Carrizo Plain Ecosystem Project
2009 Report

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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 third year of the Carrizo Plain Ecosystem Project (CPEP), a long-term study to tease apart these relationships using replicated cattle and GKR exclosures. GKR and lizard numbers appeared to have stabilized, whereas San Joaquin antelope squirrel populations continued to increase. Total plant biomass and native plant cover were both higher on plots inside cattle and GKR exclosures in comparison to plots exposed to grazing by GKR and cattle. Both consumers reduced the abundance of goldfields (*Lasthenia*), and GKR also greatly reduced the abundance of peppergrass (*Lepidium*). Seeds of these plants were the most highly favored by GKR in diet trials this year. Non-native grasses were not abundant in 2009, and the exclosures did not significantly affect the prevalence of red brome (*Bromus*). Biomass removal rates by GKR and cattle were similar, at approximately 200 pounds per acre. Cattle grazing has not significantly affected GKR population sizes or survival rates. We initiated a radio-telemetry study and found that adult GKR had high survival rates, and estimates of survival from live-trapping and telemetry were comparable. The telemetry study will be expanded next year to include juveniles. In summary, our work in 2009 marked a positive step towards quantifying interactions among native and non-native species and the effect of management strategies on the Carrizo Plain while also providing essential monitoring data for GKR and other species of concern.

Prepared by Laura Prugh, 2009

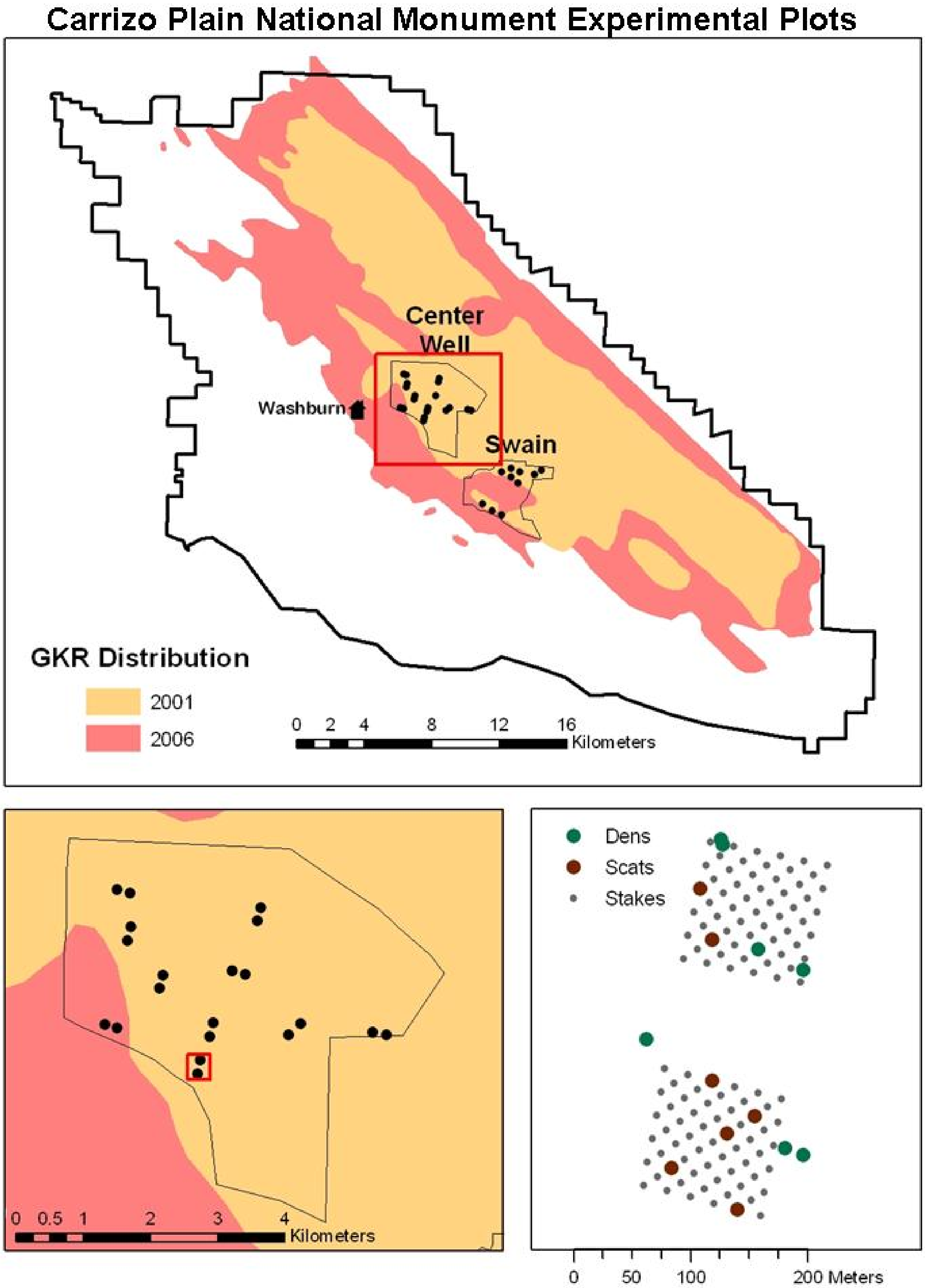

Figure 1. Map of study sites in the Carrizo Plain National Monument. Details are shown for the Center Well pasture and site CW 7. Kit fox dens and scats, as well as trap stakes, are shown for site 7.

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. Additionally, the Carrizo is now dominated by annual grasses from Europe. Thus, sound management in the Carrizo 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 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 2009, we continued monitoring the flora and fauna on these plots, conducted a kangaroo rat diet trial, and initiated a radio-telemetry study.

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, especially giant kangaroo rats and plants.

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 will use structural equation modeling to estimate the strength of interactions and indirect effects of cattle (Wootton 1994).

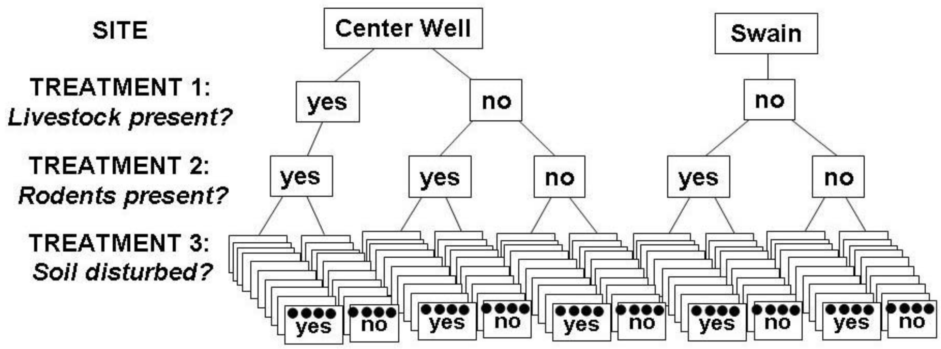

Figure 2. Experimental design of the project. There are ten blocks of each treatment combination and four nested vegetation plots (filled circles) within each block.

