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 tenth year of the Carrizo Plain Ecosystem Project (CPEP), a long-term study to quantify these relationships using replicated cattle and GKR exclosures. After three dry years, precipitation increased in 2015, and in 2016 precipitation levels rose near to the study average. GKR populations rebounded in 2016 with abundance at high levels in both spring and summer and the highest ever seen summer survival. Captures of non-GKR rodent species increased markedly during 2014 and 2015 and this trend continued in 2016, including significant increases in other kangaroo rat species. There has been a steady rise in the abundance of BNLL from the lowest measurement on record in 2013 to a record high in 2016. UTA abundance has also risen since a record low in 2011 to a study high in 2015 and 2016. SJAS densities were the highest since the peak year of 2011 though overwinter survival was lower than 2015. Native plant species richness remained high in Center Well but decreased from 2015 and non-native species richness was the highest seen in the study but still lower than native levels. In Swain pasture, native species richness dropped to the fourth lowest level in 2016. Native and non-native cover in Center Well continued to increase from lows in 2014 while in Swain pasture, native cover decreased and non-native cover increased. Cows were grazed for the first time since 2011 and differences were seen on grazed and ungrazed plots. Grazed plots had higher GKR densities than ungrazed plots in both spring and summer but results were not significant, though the summer p-value was very close to significance. UTA lizards and invertebrate richness were also more common on grazed plots. SJAS and orthopterans were more common on ungrazed plots. GKR exclosures continued to have effects on the invertebrate community in 2016 with more beetles where GKR were present and more orthopterans and ants where GKR were absent. Swain plots had the most GKR precincts overall and the most active precincts and ungrazed pastures had the least. Precipitation plots surveys continued in 2016.

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 2016, we continued monitoring the flora and fauna on these plots.

In 2014, we started an experiment to predict the consequences of climate change on the Carrizo Plain food-web. Twelve 10 x 10-m rainout shelters are used to catch half of each rainfall event, and water is then pumped to a neighboring area of the same size. By creating extreme drought and wet year conditions within our exclosure experiment, we hope to learn how kangaroo rats modify the response of plants to climate change.

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.

4. To evaluate the effects of future precipitation changes on the Carrizo Plain ecosystem.

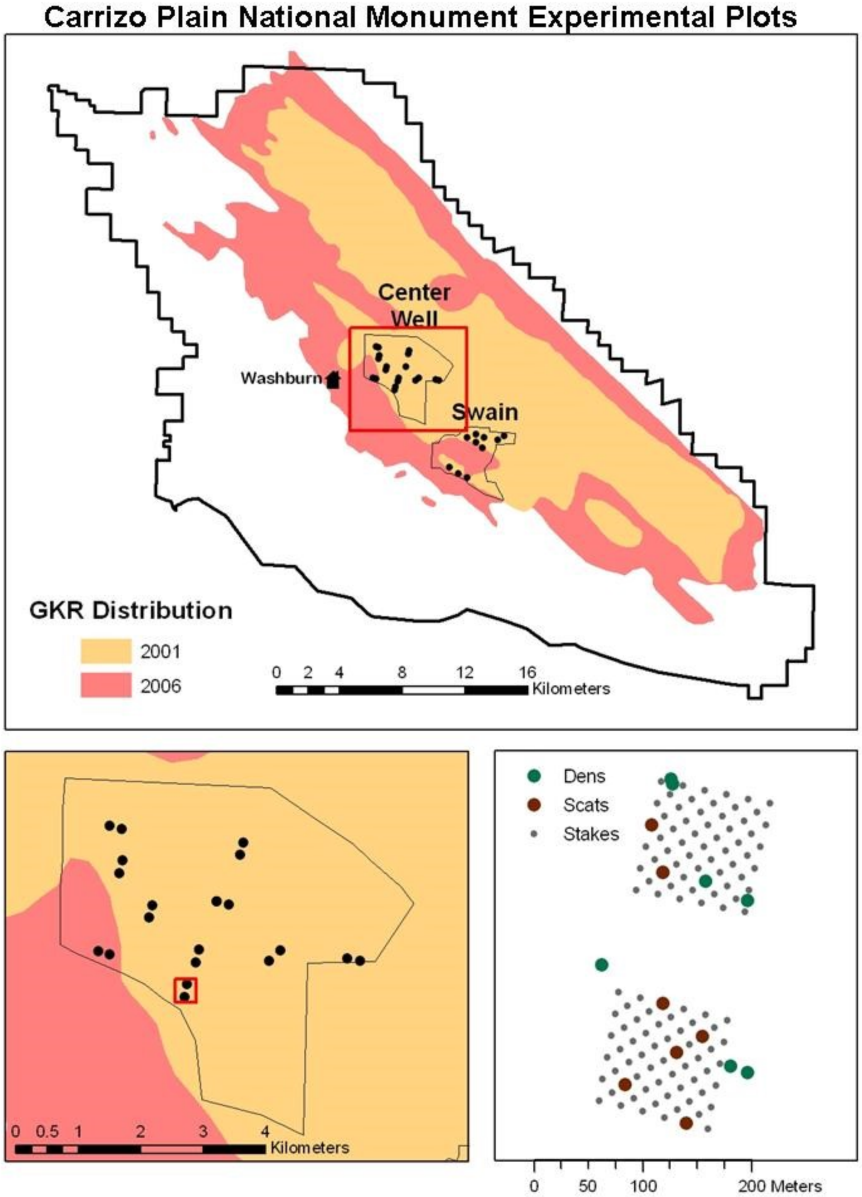

Figure 1. Map of study sites in the Carrizo Plain National Monument. Details are shown for the Center Well pasture and site CW 7. Kit fox dens and scats, as well as trap stakes, are shown for site 7.

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).

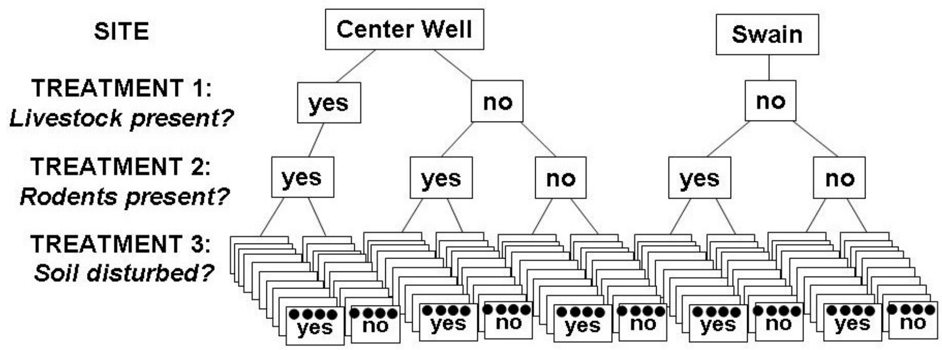

Figure 2. Experimental design of the project. There are ten blocks of each treatment combination and four nested vegetation plots (filled circles) within each block.

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 20100 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).

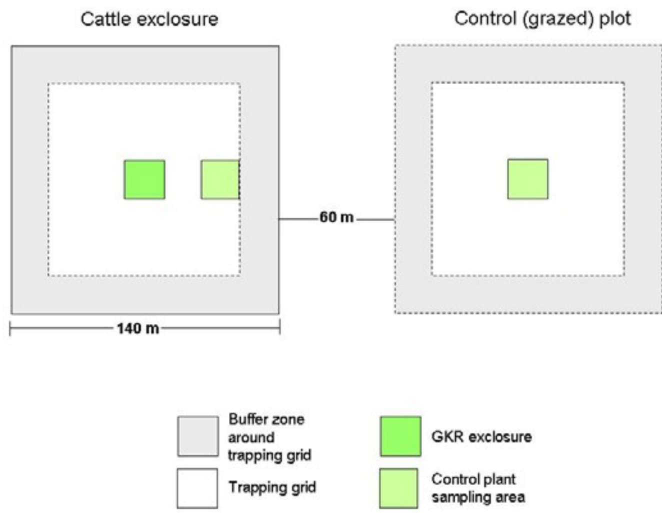

Figure 3. Nested exclosure design to separate livestock and GKR effects on plants, with paired control plot. A buffer zone around each GKR trapping grid ensured that the surveyed population was comprised of individuals living within the plot. This shows the design in Center Well; in Swain each plot is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

Precipitation plot experiment

18 sites were identified for the precipitation plot experiment and precipitation treatments were applied to the paired kangaroo rat exclosures and control plots. Precipitation plots are 10mx10m. Water is transported between paired plots within each site because of the limited road access and dispersion of our sites across a large area. Therefore, sites are grouped into 6 blocks, whereby 3 adjacent sites (each separated by ~ 500 m, each containing paired exclosure and non-exclosure plots) comprise a block. We used our extensive background dataset of plant composition on these sites to verify proper blocking. Within each block, one site was randomly assigned as a precipitation control, and precipitation treatments are not applied to either plot. On the second site, a rainout shelter was constructed over the kangaroo rat exclosure, and water is transported from the shelter to the kangaroo rat control plot on that site. The third site receives the reverse treatment, with a rainout shelter constructed over the kangaroo rat control plot and water transported to the exclosure.

We used simulations to determine that six replicate blocks should be sufficient to detect significant effects of precipitation, trophic, and engineering effects on plant communities. Mean cover of exotic grasses, native grasses, exotic forbs, and native forbs during years that were drier than average (2007-2009, 2012) and wetter than average (2010-2011) were used to determine minimum effect sizes that may be seen due to precipitation treatments. We simulated data using a Gaussian distribution and the means and variances observed on these plots from 2007-2012, and we analyzed data using generalized linear mixed models with precipitation level, burrow presence, and kangaroo rat presence as fixed effects, block as a random effect, and quadrat as a nested random effect. Four blocks were sufficient to detect significant main effects of these treatments, and six blocks were sufficient to detect interactions between engineering and precipitation with a single year of data. Additional simulations indicated that several years of data would be required to detect interactions with trophic effects and these factors.

Rainout shelters were constructed over rainfall reduction plots, using a design whereby shelters intercept a portion of each rainfall event. This design is being used successfully to manipulate rainfall in several grassland sites, including the Seviletta, Konza Prairie, and Shortgrass Steppe LTERs, and it has been shown to produce minimal microclimate artifacts (Yahdjian and Sala 2002).

Based on recent climate projections for California (Cayan et al. 2006), rainfall is reduced by 50% on rainfall reduction plots, and water is collected from shelters and added to rainfall addition plots, thus increasing precipitation by 50%. We manipulate rainfall through both additions and reductions because downscaled climate models deviate on whether future rainfall in the region will increase or decrease over the next century (Brekke et al. 2004, Maurer and Duffy 2005, Thorne et al. 2012). Because we manipulate precipitation based on relative rather than absolute annual rainfall, and expect that our experiment will encompass both dry and wet years under ambient conditions, we will be able to quantify the effects of a large range of precipitation levels on our response variables. Although climate models deviate on predicted trends and the magnitude of changes (Thorne et al. 2012), nearly all models predict increasing variability in precipitation among years (Karl et al. 1995, Timmermann et al. 1999). Our experiment will thus mimic expected changes by producing higher highs and lower lows within a reasonable range of predicted future climate scenarios.

