Carrizo Exclosure Experiment 2008 Report

22 December 2008

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Summary

Understanding interrelationships between 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 second year of a long-term study to tease apart these relationships using replicated cattle and GKR exclosures. Total plant biomass and the relative cover of native plants (RCNP) were both higher on plots inside cattle exclosures in comparison to plots exposed to cattle grazing. RCNP was also higher inside GKR exclosures in comparison to plots exposed to GKR, but GKR exclosures need to be modified to better exclude GKR before treatment effects can be adequately assessed. The abundance of most plant and animal species increased in 2008 compared to the previous year. As in 2007, estimates of reptile and San Joaquin antelope squirrel abundance were positively associated with GKR abundance. GKR diet trials showed preferences for large-seeded exotic species such as *Bromus madritensis rubens* and avoidance of small-seeded native species such as *Poa secunda*. In contrast to results in 2007, native plant cover was higher on precincts than off precincts in the Center Well pasture. This was due to dramatic increases in the abundance of the native annual forb *Amsinckia tessellata*, which occurred mainly on GKR precincts. This discrepancy among years highlights the sensitivity of this annual plant community to changes in rainfall patterns and indicates that more years of data will be necessary to adequately assess the relationships between native plant cover, cattle grazing, GKR activity, and rainfall.

Prepared by Laura Prugh, 2008

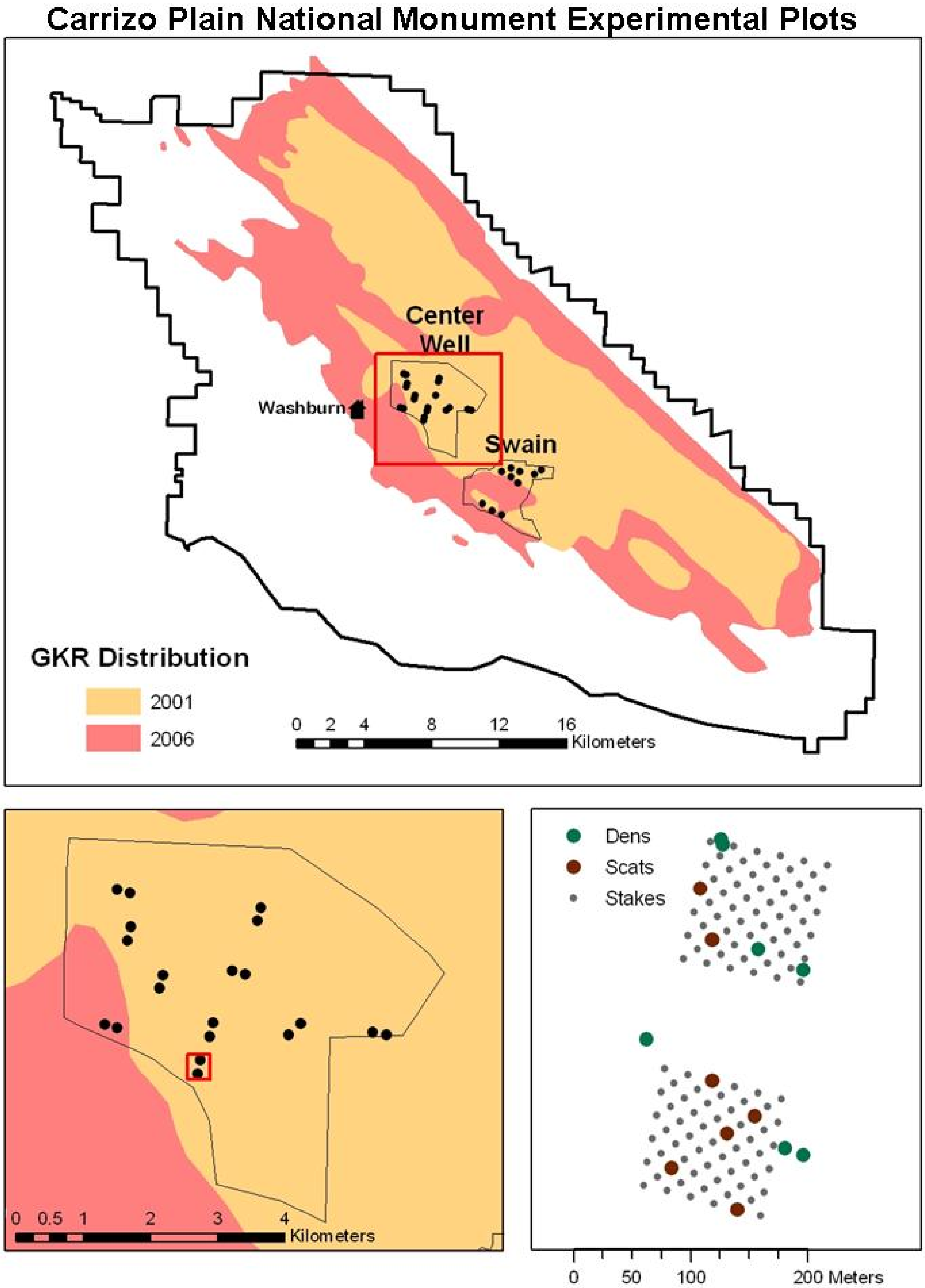

Figure 1. Map of study sites in the Carrizo Plain National Monument. Details are shown for the Center Well pasture and site CW 7. Kit fox dens and scats, as well as trap stakes, are shown for site 7.

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 importance of grazing for upland species. 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 a study 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 2008, we continued monitoring the flora and fauna on these plots, conducted a kangaroo rat diet trial, and modified the kangaroo rat exclosures.

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).