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).

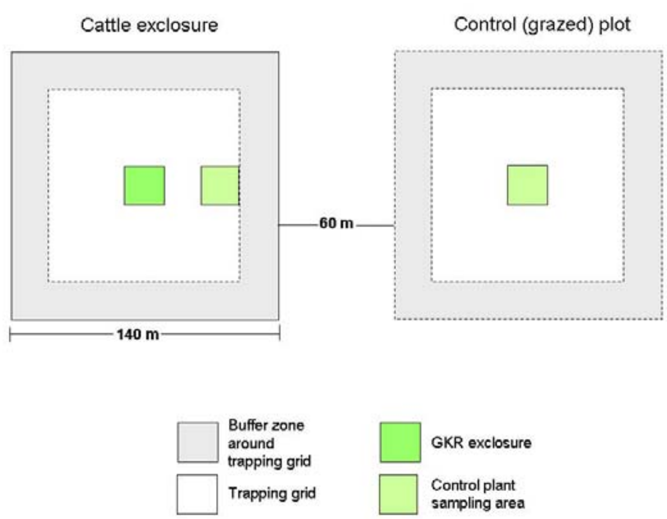

Figure 3. Nested exclosure design to separate livestock and GKR effects on plants, with paired control plot. A buffer zone around each GKR trapping grid ensured that the surveyed population was comprised of individuals living within the plot. This shows the design in Center Well; in Swain each plot is 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. In addition to the 1-m^2 plots, ocular estimates of plant cover were conducted in each 400-m^2 plant sampling area (stratified by precinct/non-precinct). Biomass samples were obtained from 1/16-m^2 plots adjacent to each 1-m^2 plot to estimate biomass in April, June, and October (peak, post-grazing, and minimum biomass). Clip plots cannot be resurveyed in the same spot and are placed adjacent to the previous clip plot.

We randomly chose one precinct and one non-precinct plot per plant sampling area to take soil samples and place i-Buttons to record soil moisture and temperature (n = 100 plots). Soil samples were collected in October 2007 and sent to the ANR Laboratory at UC Davis for chemical analysis. Total N, C, Bray-P, salinity, texture, and pH were analyzed. i-Buttons were placed 2 cm below the soil surface in April 2008 and were collected in June 2009.

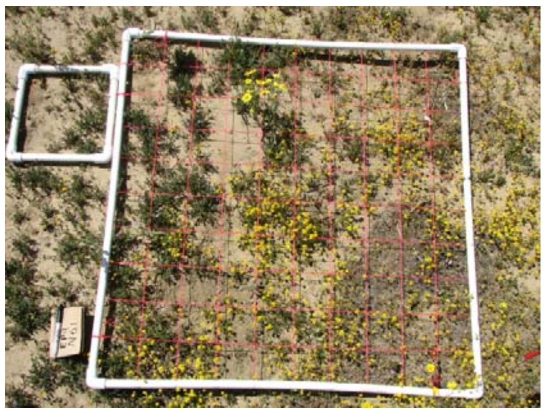

Figure 4. Plant sampling plot in a non-precinct area, showing the 1-m^2 point frame and the 1/16-m^2 clip plot.

GKR surveys

GKR precincts were counted and mapped on each 1.96-ha plot (n = 30, 20 plots (paired) in Center Well, 10 in Swain). Inactive precincts and kit fox dens were also noted. 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, minimum 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 6-May 4, 2008 (22 trap nights) and July 28-August 16, 2008 (13 trap nights).

To obtain mark-recapture estimates, I used the program R (R Development Core Team 2009) package RMark. I obtained population estimates for each trapping session as well as site fidelity 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 more accurately described as a site fidelity rate (usually referred to as “apparent survival”).

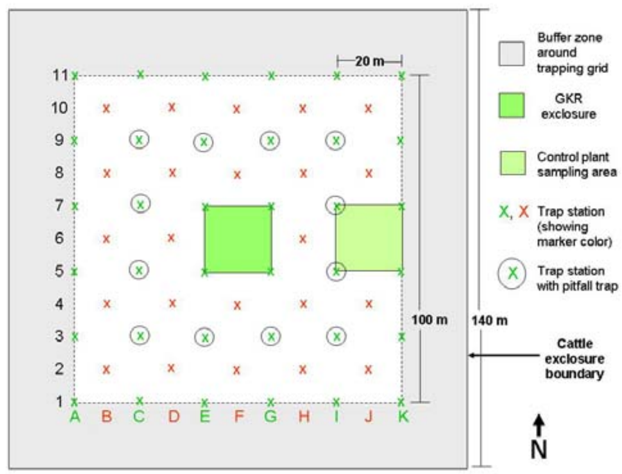

Figure 5. Detailed diagram of a cattle exclosure. Trap stations show trap locations for GKR mark-recapture surveys. Colors correspond to the spray-painted color on the stake marking the location. Letters and numbers identify the grid stakes (A1, B2, etc.).

GKR dietary preferences were determined as part of a UCB student senior thesis project in 2007 (Olney 2008) and were repeated in 2008 with a few modifications. In 2009, we conducted a final diet study, with increased replication and greater use of remote cameras. Ripe seed heads of 10 species were collected in April, and 0.5 grams of each species was placed in shallow trenches that we dug in the cleared soil of a precinct. Trenches minimized wind exposure of the seed piles. Trials were conducted on 90 precincts (three per plot) from June 13 – August 8, 2009. Seed piles were placed at dusk and collected at dawn, and remains were re-weighed to determine the quantity of each type removed. Cameras were mounted on tripods above each pile and set to record near-video, so that we could use photographs to collect data on visitation rates to the piles as a supplement to the seed weights. We also collected contents of GKR surface pit caches to examine which seeds GKR were collecting. Two caches were collected on each plot (n = 60 total), and seeds present in each cache were identified using a seed reference collection.

GKR radio-collaring

In addition to the mark-recapture sessions, we initiated a pilot study to examine the causes and rates of adult GKR mortality. GKR were radio-collared in the Swain pasture from May 26–28, 2009, and individuals were located every 3–5 days during the summer. We used miniature radiotelemetry collars (Model PD-2C, Holohil Systems Ltd., Carp, Ontario) with six month lifespans. The mass of the transmitter (4.0 g) was well below the threshold of 5% of adult GKR body mass. This pilot study will be used as part of Stephen Etter's masters thesis, which he is conducting under the supervision of Dr. Tim Karels at CSU Northridge.