Shelters consist of a steel frame that supports an array of clear acrylic v-shaped shingles that passively reduce each rainfall event by ~50%. Shingles have high light transmission, a low yellowness index, and are UV transparent. The low edge of the shelter is oriented towards the prevailing winds to minimize blow-in, and the shelter will extend 1 m beyond the edge of the plot. The holding tank is large enough to contain runoff from an hour-long downpour (1 cm of water falling on the shelter). This water is subsequently applied to the water addition plots using solar-powered water pumps, hose lines, and a sprinkler in the center of the plot. Because the pump is active during each storm, the tank does not need to hold runoff from an entire storm. The shelter roof and principle irrigation components (battery, pump, solar panel) are removed during the dry season (April-October) to minimize microclimate effects and visual impacts to visitors of the Monument.

To accurately simulate the effects of climate change on plant-animal interactions, we conduct precipitation manipulations at a large enough scale to reduce artifacts that could be created by small scale changes in kangaroo rat movements. For example, if only small plots were sheltered or watered within a kangaroo rat's territory, the kangaroo rat could over-use the watered plot and ignore the sheltered plot, thus giving results that would fundamentally differ from what would occur if precipitation were manipulated across the landscape (as is occurring with climate change). Giant kangaroo rat home ranges are small (~200 m2) and exclusive (Cooper and Randall 2007). Because kangaroo rats are fiercely territorial and our manipulations occur on a scale that will include 1-2 entire territories, it is highly unlikely that our manipulations will result in unnatural aggregations or biased within-territory space use by resident kangaroo rats.

(A)

(B)

Figure 4. Precipitation plot rainout shelter with water storage tank and solar panel (A) and irrigation system (B).

Plant and soil sampling

We established 8 1-m^2 permanent plant sampling quadrats in each of the 50 400m^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 5; 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, July and September (expected peak, post-grazing and minimum biomass). Clip plots are surveyed in a different location each sampling session. Plant height was also measured prior to clipping. In 2015 new vegetation plots were added on the precipitation plots and pre-existing vegetation plots were assigned to the precipitation plot study to pinpoint precipitation effects on vegetation. Vegetation plots were also removed in 2015 due to conflicts in location with the precipitation plot equipment.

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Figure 5. 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 6; 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/May and July/August. All captured animals were marked with an ear and PIT tag, weighed, sexed, a head measurement taken and released. Trapping occurred from April 20-May 22, 2016 (24 trap nights) and August 7- September 1, 2016 (21 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.”

GKR precinct surveys

Plots were visited in random order. Seven 140-m long transects spaced 20 m apart were slowly walked by a single observer, and all precincts detected within 10 m on either side of the transect were identified and recorded along with the UTMs for each location and whether precincts were active or inactive.

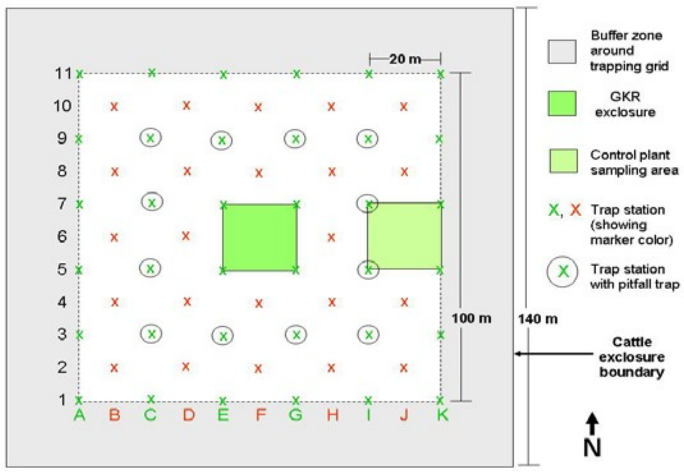


Figure 6. Detailed diagram of a cattle exclosure. Trap stations show trap locations for GKR mark-recapture surveys. Colors correspond to the spray-painted color on the stake marking the location. Letters and numbers identify the grid stakes (A1, B2, etc.).

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 85° F. All captured animals were PIT-tagged, weighed, and sexed. Trapping occurred from May 12 – June 8, 2016 (15 trap days). The RMark package was used to obtain density estimates on each plot each year.

Bird surveys

Bird surveys were not conducted this year due to budget limitations. From 2008-2012, point counts were conducted four times on each plot in the spring.

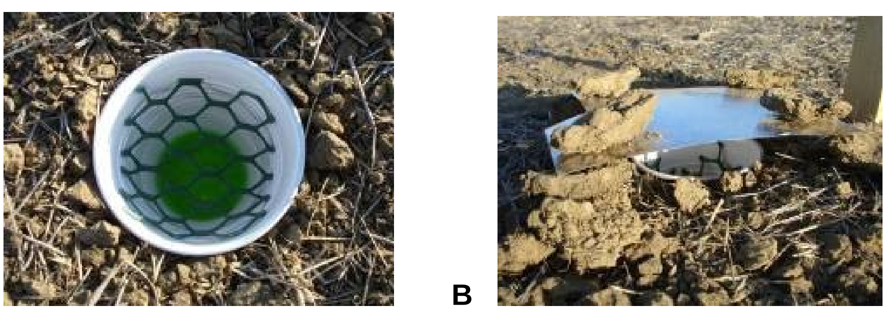
Reptile surveys

Line transect surveys were used to estimate reptile abundance on each 1.96-ha plot. Three surveys were conducted on each plot from May 16-July 10, 2016. 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. Due to budget limitations, invertebrate identification is competed about a year after collection and only 2015 results are presented here. In 2015 traps were placed on each plot between and June 8-9, 2015 (245 total traps, trap number varies per plot). Traps were flooded and many had to be reset on June 18, 2015. 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 7A). Traps were covered with 10x10" pieces of aluminum flashing with an inch of space between the cover and ground (Figure 7B). Two centimeters 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 7A). This probably filtered out larger insects as well. Upon collection, the contents of each trap was rinsed and stored in 50mL 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. In 2015 45 additional invertebrate pitfall traps were added on the precipitation plots and 26 pre-existing invertebrate pitfall traps were assigned to the precipitation plots to pinpoint precipitation effects on invertebrates.

A



B

Figure 7. Pitfall trap viewed from above (A) and from the side with the aluminum cover (B).

Spotlight survey

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 17-20, 2016, n = 4 surveys) and summer (July 26-29, 2016, 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 2016, we continued to collect scats deposited on our traps as kit foxes often marked our traps with urine and feces. We collected 8 kit fox scats in 2016. We also recorded all sightings of kit foxes during other surveys.

Kit fox den surveys

In 2010, kit fox dens found on plots or opportunistically while walking to plots were geo-referenced. Beginning in 2013 kit fox den surveys were conducted on all plots using line transect surveys. Plots were visited in random order. Seven 140-m long transects spaced 20 m apart were slowly walked by a single observer, and all dens detected within 10 m on either side of the transect were identified and recorded, along with the UTMs for each location and whether dens were active or inactive.

Cattle grazing intensity

Cattle patty counts were conducted in 2016 shortly after the cattle were removed on 7/14-7/15, 2016.

Postdoctoral projects

Postdoctoral research associate Nicolas Deguines, University of Washington, Seattle

Dr. Deguines spent six weeks in the study area in Spring 2016 to assist technician Sam West and two undergraduate students in conducting the biological surveys. Dr. Deguines finalized the publication of his results on how precipitation alters interactions in the ecological community in the Journal of Animal Ecology. He prepared the dataset and helped in the analysis led by Dr. Prugh on the extreme drought effects across the ecological community. He also leads the analysis focusing on the influences of giant kangaroo rat activities on the functioning of arthropod communities. Dr. Deguines has been actively mentored by PI Prugh via weekly individual and lab meetings. His contract ended on Nov. 30th, 2016, but collaborations and weekly Skype meetings continue.

Postdoctoral Research Associate Josh Grinath, University of Colorado Boulder

In Spring 2016, Dr. Joshua B. Grinath spent 11 weeks in the field collecting soil moisture data and soil nitrogen extractions, as well as data for plants and their associated arthropod assemblages. Dr. Grinath analyzed the historical plant dataset and data from the precipitation experiment in 2015 to test plant community composition responses to kangaroo rats and precipitation. He also analyzed data from the precipitation experiment in 2016 to assess kangaroo rat and rainfall effects on plant-arthropod communities. In addition, he has analyzed seed bank and seedling responses to the field manipulations and resource availability in greenhouse experiments at UC Boulder. To assist with measuring seedling responses from the greenhouse work, Dr. Grinath mentored three undergraduates and a high school student. He has also mentored an undergraduate honors thesis based on seedbank samples from our field experiment. Additionally, Dr. Grinath conducted a side project investigating how herbivorous spittlebugs may facilitate arthropod communities on shrubs, and he mentored another undergraduate honors thesis based on plant samples collected from this project. Moreover, Dr. Grinath led the writing of a National Science Foundation Preliminary Proposal concerning the effects of precipitation and kangaroo rats on shrub encroachment into grassland. Dr. Grinath is actively mentored by PI K.N. Suding.

Results and Discussion

Precipitation

In ten years, the Carrizo Plain Ecosystem Project has seen a wide spectrum of precipitation from record lows of around 7 cm in 2014 to record highs of nearly 40 cm in 2011. 2015 saw an increase in precipitation and 2016 had even more precipitation with levels close to the average seen over the past ten years (Figure 8).

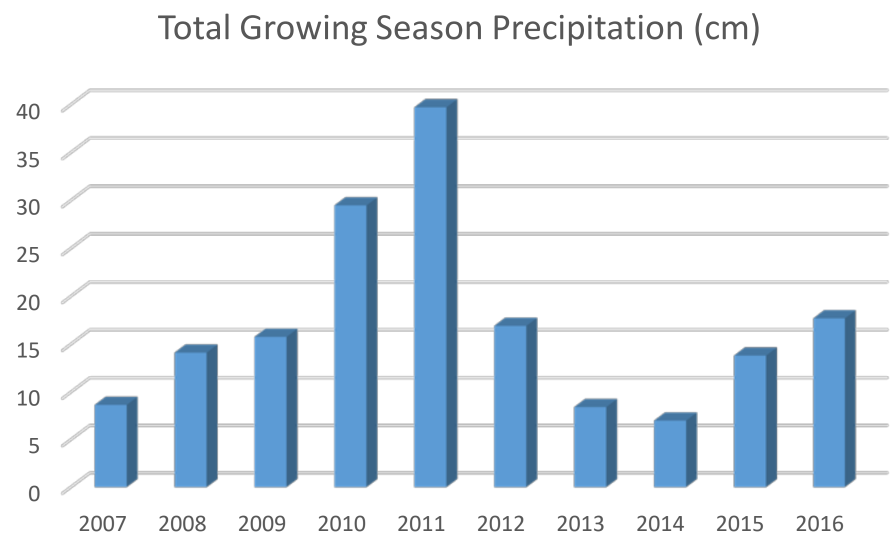


Figure 8. Growing season (October-April) precipitation (cm) levels in the Carrizo Plain National Monument from 2007 to 2016. Growing season for 2007 is defined as October 2006 through April 2007.