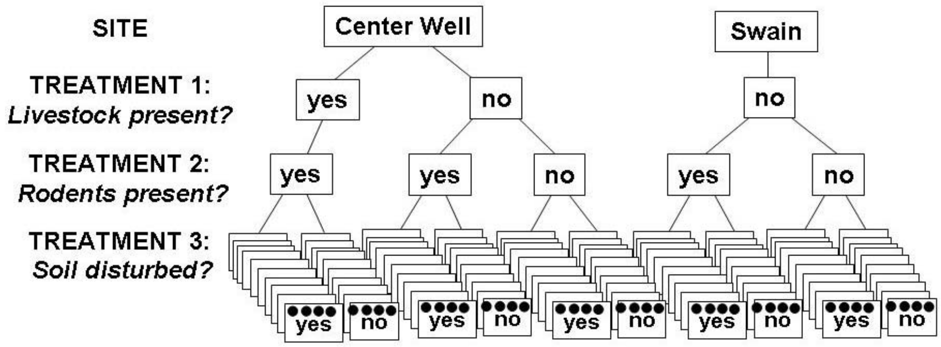

Figure 2. Experimental design of the project. There are ten blocks of each treatment combination and four nested vegetation plots (filled circles) within each block.

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).

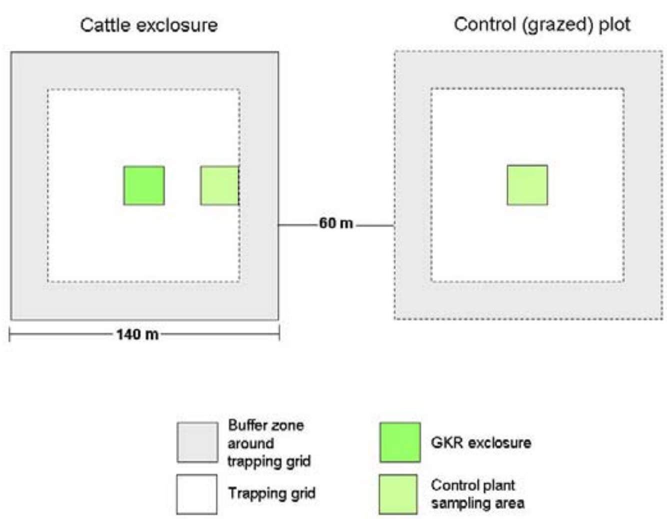

Figure 3. Nested exclosure design to separate livestock and GKR effects on plants, with paired control plot. A buffer zone around each GKR trapping grid ensured that the surveyed population was comprised of individuals living within the plot. This shows the design in Center Well; in Swain each plot is 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). In order to compare plant composition data on our plots to the monument-wide surveys conducted by Todd Keeler-wolf (CDF&G) in 2008, we also conducted surveys in 25-m^2 areas of our plots using the rapid assessment protocol. Biomass samples were obtained from 1/16-m^2 plots adjacent to each 1-m^2 plot to estimate biomass in April and October (max and min 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 will be collected in April 2009.

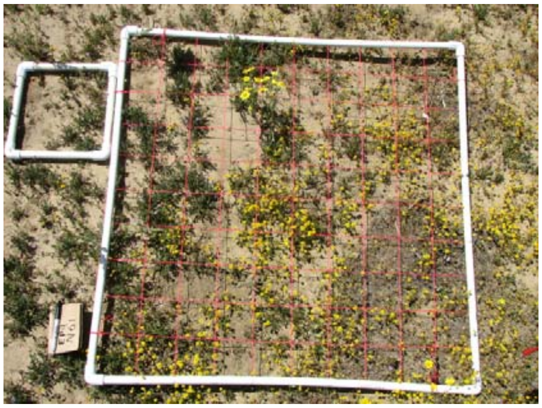

Figure 4. Plant sampling plot in a non-precinct area, showing the 1-m^2 point frame and the 1/16-m^2 clip plot.

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) by Tim Bean as part of his masters project. 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 5 nights on each grid in April and 3 nights in August. All captured animals were marked with an ear and PIT tag, weighed, sexed, and released. Trapping occurred from March 30-May 8, 2008 (29 trap nights) and July 27-August 17, 2008 (22 trap nights).

To obtain mark-recapture estimates, I used the program R (R Development Core Team 2007) 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 (sometimes referred to as “apparent survival”).

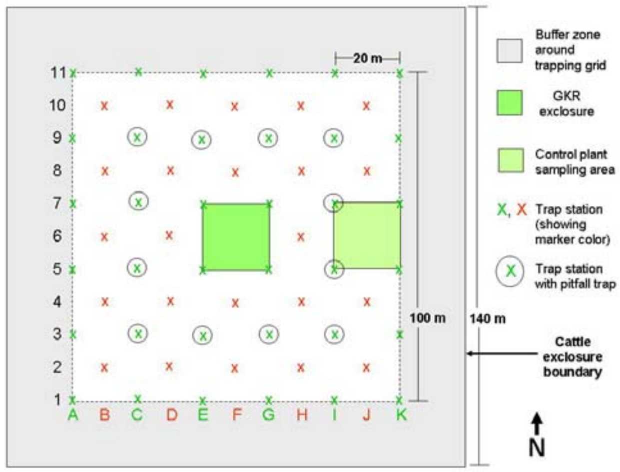

Figure 5. Detailed diagram of a cattle exclosure. Trap stations show trap locations for GKR mark-recapture surveys. Colors correspond to the spray-painted color on the stake marking the location. Letters and numbers identify the grid stakes (A1, B2, etc.).

GKR dietary preferences were determined as part of a UCB student senior thesis project in 2007 (Olney 2008). We repeated the diet trials in 2008 with a few modifications. We included more species, added a control, and used infrared cameras to ensure that seed piles were visited by GKR. Ripe seed heads of 12 species were collected in April, and 0.5 grams of each species was placed on the cleared soil of a precinct. Trials were conducted on 30 precincts (one per plot) from July 14 – 23, 2008. Seed piles were placed at dusk and collected at dawn, and remains were re-weighed to determine the quantity of each type removed. Control seed piles, which were covered with hardware cloth to prevent GKR access, were also placed and collected in the same manner. This controlled for potential seed removal by ants. We also collected contents of GKR surface pit caches to examine which seeds GKR were collecting. Several caches were collected on each plot, and seeds present in each cache were identified using a seed reference collection of plants found on our plots that was created by Rebecca Wenk in 2007.

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 26 – June 12, 2008.

