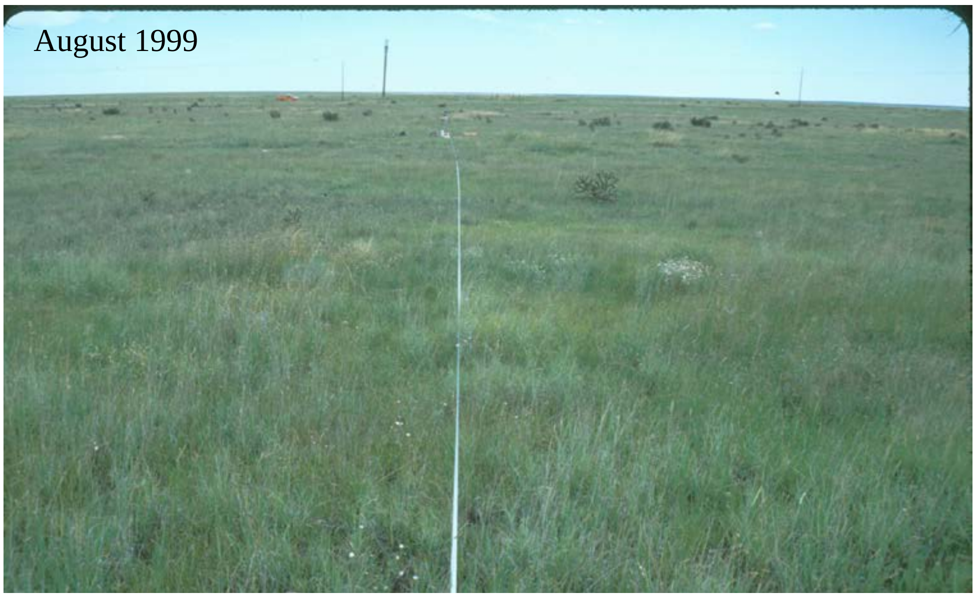
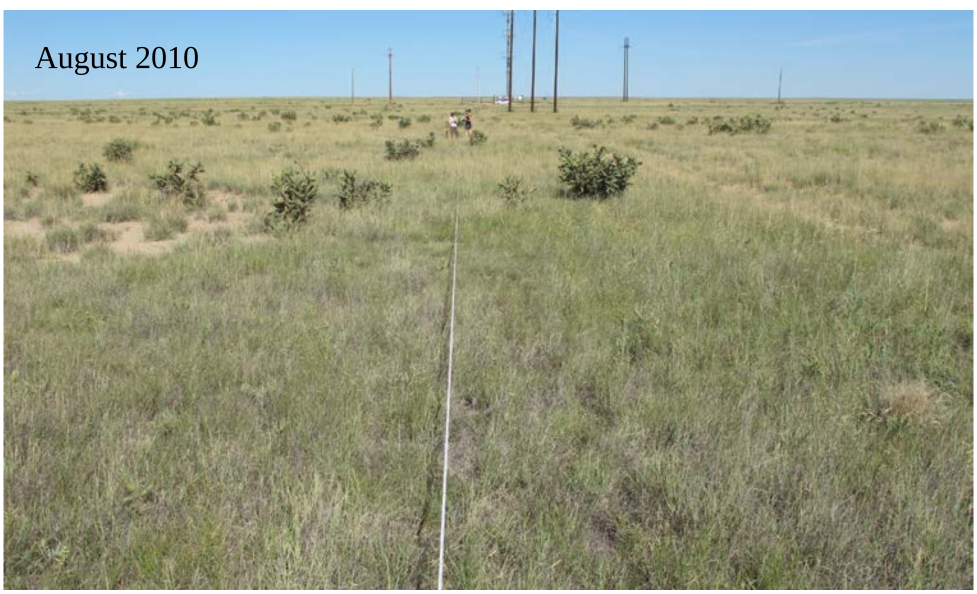
VEGETATION MONITORING

AT PUEBLO CHEMICAL DEPOT:

1999-2010





Natural Heritage Program Colorado

Colorado State University
Knowledge to Go Places

Cover photos: Plot sg65 west end in 1999 and 2010. The overall average cholla density at Pueblo Chemical Depot increased 35% following the 2002 drought, on average, cholla gained 118 plants/hectare. The power line was established in 2004.

VEGETATION MONITORING
AT PUEBLO CHEMICAL DEPOT:
1999-2010

Renée J. Rondeau

Colorado Natural Heritage Program

Colorado State University

College of Natural Resources

Campus Mail 1475

Fort Collins, CO 80523-1475

E-mail: renee.rondeau@colostate.edu

July 2013

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

Executive Summary

In 1998 the U. S. Fish and Wildlife Service (USFWS) contracted the Colorado Natural Heritage Program to set up a long-term vegetation monitoring program on U.S. Army Pueblo Chemical Depot (PCD) in Pueblo County, Colorado. The monitoring program was established to detect vegetation changes in shortgrass prairie, sandsage shrubland, and greasewood shrubland as a result of the removal of cattle grazing in 1998. Each vegetation type included areas with four different historic cattle grazing regimes: 1) grazed year-round until 1998, 2) grazed, but not year-round, until 1998, 3) grazed lightly (several times/year) since 1942, and 4) ungrazed since 1942. For the purpose of this study I consider the first two regimes "grazed" and the latter two regimes "ungrazed." All further reference to the "grazed" regime refers to its historical use prior to 1998. During the 1999-2010 years of monitoring neither grazed nor ungrazed study plots discussed in this report received any livestock grazing.

To detect temporal changes in species canopy cover, composition, density, and frequency, I established randomly chosen permanent vegetation monitoring plots in 1998. Half of the plots were placed in each of the two treatments (grazed and ungrazed areas). After a power analysis following the 1998 field season, I added ten new plots though four existing plots were found to be disturbed and were subsequently dropped. In 2001, I added two additional plots on active prairie dog colonies. During 1999, 2000, 2001, 2002, 2003, and 2010, I re-sampled the plots between August 4 and September 22. This report eliminates the 1998 dataset due to incompleteness.

For greasewood shrubland I established 13 plots (7 grazed and 6 ungrazed), for sandsage shrubland I established 11 plots (5 grazed and 6 ungrazed), and in shortgrass prairie I established 12 plots (7 grazed and 5 ungrazed). Plot gw04ug in the greasewood shrubland and plot sg63ug in the shortgrass prairie still have pass-through cattle grazing and although I re-sampled the plots each year, I have eliminated them from this analysis. Eight of the shortgrass prairie plots were located within prairie dog towns. In the riparian area of Chico Creek I established 10 photo plots (5 grazed and 5 ungrazed). These plots do not have quantitative

data associated with them. The ungrazed portion of Chico Creek still has pass-through cattle for several days in the spring and fall.

Repeated measures analysis of variance (ANOVAs) were used to assess differences among years, while unpaired *t*-tests or Mann Whitney *U*-tests were used to determine if there were differences between dominant species in grazed versus ungrazed areas in 1999.

Grazed versus ungrazed. There was no significant difference between grazed and ungrazed plots for shrubs including greasewood, rabbitbrush, cholla, and sandsage. However, sandsage was nearly significant (P=0.08) with 20% higher cover and 13% higher density in grazed plots than ungrazed in 1999; by 2010 the difference in cover had been greatly reduced and the difference in density had been eliminated. Prickly pear occurs in all of the habitats and did not exhibit a difference between grazed and ungrazed plots.

Grasses had a varied response to grazing and often depended on the habitat type. Alkali sacaton grass and blue grama, the dominant grasses, did not exhibit any significant difference between grazed and ungrazed plots in any habitat type. Galleta grass, sand dropseed, three-awn grass, and needle-and-thread grass had a significant difference between grazed and ungrazed plots in at least one habitat. For galleta grass in the greasewood and shortgrass habitats, there was a significantly lower frequency ($P \leq 0.05$) in grazed plots compared to ungrazed plots (33% vs 61%). By 2010 the difference had been reduced although not eliminated; the grazed plots gained more individuals than the ungrazed plots and in 2010 the frequency was 38% in grazed compared to 63% in ungrazed. This supports the “decreaser” status of galleta grass at PCD, that is, that galleta grass decreases with cattle grazing.

Three-awn grass is considered an “increaser” but it only exhibited this character in the greasewood habitat where there was significantly higher frequency ($P \leq 0.05$) in grazed plots versus ungrazed plots; this difference was eliminated by 2010. Sand dropseed, also considered an “increaser,” exhibited this status in sandsage habitat but not in the greasewood or shortgrass habitats. Sand dropseed, in the sandsage habitat, had significantly higher frequency

(P≤0.01) in grazed (96%) compared to ungrazed plots (72%) in 1999 and this difference was still evident in 2010 with 94% frequency in grazed and 64% in ungrazed plots.

Needle-and-thread grass, a "decreaser" at PCD, only occurs in the sandsage habitat. In 1999, grazed plots had an average frequency of 9% compared to 61% in the ungrazed plots (P≤0.05). By 2010 this difference had been greatly reduced with an average frequency of 25% in grazed plots and 58% in ungrazed plots; thus the elimination of cattle grazing in the sandsage habitat has benefitted needle-and-thread grass.

Bare ground was a good indicator of grazing, especially in the greasewood and shortgrass habitats. In the greasewood habitat, bare ground had significantly higher cover in grazed plots (28%) compared to ungrazed (17%) in 1999 (P=0.003). A convergence was evident and by 2001 the difference between grazed and ungrazed was no longer evident. Bare ground in the shortgrass habitat exhibited a similar pattern as in the greasewood habitat with significantly more bare ground in grazed plots (42%) than ungrazed plots (24%) in 1999 (P=0.004). This difference was still evident in 2010, potentially due to the presence of prairie dogs.

Kochia and Russian thistle, both annuals, are the dominant weeds within the PCD plots and were prevalent enough to measure frequency, especially in wet years. Kochia is found in the greasewood and shortgrass habitats while Russian thistle is found in all of the habitats. In greasewood plots, the frequency of kochia was significantly higher in ungrazed plots in 1999 (P≤0.01) but by 2004 this difference was largely eliminated, primarily due to an increase in the frequency of kochia in the grazed plots. Kochia showed the same trend in the shortgrass habitat. Russian thistle was similar to kochia, especially in the greasewood habitat. Looking at 2004, the peak year for Russian thistle, the frequency of Russian thistle in the ungrazed plots increased 3-fold from 2003 while the grazed plots increased 8-fold. When all habitats are combined there was a 2.5-fold increase in Russian thistle frequency in ungrazed plots and a 4-fold increase in grazed plots, supporting the argument that cattle grazing had suppressed the annual weeds and when cattle grazing was eliminated the weeds started to expand.

Drought. Annual precipitation varied over the years, from 30% above average in 1999 to 69% below average in 2002. The 2002 drought was the worst drought recorded in this area in over 100 years. The shrub and grass components responded to the drought in different ways: shrubs increased while grasses decreased. Shrub cover in the greasewood habitat significantly increased by 30% following the 2002 drought; rabbitbrush was the main contributor to this increase in cover. Shrub density in the greasewood habitat also increased, primarily due to cholla recruitment. Cholla had a significant recruitment period following the drought, gaining 34% more individuals. On average in greasewood and shortgrass habitats, cholla gained 116 plants/hectare (ha) following the drought. Sandsage, the dominant shrub of the sandsage shrubland, responded very quickly to annual precipitation. There was a 17% mortality rate of sandsage due to the 2002 drought, however, it did eventually recover from the drought and by 2010 the density was similar to pre-drought years. The prickly pear population was unaffected by the drought and did not exhibit any significant changes due to the drought.

