata	Native	0.05	0.39	0.16	0.27
Allium sp.	Native	0.02	<0.01	-	0.02
Stephanomeria pauciflora	Native	0.02	0.07	0.08	0.02
Calandrinia ciliata	Native	<0.01	<0.01	<0.01	<0.01
Capsella bursa-pastoris	Invasive	<0.01	<0.01	-	<0.01
Microseris douglasii	Native	<0.01	<0.01	<0.01	<0.01
Phlox gracilis	Native	<0.01	<0.01	<0.01	-
Amsinckia menziesii	Native	<0.01	-	-	<0.01
Lasthenia californica	Native	<0.01	0.34	0.16	0.18
Herniaria hirsuta	Invasive	<0.01	0.27	0.13	0.13
Lotus wrangelianus	Native	<0.01	0.17	0.08	0.09
Lasthenia minor	Native	<0.01	0.05	0.03	0.02
Astragalus didymocarpus	Native	-	<0.01	<0.01	<0.01
Camissonia palmeri	Native	-	<0.01	-	<0.01

Table 2 Continued.

Species	Type	Center Well	Swain	No GKR	GKR
Guillenia lasiophylla	Native	-	<0.01	<0.01	<0.01
Lepidium dictyotum	Native	-	<0.01	<0.01	<0.01
Trichostema lanceolatum	Native	-	<0.01	<0.01	-
Vulpia bromoides	Invasive	-	3.79	2.09	1.75
Lastarriaea coriacea	Native	-	0.68	0.70	0.04
Hollisteria lanata	Native	-	0.65	0.24	0.40
Plantago erecta	Native	-	0.48	0.32	0.18
Chorizanthe uniaristata	Native	-	0.24	0.16	0.09
Linanthus liniflorus	Native	-	0.24	0.19	0.07
Chaenactis glabriuscula	Native	-	0.10	0.08	0.02
Astragalus lentiginosus	Native	-	0.07	0.08	<0.01
Plagiobothrys canescens	Native	-	0.07	-	0.07
Sisymbrium altissimum	Invasive	-	0.07	0.08	<0.01
Uropappus lindleyi	Native	-	0.05	0.05	<0.01
Camissonia campestris	Native	-	0.02	<0.01	0.02

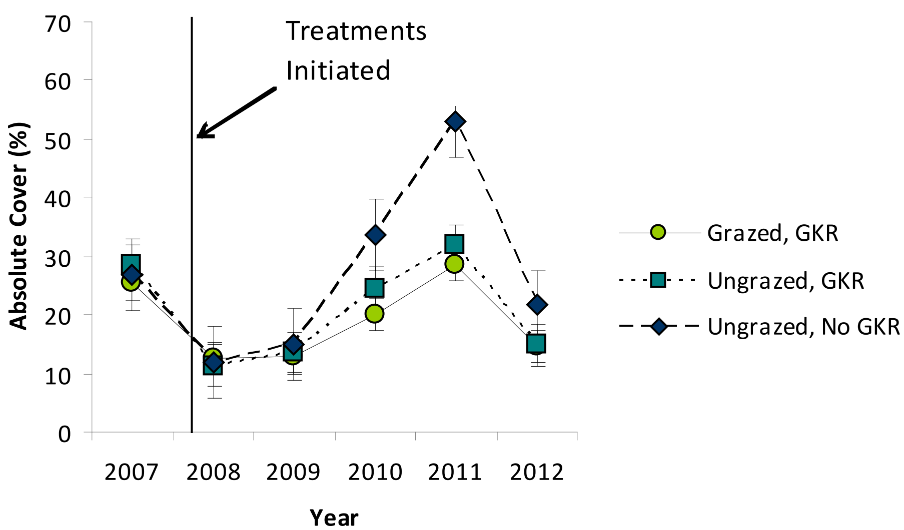

Figure 7. *Poaceae* cover in experimental plots within the Center Well pasture. Three treatments were initiated prior to the spring of 2008: kangaroo rat exclosures (ungrazed, no GKR), cattle exclosures (ungrazed, GKR), and control plots (grazed, GKR). Means and standard error bars are shown (*n* = 10 replicates per treatment).

Grazing intensity

There was not enough spring forage for grazing this year and so no cattle were turned out in the Center Well pasture.

Biomass removal by cattle and GKR.

Biomass showed an unusual trend this year with higher biomass in the fall than in the spring (Figure 8). These unusual results may be due to several factors including an earlier fall collection date (late September instead of October or November), the absence of cattle, the dramatic decline in kangaroo rat populations between spring and summer and a slight plant growth period after the spring biomass collection (personal observation, Rachel Endicott).

Without grazing cattle, only biomass removed by GKR (in both control and cattle exclosure plots) and biomass removed by wind, invertebrates and other factors (in the kangaroo rat exclosures) could be measured this year. We calculated the biomass removed by GKR by subtracting the biomass measured in control plots from the biomass measured within GKR exclosures. In 2012 Biomass was measured in April (expected peak) and September (expected minimum).

GKR foraging reduced plant biomass by 1,371 lbs/acre in Center Well and 701 lbs/acre in Swain pasture (Figure 9; Table 3). These results are similar to the two previous wet years but far higher than levels in 2008 and 2009. Removal by GKR was higher in September than in April (Figure 9; Table 3). Without grazing by GKR or cattle, RDM levels were reduced to a minimum of approximately 1,731 lbs/acre by factors such as insect herbivory, wind, and foraging by squirrels in Center Well (Table 3). In Swain these factors reduced RDM levels to a minimum of 1,383 lbs/acre and in both pastures by 1,557 lbs/acre (Table 3).

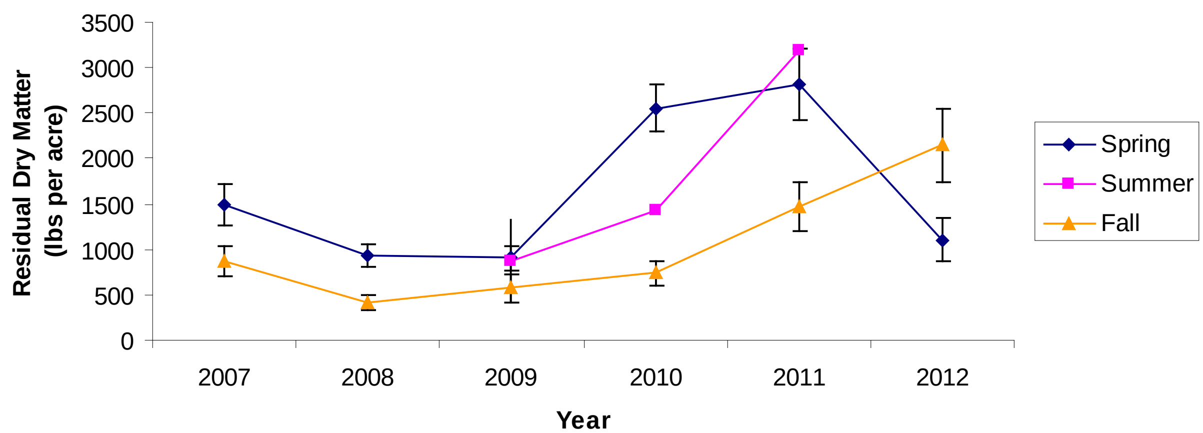

Figure 8. RDM for all years during Spring, Summer and Fall with standard error bars.

Table 3. Average (± standard error) plant biomass measured in pounds per acre on 10 replicate sites in the Center Well (CW) and Swain (SW) pastures, 2012. Center Well sites consisted of a control plot which is normally grazed by cattle, ("GKR and cattle" treatment), a cattle exclosure ("GKR only" treatment), and a GKR exclosure ("no GKR or cattle" treatment). Swain sites had a control plot ("GKR only" treatment) and a GKR exclosure ("no GKR" treatment).