Plants

General plant composition

Native plant species richness in Center Well peaked in 2010 and 2011, decreasing in subsequent years until 2015 when the peak was matched again. 2016 levels were a little lower in Center Well. Non-native plant species richness in Center Well in 2016 was the highest seen in the study, but still much lower than native levels. In Swain pasture, native plant species richness had its highest levels in 2008-2011 with richness dropping after that. 2015 saw a rise in native species richness to near peak levels but dropped to the 4th lowest richness levels in 2016. Non-native plant species richness remained about the same throughout all years (Table 1).

Native cover peaked in Center Well in 2010 and plummeted in 2012-2014. 2015 saw a marked increase in native percent cover and this increase continued in 2016. Non-native cover in Center Well peaked in 2011 and dropped in 2012-2014, increasing in 2015 and 2016. Similar to Center Well, Swain pasture saw a peak in percent cover in 2010, dropped in 2012-2014, and increased in 2015. In 2016, however, native cover in Swain pasture dropped down to the fourth lowest percentage in the study. Non-native cover in Swain peaked in 2011 and while non-native cover dropped in 2012-2014, the decrease was not as large as the decrease in native cover. Non-native cover in Swain rose in 2015 and was close to peak levels in 2016 (Table 1).

In 2014, Grass (*Poaceae)* cover was the lowest ever recorded, less than 2% cover, on all Center Well vegetation plots. Grass cover in all areas increased in 2015 and 2016 (Figure 9).

Hordeum murinum was the most commonly found grass species in Center Well pasture. *Schismus arabicus* was the dominant grass species in Swain pasture and with and without GKR.

Erodium circutarium was the most common species overall, in both pastures and in and out of GKR exclosures (Table 2). In 2016 Center Well's most common plants were *Erodium cicutarium, Lepidium nitidum and Hordeum murinum.* In Swain pasture *Erodium*, *Schismus arabicus* and Lepidium were the most prevalent. In plots with GKR and without GKR, *Erodium, Lepidium and Schismus* were also the most common plants.

Table1. Species richness and relative percent plant cover in the Center Well and Swain pastures, 2007–2016.

Metric	Type	Center Well									
		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Species richness	native	18	30	30	31	28	21	15	16	31	24
	exotic	8	7	6	7	9	7	6	4	10	10
	total	26	37	36	38	37	28	21	20	41	34
Plant cover (%)	native	23	28	42	67	35	5	2	3	17	24
	exotic	17	37	28	25	49	16	16	6	32	31
	total	40	65	70	92	84	21	18	9	49	55
		Swain									
		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Species richness	native	15	43	40	45	39	34	27	23	41	29
	exotic	7	10	8	6	7	9	6	5	6	7
	total	22	53	48	51	46	43	33	28	47	36
Plant cover (%)	native	17	20	41	57	32	7	7	6	25	16
	exotic	32	33	32	34	44	25	23	7	31	40
	total	50	52	73	90	76	32	30	13	56	56

Table 2. Relative % cover of plant species in the Center Well and Swain pastures in 2016 (n = 401 plots), and without GKR ("No GKR", inside GKR exclosures, n = 160 plots) and with GKR ("GKR", outside GKR exclosures, n = 239 plots).

Species	Type	Center Well	Swain	GKR	No GKR
Allium sp.	Native	<0.01	-	-	<0.01
Amsinckia menziesii	Native	1.00	-	1	-
Amsinckia tessellata	Native	352.00	371.00	557	166
Astragalus lentiginosus	Native	-	1.00	-	1
Astragalus oxyphysus	Native	4.00	-	<0.01	4
Astragalus sp.	Native	-	5.00	5	<0.01
Bromus madritensis	Invasive	96.00	212.00	63	245
Calandrinia ciliata	Native	347.00	9.00	332	24
Camissonia campestris	Native	-	<0.01	-	<0.01
Capsella bursa-pastoris	Invasive	4.00	-	1	3
Castilleja exserta	Native	-	<0.01	-	<0.01
Chaenactis glabriuscula	Native	-	<0.01	-	<0.01
Chorizanthe uniaristata	Native	-	12.00	11	1
Descurainia sophia	Invasive	3.00	-	<0.01	3
Dichelostemma capitatum	Native	9.00	3.00	2	6
Eriogonum gracillimum	Native	2.00	29.00	3	28
Erodium cicutarium	Invasive	3328.00	2551.00	2877	3002
Guillenia lasiophylla	Native	453.00	163.00	350	266
Herniaria hirsuta	Invasive	1.00	140.00	50	93
Hollisteria lanata	Native	-	34.00	32	2
Hordeum murinum	Invasive	1361.00	432.00	726	1067
Lasthenia californica	Native	5.00	209.00	27	187
Lasthenia minor	Native	394.00	18.00	352	60
Lembertia congdonii	Native	<0.01	-	<0.01	-
Lepidium dictyotum	Native	265.00	15.00	272	8
Lepidium nitidum	Native	2279.00	963.00	2007	1235
Linanthus liniflorus	Native	-	6.00	3	3
Lotus wrangelianus	Native	14.00	2.00	10	6
Lupinus microcarpus	Native	<0.01	4.00	<0.01	4
Malacothrix coulteri	Native	4.00	12.00	4	12
Microseris douglasii	Native	4.00	-	3	1
Microseris elegans	Native	3.00	-	3	<0.01
Monolopia lanceolata	Native	4.00	2.00	6	<0.01
Moss		-	8.00	7	1
Pectocarya penicillata	Native	35.00	112.00	104	43
Phacelia ciliata	Native	<0.01	-	<0.01	-
Plagiobothrys canescens	Native	-	<0.01	-	<0.01

Table 2 Continued

Species	Type	Center Well	Swain	GKR	No GKR
Plantago erecta	Native	-	<0.01	-	<0.01
Poa secunda	Native	-	1.00	*<0.01*	1
Salsola tragus	Invasive	5.00	-	*2*	3
Schismus arabicus	Invasive	1283.00	1816.00	*1758*	1341
Sisymbrium altissimum	Invasive	-	1.00	-	1
Sisymbrium irio	Invasive	20.00	-	*7*	13
Trichostema lanceolatum	Native	-	5.00	*5*	<0.01
Trifolium gracilentum	Native	41.00	<0.01	*18*	23
Tropidocarpum gracile	Native	225.00	32.00	*232*	25
Vulpia bromoides	Invasive	-	44.00	*16*	28
Vulpia microstachys	Native	210.00	89.00	*165*	134
Vulpia myuros	Invasive	13.00	-	*11*	2

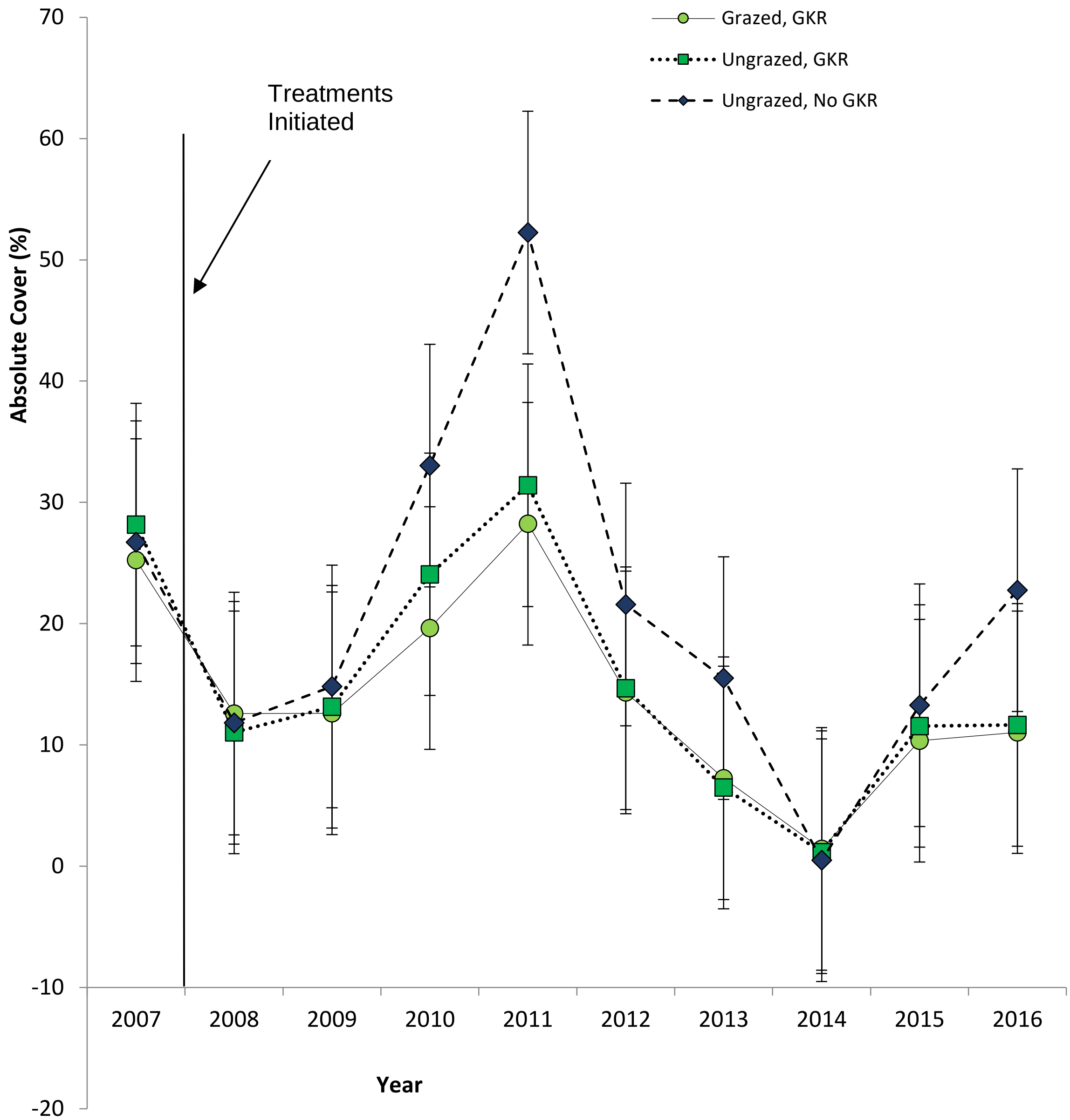


Figure 9. Grass cover in experimental plots within the Center Well pasture. Three treatments were initiated prior to the spring of 2008: kangaroo rat exclosures (ungrazed, no GKR), cattle exclosures (ungrazed, GKR), and control plots (grazed, GKR). Means and standard error bars are shown (*n* = 10 replicates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