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 14–June 4, 2009. 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 31–April 20, 2009. 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 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 29–June, 2009. 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). Soil/air temperature, 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. Density estimates of the most common reptile, the side-blotched lizard (*Uta stansburiana*), were obtained using the program DISTANCE (Thomas et al. 2006).

Invertebrate surveys

Grasshoppers were counted during reptile surveys. Additionally, pitfall traps were placed on each plot between June 9–10, 2009 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 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. Pitfall samples from 2009 are currently being processed.

A  B

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

Spotlight surveys

Ten spotlight routes ranging in length from 1.9-5.5 km (total distance = 35.4 km for all 10 routes) were surveyed 4 times from June 9–July 2, 2008. Routes were along dirt roads occurring in our study areas. Surveys were conducted in spring (May 11–19, *n* = 4 surveys) and summer (July 24–27, *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. Kit fox and lagomorph density estimates were obtained using the program DISTANCE.

Kit fox activity and diet

Kit fox dens found on plots or opportunistically while walking to plots were geo-referenced. Kit foxes often marked our rodent traps with urine and feces, and we collected scats deposited on our traps. We collected 90 kit fox scats. Scats collected in 2007 were analyzed as part of a UCB student senior thesis comparing the diets of owls, kit foxes, and coyotes in the Carrizo (Castillo 2008), but scats collected in 2008 and 2009 have not been analyzed. We also recorded all sightings of kit foxes.

Cattle grazing intensity

We counted the number of cows on our control plots in Center Well from April 7–May 3, 2009 (n = 16 surveys). Cows were counted during active foraging periods in the mornings and evenings. We also counted cow patties on our control plots shortly after the cows were removed.

Results and Discussion

Plants

General plant composition

Plant species richness (i.e., the number of species) and cover continued to increase in 2009, in both the Center Well and Swain pastures (Table 1). These increases were both due to the occurrence of more native species in both pastures, whereas exotic cover remained stable or declined (Table 1). Species composition was largely similar to 2008, with *Erodium circutarum* dominating, and relatively little *Bromus madritensis rubens* (Table 2). We observed a severe infestation of aphids (and a resulting outbreak of ladybug beetles), which targeted *Erodium*.

Table1. Species richness and plant cover in the Center Well and Swain pastures, 2007–2009.

Metric	Type	Center Well			Swain		
		2007	2008	2009	2007	2008	2009
Species richness	native	18	24	29	15	30	40
	exotic	8	7	6	7	8	8
	total	26	31	35	22	38	48
Plant cover (%)	native	14	17	25	7	8	17
	exotic	10	22	17	6	11	13
	total	24	39	42	12	19	29

Table 2. Relative % cover of plant species, 2007–2009 (n = 400 plots)

Species	Type	2007	2008	2009
Erodium cicutarium	exotic	13.9	43.8	30.1
Lepidium nitidum	native	8.2	9.1	13.9
Vulpia microstachys	native	29.4	5.6	9.1
Amsinckia tessellata	native	0.2	6.2	6.6
Schismus arabicus	exotic	7.8	8.2	6.0
Lasthenia minor	native	0.1	3.1	5.2
Lasthenia californica	native	0.7	1.6	4.0
Trifolium gracilentum	native	0.02	0.4	4.0
Poa secunda	native	4.1	2.8	3.7

Table 2 continued

Species	Type	2007	2008	2009
Calandrinia ciliata	native	0.2	3.1	3.0
Bromus madritensis rubens	exotic	18.3	3.0	2.9
Hordeum murinum	exotic	5.0	3.3	2.1
Tropidocarpum gracile	native	0.6	2.9	2.0
Pectocarya penicillata	native	0.6	1.4	1.8
Dichelostemma capitatum	native	0.1	1.1	1.2
Lotus wrangelianus	native	0.05	0.3	1.0
Lepidium dictyotum	native	0.4	0.2	0.4
Linanthus liniflorus	native	0.1	0.04	0.3
Guillenia lasiophylla	native	0.3	1.3	0.3
Microseris elegans	native	2.1	0.4	0.3
Eriogonum gracillimum	native	0.05	0.1	0.3
Chaenactis glabriuscula	native	0.04	0.1	0.3
Chorizanthe uniaristata	native	--	0.1	0.3
Lastarriaea coriacea	native	0.0	0.1	0.3
Vulpia myuros	exotic	7.3	0.02	0.2
Plagiobothrys canescens	native	--	0.1	0.2
Microseris douglasii	native	0.2	0.2	0.2
Hollisteria lanata	native	0.01	0.1	0.1
Lembertia congdonii	native	--	0.1	0.1
Uropappus lindleyi	native	--	0.1	0.1
Phlox gracilis	native	--	0.1	0.04
Plantago erecta	native	--	0.1	0.02
Herniaria hirsuta	exotic	0.02	0.01	0.02
Allium sp.	native	--	--	0.02
Astragalus lentiginosus	native	--	--	0.02
Malacothrix coulteri	native	0.01	0.02	0.01
Camissonia campestris	native	--	--	0.01
Lupinus microcarpus	native	--	0.03	0.01
Astragalus didymocarpus	native	--	--	0.01
Trifolium albopurpureum	native	--	--	0.004
Platystemon californicus	native	--	--	0.004
Monolopia lanceolata	native	--	0.04	0.004
Bromus tectorum	exotic	--	--	0.004
Bromus hordeaceus	exotic	0.04	--	0.004
Vulpia bromoides	exotic	--	0.7	--
Sisymbrium irio	exotic	--	0.02	--
Sisymbrium altissimum	exotic	0.04	--	--
Muilla maritima	native	--	0.1	--
Marrubium vulgare	exotic	0.03	--	--
Delphenium sp.	native	--	0.01	--
Crassula connata	native	--	0.01	--
Chorizanthe watsonii	native	0.02	--	--
Capsella bursa-pastoris	exotic	0.03	0.01	--
Athysanus pusillus	native	--	0.01	--
Astragalus sp.	native	--	0.01	--
Astragalus oxyphysus	native	0.01	0.01	--
Amsinckia menziesii	native	0.04	--	--

Effect of cattle and kangaroo rat exclusion

In January, we used a fog machine to locate kangaroo rat tunnels that breached the kangaroo rat exclosures, and we blocked access with hardware cloth. These repairs were effective and there was very little kangaroo rat activity inside exclosures in 2009. 133 cattle were turned out in Center Well late in the season after plants had started to dry, and they spent most of their time along roads where vegetation was greenest. Cattle were in Center Well from April 2–May 14, 2009, for a total of 188 animal use months.

Biomass removal by cattle and GKR. We calculated the biomass removed by cattle by subtracting the biomass measured on plots exposed to grazing 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 on plots within cattle exclosures (which were exposed to GKR but not cattle) from the biomass measured on plots within GKR exclosures in Center Well. Biomass was measured in April (peak), June (post-grazing), and October (minimum).