Bird surveys

Point counts were conducted four times on each plot from March 31 – April 18, 2008. 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 June 3 – July 1, 2008. 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 1.96-ha plot between June 23–25, 2008 and collected 2 weeks later. The design was modified from 2007; instead of using all 12 traps per plot as shown in Figure 5, we selected 4 of these traps and added 4 more to the center of each plot (in the GKR exclosures). We chose 4 traps that were on precincts and 4 that were off, for a total of 8 traps per plot (total $n = 240$). This design modification allows us to detect changes in the invertebrate community when GKR are excluded and also to detect potential differences on and off precincts. 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.

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 using 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 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 152 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).

Antelope abundance

We recorded the number and approximate location of all antelope (*Antilocapra americana*) seen each day. We also recorded any birds of prey or mammalian predators seen. We noted whether the animal was seen from a vehicle or on foot, and we recorded the observer(s), and the number of hours spent on foot and in vehicle.

Cattle grazing intensity

We counted the number of cows on our control plots in Center Well on a daily basis in April 2008 (n = 23 surveys). Cows were counted during active foraging periods in the mornings and evenings. We also counted cow patties on our control plots when we conducted the reptile surveys.

Results and Discussion

Plants

We gathered plant data at differing scales (1, 25, and 400 m^2). At the 1-m^2 scale we obtained pinframe estimates, which are considered to be rigorous and quantitative, and we also obtained ocular estimates, which are more subjective but faster to do (the observer estimates the cover of each species visually). Larger scale estimates were all ocular. All plant data was collected by John Chestnut. The ocular estimates corresponded closely to the pinframe estimates of the mean relative cover of native plants (RCNP) on and off precincts on each plot (n = 100, R^2 = 0.91, Figure 7A), indicating that both types of data provide comparable results. The relationship between pinframe and ocular cover estimates for all plant species encountered on plots was similarly tight (n = 2602 records, R^2 = 0.86). However, there was a fair amount of discrepancy between data collected at different scales: mean ocular RCNP estimates from 1-m^2 plots were not tightly related to ocular estimates from the corresponding 400-m^2 plots (R^2 = 0.45, Figure 7B). I used pinframe estimates in the analyses below.

Plant species richness and cover were higher in 2008 than in 2007 in both the Center Well and Swain pastures (Table 1). The increase in species richness was due to the occurrence of more native species in both pastures, whereas the increase in cover was due to higher exotic cover in both pastures (Table 1). Species richness was higher in the Swain pasture than in Center Well in 2008 (but not in 2007), whereas plant cover was twice as high in Center Well as in Swain during both years. The increase in exotic cover was primarily due to a 2-4 fold increase in the relative abundance of *Erodium circutarum* (Table 2). Exotic cover increased in Swain despite a dramatic decrease in the relative abundance of *Bromus madritensis rubens*, which was the most common plant in Swain in 2007 (Table 2).

Native plant cover differed significantly among pastures and with respect to GKR precincts; GKR precincts had opposing effects on native cover in the two pastures (linear mixed effects model; pasture $F_{1,44}$ = 10.6, p = 0.002, precinct $F_{1,44}$ = 0.23, p = 0.63, pasture*precinct $F_{1,44}$ = 8.2, p = 0.007). In Swain, native cover was higher off precincts than it was on precincts (Figure 8A), as in 2007. In Center Well the pattern was reversed, with higher native cover on precincts (Figure 8A). The high native cover in Center Well was likely due to a 100-fold increase in the abundance of *Amsinckia tessellata*, which occurred primarily on precincts. Total plant biomass was higher in Center Well than in Swain and also higher on precincts in both pastures (Figure 8B; pasture $F_{1,44}$ = 12.4, p = 0.001, precinct $F_{1,44}$ = 13.7, p < 0.001, pasture*precinct $F_{1,44}$ = 1.49, p = 0.23).

Native plant cover and total biomass were both lower on grazed plots than on paired ungrazed plots in the cattle exclosures in Center Well (Figure 9, linear mixed effects model; pasture $F_{1,14}$ = 4.8, p = 0.05, precinct $F_{1,14}$ = 7.1, p = 0.02, pasture*precinct $F_{1,14}$ = 0.35, p = 0.56). Native cover was higher within GKR exclosures in comparison to paired plots outside of exclosures in both pastures ($F_{1,44}$ = 4.5, p = 0.04), but biomass did not differ ($F_{1,44}$ = 0.14, p = 0.71). The exclosures were not very effective at preventing access by GKR, as evidenced by repeated captures of GKR inside exclosures, particularly in the densely-populated Center Well pasture. We increased the height of exclosures from 2 feet to 3 feet and added a 6-inch overhang to prevent GKR from climbing and jumping over the fence. However, GKR also have tunnels going under the exclosures despite the fact that the fencing extends 2 feet underground. This design is 1-foot deeper than those used to successfully exclude Ord's kangaroo rats (*Dipodomys ordii*) in the Chihuahuan desert (Brown and Munger 1985). GKR may have deeper tunnels than other kangaroo rat species. We used a fog machine to locate tunnels that go under the fencing, and we plan to dig down and block these tunnels with additional fencing in January 2009.

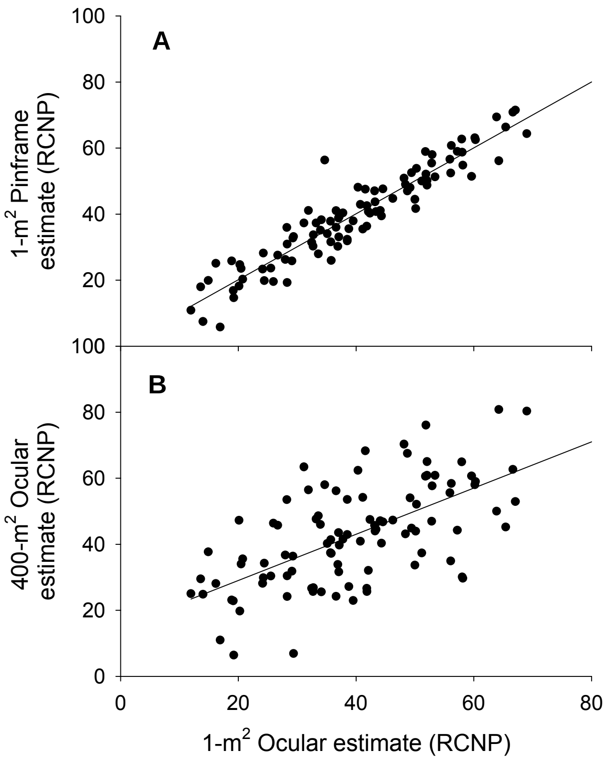

Figure 7. Comparison of (A) pinframe counts and ocular estimates of relative native percent cover (RNPC) at the 1-m^2 scale (n = 100, R^2 = 0.91), and (B) ocular estimates of RNPC at 1-m^2 and 400-m^2 scales (n = 100, R^2 = 0.45).