Treatment	Spring	Fall
GKR and cattle	508 ± 97	886 ± 134
GKR Only CW	872 ± 160	1493 ± 195
No GKR CW	1731 ± 301	2864 ± 266
GKR Only SW	1022 ± 611	2387 ± 455
No GKR SW	1383 ± 218	3088 ± 429
GKR Only CW & SW	947 ± 174	1940 ± 370
No GKR CW & SW	1557 ± 262	2976 ± 350

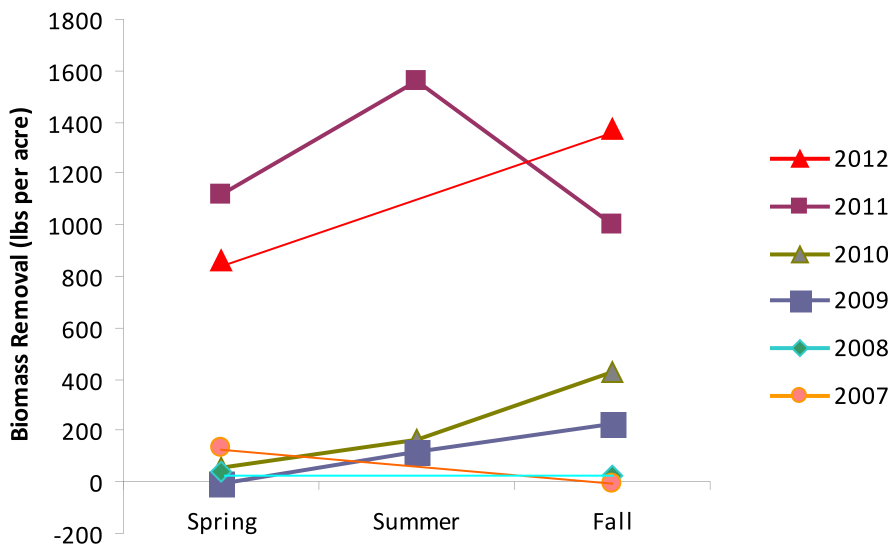

Figure 9. Biomass removal in Center Well pasture by GKR from 2007-2012, measured as the difference in biomass among cattle and GKR exclosure treatments.

Figure 10. Photograph of the kangaroo rat exclosure at Center Well 10 in April 2012.

Native and exotic plant cover

In 2011, native cover dropped in both pastures and it continued to drop in 2012 to the lowest values yet seen in this study (Table 1, Figure 11). Non-native plant cover hit an all time high in 2011 but dropped to its second lowest level in 2012 (Figure 12).

Native percent cover was 5% in Center Well and 7% in Swain. An interesting contrast was seen this year between Center Well and Swain pastures. In Center Well, GKR presence had a negative effect on native plants, with absolute percent cover higher for native plants where GKR were excluded (t = -3.685, P <0.001). Swain pasture saw the opposite result with non-natives more prevalent where GKR were excluded (t = -2.0962, P = 0.04). When combining both pastures, absolute cover for both natives and non-natives was more abundant where GKR were excluded.

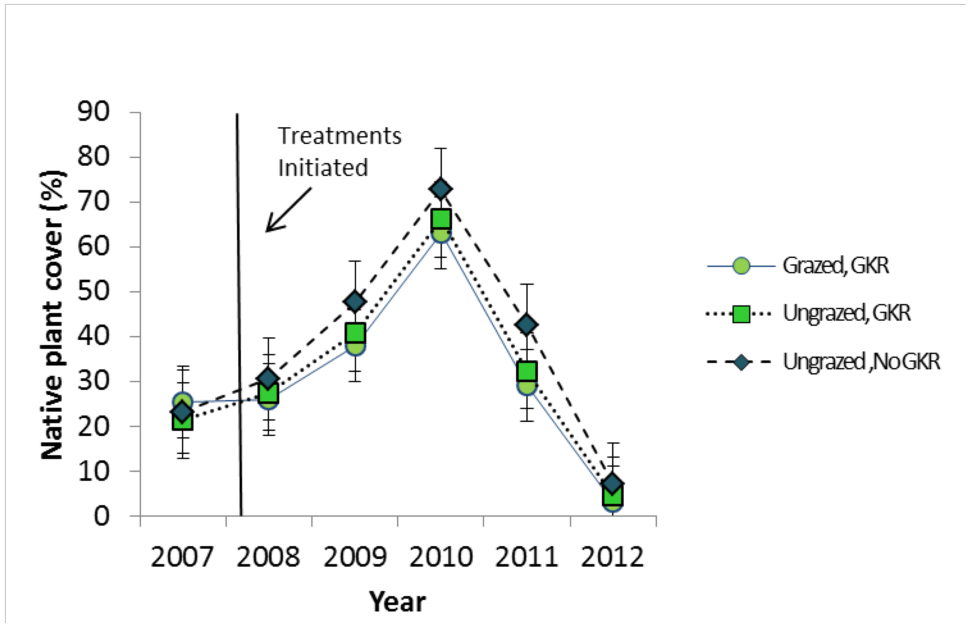

Figure 11. Native plant cover in experimental plots within the Center Well pasture. Three treatments were initiated prior to the spring of 2008: kangaroo rat exclosures (ungrazed, no GKR), cattle exclosures (ungrazed, GKR), and control plots (grazed, GKR). Means and standard error bars are shown (*n* = 10 replicates per treatment).

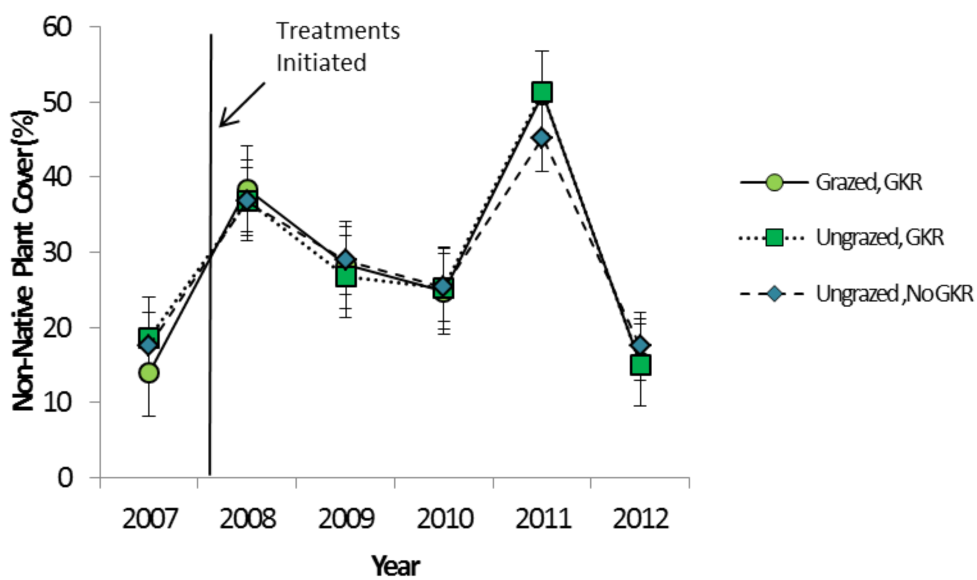

Figure 12. Non-Native plant cover in experimental plots within the Center Well pasture. Three treatments were initiated prior to the spring of 2008: kangaroo rat exclosures (ungrazed, no GKR), cattle exclosures (ungrazed, GKR), and control plots (grazed, GKR). Means and standard error bars are shown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

While overall, GKR presence reduced native plants, results from the Swain pasture continue to show that GKR foraging controls exotic grasses and promotes native bunchgrass, thus counteracting the effects of their soil disturbance, which promotes invasive grasses (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 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.