The residual dry matter (RDM) was approximately 900 pounds per acre when cattle were turned out in Center Well in April. Although the timing of biomass removal by cattle and GKR differed, they each reduced RDM levels by approximately 200 pounds per acre (Figure 7). This was comparable to the amount of RDM removed by other sources (insects, wind, etc.): biomass declined by 215 pounds per acre from April to October within kangaroo rat exclosures. There was no difference in biomass inside and outside GKR exclosures in April and June, but by October removal by GKR was similar in magnitude to that by cattle (Figure 7, Figure 8). Conversely, the difference in plant biomass inside and outside cattle exclosures had disappeared by October.

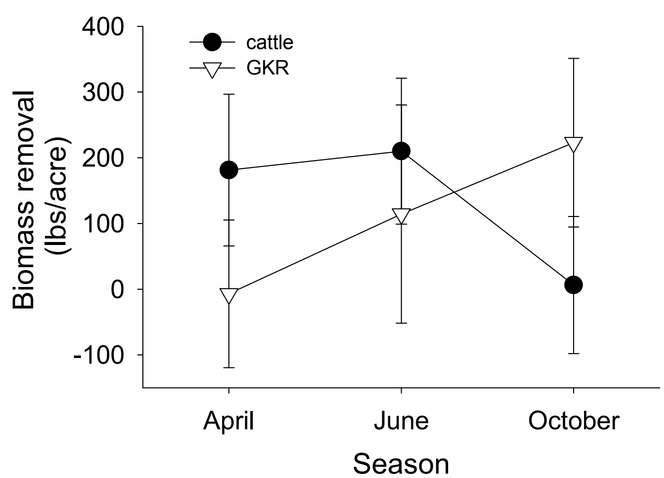

Figure 7. Biomass removal by cattle and GKR in 2009, measured as the difference in biomass among cattle and GKR exclosure treatments. Means and standard error bars are shown (*n* = 10 replicates).

A  B 

Figure 8. Photographs of the kangaroo rat exclosure at site Center Well 7 in (A) late March 2009, when GKR had not started removing biomass, and (B) late August 2009, when GKR effects on plant biomass were apparent.

Native and exotic plant cover. Native plant cover in Center Well was significantly higher where GKR were excluded, where cattle were excluded, and on GKR precincts (Figure 9; linear mixed effects model; GKR presence $F_{1,225}$ = 8.5, p = 0.003, cattle presence $F_{1,225}$ = 9.9, p = 0.002, precinct $F_{1,225}$ = 5.9, p = 0.02). The increased native cover in GKR exclosures was mainly due to higher cover of *Lasthenia sp.* and *Lepidium sp.* The increased native cover in cattle exclosures was mainly due to higher cover of *Lasthenia minor*, *Vulpia microstachys*, and *Amsinckia tessellata*. Increased native cover on precincts was mainly due to higher cover of *A. tessellata*. Exotic plant cover as a group did not respond significantly to treatments in Center Well (all p > 0.05). Although the exotics *Erodium cicutarium* and *Bromus madritensis rubens* did not respond to treatments, *Schismus arabicus* cover declined in cattle exclosures, and *Hordeum murinum* cover increased in GKR exclosures.

The effect of GKR exclosures on native plant cover was consistent among pastures (Figure 10A; GKR presence $F_{1,303}$ = 8.3, p = 0.004, pasture*GKR presence $F_{1,303}$ = 1.0, p = 0.31), but GKR precincts had opposite effects on native cover in the two pastures (Figure 10B; pasture*precinct $F_{1,303}$ = 26.1, p < 0.001). In Swain, native cover was higher off precincts than it was on precincts, whereas in Center Well native cover was higher on precincts. The high native cover on precincts in Center Well was driven by *A. tessellata*, whereas in Swain the exotic grass *Bromus madritensis rubens* was found mainly on precincts and *Poa secunda* and *Lasthenia californica* were found mainly off precincts. Interestingly, *Lasthenia minor*, which was common in Center Well but rare in Swain, was not affected by the presence of precincts.

GKR appear to have conflicting influences on red brome. *Bromus* occurred almost exclusively on GKR precincts, suggesting a positive effect, but there was a strong negative correlation between GKR numbers and red brome cover on plots with GKR present (r = -0.62, n = 30, p < 0.001), which suggests a negative effect. The abundance of brome did not differ inside vs. outside of GKR exclosures, suggesting no net effect of GKR on brome. We hypothesize that brome is common on precincts because of the soil disturbance, but that foraging by GKR limits its abundance. The artificial disturbance plots that will be initiated within GKR exclosures in 2010 should allow us to separate the foraging vs. disturbance effects of GKR on plants.

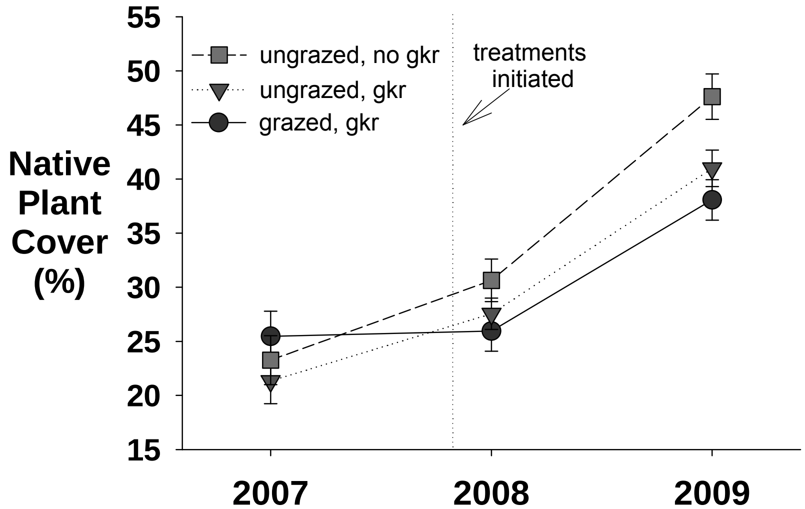

Figure 9. Native plant cover in experimental plots within the Center Well pasture. Three treatments were initiated prior to the spring of 2008: kangaroo rat exclosures (ungrazed, no gkr), cattle exclosures (grazed, no gkr), and control plots (grazed, gkr). Means and standard error bars are shown (*n* = 10 replicates per treatment).