Table1. Species richness and plant cover in the Center Well and Swain pastures, in April 2007 and 2008.

Metric	Type	Center Well		Swain	
		2007	2008	2007	2008
Species richness	native	18	24	15	30
	exotic	8	7	7	8
	total	26	31	22	38
Plant cover (%)	native	14.0	16.9	6.9	7.8
	exotic	10.1	22.3	5.5	11.4
	total	24.1	39.3	12.5	19.3

Table 2. Relative cover of plant species in each pasture, *n* = 240 plots in Center Well and 160 plots in Swain (half on precincts, half off precincts), in April 2007 and 2008.

Species	Type	Center Well		Swain	
		2007	2008	2007	2008
Erodium cicutarium	exotic	10.9	46.5	17.5	38.1
Lepidium nitidum	native	14.0	12.6	1.3	2.5
Vulpia microstachys	native	35.4	8.0	22.2	1.6
Schismus arabicus	exotic	8.9	8.0	6.4	8.4
Lasthenia minor	native	0.1	4.7	--	--
Amsinckia tessellata	native	0.1	4.6	0.4	9.2
Tropidocarpum gracile	native	1.0	4.1	0.02	1.0
Calandrinia ciliata	native	0.3	3.0	--	3.3
Hordeum murinum	exotic	7.0	2.0	2.5	5.6
Guillenia lasiophylla	native	0.6	2.0	--	0.1
Dichelostemma capitatum	native	0.1	1.0	--	1.3
Microseris elegans	native	3.8	0.6	--	0.1
Pectocarya penicillata	native	0.7	0.6	0.6	3.0
Trifolium gracilentum	native	0.03	0.4	0.02	0.4
Lasthenia californica	native	0.7	0.3	0.7	3.9
Lepidium dictyotum	native	0.8	0.3	--	0.1
Microseris douglasii	native	0.3	0.3	--	0.01
Bromus madritensis rubens	exotic	2.6	0.2	37.2	8.3
Lembertia congdonii	native	--	0.1	--	0.1
Lotus wrangelianus	native	0.1	0.1	--	0.5
Eriogonum gracillimum	native	--	0.1	0.1	0.1
Phlox gracilis	native	--	0.1	--	--
Monolopia lanceolata	native	--	0.1	--	--
Malacothrix coulteri	native	0.03	0.03	--	--
Lupinus microcarpus	native	--	0.02	--	0.04
Athysanus pusillus	native	--	0.02	--	--
Capsella bursa-pastoris	exotic	0.1	0.02	--	--
Poa secunda	native	0.01	0.02	9.1	8.1
Uropappus lindleyi	native	--	0.02	--	0.1
Vulpia myuros	exotic	12.3	0.01	1.3	0.04
Vulpia bromoides	exotic	--	--	--	2.1
Chaenactis glabriuscula	native	--	--	0.1	0.4
Hollisteria lanata	native	--	--	0.02	0.4
Chorizanthe uniaristata	native	--	--	--	0.3
Plagiobothrys canescens	native	--	--	--	0.3
Lastarriaea coriacea	native	--	--	0.1	0.3
Plantago erecta	native	--	--	--	0.2
Muilla maritima	native	--	--	--	0.1
Linanthus liniflorus	native	--	--	0.2	0.1
Sisymbrium irio	exotic	--	--	--	0.1
Crassula connata	native	--	--	--	0.03
Herniaria hirsuta	exotic	--	--	0.05	0.03
Astragalus oxyphysus	native	--	--	0.03	0.01
Astragalus sp.	native	--	--	--	0.01
Delphenium sp.	native	--	--	--	0.01
Sisymbrium altissimum	exotic	--	--	0.1	0
Amsinckia menziesii	native	0.1	--	--	--
Bromus hordeaceus	exotic	0.1	--	--	--
Chorizanthe watsonii	native	--	--	0.05	--
Marrubium vulgare	exotic	0.1	--	--	--

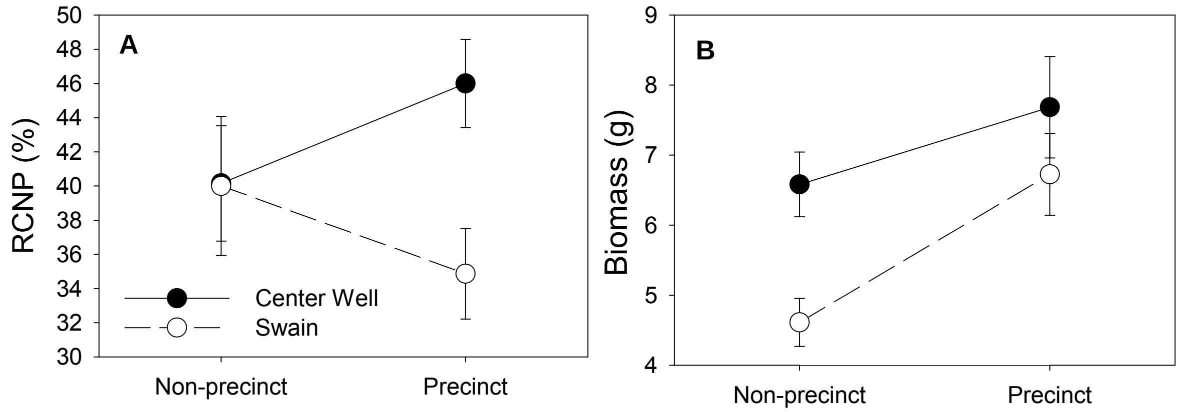

Figure 8. (A) Relative cover of native plants and (B) total plant biomass in the Center Well pasture (filled circles) and the Swain pasture (open circles), in relation to the presence of GKR precincts, in 2008. Standard error bars are shown.