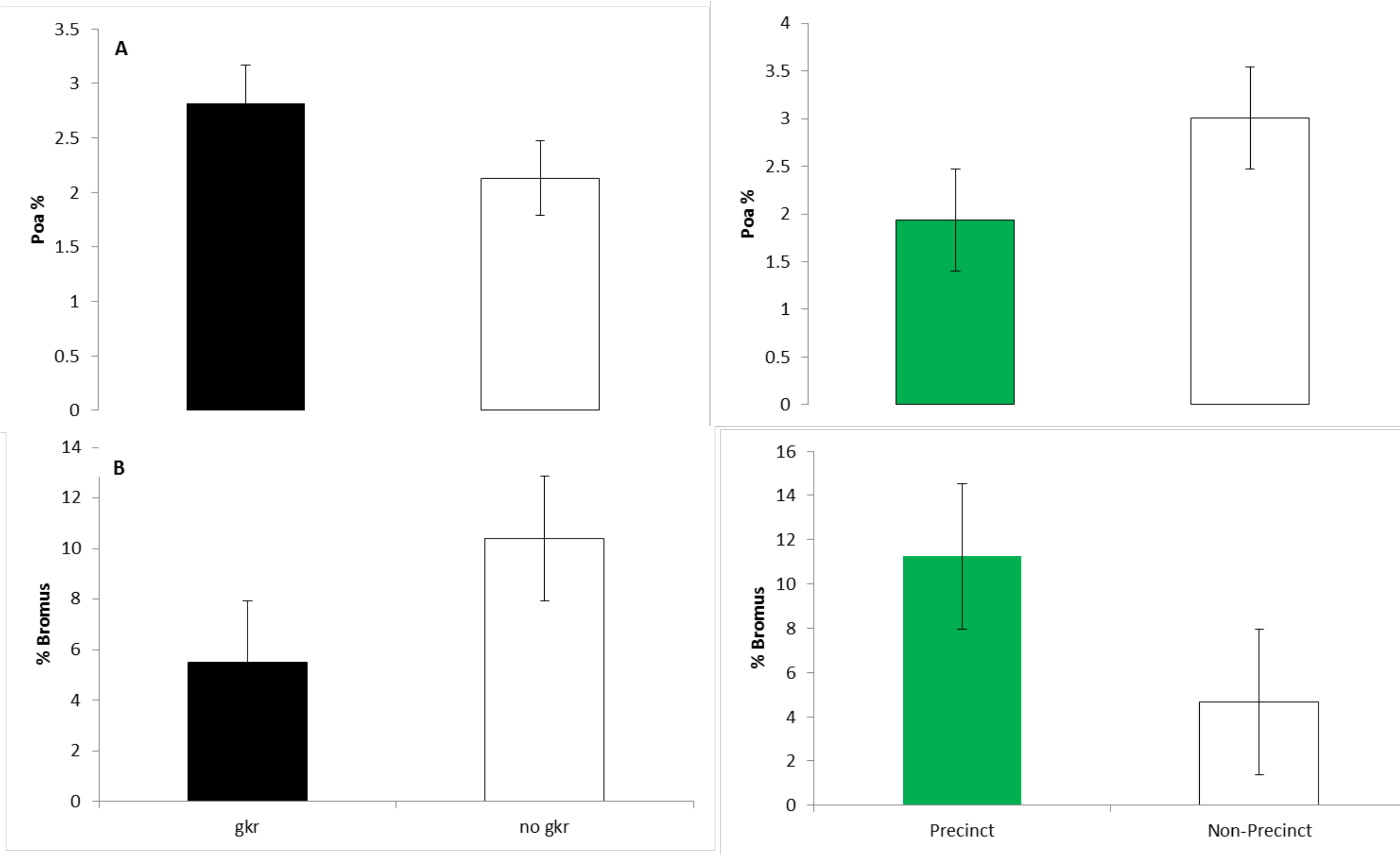

Figure 13. Cover of (A) *Poa secunda* and (B) *Bromus madritensis rubens* in the Swain pasture, 2012. Averages and standard errors are shown for plots in and out of GKR exclosures (No GKR/GKR), and on and off GKR precincts.

Gopher Activity

Despite low precipitation, 2012 was another year of high activity by gophers (*Thomomys bottae*) in the kangaroo rat exclosures. Gopher activity was low in the previous dry years and was first seen in multiple exclosures in 2010 with trapping initiated in 2011. Both percent cover of gopher activity and the number of sites with gopher activity increased in 2012 (Table 4, Figure 14). In 2012, the percent of plots with gopher activity continued to be low in areas with GKR but increased from 60% in 2011 to 90% in 2012 in GKR exclosures (Table 4).This may have been due to the higher levels of vegetation in the kangaroo rat exclosures, especially in this dry year with low overall biomass levels in the spring. Gopher activity continued to be high in the kangaroo rat exclosures in Swain, but gopher activity on the Swain control plots dropped from 90% to 30%. Gopher activity remained significantly higher in plots without GKR (Figure 13; t = -5.32, P<.005).

Table 4. Percent of sites showing gopher activity in 2011 and 2012.

	Sites with Gopher Activity				
	Center Well			Swain	
	ungrazed, no gkr	ungrazed, gkr	grazed, gkr	ungrazed, no gkr	ungrazed, gkr
2011	60%	20%	10%	100%	90%
2012	90%	40%	30%	100%	30%

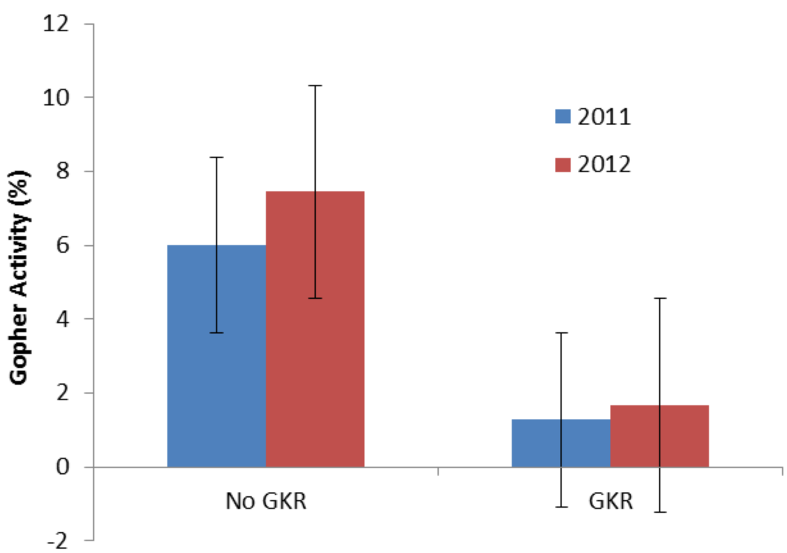

Figure 14. Percent cover of gopher activity in 2011 and 2012 with and without GKR. Standard error bars are shown.

GKR abundance

A total of 2,046 individual kangaroo rats were captured in 2012; 638 of which had not been previously marked. Only *Dipodomys ingens* were captured in 2012. Including recaptures, a total of 3,778 giant kangaroo rat captures occurred. Total trap effort was 10,869 traps*nights. Mark-recapture estimates of GKR abundance were varied among sites this year with 9-70 GKR per plot (Table 5). Given the low amounts of vegetation in the spring this year, GKR abundance was surprisingly high in Center Well during the April trapping session (Figure 15). By the August trapping session, however, populations in both pastures, dropped to the lowest levels recorded for this study. Apparent survival rates were generally low, ranging from 0.03-0.46 (Table 5).

GKR densities were higher in grazed plots in Center Well compared with ungrazed plots in cattle exclosures (Figure 15; paired t-test, $t = 2.45$, $n = 19$, $P = 0.02$). GKR densities were also significantly higher in Center Well over Swain pasture ($t = 3.12$, $P = 0.005$).