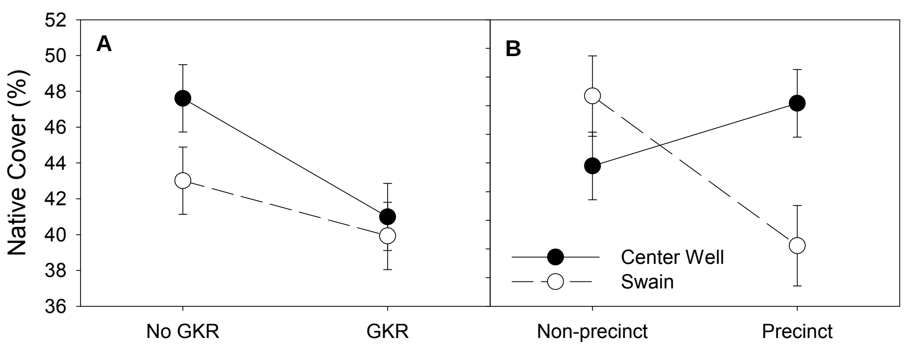

Figure 10. Native plant cover in the Center Well (filled circles) and Swain (open circles) pastures, in relation to (A) GKR presence and (B) the presence of GKR precincts, in 2009. No plots included in these analyses were grazed by cattle. Standard error bars are shown.

GKR abundance

Including recaptures, a total of 4,704 GKR captures occurred in 2009. A total of 1,781 individual kangaroo rats were captured, 1,154 of which had not been previously marked. Two of these kangaroo rats were *Dipodomys nitratoides*, and the other 1,779 individuals were *Dipodomys ingens* Total trap effort was 11,040 traps*nights. Thus, each trap had a 43% chance of catching a GKR on average, which was identical to our success rate in 2008. Mark-recapture estimates of GKR abundance varied widely among sites, from 0-65 GKR per plot (Table 3). Overall, the estimates indicate that populations have remained at high densities. Populations in the Swain pasture have been steadily increasing during the study and now match the average density of populations in Center Well (Figure 11). Center Well populations show signs that they may have started to decline.

As in 2008, GKR abundance did not differ among grazed and ungrazed plots in Center Well (Figure 11; $t_9 = -1.11$, $p = 0.3$). Site fidelity rates also varied widely among sites, ranging from 0.31-0.81 (Table 3), and fidelity rates were also not affected by cattle grazing ($t_9 = -.53$, $p = 0.61$).

The genital fungus or disease that we reported in 2008 was absent in April 2009 but reappeared in August 2009. These infections may be chiggers, which are trombiculid mites that have been seen on the genitals of other small mammals (Dr. Doug Kelt, UC Davis, personal communication). Unfortunately, samples were not collected this year. The infestation appears to be seasonal, affects juveniles with the same frequency as adults, and does not appear to cause population declines. The overall infection rate was 17% (308/1771 individuals), which was similar to last year (16%).

GKR estimates on each plot were correlated among surveys in 2008 and 2009 ($r = 0.7\text{-}0.89$, $n = 30$ plots), indicating that some plots consistently have higher densities than others. The sex ratio was approximately 1:1, and the ratio of adults to juveniles was 2.4:1 (Table 4).

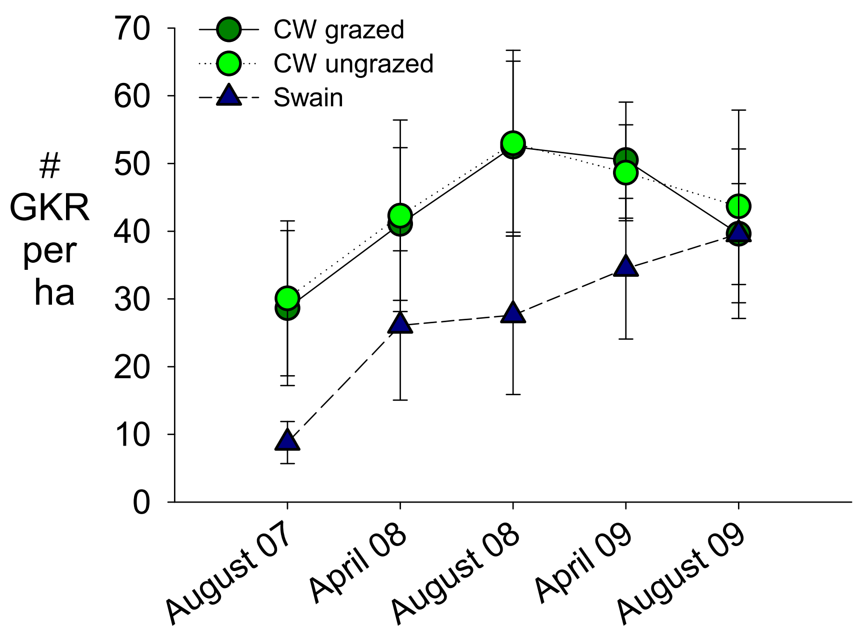

Figure 11. Average GKR population estimates in Center Well grazed plots, Center Well ungrazed plots, and Swain ungrazed plots, during each trapping session.

Table 3. GKR population size and site fidelity estimates in 2009. Site fidelity 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	Site fidelity	Fidelity SE
Center Well	Grazed	C1	49	1.55	42	3.40	0.52	0.08
Center Well	Grazed	C2	56	0.91	39	2.23	0.59	0.07
Center Well	Grazed	C3	46	0.93	30	2.16	0.59	0.08
Center Well	Grazed	C4	42	1.22	39	1.44	0.72	0.05
Center Well	Grazed	C5	55	0.65	34	0.77	0.64	0.04
Center Well	Grazed	C6	23	0.02	0	0.02	0.31	0.07
Center Well	Grazed	C7	53	0.91	37	2.19	0.58	0.06
Center Well	Grazed	C8	65	1.23	53	1.43	0.68	0.04
Center Well	Grazed	C9	54	0.87	59	1.04	0.68	0.04
Center Well	Grazed	C10	63	1.49	62	1.74	0.66	0.04
Center Well	Ungrazed	E1	45	1.03	24	2.25	0.51	0.08
Center Well	Ungrazed	E2	53	2.05	53	4.59	0.58	0.07
Center Well	Ungrazed	E3	49	0.89	32	2.09	0.63	0.08
Center Well	Ungrazed	E4	50	1.34	58	1.60	0.70	0.04
Center Well	Ungrazed	E5	45	0.56	30	0.67	0.61	0.04
Center Well	Ungrazed	E6	27	0.63	4	0.73	0.48	0.08
Center Well	Ungrazed	E7	43	1.11	57	2.81	0.55	0.06
Center Well	Ungrazed	E8	62	1.49	60	1.74	0.69	0.04
Center Well	Ungrazed	E9	57	0.66	59	0.79	0.70	0.04
Center Well	Ungrazed	E10	56	1.29	60	1.52	0.62	0.04
Swain	Ungrazed	S1	44	1.02	56	1.22	0.64	0.05
Swain	Ungrazed	S2	40	0.74	40	0.88	0.65	0.05
Swain	Ungrazed	S3	57	1.16	49	1.35	0.71	0.04
Swain	Ungrazed	S4	36	0.76	40	0.91	0.65	0.05
Swain	Ungrazed	S5	13	0.74	21	0.90	0.41	0.09
Swain	Ungrazed	S6	40	1.43	36	0.89	0.50	0.08
Swain	Ungrazed	S7	44	1.89	39	1.31	0.61	0.07
Swain	Ungrazed	S8	15	0.47	32	0.57	0.49	0.09
Swain	Ungrazed	S9	17	0.44	31	0.53	0.62	0.08
Swain	Ungrazed	S10	38	1.10	52	1.33	0.81	0.05

Table 4. Age and sex composition of GKR and San Joaquin antelope squirrels (SJAS) captured in 2009.