Grasses varied in their response to the 2002 drought; from nearly no mortality in alkali sacaton grass and galleta grass to high mortality in blue grama, three-awn grass, and sand dropseed. Recovery from drought varied for the grasses that were impacted. Blue grama was surprisingly sensitive to the 2002 drought. In the shortgrass prairie habitat blue grama declined 28%, from an average of 71% frequency in 2001 to an average of 51% in 2010. Whereas blue grama in the greasewood habitat declined 24% as it went from an average of 61% in 2001 to 47% in 2010. Blue grama in the sandsage habitat was the least impacted from the drought exhibiting only a 11% difference as it went from an average of 45% frequency in 2001 to an average of 40% frequency in 2010. Where alkali sacaton grass and blue grama co-occurred, I documented a shift in dominance, with alkali sacaton grass becoming co-dominant or dominant after the drought whereas blue grama had been dominant before the drought.

Prairie dogs. There were eight plots with prairie dogs. None of the towns were active throughout the entire study as plague came through PCD multiple times. On average a town was active for 2 out of the 7 years and inactive for 4 out of the 7 years. The presence of prairie dogs in the shortgrass prairie influenced the plant composition. Prickly pear was more than twice as abundant off of prairie dog towns as on and all indications point towards prairie dogs eating prickly pear. Three-awn grass had approximately 2.5 times higher abundance on prairie dog towns than off ($P \leq 0.05$). Russian thistle had higher frequency on prairie dog towns than off, however, it was significant only in the year 2004 ($P \leq 0.05$). Blue grama, sand dropseed, galleta grass, kochia and bare ground did not exhibit any difference in frequency or cover on or off of the prairie dog towns.

Study Area and Background Information

Location and Vegetation

The U.S. Army Pueblo Chemical Depot (PCD) is located on rolling prairie in southeastern Colorado, east of the city of Pueblo, occupying about 23,000 acres (Fig. 1). The site is best characterized as a high plains ecosystem composed of a mosaic of vegetation types including shortgrass prairie, sandsage shrubland, greasewood shrubland, and riparian vegetation (Fig. 2).

Shortgrass prairie. The shortgrass prairie is the matrix community at PCD, occupying nearly 11,500 acres. Most of the shortgrass is dominated by blue grama (*Chondrosum gracile*), but a few areas are dominated by either alkali sacaton grass (*Sporobolus airoides*) or galleta grass (*Hilaria jamesii*), depending on soil type. Some areas, especially where prairie dogs occur, may also have a significant portion of three-awn grass (*Aristida* spp.). Grass canopy cover generally averages between 35-50% and bare ground generally averages between 20-55%, depending on grazing regime.

Sandsage shrubland. The sandsage-dominated prairie occupies approximately 4,000 acres at PCD and is best characterized as a very sandy substrate dominated by sandsage (*Oligosporus filifolius*) with an average of 15% canopy cover. The ground cover is often sparse with a mix of grasses and forbs, although grasses are normally more dominant than forbs (at least during August and September). Blue grama, needle-and-thread grass (*Stipa comata*), and sand dropseed (*Sporobolus cryptandrus*) are the most common grasses, but they seldom exceed 10% canopy cover. Plains buckwheat (*Eriogonum effusum*), zinnia (*Zinnia grandiflora*), and sunflowers (*Helianthus* spp.) are common forbs, and bush morning glory (*Ipomoea leptophylla*) and yucca (*Yucca glauca*) are common shrub-like plants.

Greasewood shrubland. This shrubland occupies approximately 2,400 acres on PCD with the largest occurrence along Boone Creek. This community is recognized by the presence of greasewood (*Sarcobatus vermiculatus*) with an average of 3% canopy cover; rabbitbrush (*Chrysothamnus nauseosus*) may co-dominate and cholla (*Cylindropuntia imbricata*) may be present. The grass cover averages 50% and is often dominated by alkali sacaton grass, blue grama, or galleta grass. On about 25% of the acreage, erosion has removed the surface layer, leaving barren slick spots.

Riparian. The wooded riparian habitat is found primarily on the west portion of PCD. The dominant vegetation of this wooded riparian area is plains cottonwood (*Populus deltoides*) with native bunch grasses, whereas the southern portion of Chico Creek is sparsely vegetated with some coyote willow (*Salix exigua*) and tamarisk (*Tamarix ramosissima*).

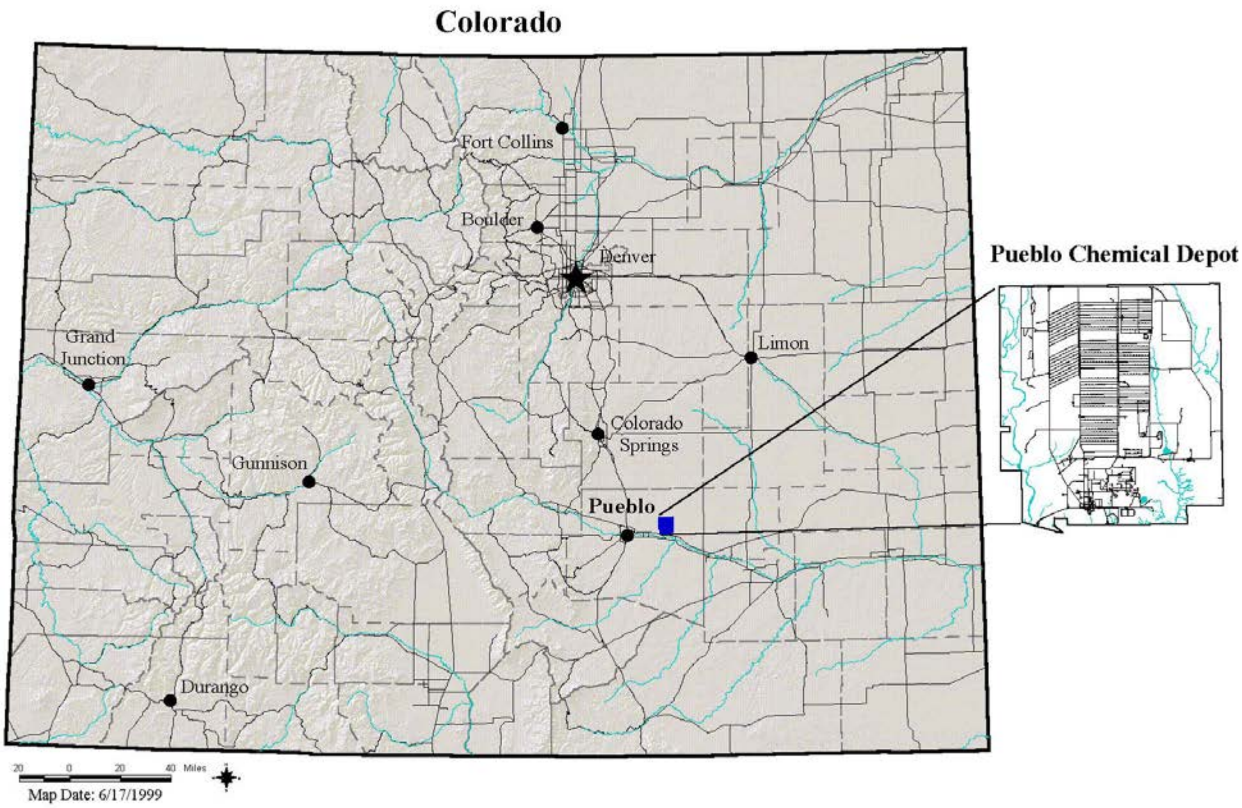


Figure 1. Location of Pueblo Chemical Depot.

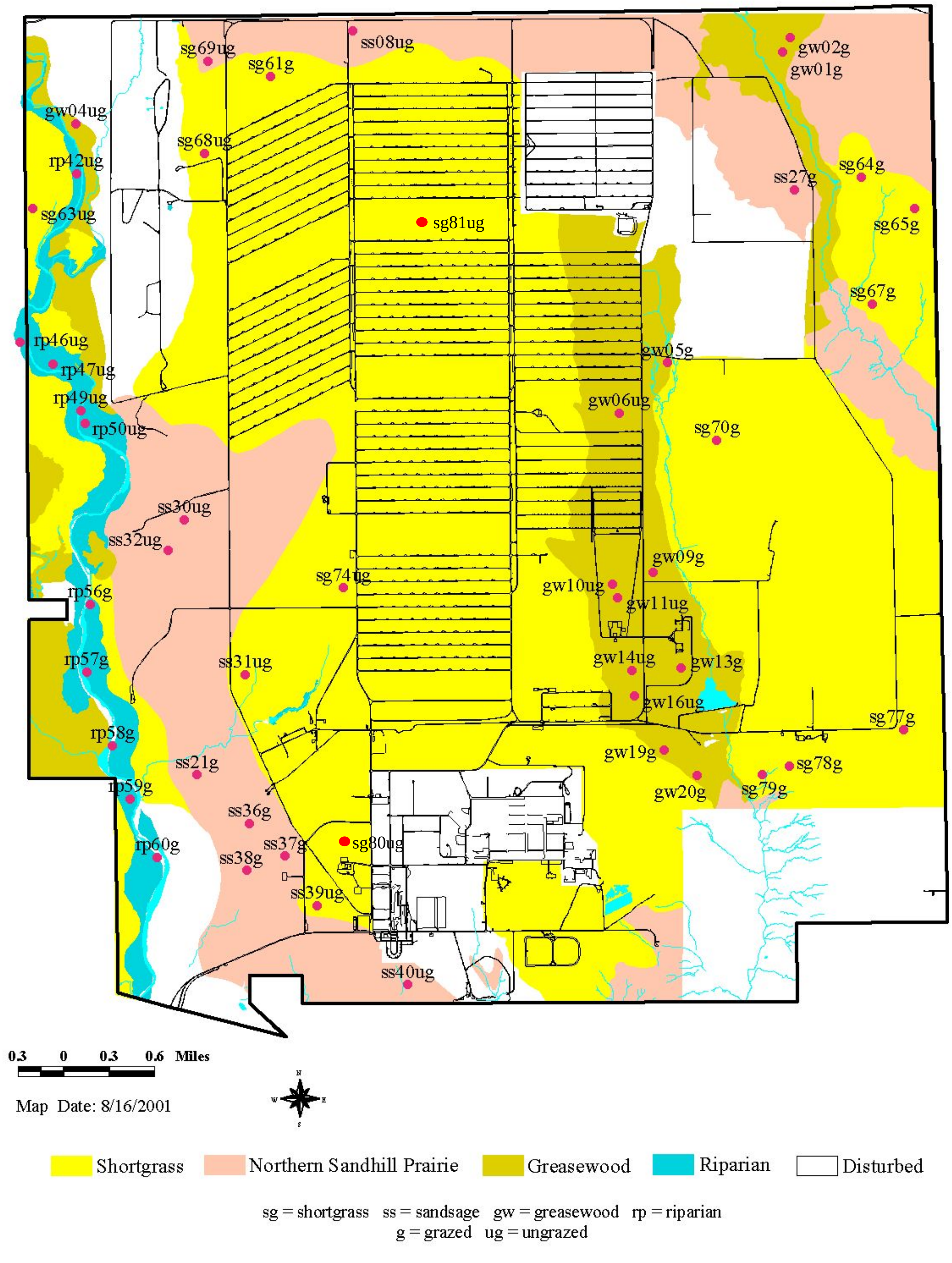


Figure 2. Vegetation types at PCD and locations of permanent vegetation sampling points.