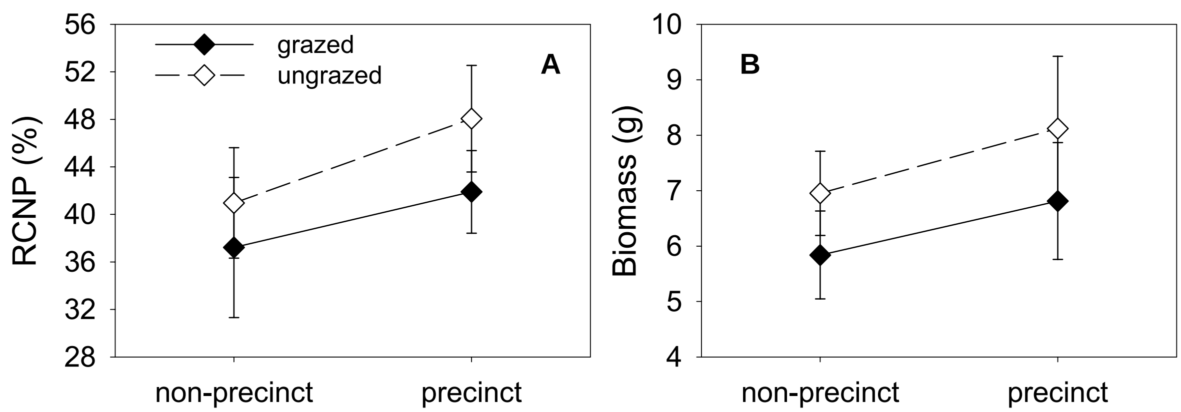

Figure 9. (A) Relative cover of native plants and (B) total plant biomass of grazed plots (filled diamonds) and paired ungrazed plots (open diamonds) in the Center Well pasture, in relation to the presence of GKR precincts, in 2008. Standard error bars are shown. Ungrazed plots were in cattle exclosures (*n* = 10 exclosures and paired plots).

GKR abundance

A total of 1,734 individual GKR were captured and marked in 2008, and a total of 5,182 captures occurred. Total trap effort was 12,240 traps*nights. Thus, each trap had a 43% chance of catching a GKR on average. The GKR was the only species captured during surveys. Mark-recapture estimates of GKR abundance varied widely among sites, from 2-72 GKR per plot (Table 3). Overall, the estimates indicate that populations are increasing and currently at high densities. GKR estimates on each plot were correlated among years (r = 0.67, n = 30 plots), indicating that some plots may consistently have higher densities than others. The sex ratio was approximately 1:1, whereas the ratio of adults to juveniles was 2.5:1 (Table 4). The mean weight of GKR was 99 grams for juveniles in April, 117 grams for juveniles in April, and 135 grams for adults, with little difference in weight between sexes (Figure 10).

GKR abundance was higher in the Center Well (CW) pasture than in Swain during all trap sessions (Figure 11). GKR abundance did not differ among grazed and ungrazed plots in Center Well, and estimates in Center Well were higher in August than in April. This increase likely reflects the emergence of young after spring trapping rather than immigration—sites that were trapped earlier tended to have the greatest increases (e.g., sites 1 and 3 in CW were the first ones surveyed in the spring and showed the greatest increases between August and April, Table 3). Site fidelity rates also varied widely among sites, ranging from 0.14-1.0 (Table 3), indicating that survival and/or dispersal rates may vary substantially across the Carrizo.

We have discovered many instances of what looks like a genital fungus or disease on GKR. We recorded all observations of the fungus during the August session, and 16% of individuals examined had the fungus (192/1210 individuals). Infection rates were the same for juveniles and adults but were higher for females (20%) than males (12%).

GKR diet

GKR diet preferences were fairly consistent with results from trials in 2007. GKR showed the greatest preference for red brome and the lowest preference for bunchgrass (Figure 12). GKR preference was positively correlated with seed size (r = 0.66, n = 12, p = 0.02). We also examined the contents of 52 surface pit caches. Contents of pit caches showed similar patterns as diet trials, with *L. nitidum* and *E. circutarium* being the most frequent items found in caches (Table 5). Red brome and other grasses were not found very often in pit caches, but GKR usually dry grasses in hay piles rather than pit caches.

Table 3. GKR population size and site fidelity estimates in 2008. 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	# GKR April	April SE	# GKR August	August SE	Site fidelity	Fidelity SE
Center Well	Grazed	C1	18	1.13	65	4.58	1.00	0.00
Center Well	Grazed	C2	52	0.38	54	2.09	0.65	0.08
Center Well	Grazed	C3	23	0.47	52	2.67	1.00	0.00
Center Well	Grazed	C4	30	0.65	44	1.83	0.66	0.09
Center Well	Grazed	C5	57	0.38	51	1.12	0.68	0.05
Center Well	Grazed	C6	27	0.45	7	1.26	0.25	0.09
Center Well	Grazed	C7	56	0.34	67	1.88	0.76	0.07
Center Well	Grazed	C8	51	0.71	63	1.93	0.75	0.06
Center Well	Grazed	C9	56	0.63	58	1.73	0.68	0.06
Center Well	Grazed	C10	44	1.21	63	3.01	0.66	0.07
Center Well	Ungrazed	E1	9	0.54	46	2.90	1.00	0.00
Center Well	Ungrazed	E2	41	0.85	72	4.18	0.72	0.09
Center Well	Ungrazed	E3	18	0.75	52	3.66	1.00	0.00
Center Well	Ungrazed	E4	57	0.91	54	2.31	0.58	0.07
Center Well	Ungrazed	E5	62	0.36	41	1.05	0.61	0.06
Center Well	Ungrazed	E6	24	0.41	7	1.18	0.20	0.09
Center Well	Ungrazed	E7	62	0.41	57	2.08	0.52	0.07
Center Well	Ungrazed	E8	39	0.87	67	2.35	0.77	0.06
Center Well	Ungrazed	E9	62	0.54	65	1.53	0.77	0.05
Center Well	Ungrazed	E10	52	0.82	70	2.19	0.66	0.06
Swain	Ungrazed	S1	38	0.73	32	1.93	0.50	0.09
Swain	Ungrazed	S2	32	0.79	34	2.09	0.43	0.09
Swain	Ungrazed	S3	45	1.16	46	2.83	0.69	0.08
Swain	Ungrazed	S4	50	0.60	48	1.66	0.73	0.07
Swain	Ungrazed	S5	14	0.41	16	1.22	0.65	0.14
Swain	Ungrazed	S6	25	2.80				
Swain	Ungrazed	S7	31	3.29				
Swain	Ungrazed	S8	2	0.60	11	1.79	0.19	0.17
Swain	Ungrazed	S9	7	0.42	13	1.24	0.14	0.13
Swain	Ungrazed	S10	24	1.31	28	3.28	0.57	0.12

Table 4. Age and sex composition of GKR and San Joaquin antelope squirrels (SJAS) captured in 2008. Some animals escaped before their sex and/or age had been determined.