		Female	Male	Unknown	Total
GKR	Adult	667	604	2	1273
	Juvenile	272	251	4	527
	Unknown	2	2	12	16
	Total	941	857	18	1816

SJAS	Adult	59	106	7	172
	Juvenile	31	12	1	44
	Unknown	2	3	6	11
	Total	92	121	14	227

GKR diet

GKR preferred seeds from all native species offered in diet trials except *Poa secunda* (Figure 12). Results for the grasses were largely consistent with previous years, in that GKR preferred *Bromus* and avoided *Poa, Schismus,* and *Hordeum*. In contrast to previous years, however, GKR preferred the native grass *Vulpia microstachys* and did not prefer the exotic forb *Erodium* (Figure 12). GKR preference in 2009 was negatively correlated with seed moisture content (r = -0.85, n = 8, p = 0.01) and was not correlated with seed size (r = 0.21, n = 10, p = 0.56) or any other seed nutrients (all $p > 0.05$). We also examined the contents of 61 surface pit caches. Consistent with diet trials, the frequency of *Erodium* in caches declined and the frequency of *Vulpia* increased compared with 2008 (Table 5). Surprisingly, *Lasthenia* was rarely found in surface caches despite being highly preferred in diet trials and abundant on many sites.

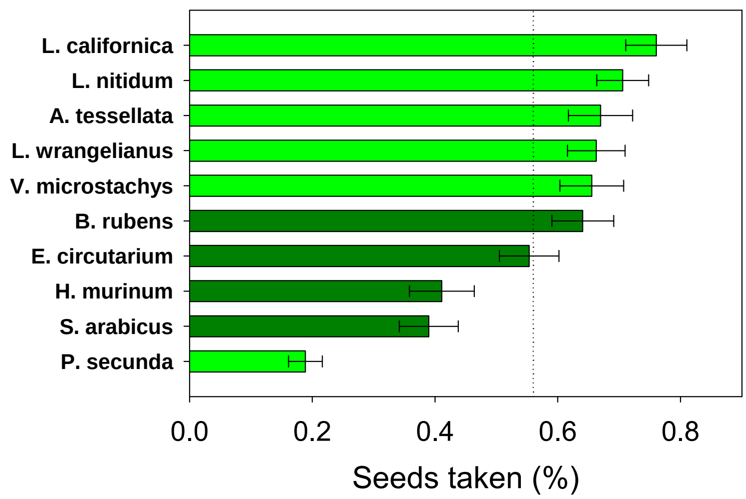

Figure 12. GKR seed preferences in 2009. The average percent of seeds taken (with 95% confidence intervals) from trials in which seed piles of 10 species were offered to GKR (n = 101 trials). The dotted vertical line shows the average percent of seeds taken across all species. Bars of native plants are light green, and bars of exotic plants are dark green.

Table 5. Relative occurrence of plant species in GKR surface seed caches collected in 2008 (*n* = 52 caches) and 2009 (*n* = 61 caches).

Species	Relative occurrence 2008	Relative occurrence 2009
Lepidium nitidum	0.20	0.33
Bromus madritensis rubens	0.03	0.22
Vulpia microstachys	0.06	0.20
Erodium cicutarium	0.35	0.11
Schismus arabicus	0.12	0.04
Amsinckia tessellata	0.05	0.03
Lasthenia sp.	0.07	0.03
Monolopia lanceolata	0	0.02
Calandrinia ciliata	0.03	0.01
Plantago erecta	0.01	0.01
Poa secunda	0	0.01
Vulpia myuros	0.004	0.004
Isocoma acradenia	0.0002	0.001
Lotus wrangelianus	0.0002	0.001
Eriogonum gracillimum	0	0.001
Guillenia lasiophylla	0.003	0.0001
Capsella bursa-pastoris	0	0.0001
Tropidocarpum gracile	0.05	0
Microseris sp.	0.01	0
Uropappus lindleyi	0.01	0
Lepidium dictyotum	0.004	0
Hordeum murinum	0.003	0
Chaenactis glabriuscula	0.001	0
Pectocarya penicillata	0.001	0

Radio-telemetry

A total of 48 GKR were radiocollared, and 715 telemetry locations were obtained from May-August 2009. Collars were removed from all individuals in August and September. There were five documented mortality events; two were suspected to be avian, one mammalian, and two unknown. Survival during the three-month summer period was 0.88 (95% confidence interval = 0.80-0.98), which corresponds to an average monthly survival rate of 0.96 (95% CI = 0.93-0.99). The monthly apparent survival rate of adults on these sites estimated from trapping data was 0.90 (95% CI = 0.86-0.93). Thus, estimates from telemetry data roughly corresponded to those from trapping data, and survival rates were relatively high for a small mammal. The telemetry study will be expanded next year by Steve Etter to include juveniles, allowing further refinement of survival estimates, calculation of dispersal distances, and identification of causes of mortality.

SJAS abundance

Antelope squirrel populations increased from an average density of approximately 3 per hectare in 2008 to 8 per hectare in 2009, and the rate of population increase was highest in the Swain pasture (Figure 13). A total of 227 individual antelope squirrels were captured, and a total of 753 captures occurred. As in 2008, the sex ratio was male-biased (0.76 females per male) and far more adults were captured than juveniles (Table 4). SJAS estimates on each plot were correlated between 2008 and 2009 (r = 0.48, n = 30 plots, p = 0.01).