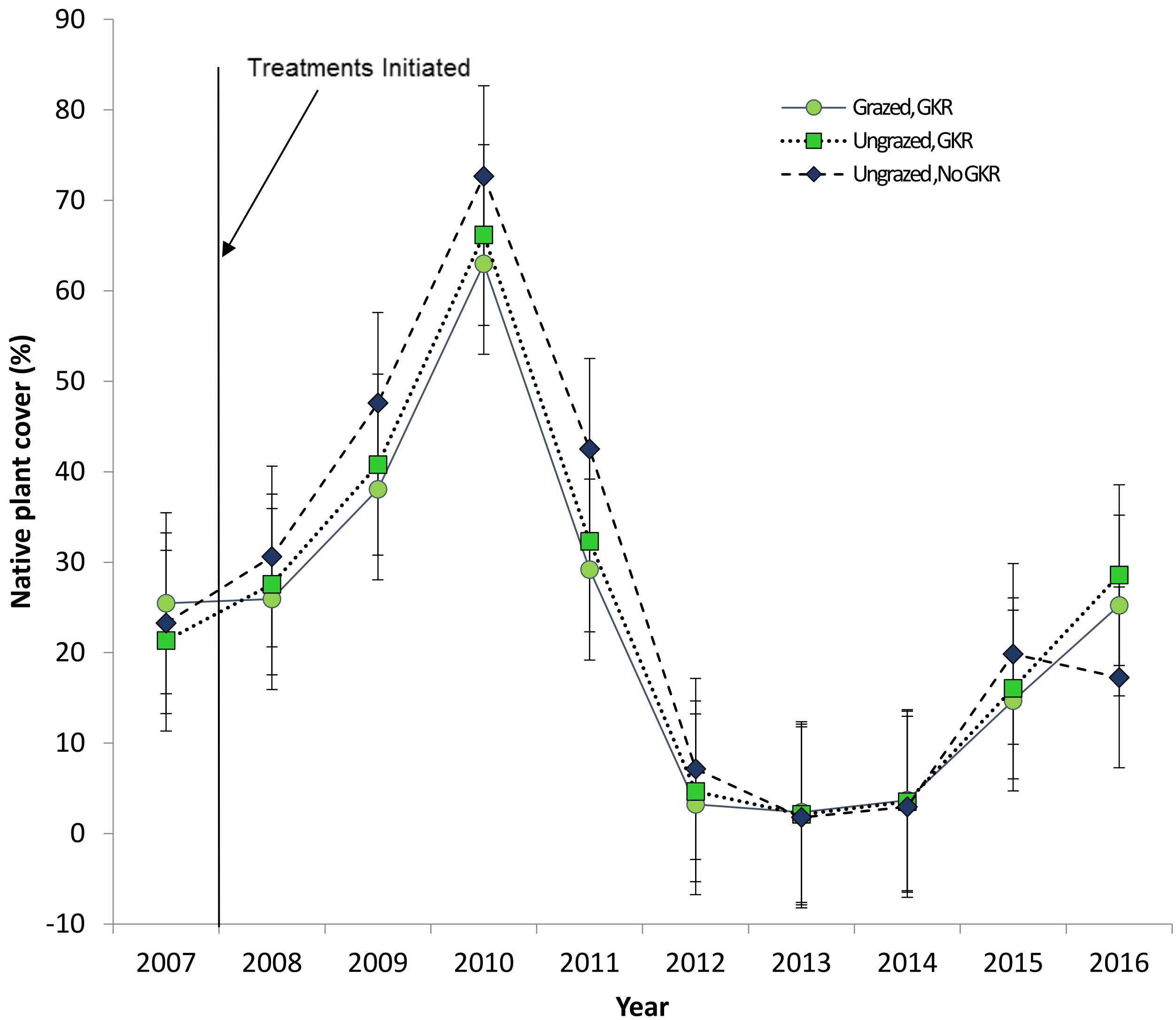


Figure 10. Native plant cover in experimental plots within the Center Well pasture. Three treatments were initiated prior to the spring of 2008: kangaroo rat exclosures (ungrazed, no GKR), cattle exclosures (ungrazed, GKR), and control plots (grazed, GKR). Means and standard error bars are shown (*n*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

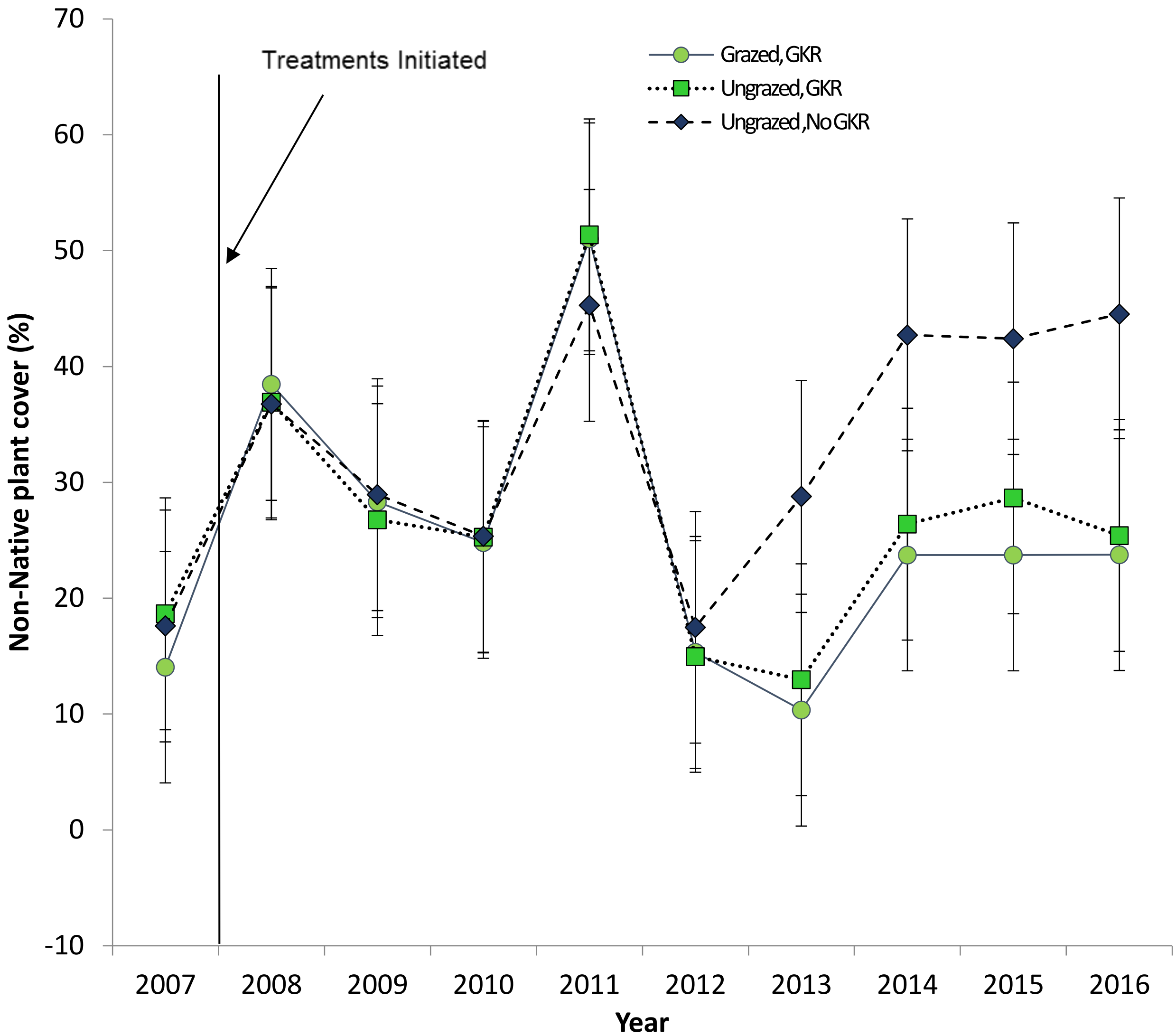


Figure 11. Non-Native plant cover in experimental plots within the Center Well pasture. Three treatments were initiated prior to the spring of 2008: kangaroo rat exclosures (ungrazed, no GKR), cattle exclosures (ungrazed, GKR), and control plots (grazed, GKR). Means and standard error bars are shown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

Grazing Intensity

Cows were grazed in Center Well pasture for the first time since 2011 from April 13-July 13, 2016, resulting in 524 animal use months (Table 3). There was a low correlation in 2016 between grazing intensity and plant biomass (r = 0.2), however the correlation for all years is stronger (r = 0.64) indicating that overall there is a correlation between grazing intensity and plant biomass.

Table 3. Average counts of cows seen (2008-2010) on control (grazed) plots in the Center Well pasture (*n* = 29 surveys), and the total number of cowpies found on each plot (2008-2011 and 2016).

Plot	2008		2009		2010		2011	2016
	N cows	N patties	N cows	N patties	N cows	N patties	N patties	N patties
C1	3.17	459	0	24	1.31	418	253	601
C2	0.83	216	0.25	25	0.38	402	191	901
C3	1.30	155	0.13	35	1.48	219	234	240
C4	2.09	166	0.13	32	1.86	273	307	432
C5	0	4	0	11	0	129	58	185
C6	1.70	162	0	12	4.21	439	223	346
C7	0	132	0	3	0.59	238	147	180
C8	0.13	143	0	40	0.28	213	143	192
C9	0.17	125	0	16	0.10	303	132	356
C10	0.26	86	0	2	0.38	289	185	249

Effect of cattle and kangaroo rat exclusion

Biomass removal by cattle and GKR.

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

The peak residual dry matter (RDM) prior to grazing by cattle was approximately 1,513 pounds per acre in 2016 (Table 4). Biomass removal by GKR was higher in the fall than in the spring and there was actually more biomass outside the GKR exclosures than inside in the summer. Cattle removed approximately 300 lbs/acre and GKR removed approximately 300 lbs/acre in the spring and close to 500 lbs/acre in the fall.

Table 4. Average (± standard error) plant biomass measured in pounds per acre on 10 replicate sites in the Center Well (CW) pasture, 2016. 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).

Treatment	April	July	September
GKR and cattle	1513 ± 316	1009 ± 184	665 ± 162
GKR only	1805 ± 220	1750 ± 296	1140 ± 233
No GKR or cattle	2118 ± 469	1523 ± 180	1611 ± 369

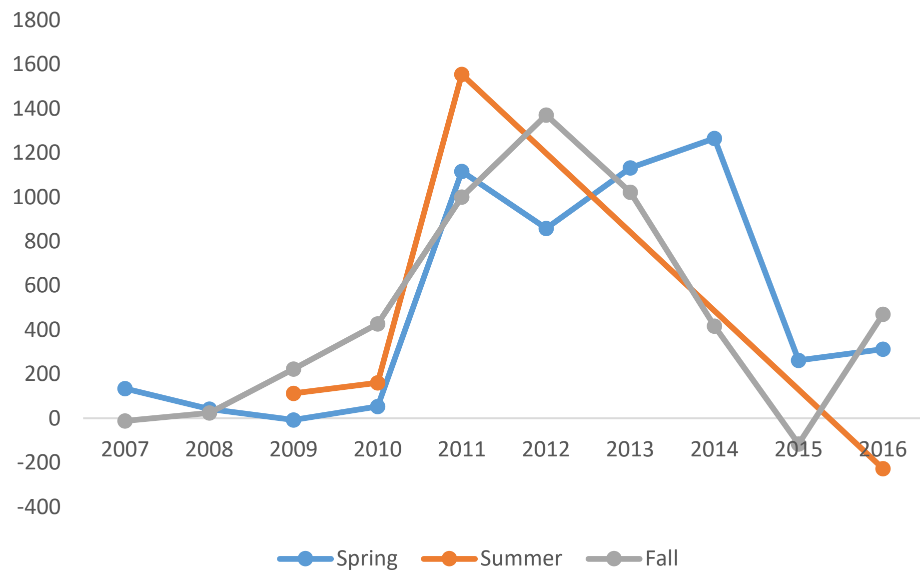


Figure 12. Biomass removal in Center Well pasture by GKR from 2007-2016, measured as the difference in biomass in and out of GKR exclosures.