General Site History

Prior to settlement by Europeans, the eastern plains of Colorado were inhabited by many Native American tribes that relied heavily on bison (*Bison bison*) for subsistence. Although it is unclear how large the bison herd was in this area, we are certain that bison were a major influence on shortgrass prairies of Colorado (Benedict et al. 1996). As late as 1872, buffalo could be found in the Pueblo area. Hornaday (1889: 493) stated, "On the west, a few small bands ranged as far as Pikes Peak and the South Park, but the main body ranged east of the town of Pueblo, Colorado." Although bison populations were affected as early as the 17th century with the introduction of horses (Sherrow 2001, Martin and Szuter 1999), the major extermination of bison began in the 1840s and the final and largest killings took place between 1872 and 1874 (Hornaday 1889).

Some of the most notable early expeditions to pass through the area included those of Pike (1806-1807), Long (1820), Fremont (1843-1845), Gunnison-Beckwith (1853-1854), and Wheeler (1869-1879) (National Park Handbook 116, 1982). The Long expedition traveled along the Arkansas River just south of PCD on July 20, 1820 and did not mention any large herds of bison (Evans 1997).

From at least the early 1900s to 1941, the depot property was a mixture of private and state-owned parcels with cattle ranching as the primary use. The location of the depot was selected in 1941 prior to the entry of the United States into World War II and construction began in 1942. The depot functioned as a storage, maintenance, distribution, and disposal facility for munitions and other military equipment for the U.S. Army for approximately 52 years (1942-1994). During the Korean War, the depot reached its highest civilian strength of nearly 8,000 employees. The depot was designated for realignment in 1988 with all missions except storage of chemical munitions terminated on September 30, 1994. Although all conventional munitions were removed between 1991 and 1994, mustard agent is currently stored at PCD.

Most of the ungrazed portions of shortgrass prairie have been altered by past activities. For example, in the munitions storage area considerable disturbance occurred in the process of building and maintaining the bunkers. This included seeding followed by oil application to prevent wind erosion. In addition, many ditches were built to control runoff. The combination of seeding, ditching, and a vast network of roads has altered the plant species composition in ways that make much of the bunker area inappropriate for consideration as representative of ungrazed conditions.

Climate

The following data are from the Western Regional Climate Data Center (WRCC), posted at www.wrcc.dri.edu. At the Pueblo Airport (in the vicinity of PCD), temperatures vary from a mean daily January minimum of 13.9° F (-10° C) to a mean daily July maximum of 92.9° F (33.8° C) (as of 2010). [Note: in the 2003 report (Rondeau 2003) the mean daily July maximum was 92.4° F, so there was nearly a 0.5 degree increase in the July maximum from 2002 to 2010.] From 1954 to 2010, yearly mean annual precipitation has been 11.9 inches (SD = 3.2 inches) (30 cm, SD = 8 cm), about 33% of which falls during July-August, the period of maximum plant production (Table 1, Fig. 3). On average, June experiences drought conditions with the average monthly precipitation falling below the average monthly temperature (Fig. 3). Annual precipitation varied over the years, from 30% above average in 1999 to 69% below average in 2002 (Fig. 4). On April 30, 1999 a large storm brought in more than 5 inches of rain creating a 100-year flood event in Chico Creek (average April rainfall is 1.1 inches (2.8 cm)). The timeframe of this study included a pre-drought period (1999-2001), a drought period (2002-2003) and a post-drought period (2004-2010). The 2002 drought was the most severe since local weather records were initiated in 1954, and included a growing season mean temperature approximately 1.5-2° F (1° C) higher than the long term average. The Rocky Ford weather station has data going back until 1894 and the 2002 drought was the worst recorded drought in the 115 years of record keeping.

In the PCD study area, in 2002, only 0.81 in (20.5 mm) of precipitation fell in April-June, and 1.5 in (40 mm) in July-September, with less than 3.6 in (91.4 mm) for the entire water year (October 2001-September 2002). While 2003 was only 1.3% below total average annual precipitation, one third of the precipitation fell in a single unusually wet month (June).

Table 1. Annual precipitation for water year (October-September), 1998-2010. From Pueblo WSO Station (source: WRCC).

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Annual
1998	0.83	1.53	0.38	0.1	0.17	1.94	1.88	1.04	0.68	2.42	0.93	0.41	12.31
1999	1.6	0.46	0.33	0.11	0.01	0.56	5.3	1.84	0.19	1.86	2.98	0.31	15.55
2000	0.62	0.02	0.05	0.34	0.04	2.94	1.21	0.85	0.8	3.03	0.92	0.36	11.18
2001	0.6	0.08	0.21	0.81	0.16	0.51	0.48	2.67	1.1	2.7	2	0.49	11.81
2002	0.07	0.44	0.22	0.43	0.07	0.04	0.16	0.22	0.43	0.84	0.3	0.42	3.64
2003	0.67	0.02	0.34	0.01	0.81	0.81	1.9	1.56	3.72	0.32	1.17	0.44	11.77
2004	0.08	0.04	0.05	0.51	0.65	0.55	4.85	0	1.93	0.76	3.53	0.22	13.17
2005	0.23	0.58	0.25	0.38	0.2	1.74	1.55	1.16	1.15	0.8	1.39	0.94	10.37
2006	1.6	0	0.24	0.52	0	0.62	0.16	0.98	0.24	3.13	3.78	1.64	12.91
2007	1.96	0.18	0.65	0.42	0.11	0.42	2.83	2.46	1.53	1.52	2.6	0.1	14.78
2008	0.33	0.14	0.47	0.19	0.25	0.62	0.97	0.96	0.89	1.53	2.76	0.77	9.88
2009	0.66	0.5	0.29	0.04	0.04	0.72	1.54	1.06	1.2	5.39	2.71	0.95	15.1
2010	1.92	0.05	0.18	0.19	0.77	1.01	1.14	2.84	0.9	2.28	1.76	0.07	13.11
Mean 1954-2010	0.78	0.48	0.34	0.31	0.29	0.82	1.22	1.45	1.32	1.96	2.13	0.83	11.93

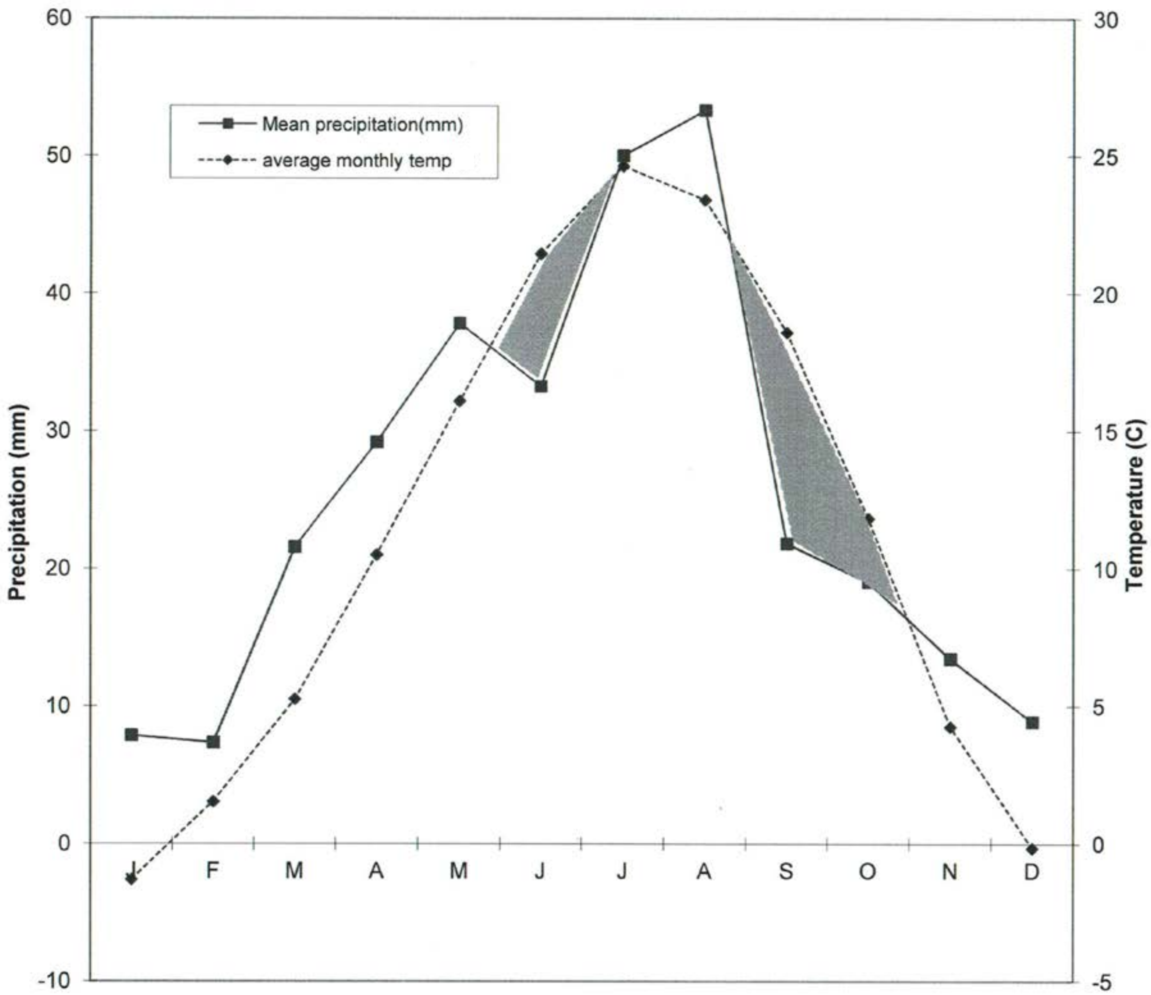


Figure 3. Mean monthly precipitation and temperature at the Pueblo Airport WSO. Shaded areas indicate where precipitation falls below temperature and represent drought conditions. Data are from 1955-2000.

July-September precipitation was 60% below average. Although the mean annual temperature for 2002 was average, the mean growing season temperature (April-September) was approximately 3° F (1° C) higher than average. Mean temperature in the growing season for 2003 was also well above the long-term average. Since 1955, only five years have had mean growing season temperatures as warm or warmer than 2002 (High Plains Regional Climate Center 2010).