		Female	Male	Unknown	Total
GKR	Adult	606	593	9	1208
	Juvenile	263	215	5	483
	Unknown	4	11	28	43
	Total	873	819	42	1734
SJAS	Adult	32	41	1	74
	Juvenile	4	1	0	5
	Unknown	0	0	0	0
	Total	36	42	1	79

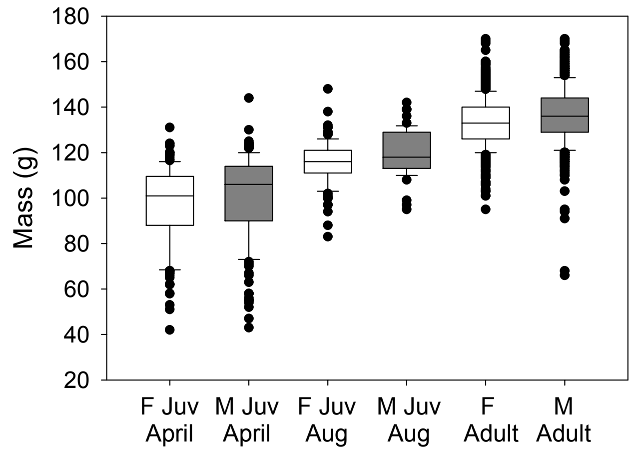

Figure 10. Average mass of of female (white boxes) and male (grey boxes) GKR in different age classes and seasons in 2008. Boxplots show medians (horizontal lines), interquartile ranges (boxes), the extent of non-outlier datapoints (whiskers), and outliers (points).

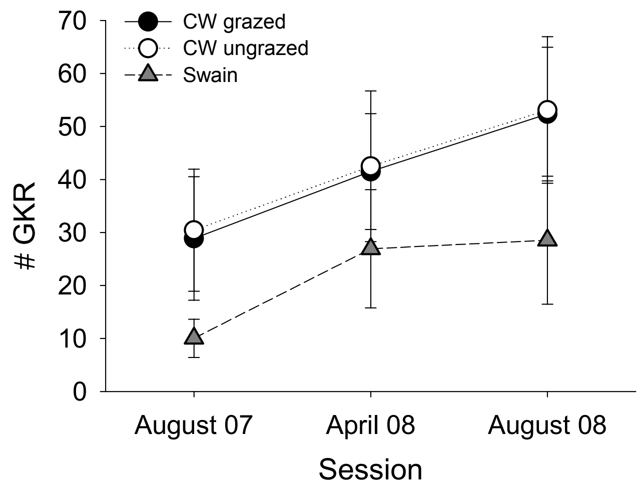

Figure 11. Average GKR population estimates (number of GKR per 1.96-ha plot) in Center Well grazed plots (closed circles), Center Well ungrazed plots (open circles), and Swain ungrazed plots (grey triangles), in each trapping session.

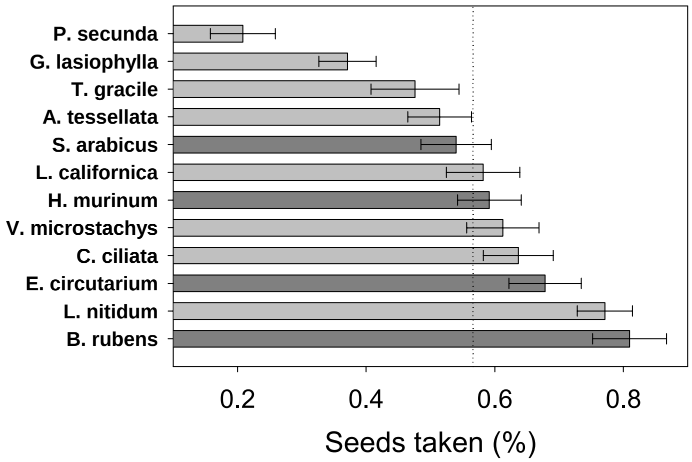

Figure 12. GKR seed preferences in 2008. The average percent of seeds taken (with standard error bars) from trials in which seed piles of 12 species were offered to GKR (n = 30 trials). The dotted vertical line shows the average percent of seeds taken across all species.

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

Species	Relative occurrence
Erodium cicutarium	0.35
Lepidium nitidum	0.20
Schismus arabicus	0.12
Lasthenia californica	0.07
Vulpia microstachys	0.06
Tropidocarpum gracile	0.05
Amsinckia tessellata	0.05
Calandrinia ciliata	0.03
Bromus madritensis rubens	0.03
Microseris douglasii	0.01
Uropappus lindleyi	0.01
Plantago erecta	0.01
Lepidium dictyotum	0.004
Vulpia myuros	0.004
Guillenia lasiophylla	0.003
Hordeum murinum	0.003
Chaenactis glabriuscula	0.001
Pectocarya penicillata	0.001
Isocoma acradenia	0.0002
Lotus wrangelianus	0.0002

SJAS abundance

A total of 79 SJAS were captured and marked, and a total of 272 captures occurred. The sex ratio was male-biased (0.86 females per male) and far more adults were captured than juveniles (Table 4). Capture rates were too low to conduct separate mark-recapture analyses in each plot, so I calculated a combined mark-recapture estimate for SJAS abundance on all of our plots in each pasture using the program CAPTURE. I divided the estimates by the number of plots in each pasture. SJAS abundance was higher in 2008 than in 2007 in both pastures (Figure 13). SJAS abundance was higher in Center Well than in Swain in 2007, but abundance did not differ among pastures in 2008 (Figure 13). SJAS estimates on each plot were not highly correlated among years (r = 0.35, n = 30 plots).