Gopher Activity

No gopher (*Thomomys bottae*) activity was recorded in 2016. In 2015 only 5 sites had gopher activity (Table 5). Gopher activity was low in the previous dry years and was first seen in multiple exclosures in 2010 with trapping initiated in 2011.

Table 5. Gopher activity

	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%
2013	80%	40%	10%	100%	70%
2014	40%	10%	0%	90%	60%
2015	40%	10%	0%	0%	0%

GKR Abundance

A total of 1,641 individual kangaroo rats were captured in 2016, 1,502 of which had not been previously marked. Including recaptures, a total of 4,073 giant kangaroo rat captures occurred. Total trap effort was 10,863 traps*nights.

Captures of *Peromyscus maniculatus* and unknown rodents remained similar in 2015 and 2016 (*Peromyscus*: 2015: 32, 2016: 25, Unknown: 2015: 7, 2016: 5). Numbers for *Perognathus* species declined from 20 in 2015 to 11 in 2016. *Onychomys* species nearly doubled from 12 species in 2015 to 23 in 2016. The most significant changes in non GKR rodents was seen in the two other kangaroo rat species. *Dipodomys hermenii* rose from 1 capture in 2015 to 14 captures in 2016 and *Dipodomys nitratoides brevinasus* numbers rose dramatically from 26 in 2015 to 269 in 2016.

Mark-recapture estimates of GKR abundance during both trapping sessions were variable among sites with 0.81 to 67.96 GKR per plot (Table 6). Apparent survival rates varied from 0.70 to 1.00 (Table 7).

Grazed plots had higher GKR densities than ungrazed plots in both spring and summer but results were not significant, though the summer p-value was very close to significance (spring: t = 0.26312, P = 0.7984, n = 10, summer: t = 2.1657, P = 0.05852, n = 10). GKR densities were higher in Center Well pasture than in Swain pasture in both spring and summer but results were only significant in summer (t = 2.6134, P = 0.02812, n = 10).

Overwinter apparent survival was high and summer apparent survival was the highest ever seen in the study (Figure 14). Nearly half of the juveniles captures in spring 2016 were recaptured during summer trapping and had matured to adults. Reproduction remained similar to 2015, increased from the past few years, with 0.13 juveniles per adult.

The seasonal genital lesions (likely trombiculid mites) that appear in August trapping sessions decreased to 31% this year from 58% in 2015.

GKR estimates on each plot were not correlated in spring 2015 and spring 2016 but were correlated in the summer sessions (r = 0.542, P = 0.05, n = 30).

Table 6. GKR population size and site fidelity (apparent survival) estimates. The number of GKR on each plot were estimated for the April and August 2016 mark-recapture sessions. The proportion of GKR remaining on each site between trapping periods was also estimated (site fidelity). 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	37.88	1.99	51.65	2.51	0.90	0.08
Center Well	Grazed	C2	38.81	1.16	61.81	1.70	1.00	0.01
Center Well	Grazed	C3	30.35	1.76	57.82	2.30	0.92	0.07
Center Well	Grazed	C4	26.99	1.59	46.52	1.29	0.80	0.09
Center Well	Grazed	C5	50.50	0.81	67.96	0.90	0.90	0.03
Center Well	Grazed	C6	12.67	1.52	29.25	1.27	0.70	0.12
Center Well	Grazed	C7	50.78	1.61	58.58	2.41	0.72	0.09
Center Well	Grazed	C8	30.14	1.34	50.08	1.48	0.90	0.03
Center Well	Grazed	C9	45.28	0.95	57.88	1.04	0.92	0.03
Center Well	Grazed	C10	34.09	1.30	64.02	1.44	0.91	0.03
Center Well	Ungrazed	E1	28.31	1.45	40.20	1.90	0.88	0.10
Center Well	Ungrazed	E2	40.22	2.04	63.76	2.95	1.00	0.01
Center Well	Ungrazed	E3	37.08	1.32	48.84	1.72	0.91	0.08
Center Well	Ungrazed	E4	31.45	1.82	47.91	1.47	0.82	0.09
Center Well	Ungrazed	E5	44.84	0.86	64.35	0.96	0.89	0.03
Center Well	Ungrazed	E6	11.17	1.21	17.83	0.99	0.76	0.11
Center Well	Ungrazed	E7	45.13	1.81	58.29	2.73	0.73	0.09
Center Well	Ungrazed	E8	41.62	1.67	57.83	1.82	0.90	0.03
Center Well	Ungrazed	E9	39.10	0.91	39.67	1.00	0.90	0.03
Center Well	Ungrazed	E10	33.07	1.11	43.81	1.21	0.90	0.03
Swain	Ungrazed	S1	46.14	0.97	47.72	1.07	0.89	0.03
Swain	Ungrazed	S2	33.57	0.85	40.04	0.95	0.89	0.03
Swain	Ungrazed	S3	41.28	0.96	57.88	1.07	0.90	0.03
Swain	Ungrazed	S4	46.20	0.98	45.78	1.07	0.89	0.03
Swain	Ungrazed	S5	37.86	0.98	36.38	1.09	0.86	0.04
Swain	Ungrazed	S6	41.82	4.07	42.42	1.83	0.79	0.07
Swain	Ungrazed	S7	34.81	3.74	51.41	1.87	0.81	0.07
Swain	Ungrazed	S8	0.81	0.47	15.96	0.56	0.83	0.05
Swain	Ungrazed	S9	7.69	0.43	18.81	0.51	0.88	0.04
Swain	Ungrazed	S10	29.18	0.98	46.76	1.10	0.92	0.02

Table 7. Age and sex composition of Giant Kangaroo Rats captured in 2016.

		Female	Male	Unknown	Total
GKR	Adult	527	876	13	1416
	Juvenile	32	155	3	190
	Unknown	2	2	31	35
	Total	561	1033	47	1641

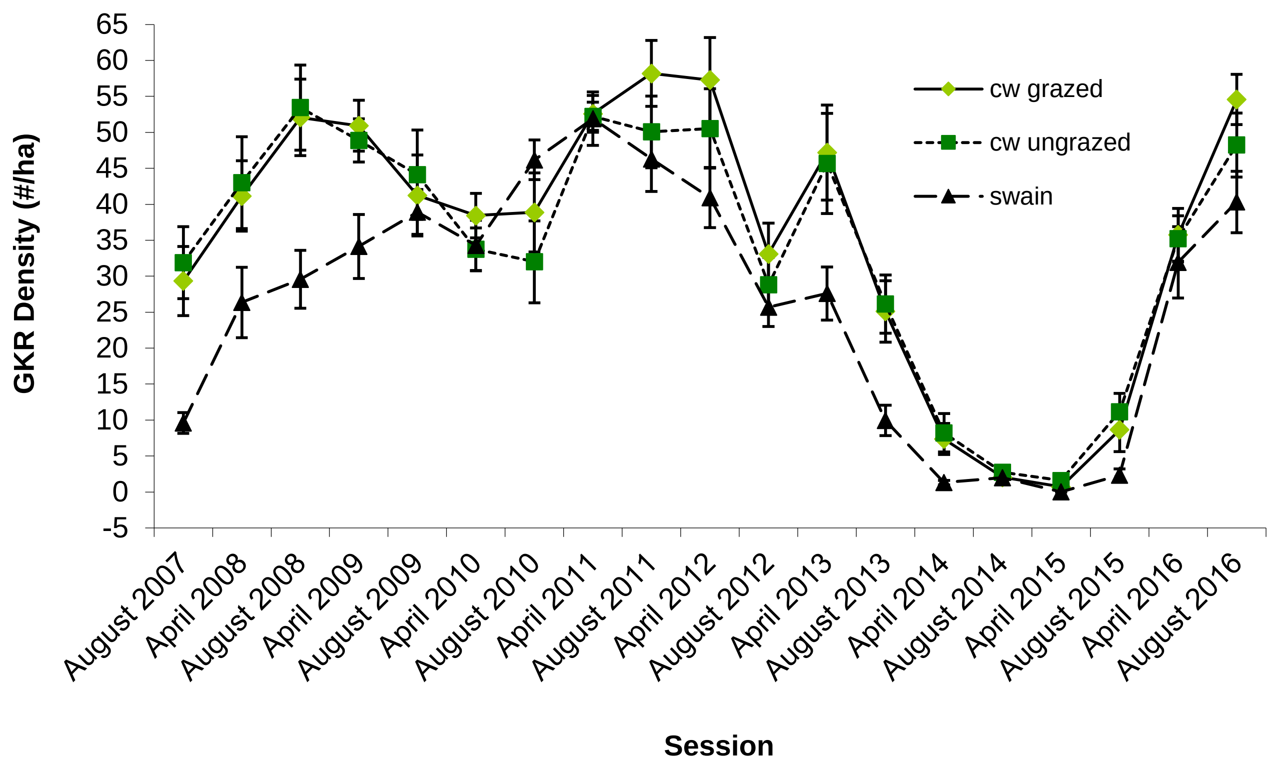


Figure 13. Average GKR population estimates in Center Well grazed plots, Center Well ungrazed plots, and Swain ungrazed plots, from April 2008 to August 2016. Standard error bars are shown (*n* = 10 grids per treatment).