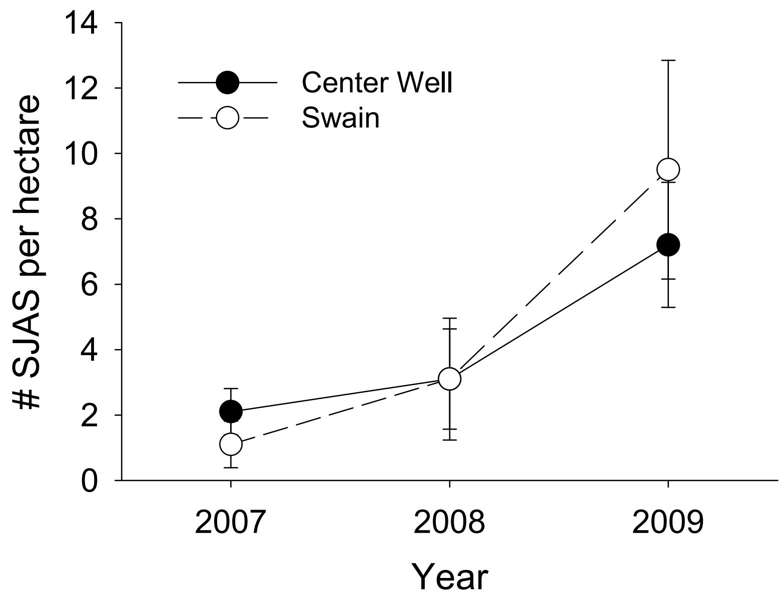

Figure 13. Estimates of San Joaquin antelope squirrel abundance on 1.96-ha plots in each pasture (with 95% confidence intervals).

Bird abundance

Bird abundance on our plots increased 2.6-fold compared with 2008, which is similar to the increase in antelope squirrel numbers. A total of 1,256 individuals from 18 bird species were detected during point counts, 312 of which were either on or flying over our plots. As in previous years, the most common birds found on our plots were horned larks, ravens, and meadowlarks (Table 6).

Table 6. Total counts of birds detected on or flying over plots, 2007–2009.

Common Name	Scientific Name	2007	2008	2009
Horned Lark	*Eremophila alpestris*	545	61	203
Common Raven	*Corvus corax*	16	43	55
Western Meadowlark	*Sturnella neglecta*	11	3	33
Violet-green Swallow	*Tachycineta thalassina*	0	0	7
Dusky Flycatcher	*Empidonax oberholseri*	0	0	6
American Kestrel	*Falco sparverius*	0	0	2
Chipping Sparrow	*Spizella passerina*	0	0	1
Ferruginous Hawk	*Buteo regalis*	0	0	1
Mountain Plover	*Charadrius montanus*	0	0	1
Mourning Dove	*Zenaida macroura*	0	0	1

Northern Mockingbird	*Mimus polyglottos*	0	0	1
Red-tailed Hawk	*Buteo jamaicensis*	0	5	1
Brewer's Blackbird	*Euphagus cyanocephalus*	3	0	0
Golden Eagle	*Aquila chrysaetos*	0	1	0
Lark Sparrow	*Chondestes grammacus*	0	2	0
Loggerhead Shrike	*Lanius ludovicianus*	0	2	0
Savannah Sparrow	*Passerculus sandwichensis*	0	1	0
Vesper Sparrow	*Pooecetes gramineus*	0	1	0

Reptile abundance

A total of 631 side-blotched lizards (*Uta stansburiana*) and 18 BNLL (*Gambelia sila*) were seen during reptile surveys. No other reptile species were seen during surveys. All 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. In addition to the 18 live sightings, we found a dead BNLL on another Swain site that had puncture wounds, likely from a raptor. We salvaged the specimen and deposited it in the UC Berkeley Museum of Vertebrate Zoology. *Uta* density was far higher and more variable among sites in Center Well than in Swain (Figure 14). Density estimates on each plot were highly correlated between 2008 and 2009 (r = 0.82, n = 30 plots, p < 0.01), indicating that certain areas are consistently high or low quality sites for *Uta*.

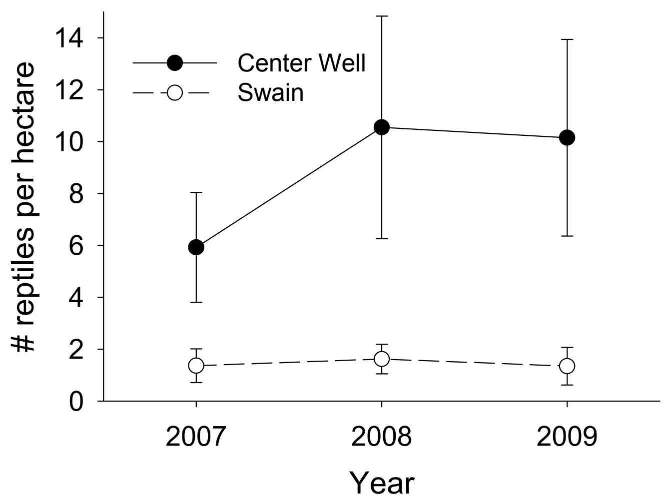

Figure 14. Estimates of reptile density each year in each pasture, calculated using the program DISTANCE. 95% confidence intervals are shown.

Invertebrate abundance

Counts of grasshoppers seen during reptile surveys declined in 2009 (Figure 15). Grasshoppers have been consistently more abundant in the Swain pasture (Figure 15). In contrast, invertebrate species richness and biomass were higher in Center Well in 2007 (Figure 16), and there was no difference in the richness or biomass of invertebrates among pastures in 2008. Data from 2009 are currently being processed. We have been building a reference collection of pinned insects to aid identification, and we are also setting aside specimens to build a collection for the Carrizo visitor's center. Grasshopper counts on each plot were correlated among years (r = 0.48, n = 30, p =0.01), as was invertebrate richness (r = 0.63).

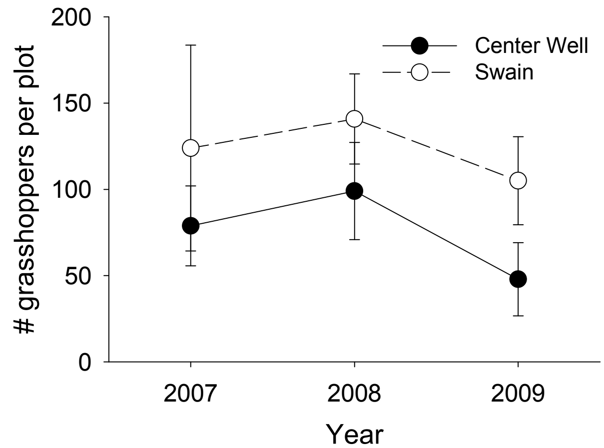

Figure 15. Mean counts of grasshoppers seen during reptile surveys on each plot in the Center Well and Swain pastures. 95% confidence intervals are shown.