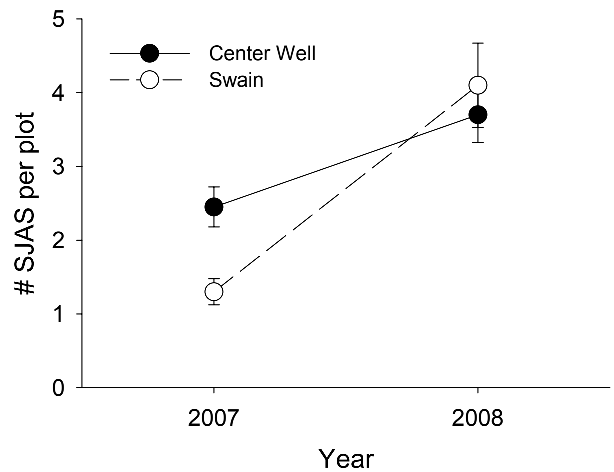

Figure 13. Estimates of San Joaquin antelope squirrel abundance on 1.96-ha plots in each pasture (with standard error bars).

Bird abundance

A total of 796 individuals from 18 bird species were detected during point counts, 119 of which were either on or flying over our plots. While fewer birds were detected in 2008 than in 2007, diversity was higher. In 2007, horned larks (*Eremophila alpestris*) accounted for 95% of observations and only 3 species were detected on plots, whereas in 2008 horned larks accounted for 51% of observations and 9 species were detected on plots (Table 6). These differences may be explained by the fact that point counts were conducted after the breeding season in 2007 (mid-late May) and during the breeding season in 2008 (April).

Table 6. Total counts of birds detected on or flying over plots in 2007 and 2008.

Common Name	Scientific Name	2007	2008
Horned Lark	*Eremophila alpestris*	545	61
Common Raven	*Corvus corax*	16	43
Red-tailed Hawk	*Buteo jamaicensis*	0	5
Western Meadowlark	*Sturnella neglecta*	11	3
Lark Sparrow	*Chondestes grammacus*	0	2
Loggerhead Shrike	*Lanius ludovicianus*	0	2
Golden Eagle	*Aquila chrysaetos*	0	1
Savannah Sparrow	*Passerculus sandwichensis*	0	1
Vesper Sparrow	*Pooecetes gramineus*	0	1
Brewer's Blackbird	*Euphagus cyanocephalus*	3	0

Reptile abundance

A total of 675 side-blotched lizards (*Uta stansburiana*) and 7 BNLL (*Gambelia sila*) were seen during reptile surveys. All BNLL were geo-referenced. As in 2007, all BNLL sightings were in the Swain pasture. Reptile density was higher in 2008 in both pastures, and density was higher in Center Well than in Swain in both years (Figure 14). Density estimates on each plot were highly correlated among years (r = 0.90, n = 30 plots), indicating that certain areas may consistently produce more reptiles than others.

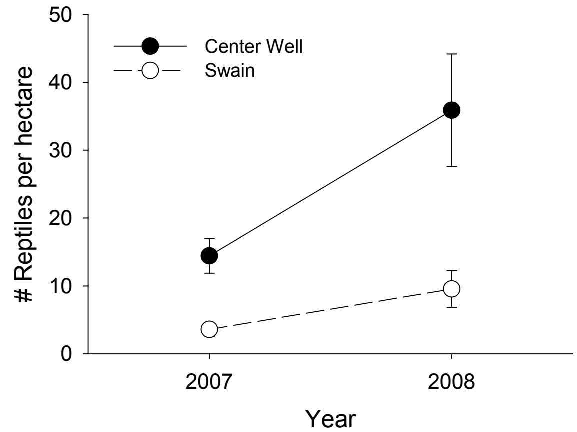

Figure 14. Estimates of reptile density each year in each pasture, calculated using the program DISTANCE. Standard error bars are shown.

Invertebrate abundance

Counts of grasshoppers seen during reptile surveys were slightly higher in 2008 than in 2007 (Figure 15). Unlike other surveys, grasshoppers were more abundant in Swain than in Center Well during both years (Figure 15). Grasshopper counts on each plot were not correlated among years (r = 0.17, n = 30). The pitfall trap data for 2007 was processed and data for 2008 is currently being processed. In 2007, the average richness per trap was 17.5 species in Center Well and 12.9 species in Swain. Invertebrate biomass was more than twice as high in Center Well as in Swain (3.5 grams per sample in CW versus 1.5 grams in Swain, n = 360 samples). Thus, the greater abundance of grasshoppers in Swain does not reflect the pattern shown by all invertebrates.

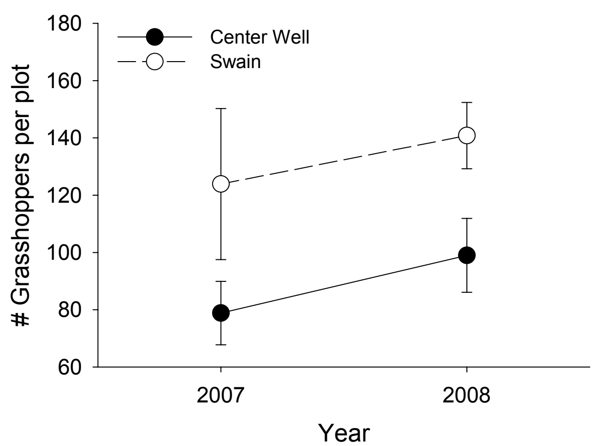

Figure 15. Mean counts of grasshoppers seen during reptile surveys on each plot. Standard error bars are shown.