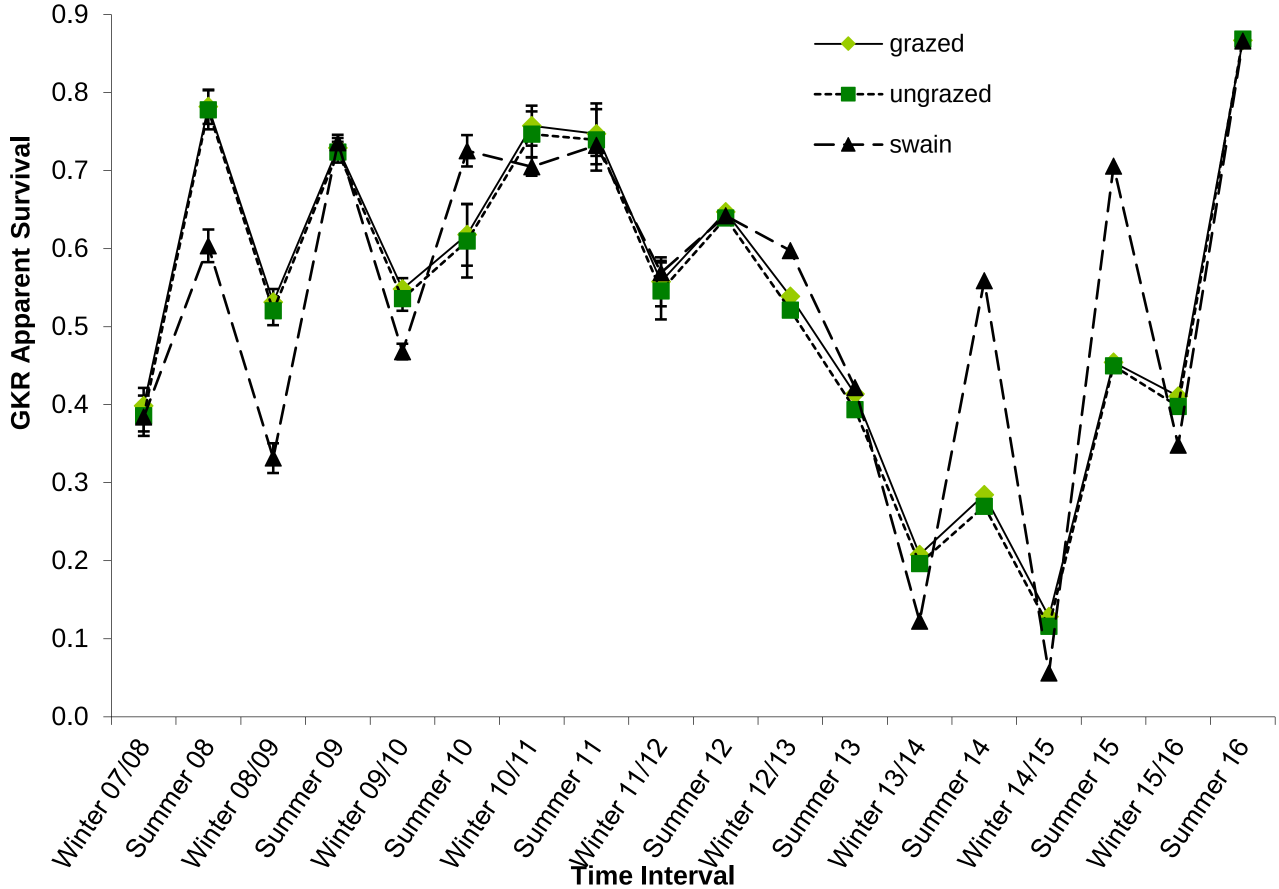


Figure 14. Average GKR apparent survival (site fidelity) estimates in Center Well grazed plots, Center Well ungrazed plots, and Swain ungrazed plots, from winter 2008 to summer 2016. Standard error bars are shown (n = 10 grids per treatment).

GKR Supplemental Feeding Plots

Three new plots were installed in Swain Pasture in 2015, following the same grid design as this study, though without kangaroo rat exclosures. The plots were installed for a supplemental feeding study led by California Fish and Wildlife under Bob Stafford. The three plots were set up adjacent to CPEP Swain plots 1-3. Data on the supplemental plots was similar to data on CPEP Swain plots.

A total of 83 individual kangaroo rats were captured on the supplemental feeding plots. Including recaptures, a total of 167 giant kangaroo rat captures occurred. Total trap effort was 360 traps*nights.

There were 52 male and 31 female GKR captured and 78 adults and 5 juveniles.

Other species captured on the supplemental plots were: 1 *Peromyscus maniculatus*, 2 *Onychomys*, 1 *Dipodomys hermenii* and 110 *Dipodomys nitratoides brevinasus*.

The seasonal genital lesions (likely trombiculid mites) were present on 89% of GKR trapped on the supplemental feeding plots.

GKR Precinct Surveys

All plots were surveyed for precincts in 2016. 4,353 active and 77 inactive precincts were counted, mirroring the increase in the giant kangaroo rat population. In contrast, in 2015, with record low kangaroo rat populations, 1,041 active and 2,209 inactive precincts were counted. Swain plots had the most precincts overall and the most active precincts and ungrazed pastures had the least (Table 8).

Table 8. Total active and inactive precincts on all plots.

	Grazed	Ungrazed	Swain	Total
Active	1435	1321	1595	4351
Inactive	15	38	22	75
Total	1450	1359	1617	4426

SJAS Surveys

A total of 265 individual antelope squirrels were captured and a total of 710 captures (including recaptures) occurred. There were slightly more female captures (Table 9). SJAS densities were the highest since the peak year of 2011 (Figure 15). SJAS densities were significantly different between grazed and ungrazed plots this year (t = -2.7967, df = 9, P = 0.02083, n = 10), with more SJAS found on ungrazed plots. Swain pasture had more SJAS than Center Well but results were not significant (Grazed: t = -0.842, df = 9, P = 0.4216, Ungrazed: t = 1.8412, df = 9, P = 0.09872) (Figure 15 & 16).

Apparent survival of SJAS was significantly lower than in 2015 (t = -1.9876, df = 29, P = 0.05637) (Figure 17). Apparent survival of SJAS was not significantly different between grazed and ungrazed pastures or between Swain and Center Well pastures. Recruitment was low in 2016, with 0.16 juveniles per adult female (Table 8). SJAS estimates on each plot were not correlated between 2015 and 2016 (r = 0.27, P = 0.15; Figure 17).

Table 9. Age and sex composition of San Joaquin antelope squirrels (SJAS) captured in 2016.

		Female	Male	Total
SJAS	Adult	101	134	235
	Juvenile	11	6	17
	Unknown	0	0	13
	Total	112	140	265

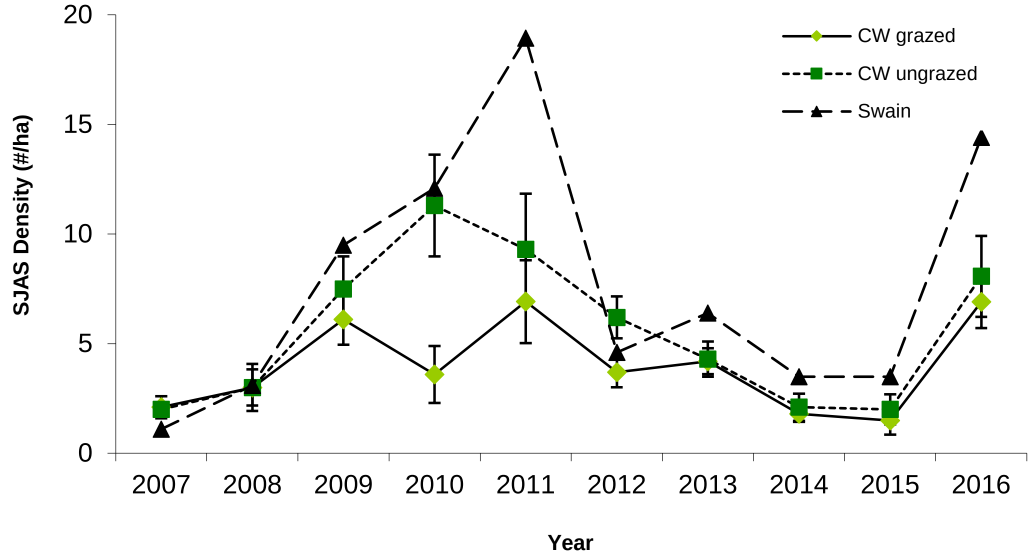


Figure 15. Estimates of San Joaquin antelope squirrel density 2007-2016. Average annual density (± standard error) in Center Well grazed plots, Center Well ungrazed plots, and Swain ungrazed plots.

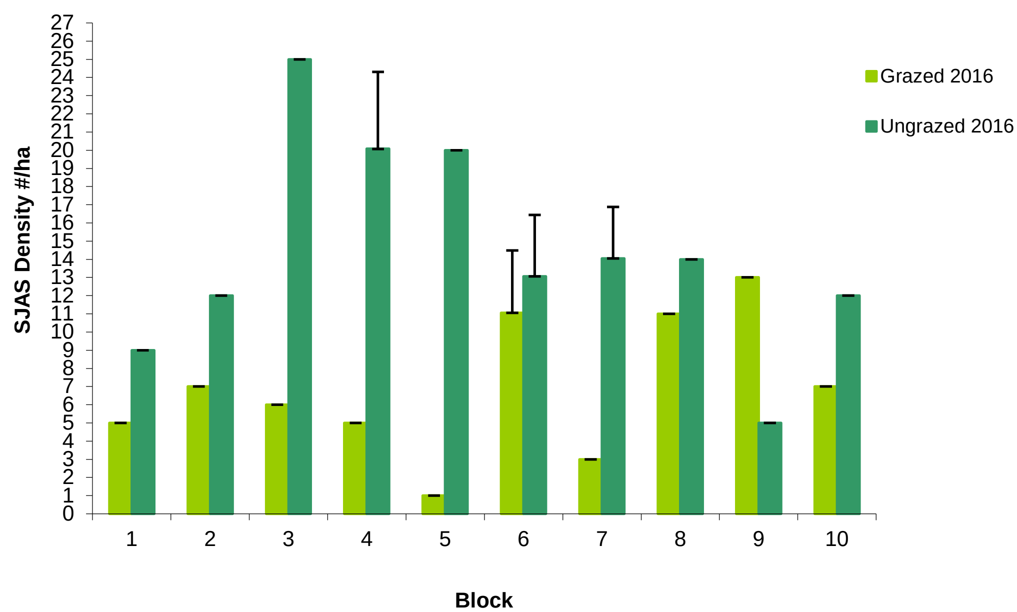


Figure 16. Average annual density (± standard error) in 2016 on each replicate site (block) in Center Well, with 95% confidence intervals.

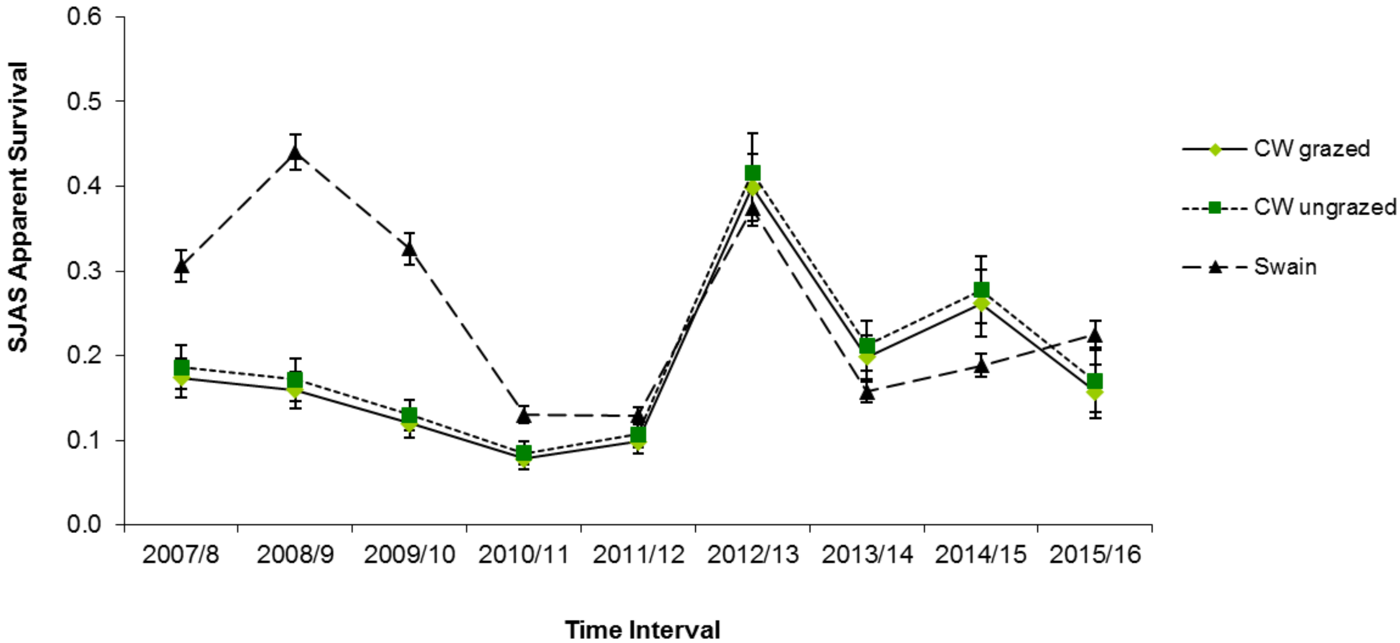


Figure 17. Apparent survival of San Joaquin antelope squirrels on Center Well grazed plots, Center Well ungrazed plots, and Swain ungrazed plots, 2007-2016. Standard error bars are shown.