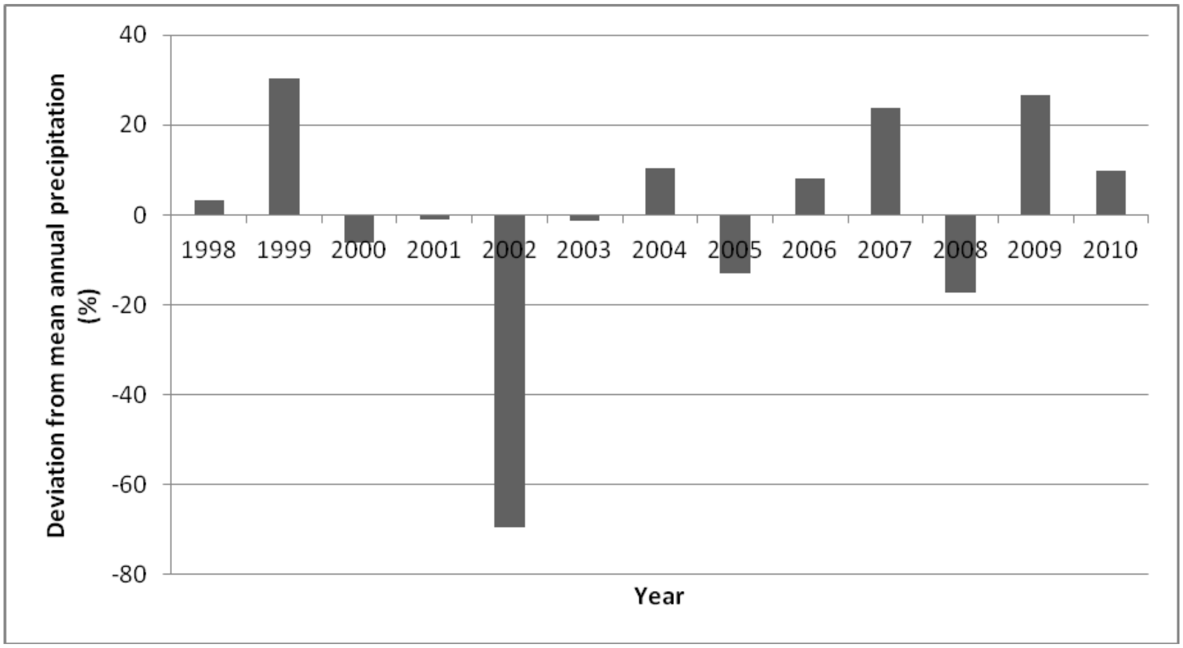
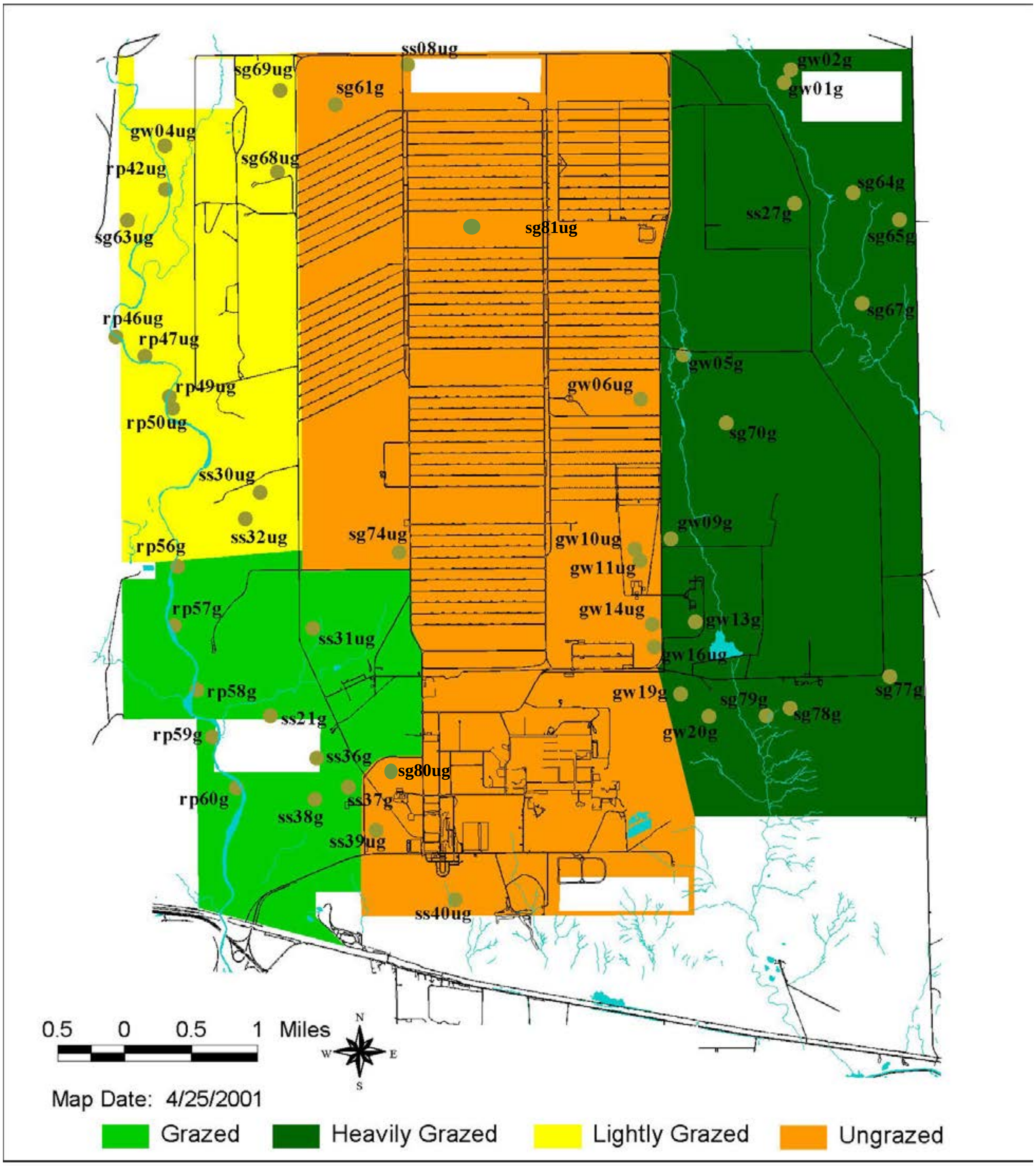


Figure 4. Deviation from mean annual precipitation at PCD (1998-2010). Water year (October-September) was used for calculating the mean. Mean is from 1955-2010.

Grazing History

PCD has experienced varied cattle grazing intensities, ranging from areas which have been ungrazed since 1942 within the munitions storage area to year-round heavy grazing in the eastern area (Fig. 5). From 1942 to 1998, cattle grazing was permitted on 7,600 of the 23,000 acres at PCD (Steranka 1996, as cited in Rust 1999). According to the U.S. Fish and Wildlife Service (1987), one cow per 35 acres was allowed, or approximately 220 head total. Although areas within the munition storage area have not been grazed by domestic livestock since acquisition of the post in 1942, this area was previously grazed. Areas within the ungrazed portion that were used for munitions storage were mechanically disturbed during construction of the weapons storage facilities in 1942. In 1995, an ecological study found differences in the amount of plant species canopy cover and relative plant abundance between the grazed and ungrazed areas (Rust 1999). Canopy cover and abundance of unpalatable grasses, forbs, and shrubs were found to be greater in grazed areas.



gw = greasewood rp = riparian sg = shortgrass ss = sandsage
g = grazed ug = ungrazed

Figure 5. Grazing regimes at PCD with locations of permanent vegetation sampling points.

The increasing shrubs included sandsage, rabbitbrush, prickly pear cacti (*Opuntia* spp.), and cholla; the increasing grasses and forbs included purple three-awn grass (*Aristida purpurea*), squirreltail (*Elymus elymoides*), blue grama, horseweed (*Conyza canadensis*), annual sunflower (*Helianthus annuus*), western ragweed *(Ambrosia psilostachya)*, and alyssum (*Alyssum desertorum*). Rust (1999) also reported decreases in canopy cover and abundance of the following plant species in response to year-round grazing: spreading fleabane (*Erigeron divergens*), side-oats grama (*Bouteloua curtipendula*), sandreed grass (*Calamovilfa longifolia*), sand bluestem (*Andropogon hallii*), and switchgrass (*Panicum virgatum*).

In June of 1998, all livestock were removed from PCD, with the exception of pass-through cattle in spring and fall along Chico Creek in the NW quarter of PCD. Although most livestock grazing has been eliminated from PCD, grazing may be reestablished in the future as a management tool.

Currently, black-tailed prairie dogs (*Cynomys ludovicianus*) and pronghorn (*Antilocapra americana*) are the primary grazers of the shortgrass prairie of PCD. The prairie dogs form large colonies that greatly influence the canopy cover and composition of the shortgrass prairie. In the early months of 1999 there were approximately 2,800 acres of live prairie dog towns at PCD. In May of 1999, plague-positive fleas were collected from prairie dog burrows and by September of 1999 prairie dog coverage had dropped over 15-fold, to approximately 160 acres. Recovery began in 2000, and as of 2002 approximately 2,000 acres were occupied and by 2005 the occupied area was approximately 3,400. In 2006 another plague event occurred and decreased the occupied area to about 2,700 acres. No prairie dog surveys have been conducted since 2006 but between 2006 and 2010 the occupied area has remained relatively constant (M. Canestorp, pers. comm., 2012).

Soils

Soil type is an important abiotic factor that affects both flora and fauna. For example, prairie dogs occur more often in loams than in sand (Reading and Matchett 1997). PCD has a variety of soil types from well-drained sands, where sandsage dominates, to poorly drained clays, where greasewood dominates. The four dominant vegetation types in this study each occurred on multiple soil types. The plant species composition within these vegetation types was often associated with specific soil conditions. I briefly describe these soil types and their plant associations. The soil and plant composition descriptions are modified from the soil survey of the Pueblo area (USDA 1979).

<u>Stoneham loam.</u> This soil type is the dominant soil type for shortgrass prairie at PCD (Fig. 6). It consists of deep, well-drained loams and clay loams with a brownish color. Permeability is moderate and the available water capacity is high. The surface layer and the upper part of the subsoil are mildly alkaline, and the lower part of the subsoil is moderately alkaline. The native vegetation is mainly blue grama, galleta grass, sand dropseed, and cactus.

Plots on the Stoneham loam soil type: sg61ug, sg68ug, sg69ug, sg70g, sg74ug, sg77g, sg78g, sg80ug, and sg81ug.

<u>Razor clay, eroded.</u> This soil type also has shortgrass prairie vegetation but it occupies a smaller area than the Stoneham loam soils (Fig. 6). In addition to shortgrass vegetation, some of these soils have greasewood shrubland (Fig. 6). It consists of moderately deep, well-drained soils of heavy clay loam and silty clays at subsurface. These soils formed on uplands in clayey residuum weathered from shale. They are underlain by shale at a depth of 50 to 100 cm. The surface layer is a light olive-brown heavy clay loam about 10 cm thick. The main native grass is alkali sacaton grass. I have four shortgrass plots on this soil type of which only one (sg65g) is dominated by alkali sacaton grass; the other three plots are dominated by blue grama. The two greasewood plots on this soil type are dominated by blue grama although alkali sacaton grass is present.

Plots on the Razor clay soil type: sg64g, sg65g, sg67g, sg79g, gw01g, and gw02g.