The overwinter survival rate was the second highest on record for this study (the highest being in 2011) but summer apparent survival was the lowest on record (Figure 16). Reproduction was the lowest yet recorded (Table 6; 0.006 juveniles per adult, compared with 0.4 in 2008 and 2009 and 0.3 in 2010 and .04 in 2011) and may account in part for the low summer survival.

The seasonal genital lesions (likely trombiculid mites) that appear in August trapping sessions were the highest yet recorded (77%). This is surprising given the trend of the previous years where the two wet years showed high rates of genital lesions (2011 (74%) and 2010 (66%)),while the previous dry years have had low rates. These results seem to indicate that high precipitation is only one factor causing these lesions. It is unknown whether the lesions have any impacts on GKR demographics.

GKR estimates on each plot were correlated in Spring 2011 and 2012 ($r = .515$, $P = 0.05$, $n = 30$) but not in the Summer. This was likely due to the steep decline in densities between spring and summer 2012.

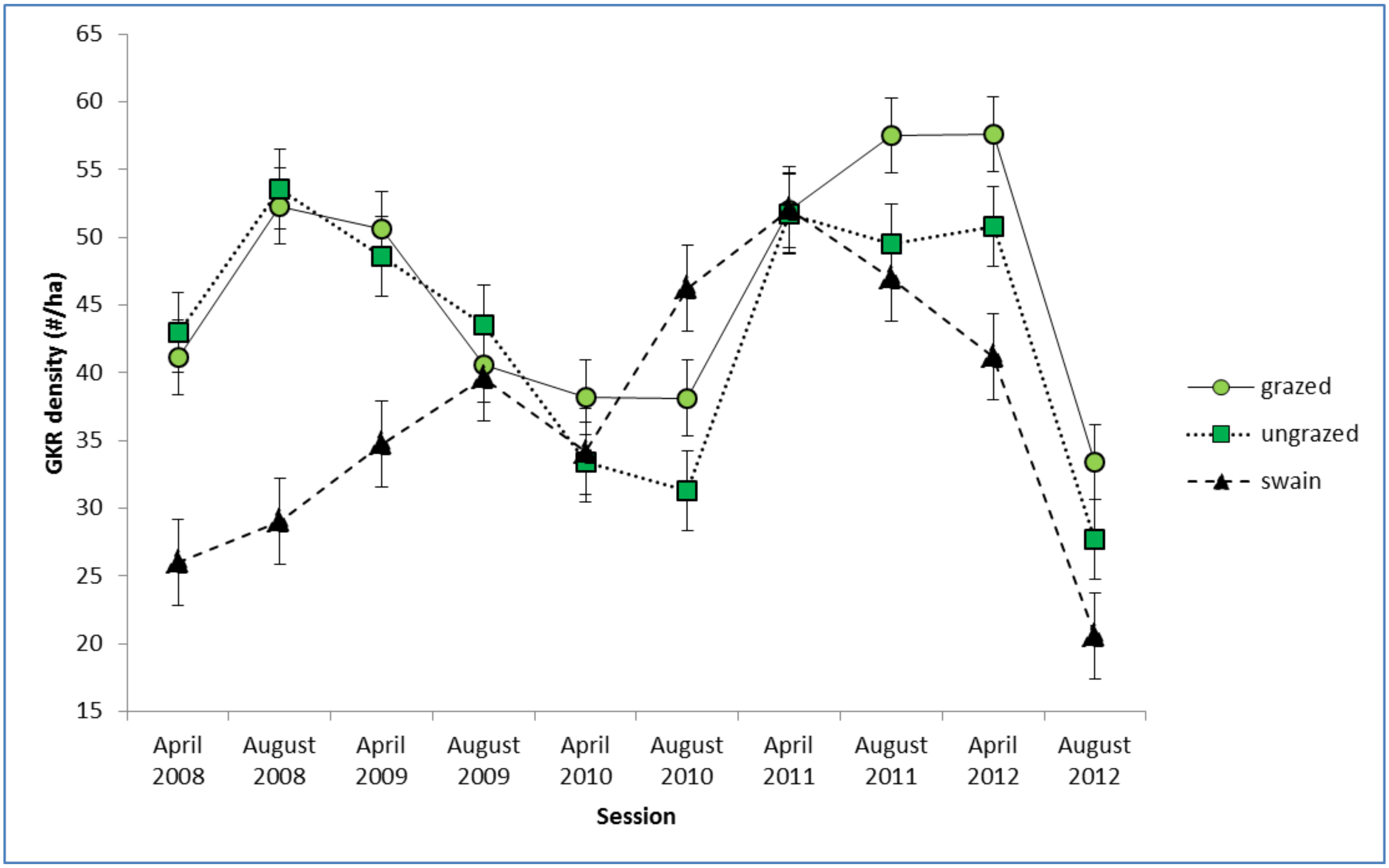

Figure 15. Average GKR population estimates in Center Well grazed plots, Center Well ungrazed plots, and Swain ungrazed plots, during each trapping session.

Table 5. GKR population size and apparent survival estimates in 2012. 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	59	1.81	51	24.75	0.84	0.38
Center Well	Grazed	C10	72	0.92	40	2.03	0.59	0.03
Center Well	Grazed	C2	69	0.87	31	2.86	0.46	0.08
Center Well	Grazed	C3	70	1.65	50	22.17	0.87	0.33
Center Well	Grazed	C4	44	0.59	18	1.34	0.55	0.04
Center Well	Grazed	C5	61	0.48	28	1.13	0.57	0.04
Center Well	Grazed	C6	10	0.47	10	1.14	0.39	0.05
Center Well	Grazed	C7	60	1.27	22	6.28	0.41	0.15
Center Well	Grazed	C8	65	0.82	24	1.77	0.56	0.04
Center Well	Grazed	C9	67	0.61	59	1.45	0.60	0.03
Center Well	Ungrazed	E1	25	1.08	26	14.05	0.80	0.46
Center Well	Ungrazed	E10	59	0.76	30	1.69	0.55	0.04
Center Well	Ungrazed	E2	64	1.31	31	4.10	0.44	0.08
Center Well	Ungrazed	E3	51	1.13	30	14.71	0.83	0.40
Center Well	Ungrazed	E4	45	0.58	16	1.30	0.54	0.04
Center Well	Ungrazed	E5	62	0.47	41	1.11	0.55	0.04
Center Well	Ungrazed	E6	17	0.42	10	1.01	0.47	0.05
Center Well	Ungrazed	E7	55	1.86	19	8.61	0.38	0.15
Center Well	Ungrazed	E8	69	0.90	24	1.91	0.55	0.04
Center Well	Ungrazed	E9	62	0.47	51	1.13	0.58	0.03
Swain	Ungrazed	S1	53	0.58	22	1.31	0.56	0.04
Swain	Ungrazed	S10	40	0.51	16	1.18	0.66	0.04
Swain	Ungrazed	S2	36	0.42	15	0.98	0.54	0.04
Swain	Ungrazed	S3	64	0.64	34	1.46	0.58	0.04
Swain	Ungrazed	S4	51	0.55	23	1.26	0.55	0.04
Swain	Ungrazed	S5	38	0.55	9	1.24	0.49	0.04
Swain	Ungrazed	S6	47	0.89	27	1.45	0.57	0.08
Swain	Ungrazed	S7	38	1.46	28	2.31	0.63	0.08
Swain	Ungrazed	S8	15	0.27	10	0.66	0.41	0.05
Swain	Ungrazed	S9	30	0.28	22	0.70	0.57	0.04

Table 6. Age and sex composition of GKR and San Joaquin antelope squirrels (SJAS) captured in 2012.