Reptile abundance

In 2016, a total of 470 side-blotched lizards (*Uta stansburiana)* and 44 blunt-nosed leopard lizards (*Gambelia sila*) were seen during reptile surveys (Table 10). All blunt-nosed leopard lizards (BNLL) sightings were geo-referenced. The majority of BNLL are documented in Swain pasture, however in 2014 BNLL were documented for the first time in Center Well pasture, at site 5. Although there were no BNLL sightings in Center Well during 2015, 3 BNLL sightings were documented during reptile surveys in 2016 as well as 7 additional sightings in or near Center Well 5 during other activities. There has been a steady rise in the abundance of BNLL from the lowest measurement on record in 2013 (2) to a record high in 2016 (44). UTA abundance has also been on an increase since a record low in 2011 (42) reaching the third highest abundance on record in 2015 (470). The total UTA abundance remained constant in 2016 (470). In 2015, grazed pastures had a significantly higher number of UTAs than ungrazed pastures (t = 2.2648, P = 0.04979), but this trend did not continue in 2016 (t = -0.6767, P = 0.5156). UTA abundance in Swain pasture increased in 2016 matching the record high in 2012 (97). On top of UTA and BNLL sightings, one coast horned lizard (*Phrynosoma coronatum*) was seen during surveys in Swain pasture (Swain 10).

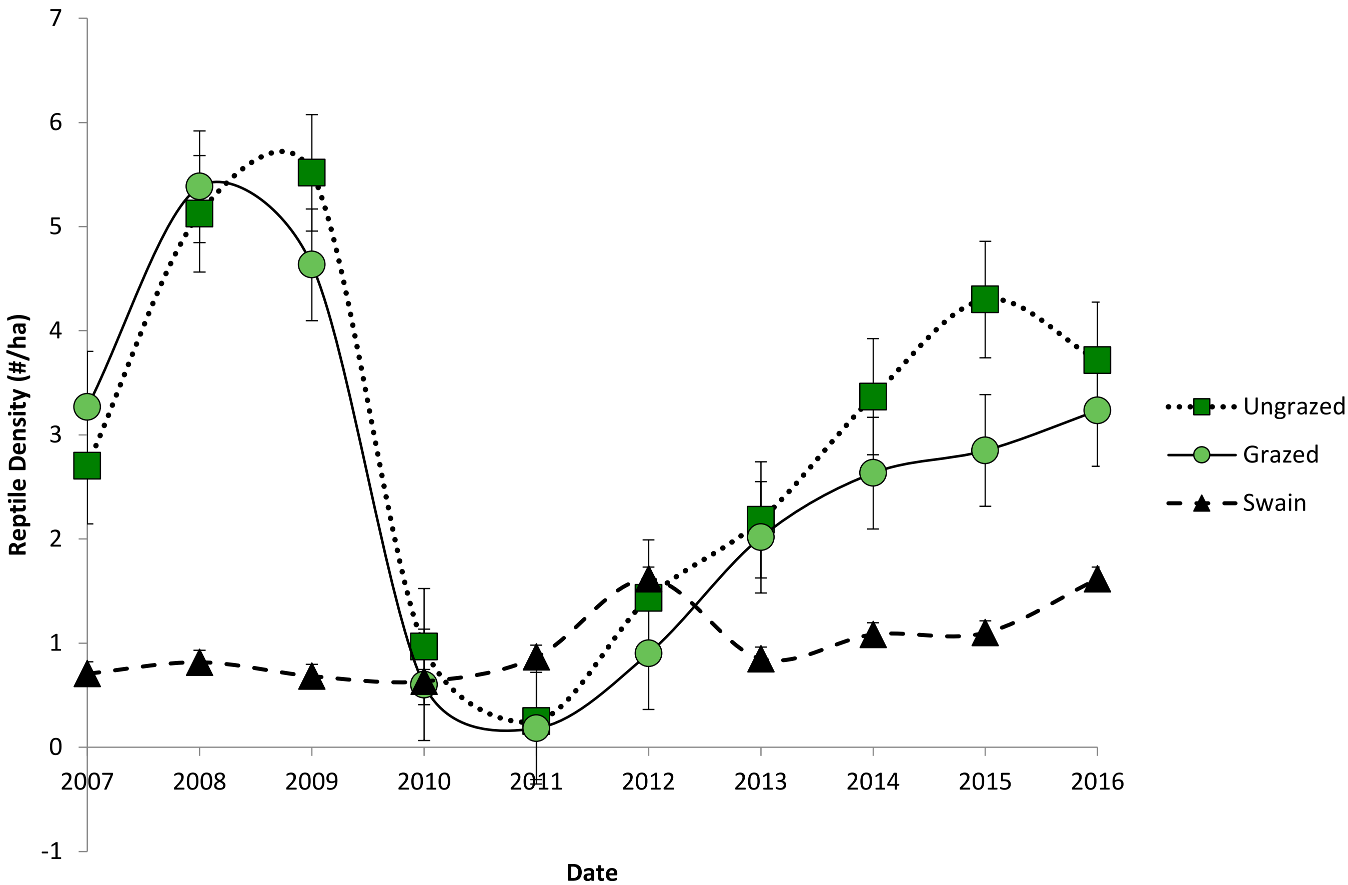


Figure 18. Estimates of reptile density each year (2007-2016) from 3 replicate surveys on Center Well grazed plots, Center Well ungrazed plots, and Swain ungrazed plots. Standard error bars are shown.

Table 10. Totals of Blunt Nosed Leopard Lizards (*Gambelia sila)* and Side Blotch Lizards (*Uta stansburiana)* from 2007-2016.

Species	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
UTA	419	675	631	114	42	200	301	414	470	470
BNLL	4	7	19	18	36	37	2	11	25	44

Invertebrates

Invertebrate identification continues to run 1 year behind reporting and 2015 data is discussed here.

GKR exclosures continued to have effects on the invertebrate community in 2015. Where GKR were present, there were a higher number of beetles (Figure 19 & 20 t = 2.6156, *P* = 0.01232). Orthopterans and ants were more common where GKR were absent (Figure 19 & 20, t = -2.6626, *P* = 0.01094, t = -3.6288 *P* = 0.000766). Grazed areas had higher richness than ungrazed areas and orthopterans were more common in ungrazed areas (Figure 19 & 20, t = -4.7818, *P* = 7.121e-06). In 2012 there was a record high for invertebrate biomass due to the large number of orthopterans. In 2013 biomass levels dropped to record lows in all but the cattle exclosures and in 2014 biomass levels remained low. In 2015, biomass increased close to average levels (Figure 19 & 20).

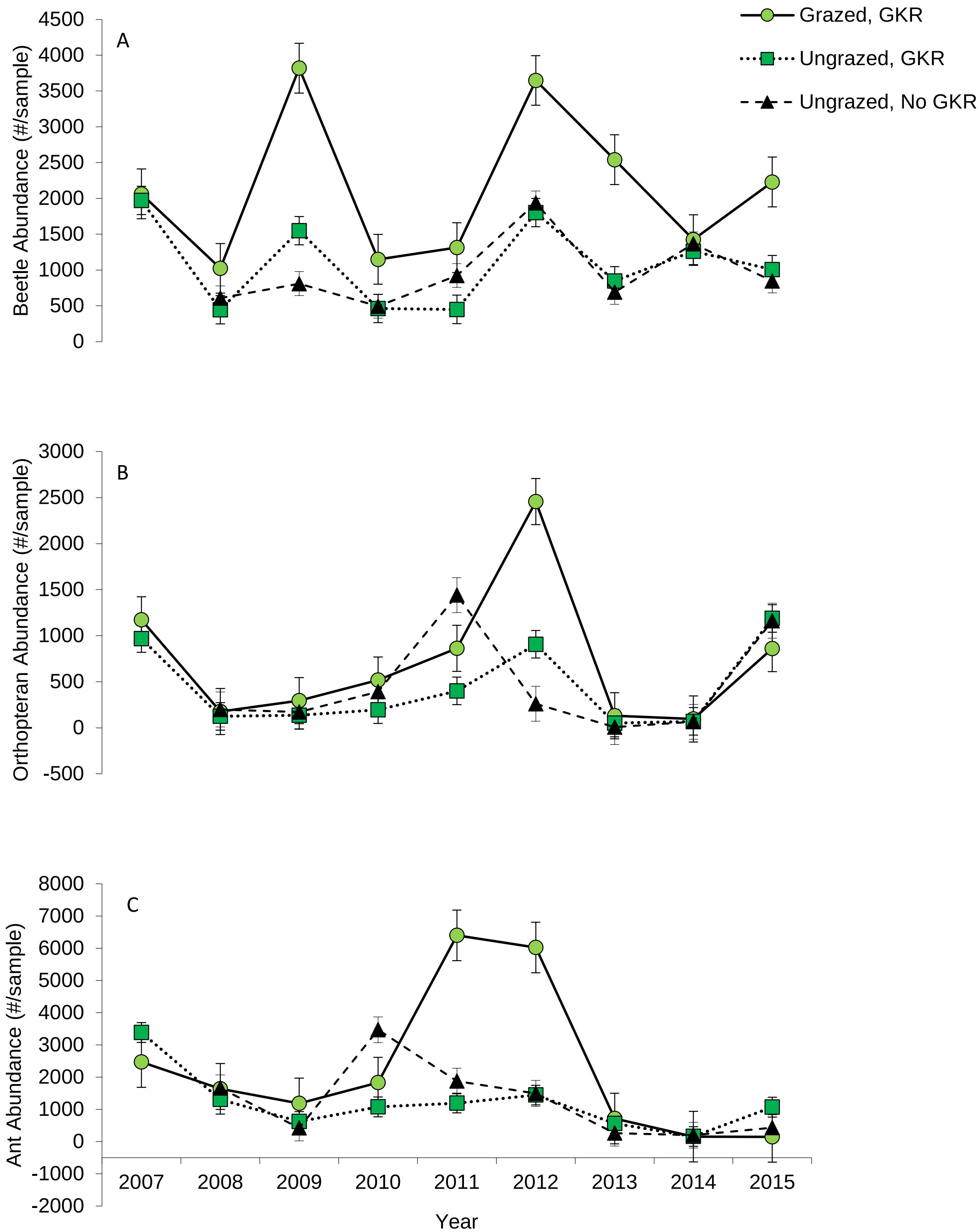


Figure 19. Response of (A) beetle, (B) orthopteran and (C) Ant abundance to GKR and cattle exclosures in the Center Well pasture, 2007-2015. Standard error bars are shown.