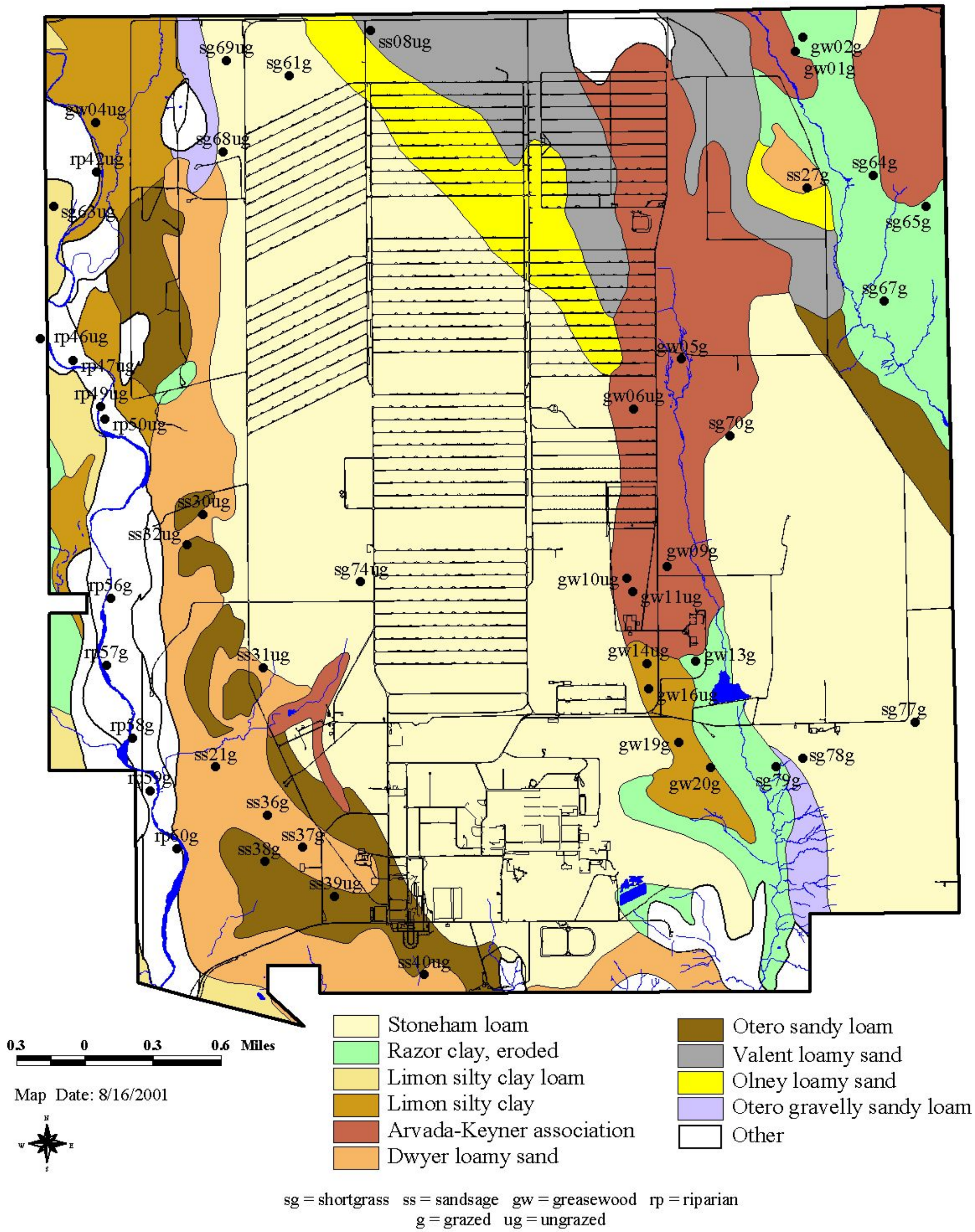


Figure 6. Soil types at PCD with the locations of permanent vegetation sampling points.

Limon silty clay loam. This soil type occurs on only a small portion of western PCD and is vegetated with four-winged saltbush (*Atriplex confertifolia*) and galleta grass (Fig. 6). It consists of deep, well-drained soils that formed on alluvial fans and terraces in clayey alluvium. The surface layer is grayish-brown silty clay loam about 10 cm thick. The subsurface layer is light brownish-gray silty clay about 35 cm thick. Permeability is slow and the available water capacity is high. The surface and subsurface layers are moderately alkaline and the underlying material is moderately alkaline or strongly alkaline. The native grasses are mainly galleta grass, blue grama, and alkali sacaton grass.

Plot on this soil type: sg63ug.

Arvada-Keyner association. This soil type is the dominant soil for the greasewood shrubland vegetation found at PCD (Fig. 6). It consists of deep, well to moderately drained soils that formed on terraces in loamy alluvium derived mostly from mixed sedimentary rock. The surface layer is light brownish-gray sandy loam about 8 cm thick. The upper part of the subsoil is brown, heavy clay loam about 5 cm thick, and the lower part is pale brown and very pale brown heavy clay loam about 5 cm thick. On about 25% of the acreage covered by the Arvada-Keyner association, erosion has removed the surface layer, leaving barren slick spots. Runoff is slow on the Arvada soil and medium on the Keyner soil. The native grasses are mainly alkali sacaton grass, blue grama, and galleta grass. Greasewood and cactus are abundant in places.

Plots on this soil type: gw05g, gw06ug, gw09g, gw10ug, gw11ug, and gw13g.

Limon silty clay. This soil type also supports greasewood shrubland communities at PCD (Fig. 6). It consists of deep, well-drained soils that formed on fans and terraces in clayey alluvium. The surface layer is grayish-brown silty clay. The subsurface is light brownish-gray silty clay. Permeability is slow and the available water capacity is high. The surface and subsurface layers are moderately alkaline and the underlying material is strongly alkaline. About 15% of the surface area is covered by barren slick spots. The native vegetation is mainly alkali sacaton grass, blue grama, galleta grass, and greasewood.

Plots on this soil type: gw04ug, gw14ug, gw16ug, gw19g, and gw20g.

Dwyer loamy sand. This soil type usually has sandsage shrubland vegetation. It consists of deep, excessively drained soils that formed on uplands in wind-blown sand. Permeability is very rapid and the available water capacity is low. The surface layer and subsurface layers are mildly alkaline. The native grasses are mainly needle-and-thread grass, blue grama, and sand dropseed. Yucca is also abundant.

Plots on this soil type: ss21g, ss27g, ss30ug, ss31ug, ss32ug, ss36g, ss37g, and ss40ug.

Otero sandy loam. This soil type intermingles with the Dwyer loamy sand and also supports sandsage shrubland vegetation (Fig. 6). It consists of deep, well-drained soils that formed on terraces in wind-sorted alluvium. Permeability is rapid and the available water capacity is moderate. The native vegetation is mainly sandsage, blue grama, sand dropseed, galleta grass, and yucca.

Plots on this soil type: ss32ug, ss38g, and ss39ug.

Valent loamy sand. This soil type occupies the northern portion of PCD (Fig. 6) and is primarily vegetated with sandsage shrubland. It consists of deep, excessively drained soils that formed on uplands in wind-deposited sand. Permeability is very rapid and the available water capacity is low. The native vegetation is mainly sand bluestem, sandreed grass, blue grama, sand dropseed, sandsage, and yucca. At PCD sand bluestem and sandreed grass are mostly absent.

Plot on this soil type: ss08ug.

Sampling and Management Objectives

In 1998 I developed sampling and management objectives. My primary sampling goal of monitoring the vegetation at PCD was to be able to detect a 20% change at $P = 0.1$ for dominant species canopy cover, density (for shrubs), and frequency. I was especially interested in the areas where grazing was removed in late spring of 1998.

The following management and sampling objectives were developed with only the vegetation component in mind. These were subject to change as an integrated ecosystem management approach was developed. For example, the vegetation objective "reduce the amount of bare ground" would merit modification if management for mountain plover (*Charadrius montanus*) was desired (Knopf and Miller 1996, Knopf and Rupert 1996). For example, a suitable objective for plover management would be to "maintain approximately 30% bare ground."

Management objectives have been modified from those originally reported (Rondeau and Kettler 1999; Rondeau 2001) and are summarized below.

> **Management objective 1**: *Increase* the average cover of litter by 20% in the **grazed** portion of the shortgrass prairie and greasewood shrubland at PCD between 1998 and 2010. *Increase* the average canopy cover and frequency of needle-and-thread grass in the **grazed** portion of the sandsage shrubland between 1998 and 2010. *Increase* the average canopy cover of galleta grass in the grazed portion of the greasewood shrubland between 1998 and 2010.

> **Sampling objective 1**: I want to be 90% sure of detecting a 20% change in the absolute cover and frequency of needle-and-thread grass and galleta grass and cover of litter and will accept a 10% chance that change took place when it really did not (false-change error).

Management objective 2: *Decrease* the average cover of bare ground in shortgrass prairie and greasewood shrubland and the cover and frequency of sand dropseed in sandsage shrubland by 20% in the **grazed** portions of PCD between 1998 and 2010.

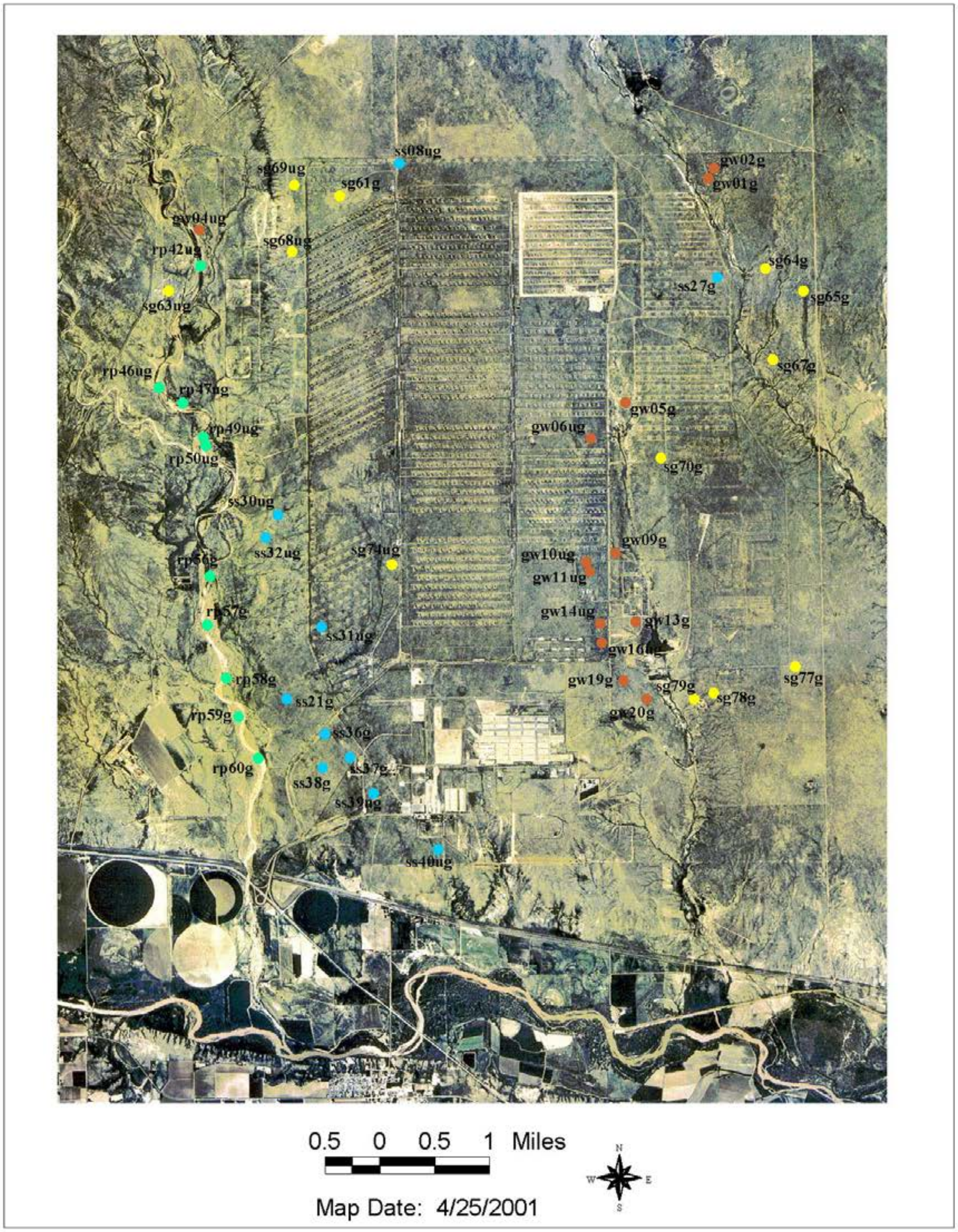
Sampling objective 2: I want to be 90% sure of detecting a 20% change in the cover of bare ground and cover and frequency of sand dropseed in the grazed portions of PCD between 1998 and 2010 and will accept a 10% chance that change took place when it really did not (false-change error).