		Female	Male	Unknown	Total
GKR	Adult	1011	993	1	2005
	Juvenile	6	6	0	12
	Unknown	3	1	52	56
	Total	1020	1000	53	2073
SJAS	Adult	64	62	0	126
	Juvenile	12	2	0	14
	Unknown	0	0	1	1
	Total	76	64	1	141

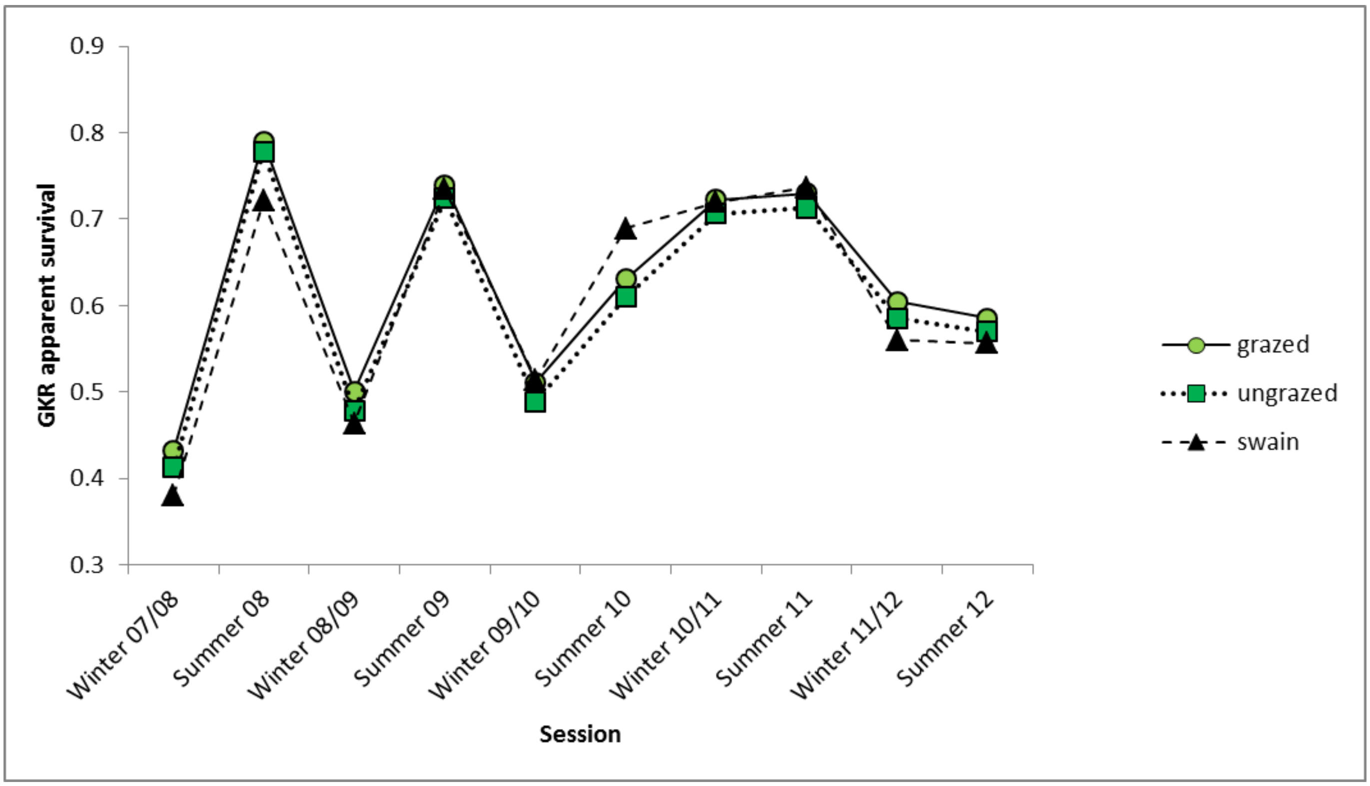

Figure 16. Average GKR apparent survival estimates in Center Well grazed plots, Center Well ungrazed plots, and Swain ungrazed plots, from winter 2008 to summer 2012. Standard error bars are shown (n = 10 grids per treatment).

SJAS abundance

A total of 141 individual antelope squirrels were captured and a total of 557 captures (including recaptures) occurred. For the first time there were more females (76) captured than males (64) (Table 6). In 2012, SJAS overall density levels (14.7 SJAS/ha) were less than half of those in 2011 (35.2 SJAS/ha) and were in the middle of the density levels of the previous dry years (Figure 17A). SJAS densities were higher on ungrazed plots, following the trend of the last four years (t = -3.34, df = 9, P = 0.009) and densities in Swain fell below those on ungrazed plots, similar to the dry year of 2007 (Figure 17A&B).

Apparent survival of SJAS increased slightly in 2012, again following the trend of previous dry years when increases were seen from 2007-2008 and 2008-2009 whereas apparent survival decreased slightly in the wet years. There was a dramatic drop in recruitment from 2011, with the number of juveniles per female ranging from 1.93 to 2.47, and in 2012, the number of juveniles per female was below 0.30 for all treatments (Figure 18b).

The higher densities on ungrazed plots in Center Well were due to increased reproduction rather than differences in survival (Figure 18). SJAS estimates on each plot were not correlated between 2011 and 2012, which may be due to the large drop in density between years (Figure 17).

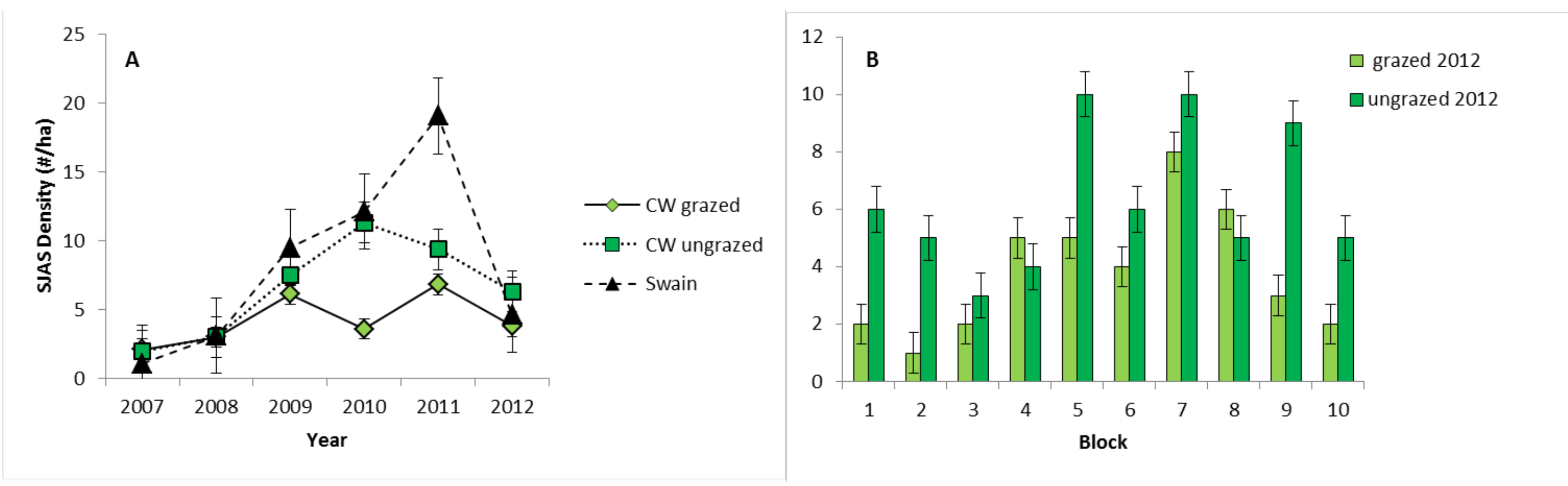

Figure 17. Estimates of San Joaquin antelope squirrel density. (A) Average annual density (± standard error) in Center Well grazed plots, Center Well ungrazed plots, and Swain ungrazed plots. (B) Density in 2012 on each replicate site (block) in Center Well, with 95% confidence intervals.