Grazing intensity

Cattle grazed on Center Well from March 23 – May 8, 2008, for a total of 407 animal unit months of use (cattle x months). Counts of cows seen on our control plots were highly correlated with counts of cow patties during reptile surveys (r = 0.80, n = 10). Grazing intensity varied widely among plots, with a 100-fold range in the number of cow patties counted (Table 7). Average plant biomass was positively correlated with the average number of cows counted on each plot (r = 0.62, n = 10, p = 0.05). This result is surprising; I expected plant biomass to be negatively correlated with the number of cows, because lots of cows foraging on a plot should reduce its biomass. The positive relationship may therefore be an indicator of cow preference for high biomass areas rather than an indicator of their effect on plants. Because plant surveys are conducted concurrently with cattle grazing, the true impacts of grazing on the plant community may take several years to discern. This result also highlights the importance of using an experimental approach, as the comparison between grazed and ungrazed plots showed the expected reduction in plant biomass with grazing.

Table 7. Average and standard error (SE) of cow counts on control (grazed) plots in the Center Well pasture (n = 23 surveys), and the total number of cow patties seen on each plot during reptile surveys.

Plot	*N* cows	SE	*N* patties
C1	3.17	1.08	459
C2	0.83	0.59	216
C3	1.30	0.77	310
C4	2.09	0.70	166
C5	0	0	4
C6	1.70	1.02	162
C7	0	0	132
C8	0.13	0.13	143
C9	0.17	0.14	125
C10	0.26	0.26	86

Species associations

To investigate the effect of GKR on other species, we examined associations among all of the flora and fauna surveys conducted on our plots (Table 8). As in 2007, burrow-dependent species such as San Joaquin antelope squirrels and reptiles were positively associated with GKR. The only species surveyed that were negatively associated with GKR were birds. This is likely due to the positive effect that GKR have on antelope squirrels. Most of the birds detected in our surveys were ground nesting horned larks (*Eremophila alpestris*), which may have avoided areas with large numbers of squirrels to avoid nest predation. Supporting this idea, the negative correlation between squirrels and birds was stronger than between birds and GKR. Interestingly, more cow patties were counted on plots with more GKR precincts. Previous work has indicated that cows prefer to graze on precincts because the plant nitrogen content is higher (Williams et al. 1993), so cows may concentrate their foraging activities in areas with lots of burrows.

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.

2008	Native plant cover	Biomass	GKR	Precincts	Squirrels	Grass-hoppers	Reptiles	Birds
Biomass	**0.44**							
GKR	**0.46**	-0.25						
Precincts	**0.44**	0.07	**0.74**					
Squirrels	0.24	-0.02	**0.41**	0.35				
Grasshoppers	0.11	-0.17	0.29	0.17	**0.40**			
Reptiles	0.20	-0.23	**0.60**	**0.54**	-0.20	0.02		
Birds	-0.10	0.05	**-0.39**	-0.31	**-0.51**	-0.26	-0.24	
Cows	-0.14	0.11	0.23	**0.37**	-0.06	-0.27	0.13	0.05

Conclusions and Future Directions

Surveys in 2008 revealed increases in plant species richness and biomass, and higher densities of giant kangaroo rats, San Joaquin antelope squirrels, reptiles, and grasshoppers in comparison to surveys in 2007. Birds were the only taxonomic group surveyed with lower densities than in 2007, but this may reflect seasonal differences in the timing of surveys. Because bird counts were conducted after the breeding season in 2007, we encountered many large flocks of horned larks. This did not occur in 2008, because counts were conducted during the breeding season when birds were spaced out in breeding territories. The Center Well pasture had higher densities of GKR, SJAS, and reptiles than the Swain pasture, a finding that is also consistent with results from 2007.

The 2008 GKR surveys conducted as part of this project have provided useful data for the conservation of this species and other threatened and endangered upland species. We have established a remarkably large population of marked individuals within a substantial portion of their core range. We have confirmed that GKR play an important role in providing refuge for other burrow-dependent species in the Carrizo, such as squirrels and reptiles. We are also starting to detect differences in the plant community in response to our grazing exclosure treatment. In the coming year we plan to increase the effectiveness of our GKR exclosures and hope to see treatment effects soon thereafter.

In contrast to results from 2007, native plant cover was actually higher on precincts than off precincts in Center Well. This highlights the dramatic changes in plant composition that can occur in an annual plant community that is sensitive to rainfall patterns. Because of the 100-fold increase in the abundance of *Amsinckia*, a tall native forb, native plant cover was positively correlated with plant biomass in 2008. In contrast, native plant cover was negatively correlated with biomass in 2007.

We did not detect an effect of cattle grazing on GKR demographics, but this was the first year since construction of cattle exclosures that grazing occurred on the monument. Additional years of data will be needed to detect grazing effects and to determine the effect that rainfall will have on the dynamics of this system. In both 2007 and 2008, rainfall levels were below average. The exclusion of cattle did have an effect on the plant community, however, increasing the level of biomass and reducing exotic plant cover in comparison to grazed control plots.

Our assessment of GKR dietary preferences will be prepared for a peer-reviewed publication, and it will also be used in planning restoration experiments. We will add a graduate student to the project in 2009 to initiate a restoration project funded by the USDA. This project will use our existing experimental framework to examine the effect of kangaroo rats on native seeding efforts.

Our finding of the genital fungus or disease on GKR warrants further investigation. Given the high incidence of its occurrence, it could play an important role in GKR population dynamics. We also plan to monitor GKR using radio-telemetry in order to fill key knowledge gaps. Currently, nothing is known about dispersal of GKR, which is a key parameter needed to identify areas that may be colonized naturally and to predict the spread of newly established populations. Additionally, we do not know the rates of juvenile or adult mortality, or the main causes of mortality. While our bi-annual trapping provides population estimates and data on site fidelity, we need radio telemetry data in order to estimate causes and rates of mortality and dispersal. Our collaborator from Cal State Northridge, Tim Karels, will initiate a radio-telemetry project in the spring of 2009 to address these key questions.

Acknowledgements

We would like to sincerely thank our agency partners, whose support and cooperation are key to the continued success of this project. BLM provided funding, housing, use of tools and equipment, and L. Saslaw and J. Hurl provided logistical and field support. T. Palmisano and B. Stafford of CDF&G provided assistance and a field vehicle. TNC provided funding, and we thank T. Maloney and S. Butterfield for their support. J. Roser, J. Chestnut, N. Petersen, N. Raubitschek, and C. Daman provided invaluable assistance in the field. L. Navagata and B. Bonds helped in the lab.

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