Methods

Upland

The uplands include shortgrass prairie, greasewood shrubland, and sandsage shrubland vegetation. In order to detect changes in species canopy cover, composition, density, and frequency over time, I established randomly chosen permanent vegetation monitoring plots in 1998 with an equal number in the grazed versus ungrazed treatments. After the 1998 field season, I examined the variability of the first year's data and determined that ten additional plots were warranted to most likely meet the stated sampling objectives (Rondeau and Kettler 1999). At the same time, four plots that had been disturbed due to previous seeding and ditching activities were dropped from subsequent sampling (these plots are not included on the current maps). Figures 2 and 5 represent the placement of the plots relative to vegetation and grazing respectively. Figure 7 shows the placement of the plots as viewed with a 1995 aerial photo.

Complete sample years were 1999-2003 and 2010. In 2004 I only collected frequency data. I resampled the plots between August 4 and September 22. I generally resampled the plots within two weeks of their original sample date. For greasewood shrubland I established 13 plots (7 grazed and 6 ungrazed), and for sandsage shrubland habitat I established 11 plots (5 grazed and 6 ungrazed). In shortgrass prairie I established 12 plots (7 grazed and 5 ungrazed).



● Greasewood ● Riparian ● Shortgrass ● Northern Sandhill Prairie

g = grazed ug = ungrazed

Figure 7. 1995 aerial photo of PCD with locations of permanent vegetation sampling points.

As detailed in the grazing history section, plots labeled “grazed” were grazed by cattle until 1998 and plots labeled “ungrazed” have not been grazed by cattle since 1942.

Three of the grazed (sg70g, sg77g, and sg78g) and one of the ungrazed (sg61ug) plots in the shortgrass prairie are located within prairie dog towns. In 2001, I established two additional shortgrass prairie plots in areas ungrazed by cattle but within prairie dog towns (sg80ug and sg81ug). In April 1999, plague severely reduced prairie dogs at PCD, eliminating prairie dogs from plots sg61ug, sg70g, and sg78g. In 2002, prairie dogs moved back into plot sg61ug and were inactive in plots sg70g and sg78g. In 2002, the plots within active prairie dog colonies were sg61ug, sg77g, sg80ug, and sg81ug. In June of 2000, a lightning-induced fire burned the vegetation on sg65g plot. In November of 2001, a human-induced fire lightly burned plot sg70g.

Upland Plot Design

A stake was placed at the center of each site. Four transects were established at each plot by placing flexible 50 m tapes along the cardinal directions and marking the beginning (center of plot), middle, and end of each transect with two-foot rebar (Fig. 8).

To estimate shrub canopy cover, a line-intercept method (Bonham 1989) was used along each of the four transects with 1 cm increments. Within the canopy of a plant, gaps in live green vegetation less than 10 cm in length were considered to be continuous cover.

To estimate herbaceous ground cover, eight point-frames (or microplots) (Bonham 1989), each 55 x 30 cm with 50 points (each point 5 cm apart) were placed every 5 meters along each of the four 50 m transects (Fig. 8). The first frame placement was randomly selected, then each subsequent frame was placed 5 m from the preceding one. Only live plants (green to light green) were measured.

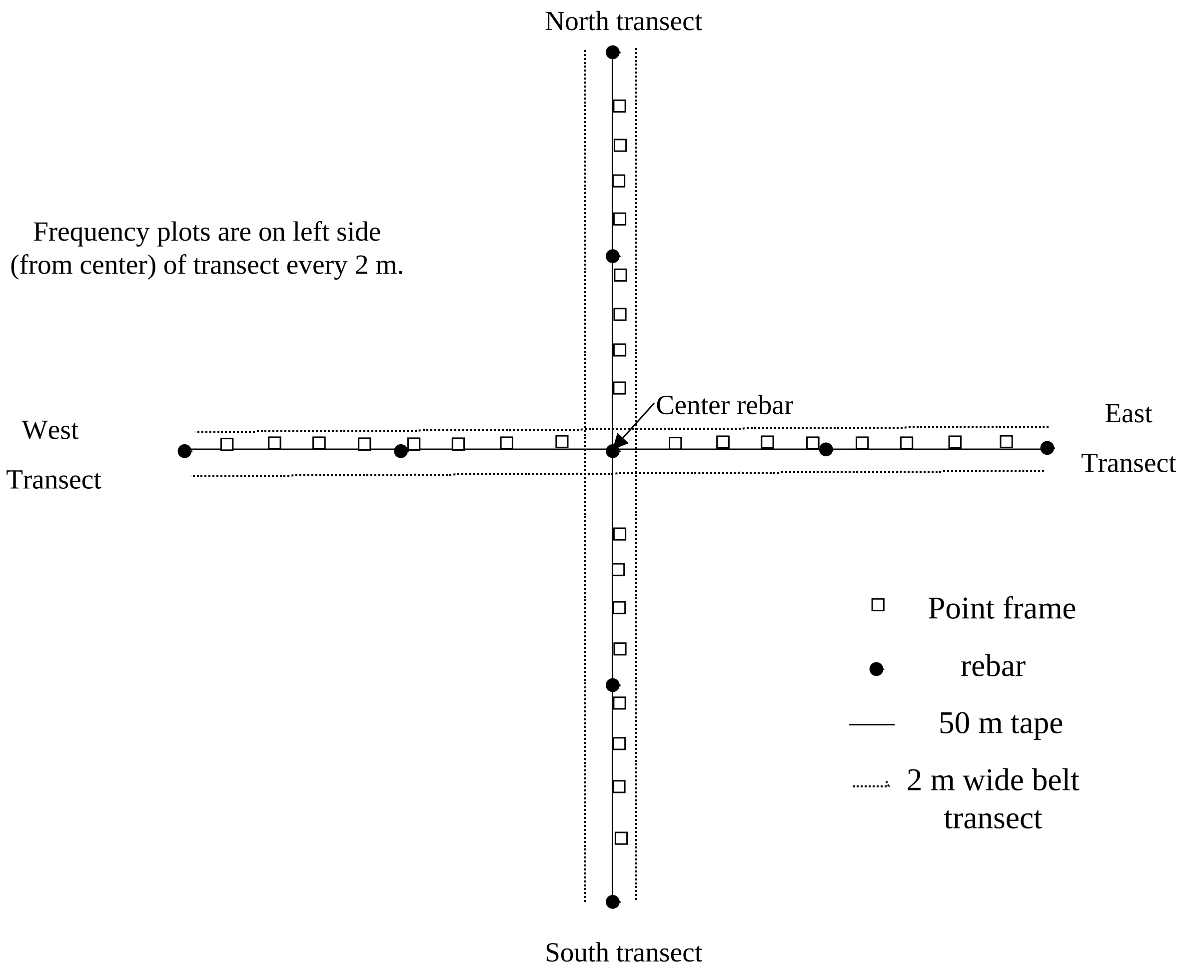


Figure 8. Configuration of an upland vegetation sampling site.

Standing dead (usually brown in color), ground litter, or stump remains of grass clumps were considered litter. Bare soil, macrophytic crusts, or pebbles were considered bare ground. The percent of shrubs present within the microplot were not counted as cover because shrub cover was measured using the line-intercept method. The ground cover below the shrub (e.g. grass, litter, or bare ground) was recorded as cover for that location. In general, especially during dry years, canopy cover of grasses, forbs, litter, and bare ground sums to 100%. In wetter years, it was possible to have greater than 100% cover within a microplot because forbs (e.g. Russian thistle (*Salsola* sp.) and sunflower) often form an overstory with blue grama or other species growing beneath.

To measure density (Bonham 1989) a 50 m x 2 m belt transect was used. This was done by measuring a 1 m band on both sides of each 50 m transect (Fig. 8). Any shrub that had vegetation within this area was counted; i.e., the plant did not have to be rooted within the area. Yucca is rhizomatous and therefore difficult to distinguish individual plants, hence we counted individual stems. It may also be difficult to distinguish individual greasewood plants. For this species we counted discrete clumps as individuals. All other shrubs were easily distinguished as individuals. To avoid double counting at the center point of the site, we counted only the north and south transects in the region of overlap.

Frequency of dominant or indicator species was measured with 25 nested-frequency plots per 50 m transect (Elzinga et al. 1998) placed every 2 m on the left side of the transect (as viewed from center stake) beginning at the 2 m mark. The appropriate plot size for detecting statistical differences in the frequency of a species is influenced by the density and dispersion of that species within a community (Hyder et al. 1963, 1965, and 1975 as cited in Winter et al. 2002). Small plots sample the dominant species (e.g., blue grama) at optimal frequencies, but fail to detect less common species. I used three different plot sizes (nested frequency plots) because concurrent use of small and large sizes ensures adequate sampling of species that are common and abundant as well as species that are less commonly encountered (Hyder et al. 1975 as cited in Winter et al. 2002). The nested-frequency frame sizes used were as follows: a) 0.1 m x 0.1 m = scored as F2, b) 0.31 m x 0.31 m = scored as F3, and c) 1 m x 1 m = scored as F4. The 0.1 m x 0.1 m and 0.31 m x 0.31 m frame sizes were placed in the lower left corner (as viewed from center of 1 m x 1 m plot). The species included in the nested-frequency plots were three-awn grass, plains buckwheat, prickly pear, blue grama, alkali sacaton grass, sand dropseed, needle-and-thread grass, kochia (*Bassia scoparia*), and Russian thistle. Prickly pear presence was based on existence of a pad within the sampling frame. All other species had to be rooted within the plot to be counted.

In addition to measuring canopy cover, density, and frequency, a species list was made for the entire 100 m x 100 m area of each site (see Appendix A for PCD plant list). Each 2-foot rebar that marked the ends and middle of the transect were labeled with the plot number engraved into aluminum tags. Universal Transverse Mercator (UTM) coordinates were recorded at the center post of each plot using a precision lightweight global positioning system receiver (PLGR).

Reference photographs were taken from both ends of each transect (landscape views) as well as at the 3rd and 5th microplots (views looking straight down). From 1998-2002, I used a Nikon 2000 35-mm camera with a 35-80 mm lens set for 35 mm. In 2003, 2004, and 2010, I used an Olympus digital camera.

See Appendix B for sample field forms.

Riparian

For the grazed and ungrazed riparian areas I randomly selected five sites along Chico Creek (Fig. 5). During 1998, 1999, and 2000 I collected frequency data, but this proved to be of limited value and I discontinued the frequency monitoring. Repeat photos are the only data currently collected from Chico Creek.

Statistical Analysis

All data was checked for normality (proc univariate in SAS) and a square root transformation was used for non-normal data. For normally distributed species, I conducted an unpaired one-tailed *t*-test between grazed/ungrazed on all species for years 1999 and 2000 for those species that were considered “increasers” or “decreasers” in the management objectives. For species that were not normally-distributed, even after transforming data, I conducted a Mann-Whitney U test. For the species that we did not discern as increasers/decreasers (weeds) I ran an unpaired two-tailed *t*-test or a Mann-Whitney *U*-test. For those species that had a significant difference ($P \leq 0.05$) between grazed and ungrazed, in either 1999 or 2000, I conducted a repeated measures ANOVA (Glantz 1992), using SAS 9.3 software to ascertain if there was detectable difference in canopy cover, density, and frequency of dominant species among the years 1999-2010. Frequency plot sizes used for the analyses were F3 for blue grama and F4 for the remaining species.