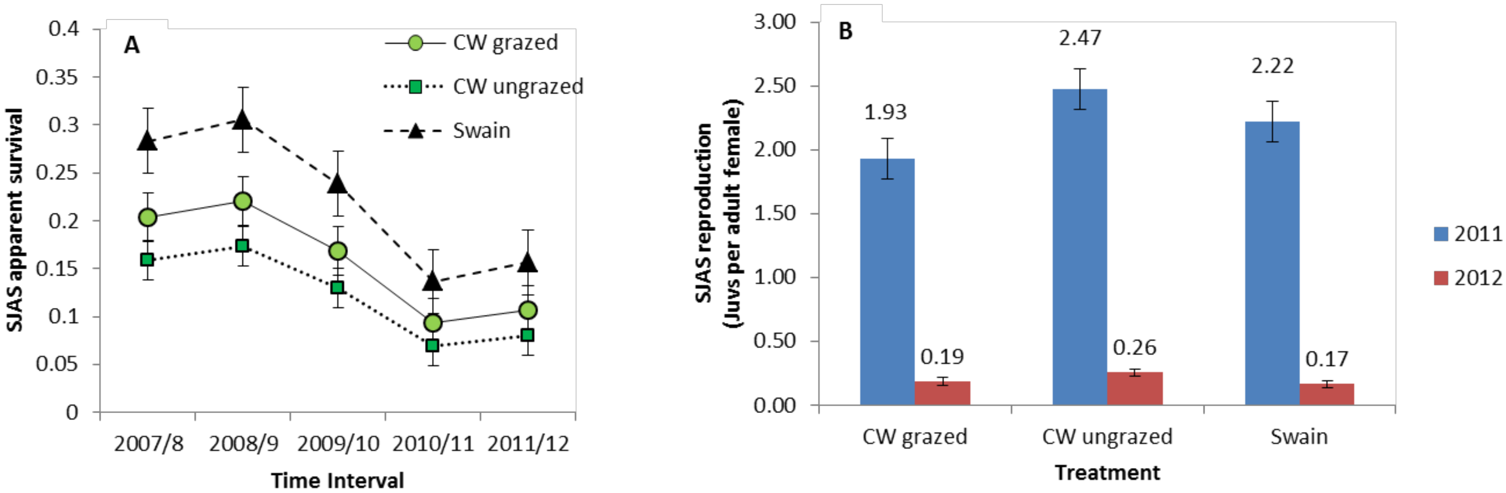

Figure 18. (A) Apparent survival of San Joaquin antelope squirrels on Center Well grazed plots, Center Well ungrazed plots, and Swain ungrazed plots, 2007-2012. (B) SJAS reproduction in 2011 and 2012 in the three treatments. Standard error bars are shown.

Bird abundance

Bird abundance dropped from the record 1,347 individuals counted, on or over plots, in 2011 to 257 birds in 2012. This is the second lowest record in 6 years, the lowest occurred in 2008 with 119 birds (Table 7). Bird diversity was also down this year with only 12 species of 1,532 birds counted during bird surveys (this includes birds off plot). 2011 saw the highest number of species (20) and 2009 and 2010 were more similar to 2012 with 14 species. 2007 and 2008 both had less than 10 species counted during bird surveys.

As in previous years the most common birds found on plots were horned larks, however 2012 saw the second lowest counts (119) for this species (2008 had the lowest count at 61). Western meadow larks had the second highest count on record (51), but this was less than half the number counted in 2011. Savannah sparrow counts were the third lowest and common ravens the second lowest in six years (Table 7).

Table 7. Total counts of birds detected on or flying over plots, 2007-2012.

Common Name	Scientific Name	2007	2008	2009	2010	2011	2012
Horned Lark	*Eremophila alpestris*	545	61	203	158	543	119
Western Meadowlark	*Sturnella neglecta*	11	3	33	8	132	51
Savannah Sparrow	*Passerculus sandwichensis*	0	1	3	41	504	28
Common Raven	*Corvus corax*	16	43	55	45	101	28
Lark Sparrow	*Chondestes grammacus*	0	2	0	0	5	8
Loggerhead Shrike	*Lanius ludovicianus*	0	2	0	0	0	7
Cliff Swallow	*Petrochelidon pyrrhonota*	0	0	0	3	0	6
Unidentified Sparrow	*Emberizidae (gen, sp)*	0	0	0	1	18	4
Red-tailed Hawk	*Buteo jamaicensis*	0	5	1	1	1	3
White-crowned Sparrow	*Zonotrichia leucophrys*	0	0	0	1	20	1
Ferruginous Hawk	*Buteo regalis*	0	0	1	0	1	1
American Pipit	*Anthus rubescens*	0	0	0	39	0	1
California Quail	*Callipepla californica*	0	0	0	0	5	0
Mourning Dove	*Zenaida macroura*	0	0	1	0	2	0
Unidentified Hawk	*Accipitridae (gen, sp)*	0	0	0	1	1	0
Northern Mockingbird	*Mimus polyglottos*	0	0	1	0	1	0
Prairie Falcon	*Falco mexicanus*	0	0	0	2	0	0
House Finch	*Carpodacus mexicanus*	0	0	0	0	0	0
Unidentified Swallow	*Hirundidae (gen, sp)*	0	0	0	0	0	0
Violet-green Swallow	*Tachycineta thalassina*	0	0	10	1	4	0
Lawrence's Goldfinch	*Carduelis lawrencei*	0	0	0	0	3	0
Western Kingbird	*Tyrannus verticalis*	0	0	0	0	3	0
Lincoln's Sparrow	*Melospiza lincolnii*	0	0	0	0	1	0
California Thrasher	*Toxostoma redivivum*	0	0	0	0	1	0
Short-eared Owl	*Asio flammeus*	0	0	0	0	1	0
Northern Harrier	*Circus cyaneus*	0	0	0	1	0	0
Greater Roadrunner	*Geococcyx californianus*	0	0	0	0	0	0
Common Pauraque	*Nyctidromus albicollis*	0	0	0	0	0	0
Unidentified Thrush	*Turdidae (gen, sp)*	0	0	0	0	0	0
White-tailed Kite	*Elanus leucurus*	0	0	0	0	0	0
Red-winged Blackbird	*Agelaius phoeniceus*	0	0	0	18	0	0
Long-billed Curlew	*Numenius americanus*	0	0	0	5	0	0
Chipping Sparrow	*Spizella passerina*	0	0	1	0	0	0
Dusky Flycatcher	*Empidonax oberholseri*	0	0	6	0	0	0
American Kestrel	*Falco sparverius*	0	0	2	0	0	0
Mountain Plover	*Charadrius montanus*	0	0	1	0	0	0
Sage Sparrow	*Amphispiza belli*	0	0	1	0	0	0
Brewer's Blackbird	*Euphagus cyanocephalus*	3	0	0	0	0	0
Unidentified Bird	*Aves (gen, sp)*	0	0	0	0	0	0
Golden Eagle	*Aquila chrysaetos*	0	1	0	0	0	0
Vesper Sparrow	*Pooecetes gramineus*	0	1	0	0	0	0
Total		575	119	319	325	1,347	257

Reptile abundance

A total of 200 side-blotched lizards (*Uta stansburiana*) and 37 blunt-nosed leopard lizards (*Gambelia sila*) were seen during reptile surveys, 7 unidentified lizards were also seen (Table 8). All blunt-nosed leopard lizard (BNLL) sightings were geo-referenced. As in previous years, all BNLL sightings during surveys were in the Swain pasture, however three sightings of BNLL were documented during other activities on or near Center Well 5, including two juveniles. Sightings occurred on all 10 sites in Swain, indicating that BNLL are distributed throughout the pasture. BNLL abundance was similar to 2011 with 37 sightings during surveys in 2012 and 36 in 2011. These are the highest numbers recorded for BNLL for the six years. The dry years of 2007-2008 had less than 10 BNLL sightings during surveys and 2010 had less than 20 sightings. UTA sightings were the lowest ever recorded in 2011 (42) but they were back up this year with 200 counted. 2012 UTA sightings were below the previous three dry years (2007=419, 2008=675, 2009=631) but were higher than the wet year of 2010 (114) (Figure 19; Table 8). *Uta* densities were higher on ungrazed pasture in Center Well ($t = -2.5512$, $P = 0.03$). This is similar to results found in 2010, a wet year. The correlation between grazing and *Uta* densities remains unclear as no relationship has been found in most years.