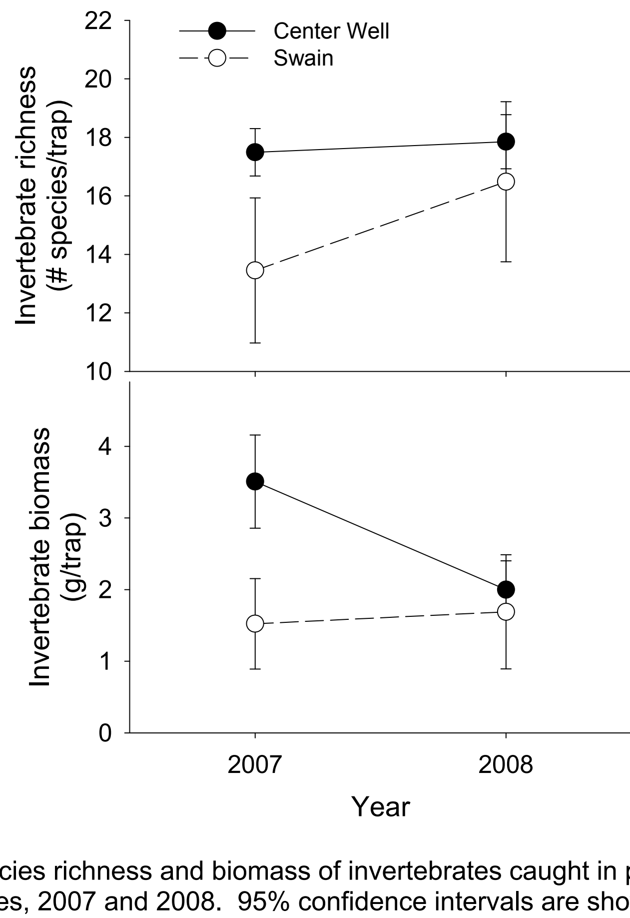

Figure 16. Mean species richness and biomass of invertebrates caught in pitfall traps in the Center Well and Swain pastures, 2007 and 2008. 95% confidence intervals are shown.

Grazing intensity

Cattle grazed on Center Well from April 2 to May 14, 2009, for a total of 188 animal use months. Few cows were seen on control plots, but cow counts were still positively correlated with counts of cow patties (Table 7; $r = 0.46$, $n = 10$). Cow patty counts are likely a more accurate measure of grazing intensity on plots. Despite far fewer signs of cattle activity on control plots in 2009 compared with 2008 (Table 7), cattle removed a similar amount of plant biomass in 2008 and 2009.

Table 7. Average counts of cows seen on control (grazed) plots in the Center Well pasture (n = 16 surveys), and the total number of cow patties found on each plot.

Plot	2008		2009	
	N cows	N patties	N cows	N patties
C1	3.17	459	0	24
C2	0.83	216	0.25	25
C3	1.30	155	0.13	35
C4	2.09	166	0.13	32
C5	0	4	0	11
C6	1.70	162	0	12
C7	0	132	0	3
C8	0.13	143	0	40
C9	0.17	125	0	16
C10	0.26	86	0	2

Species associations

Table 8 shows the associations among the flora and fauna on our plots. The relationship between GKR and active precinct counts was weaker than in 2008, and antelope squirrel numbers were not significantly correlated with any other species. As in 2008, horned lark numbers were negatively correlated with GKR numbers. Horned larks and grasshoppers were more common on plots with higher plant biomass. Numbers of kit foxes seen on plots were positively correlated with GKR and lizard numbers and negatively correlated with grasshopper numbers. Native plant cover was not significantly associated with plant biomass or any of the faunal surveys.

Table 8. Matrix of correlation coefficients (r) among species counts on each of the 30 plots. Significant correlations (p < 0.05) are highlighted in bold.

2009	Squirrels	N GKR	Precincts	Horned larks	Lizards	Plant Biomass	Native cover	Kit foxes
N GKR	0.08							
Precincts	0.04	**0.35**						
Horned larks	0.17	**-0.42**	**-0.36**					
Lizards	-0.29	**0.56**	0.27	-0.18				
Biomass	-0.11	-0.31	-0.30	**0.64**	0.05			
Native cover	-0.01	-0.32	-0.04	0.13	-0.15	-0.04		
Kit foxes	-0.01	**0.38**	0.05	-0.26	**0.47**	-0.31	0.07	
Grasshoppers	-0.22	-0.19	-0.11	**0.36**	0.00	**0.54**	-0.17	**-0.51**

Conclusions and Future Directions

Surveys in 2009 showed that native plant species richness and biomass have continued to increase in our study pastures. In 2007 and 2008, populations of GKR, antelope squirrels, and lizards were markedly lower in the Swain pasture, which had higher plant biomass than Center Well. In 2009, however, GKR populations stabilized or declined in Center Well while populations in Swain increased, despite plant biomass remaining higher in Swain. We suspect that GKR may have become food-limited in Center Well, whereas conditions in Swain allow for continued population increases. This spatial variation in growth trajectories of GKR may be important for maintaining populations during times of extreme conditions: the collective GKR population is less likely to drop to extinction if sub-populations are highly localized in their dynamics. The timing of changes in GKR populations and plant biomass during the next few years, when combined with existing data, should allow us to determine whether plant biomass regulates GKR numbers or GKR numbers regulate plant biomass.

Our experimental exclosures allowed us to quantify the relative loss of plant biomass due to GKR, cattle, and other processes. In 2009, we found that GKR (at an average density of 42/ha) removed approximately 200 pounds of plant material per acre between April and October, which is roughly equivalent to the biomass removed by cattle (with 188 animal use months). A wet year with high biomass should allow us to calculate the maximum amount of biomass that GKR can remove. Thus far, grazing by cattle has not been detrimental or beneficial to GKR populations, but this could change with higher or lower precipitation levels. Both cattle and GKR suppressed native plant cover, and GKR effects were stronger. Our diet trials showed that the two native species most strongly affected by GKR presence, *Lasthenia* and *Lepidium*, were also the species most highly preferred by GKR.

In the 2010 field season, we will continue to monitor flora and fauna on our experimental plots. Additionally, several new graduate student projects will be initiated. Chris Gurney will begin his masters project under the supervision of J. Brashares at UC Berkeley. He will conduct restoration experiments to examine the effect of GKR and cattle on native seeding efforts. Steve Etter will begin his masters project under the supervision of Tim Karels at CSU Northridge. He will study the survival and dispersal patterns of adult and juvenile GKR using radio-telemetry. Tim Bean recently completed his masters on GKR distribution modeling with J. Brashares and will continue on as a doctoral student. He will continue to study the use of remote sensing to monitor GKR populations, and he also hopes to conduct Carrizo-wide GKR surveys and genetic analyses as part of his project. Prior to the field season, manuscripts will be prepared for peer-reviewed publication. A paper examining the effect of moonlight on GKR activity and capture success has been submitted to the *Journal of Mammalogy*, and a paper examining the direct and indirect effects of GKR on other species using structural equation modeling is currently being prepared for publication.

Products of the Carrizo Plain Ecosystem Project

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2) Olney, B. 2008. Seed preferences of the giant kangaroo rat (*Dipodomys ingens*) in grasslands of the Carrizo Plain, California. Senior honors thesis. University of California, Berkeley.
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