RESULTS

Cattle Grazing Treatment. The following results provide the effect of cattle grazing versus no cattle grazing as well as a year-by-grazing interaction following the elimination of all cattle grazing in 1998. The plots that were grazed by cattle up until 1998 are considered "grazed" and plots that were not grazed by cattle since 1942 are considered "ungrazed." The grazed versus ungrazed data are summarized below and in Figures C-1 through C-21 of Appendix C.

Shrubs and Succulents. Greasewood, rabbitbrush, cholla, sandsage, and prickly pear are the dominant shrubs and succulents at PCD. Greasewood dominates the greasewood habitat and was essentially non-existent in any other habitat. Rabbitbrush reaches its maximum density and cover in greasewood habitat but it also occurs in low density and cover in the shortgrass habitat. Cholla is present in both greasewood and shortgrass habitats. Sandsage dominates the sandsage habitat and may occur in low density and cover in greasewood and shortgrass habitats. The following results consider each species by habitat and, when possible, all habitats combined.

Shrub summary. There was no significant difference between grazed and ungrazed plots for any of the shrubs. However, the difference in sandsage was nearly significant (P=0.08) with 20% higher cover and 13% higher density in grazed plots than ungrazed in 1999 (Table 2). By 2010 the difference in sandsage was reduced to 8% higher cover and 1% higher density (Fig. C-1). The shrub cover in the greasewood habitat increased with time, especially after the 2002 drought; it increased over 30% from pre-drought (2001) to post-drought (2010) (8 to 11% actual cover; Figs. 9 and C-2). Most of the increase in cover came from rabbitbrush, which had a 58% increase from pre-drought to post-drought average (3.4-5.4% actual cover; p <0.01; Rondeau et al. 2013) (Figs. C-3 and C-4). Cholla had the largest proportional increase in density and cover of any shrub at PCD with an average increase in density of 34% (an increase from 340 to 457 plants/ha), while the average increase in cover was 68% (an increase from 1.0% to 1.6%). The majority of this increase occurred post-drought (Figs. 10, C-5, and C-6). The cholla density on plots with high clay content (all greasewood plots and four shortgrass plots) had a higher rate of increase than those plots on sandy loam soils.

Table 2. Desired trend for management objectives for shrubs on grazed areas at PCD for year 1999. Density is individuals per hectare.

Species	**Observed differences**		**P-value**	**Stated expected direction of difference (grazed vs ungrazed)**	**Observed direction of difference (grazed vs ungrazed)**
	Grazed (mean)	**Ungrazed (mean)**			
Sandsage—sandsage habitat					
Cover (%)	18	15	0.08	Increaser	0
Density	11,285	9,950	0.08	Increaser	0
n	5	6			
Greasewood—greasewood habitat					
Cover (%)	3	4	ns	Increaser	0
Density	1,354	975	ns	Increaser	0
n	7	5			
Rabbitbrush—greasewood and shortgrass habitats					
Cover (%)	2	3	ns	Increaser	0
Density	1,185	1,433	ns	Increaser	0
n	14	9			
Cholla—greasewood and shortgrass habitats					
Cover (%)	1	1	ns	Increaser	0
Density	303	508	ns	Increaser	0
n	14	9			
Prickly pear (F4)—all habitats					
Frequency (%)	31	37	ns	Increaser	0
n	19	15			

n = number of plots

ns = not significant

F4 = 1 m x 1 m plot size

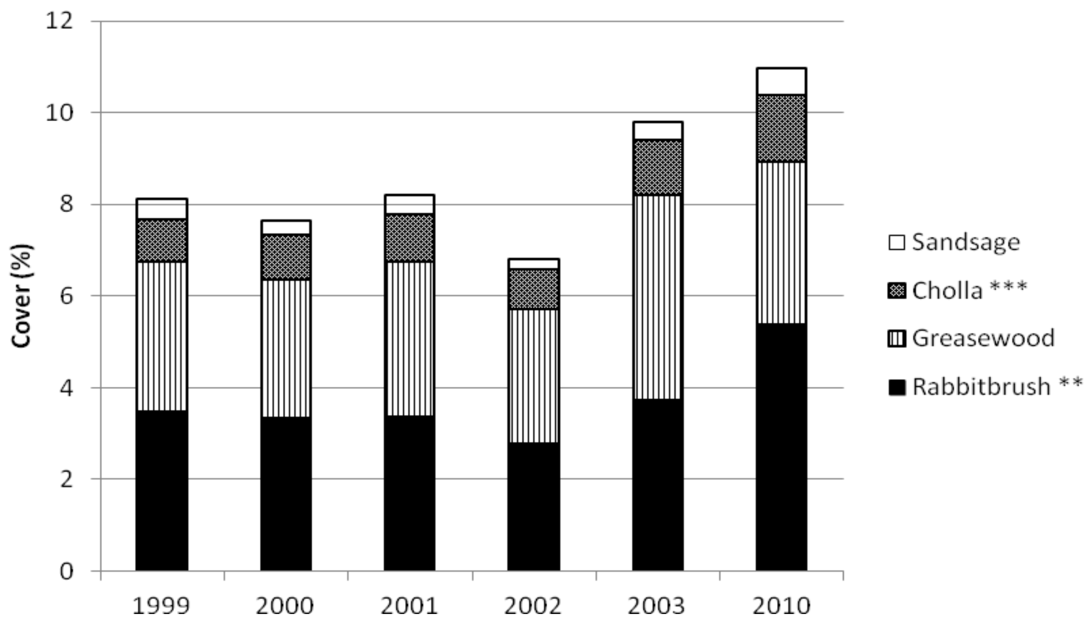


Figure 9. Total shrub cover in all greasewood plots, 1999-2010 (n=13). The years 2002 and 2003 were the strongest drought episode in over 100 years. Consistent trends among plots in slope for the period 1999-2010 were tested against a null hypothesis of equal ranks of negative and positive slopes using a Wilcoxon signed-ranked test; **p<0.01, ***p<0.001. Total shrub cover significantly increased over time (P≤ 0.001, Rondeau et al. 2013).

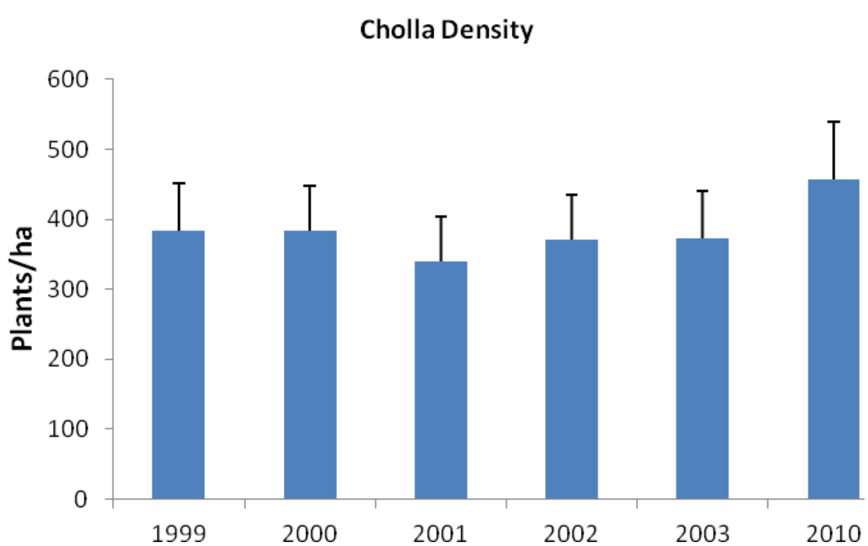


Figure 10. Mean cholla density (+ 1 SE) in all habitats combined, 1999-2010 (n=23 (1999-2000) and 25 (2001-2010)). Cholla density increased 34% between 2001 (pre-drought) and 2010 (post-drought). The 2002 drought was the worst recorded drought in over 100 years. The decrease in density in 2001 was in response to an increase in sample size.

Greasewood. Greasewood is a long-lived and deep-rooted shrub that prefers swales with access to groundwater (Fig. 11). At PCD it is primarily found along Boone Creek and it is often co-dominant with rabbitbrush. There was no grazing treatment effect in either cover or density (Table 2, Figs. 12 and C-1). Greasewood tolerated the drought quite well and may have even benefitted from it as greasewood cover reached its highest in 2003, one year after the drought (Fig. 12). Throughout the study, canopy cover was seldom very high, with an average between 3 and 4%, while the density was also a moderate 48 plants/ha. Greasewood and rabbitbrush had equal cover during all years except 2010 when rabbitbrush had significantly higher cover than greasewood ($p<0.05$; Rondeau et al. 2013).

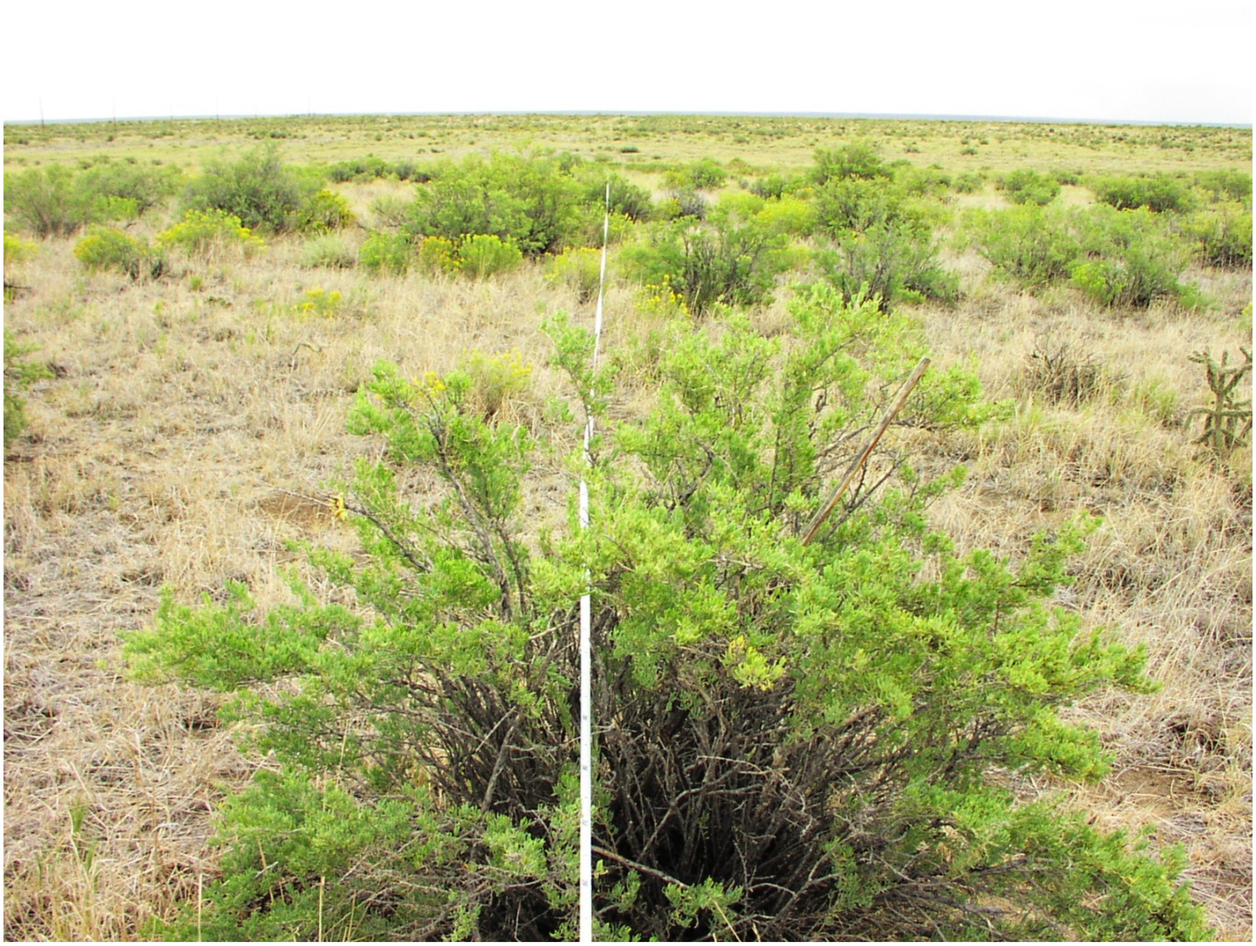


Figure 11. Greasewood at plot gw10, 2010.