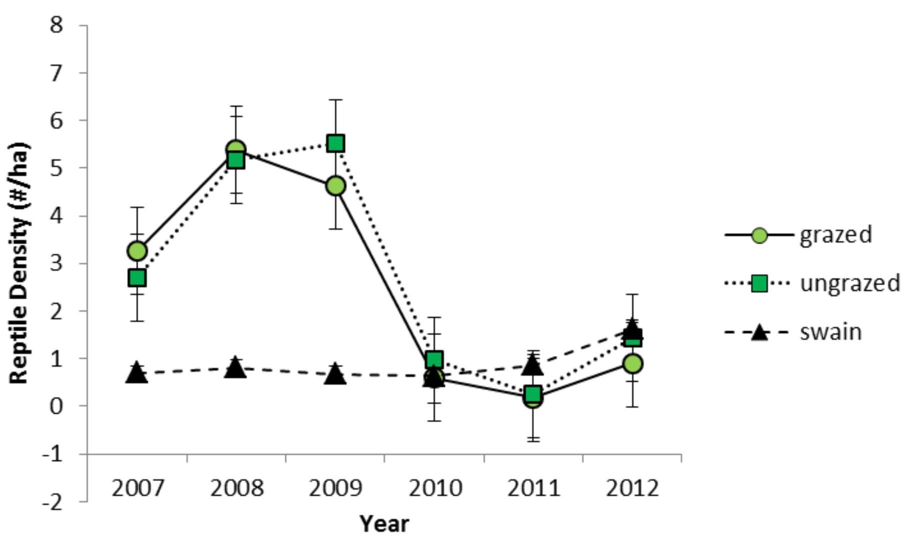

Figure 19. Estimates of reptile density each year from 3 replicate surveys on Center Well grazed plots, Center Well ungrazed plots, and Swain ungrazed plots. Standard error bars are shown.

Table 8. Totals of Blunt Nosed Leopard Lizards (*Gambelia sila)* and Side Blotch Lizards (*Uta stansburiana)* over time.

Species	2007	2008	2009	2010	2011	2012
BNLL	4	7	19	18	36	37
UTA	419	675	631	114	42	200

Invertebrates

GKR exclosures had strong effects on the invertebrate community in 2012. Invertebrate biomass and orthopteran abundance were higher where GKR were present in both pastures (Figure 20A&C; $t = 4.1304$, $P < 0.001$, and $t = 6.5903$, $P < 0.001$). Beetle abundance was also higher where GKR were present with both pastures combined ($t = 6.5903$, $P < 0.001$). Invertebrate richness was higher in grazed areas and where GKR were present but results were not significant (Figure 21). Invertebrate biomass rose to the highest levels seen in the study (Figure 20A) due in large part to an increase in grasshopper biomass (Figure 22).

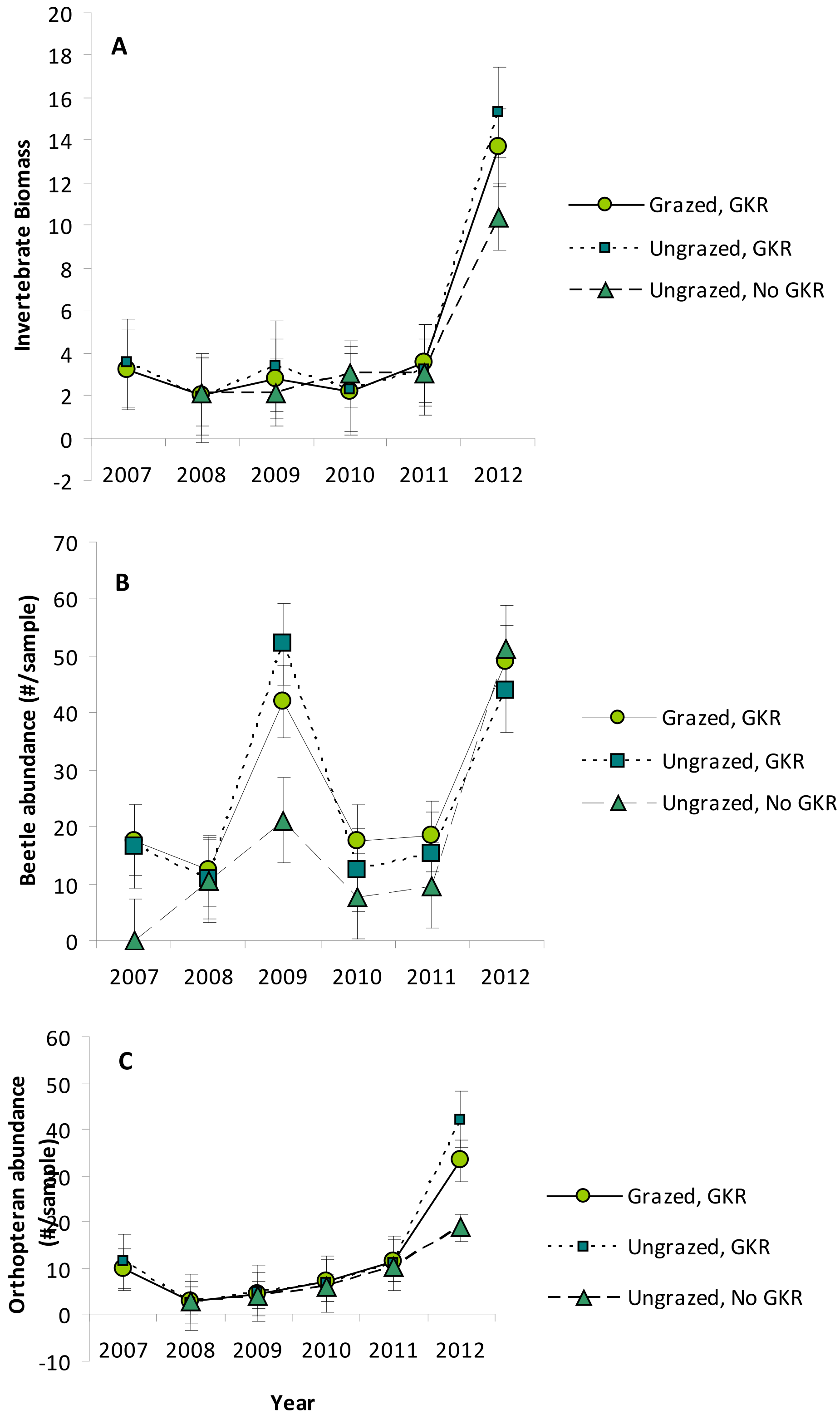

Figure 20. Response of (A) invertebrate biomass (B) beetle abundance, and (C) orthopteran abundance to GKR and cattle exclosures in the Center Well pasture, 2007-2012. Standard error bars are shown.