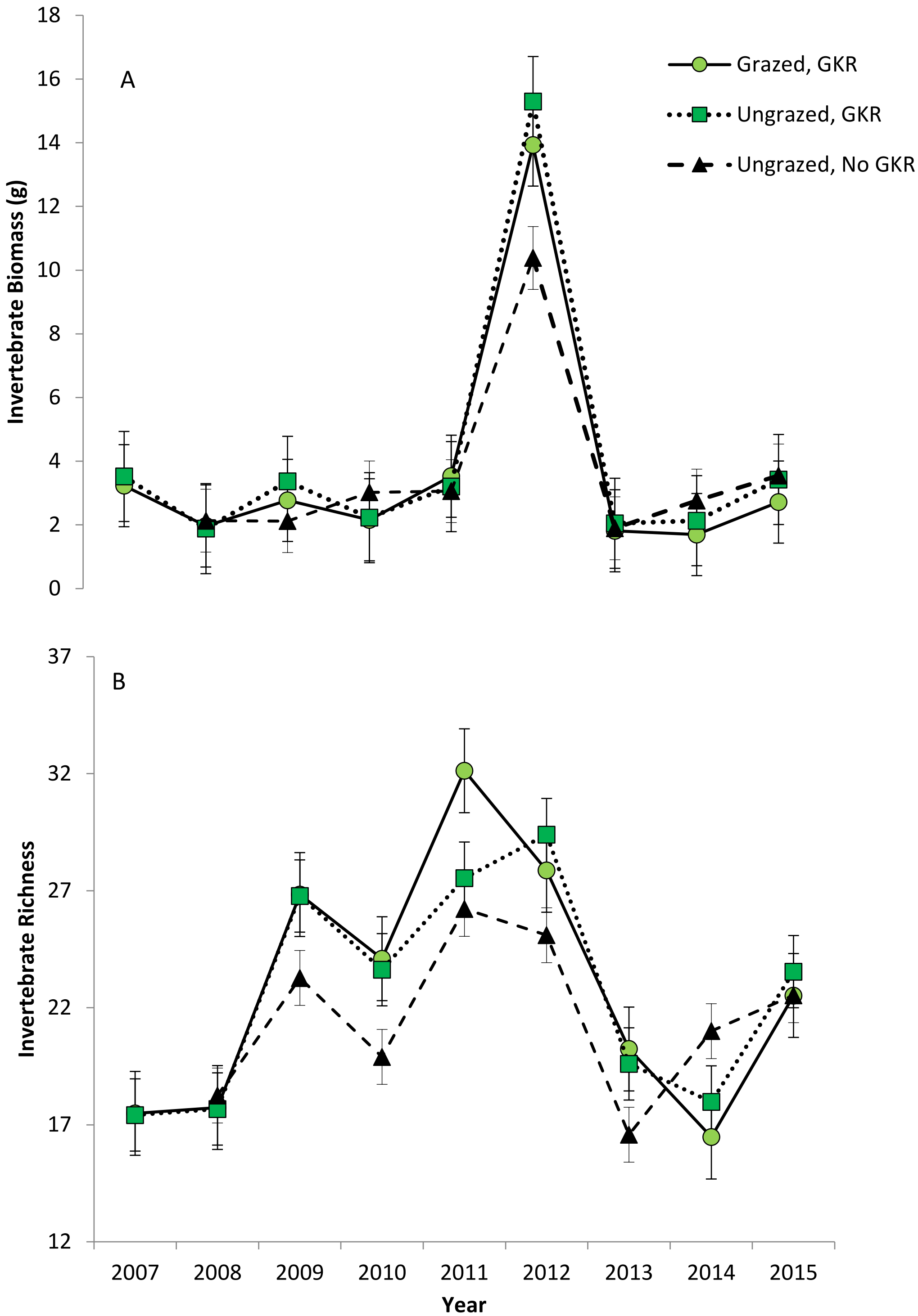


Figure 20. Response of invertebrate biomass (grams) (A) and richness (B) to GKR and cattle exclosures in the Center Well pasture, 2008-2015. Standard error bars are shown.

Kit Fox Dens

All plots were surveyed for kit fox dens in 2016. Only 14 dens were identified in 2016, half were active and half inactive. It is likely that all dens were not detected, perhaps due to higher vegetation levels, as 100 kit foxes were seen during spotlighting in 2016. In past years, high numbers of kit fox sightings corresponded with high numbers of kit fox dens. For example in 2015 only 49 kit foxes were seen during spotlighting, yet 89 inactive dens were found and in 2014 with 144 kit fox sightings during spotlighting, there were 28 active and 144 inactive dens. In 2016 only 7 plots had kit fox dens. Active dens were recorded on one grazed plot and two swain plots and inacitive dens found in two cattle exclosures and three swain plots. In 2013 active dens were more common in cattle exclosures but in 2014 active dens were common on both control and exclosure plots. In 2014 and 2015 cattle exclosures had the greatest number of inactive and active dens combined.

Species associations

Table 11 shows the associations among the flora and fauna on our plots. GKR density and survival are often negatively associated with squirrel densities, but in 2016 there was a slight, though not significant, positive association between them. There was a strong correlation between plant diversity and richness and plant height and biomass. GKR survival was correlated with GKR density and lizard density was also correlated with GRK density and survival.

Table 11. 2016 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.

2016	*N squirrels*	*N* GKR	GKR survival	*N lizards*	Plant Height	Plant Biomass	Plant Diversity
N GKR	0.27						
GKR survival	0.15	**0.57**					
N Lizards	-0.08	**0.57**	**0.52**				
Plant Height	**-0.36**	0.15	**0.35**	0.29			
Plant Biomass	**-0.37**	0.01	0.21	0.16	**0.56**		
Plant Diversity	0.01	0.13	**0.38**	0.31	**0.34**	-0.05	
Plant Richness	0.00	0.02	**0.34**	0.23	0.42	0.02	**0.95**

Conclusions and Future Directions

2016 was a year of recovery at all trophic levels in the Carrizo plain. Rainfall led to a large amount of vegetation and cattle were grazed for the first time in four years. Precipitation increased again from 2015 and vegetation levels remained close to 2015 increases, after three years of drought and severe drops at all trophic levels. Swain native cover was an exception, with richness and percent cover dropping from 2015 levels.

Cattle were grazed for the first time since 2011. The peak residual dry matter (RDM) prior to grazing by cattle was approximately 1,513 pounds per acre in 2016. Biomass removal by GKR was higher in the fall than in the spring. Data showed that there was more biomass outside the GKR exclosures than inside in the summer however this may have been due to errors and absences in vegetation collection. A familiar trend was seen on grazed verses ungrazed plots with more GKR on grazed and more SJAS on ungrazed plots.

Captures of non-GKR species remained high in 2016, especially among other kangaroo rat species. Captures of non-GKR species began to rise as GKR populations fell between 2013 and 2015 and GKR tend to dominate and exclude other rodent species. Though GKR populations rose in 2016, resident non-GKR populations likely also benefited from the high vegetation levels. Declines in non-GKR species may be seen in 2017 if GKR populations remain high.

GKR overall density increased dramatically from 2015, rising to the third highest level of the study. GKR apparent survival was the highest ever seen. Nearly half of all juveniles captured in spring 2016 were recaptured in the summer. All plots were surveyed for precincts in 2016. 4,353 active and 77 inactive precincts were counted, mirroring the increase in the giant kangaroo rat population.

SJAS density was the highest since 2011, however apparent survival was lower than in 2015 and recruitment was low. SJAS populations may have still been in recovery in 2016 and higher survival and recruitment levels may be seen in 2017.

There has been a steady rise of BNLL since 2013, when only two BNLL were recorded during surveys to a record high in 2016. UTA lizards have also been increasing from a low in 2011 to 2015 and 2016 numbers which are the third highest densities recorded.

Precipitation plots were installed in fall of 2014 and preliminary data is being reviewed. The plots were re-installed in 2015 and 2016.

Products of the Carrizo Plain Ecosystem Project

51) Deguines, N., Brashares, J.S., Prugh L.R. 2017. Precipitation alters interactions in a grassland ecological community. Journal of Animal Ecology.
50) Deguiines, N. 2017. Effets du climat sur un écosystème aride californien (Climate effects on an arid ecosystem in California"). Talk presented at the National Museum of National Museum of Natural History. Paris, France.
49) Grinath, J.B., Deguines, N., Chesnut, J., Prugh, L.R., Brashares, J.S., Suding, K.N. In Review. Precipitation legacies drive strength of ecosystem engineering effects. Ecology. In Review.
48) Grinath, J.B., Deguines, N., Prugh, L.R., Brashares, J.S., Suding, K.N. 2016. Lagged effects of precipitation drive plant community composition responses to ecosystem engineering. Ecological Society of America Annual Meeting in Ft. Lauderdale, FL (August 7-12, 2016). (presentation)
47) Casto, G., Grinath, J.B., Gabbert, W., Bullock, M., Vittoria, K., and Suding, K.N. 2016. Nitrogen and water availability alter germination of grassland annual plants. UC Boulder Ecology and Evolutionary Biology Undergraduate Poster Fair, Boulder, Colorado. (poster)
46) Gabbert, W., Grinath, J.B., Casto, G., Bullock, M., Vittoria, K., and Suding, K.N. 2016. Effects of nitrogen and water availability on an invasive grass, Hordeum murinum. UC Boulder Ecology and Evolutionary Biology Spring Symposium, Boulder, Colorado. (poster)
45) Deguiines, N. 2015. Precipitation effects on a semi-arid food web – Preliminary findings from the Carrizo Plain ecosystem. Talk presented at the annual Ecological Society of America. Baltimore, Maryland.
44) Deguines, N. 2015. Carrizo Plain Ecosystem Project Educational Brochure. Available on request and in the Goodwin Education Center.
43) Doran, B. 2015. Observer bias of giant kangaroo rat precinct indexing. The Wildlife Society Student Conclave poster competition, Kingsville, Texas. (poster)
42) Endicott, R. 2015. Carrizo Plain Ecosystem Project combined report 2014 & 2015. Prepared for agency partners. 37p.
41) Moran, M. 2015. Nighttime Investigation. Developed by the Learning Design Group at the University of California, Berkeley's Lawrence Hall of Science. Brooklyn: Amplify. Print.
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