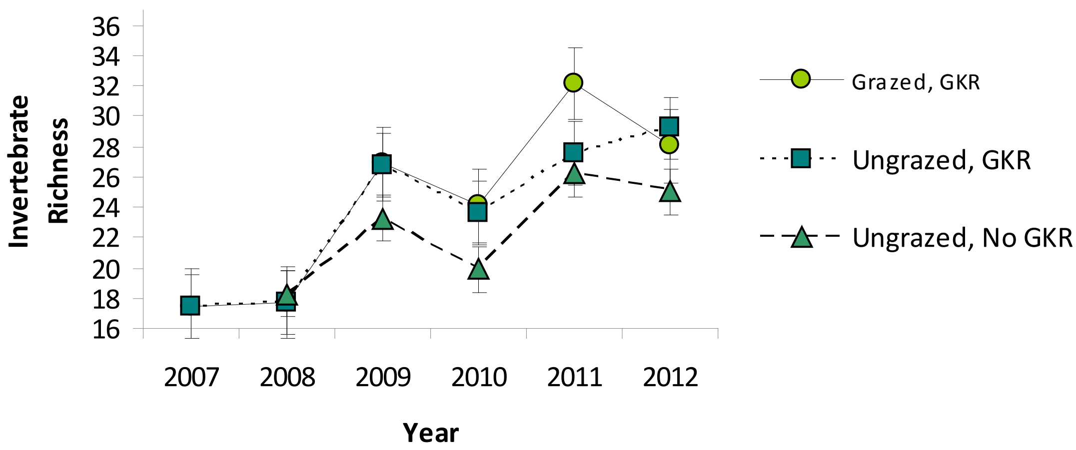

Figure 21. Response of invertebrate richness to GKR and cattle exclosures in the Center Well pasture, 2007-2012. Standard error bars are shown.

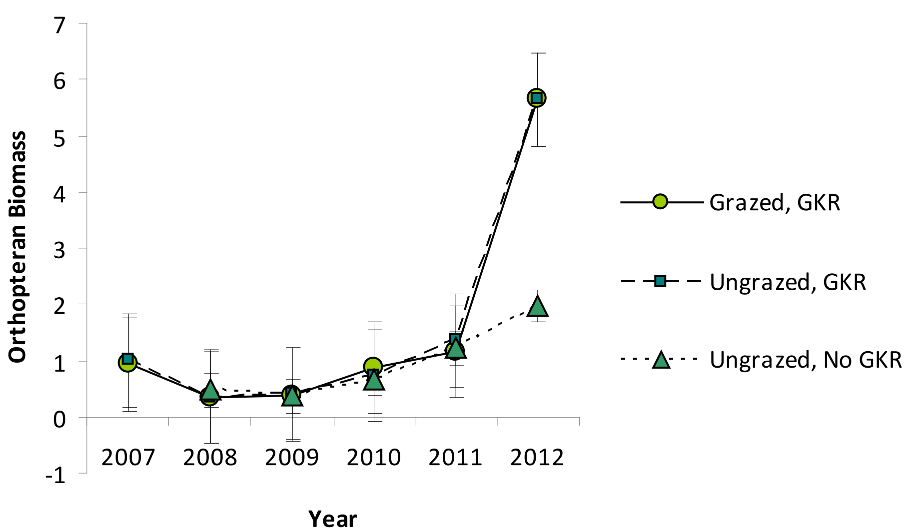

Figure 22. Response of orthopteran biomass to GKR and cattle exclosures in the Center Well pasture, 2007-2012. Standard error bars are shown.

Species associations

Table 9 shows the associations among the flora and fauna on our plots. 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. Lizards were positively correlated with native plant cover and *Uta* lizards may benefit from more native species in their habitat.

Table 9. 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.

2012	*N squirrels*	*N GKR*	*GKR Survival*	*N Birds*	*Bird Richness*	*N Lizards*	*Native Cover*	*Plant Biomass*	*Plant Height*	*Plant Richness*	*Invert Richness*
N GKR	-0.08										
GKR Survival	-0.16	**0.60**									
N Birds	-0.07	**-0.48**	-0.16								
Bird Richness	0.14	**-0.36**	-0.09	**0.79**							
N Lizards	0.31	0.32	0.12	-0.03	0.18						
Native Cover	-0.12	0.07	0.33	0.16	0.32	**0.43**					
Plant Biomass	-0.05	-0.25	-0.03	**0.70**	**0.60**	0.33	**0.47**				
Plant Height	0.23	**-0.35**	0.03	**0.37**	**0.44**	0.11	**0.45**	**0.62**			
Plant Richness	-0.12	-0.19	0.09	**0.41**	**0.51**	0.07	**0.56**	**0.37**	0.24		
Invert Richness	0.07	0.13	-0.06	-0.33	-0.19	0.29	-0.01	-0.11	-0.21	-0.07	
Invert Biomass	-0.15	**0.41**	0.16	**-0.54**	**-0.59**	-0.34	-0.29	**-0.55**	-0.34	**-0.53**	-0.17

Conclusions and Future Directions

2012 was a year of contrasts in the Carrizo. While rainfall was below average (16 cm), it was not as low as in the previous three dry years. A striking feature this year was the increase in biomass from spring to fall, possibly due to the absence of cattle, a drop in GKR densities between spring and summer and a slight growth in vegetation after the April biomass collection period.

Native cover dropped dramatically this year with the lowest levels seen in the study so far. It is interesting to note that these results were collected in the spring and so it is not known if the increase in biomass seen in the fall was due to growth of native, non-native plants or both.

Our exclosures allow us to determine what proportion of vegetation loss was due to cattle, GKR, or other forces (wind, insects, etc.). Without cattle grazing, we were only able to calculate biomass removed by GKR and other factors. In both pastures combined, GKR foraging removed 1,036 lbs/acre and other factors removed 1,557 lbs/acre (Table 5).

While no cattle were grazed this year, there did appear to be a continued impact on species with both SJAS and *Uta* showing higher densities on ungrazed plots. GKR densities were higher on grazed plots. Invertebrate richness was also higher on grazed plots but results were not significant.

GKR exclosures showed a strong effect on invertebrates. Invertebrate biomass and orthopteran abundance were higher where GKR were present in both pastures as well as within each pasture and beetle abundance was also higher where GKR were present when results from both pastures were combined. Invertebrate biomass rose to the highest levels seen in the study due in large part to a large increase in grasshopper biomass.

Gopher activity was again higher in GKR exclosures, indicating that GKR may be competitively dominant, or that gophers prefer the thick vegetation that occurs in exclosures. While there was a high rate of gopher activity this year, the activity was highly localized and occurred on only a small number of vegetation plots (8.25%).

A 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.

2012 was an interesting year with some results corresponding to other dry years and some results similar to the wet years. The contrast between 2011, with the highest rate of precipitation and highest species levels of the study, may have played a part in the results seen in the spring.

In the 2013 field season, we will continue to monitor flora and fauna on our experimental plots. Data collection was completed this year for three graduate students with completed dissertations expected by the end of the year. A new graduate project was initiated this year and will continue in 2013.

Products of the Carrizo Plain Ecosystem Project

29) Bean, W.T. (2012). Spatial population dynamics of the giant kangaroo rat. PhD Dissertation. University of California, Berkeley, Berkeley, CA 2012.
28) Gurney, C.M., L.R. Prugh, and J.S. Brashares. (in revision). 2012. Restoring Natives in a Semi-arid Grassland: The Effects of Rodent Granivory and Soil Disturbance. Journal of Arid Environments.
27) Gurney, C.M. (2012). Giant Kangaroo Rats (Dipodomys ingens) and Plant Ecology at Carrizo Plain National Monument. MS Thesis. University of California, Berkeley, Berkeley, CA. 2012.
26) Endicott, R.L., Prugh, L.R., Brashares, J.S. 2012. Surplus killing by endangered San Joaquin kit foxes (Vulpes macrotis mutica) is linked to a local population decline of endangered giant kangaroo rats (Dipodomys ingens). The Southwestern Naturalist, submitted November 2012.
25) Bean, W.T., Stafford, R., Prugh, L.R., Butterfield, H.S., and J.S. Brashares. An Evaluation of Monitoring Methods for the Endangered Giant Kangaroo Rat. Wildlife Society Bulletin, published online August 10, 2012.
24) Bean, W.T., Stafford, R., Butterfield, H.S., and J.S. Brashares. Following the Food: Incorporating Spatial and Temporal Resource Availability in Species Distribution Models. Talk presented at the 1st North American Congress for Conservation Biology, July 16, 2012.
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