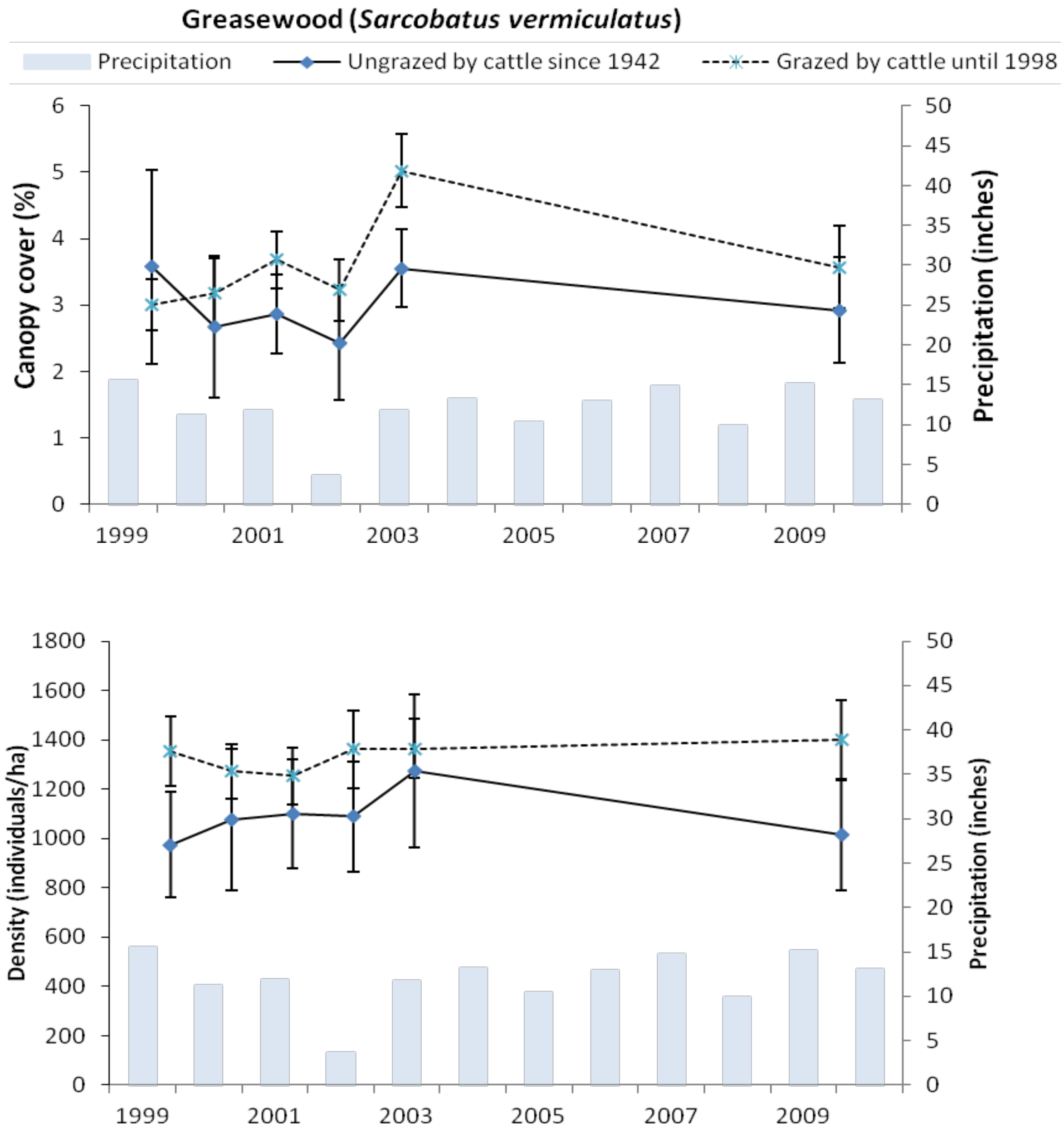


Figure 12. Greasewood mean cover and density (± 1 SE), 1999-2010 (n=7 grazed and 5 ungrazed). There was no significant difference between grazed and ungrazed plots. The highest cover was in 2003, one year after the drought. In 2010 it was similar to pre-drought years. Density remained stable throughout the study.

Rabbitbrush. Rabbitbrush is also a long-lived and deeply-rooted shrub; it grows in clay and loam soils at PCD (Fig. 13). It is primarily found as a co-dominant in the greasewood shrubland habitat and is occasionally found in shortgrass at low density and cover. Neither the greasewood plots nor the shortgrass plots had a grazing treatment effect in either cover or density of rabbitbrush (Table 2 and Fig.14); the average canopy cover ranged from 3 to 6% in greasewood plots and remained less than 1% in shortgrass plots. There was a year effect for rabbitbrush cover in the greasewood plots, which had a 58% increase from pre-drought to post-drought average (3.4-5.4% actual cover; p <0.01; Rondeau et al. 2013) and a 43% increase in all habitats combined (Figs. 14 and C-3). Rabbitbrush density was anomalous in its consistent decline in density (Fig. C-4), indicating that individual plants enlarged, and that well-established plants may access moisture effectively enough to grow during relatively short droughts.

Figure 13. Rabbitbrush at plot gw05, 2002 (top) and 2010 (bottom). On average, rabbitbrush cover increased 58% in greasewood plots between 2002 (drought) and 2010.

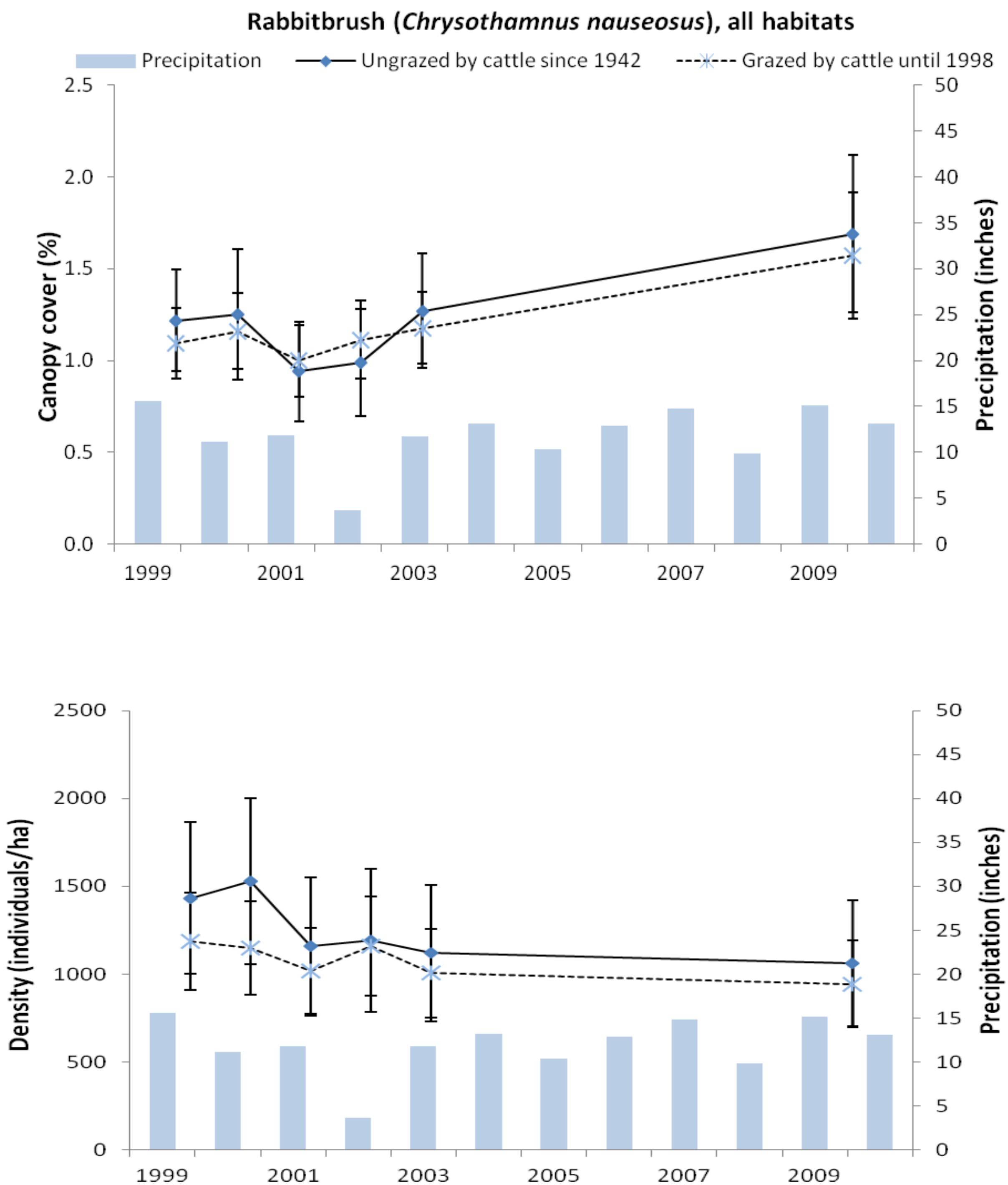


Figure 14. Rabbitbrush mean cover and density (± 1 SE) in all habitats combined, 1999-2010 (n=14 grazed and 9 ungrazed (1999-2000), 11 ungrazed (2001-2010)). Rabbitbrush did not exhibit a difference between grazed and ungrazed plots. Rabbitbrush cover increased by 43% after the 2002 drought, while density declined by 8%.

Cholla. Cholla is found in both shortgrass and greasewood habitats and is absent from sandsage habitat as it has a preference for clay or loamy soils rather than sandy soils (Fig. 15). At PCD, cholla was more abundant in greasewood habitat than in shortgrass habitat. Cholla in the greasewood habitat averaged 1-2% cover and 550-730 plants/ha, while cholla in the shortgrass habitat averaged 0.2-0.6 % cover and 150-206 plants/ha (Figs. C-5 and C-6). Cholla has been considered an increaser by some authors; however, there was no grazing treatment effect at PCD (Table 2 and Fig. 16). Cholla had the largest proportional increase in density and cover over time of any shrub at PCD. The average increase in density was 35%, or 118 plants/ha, while the average increase in cover was 68%, or 1.0% to 1.6%. The majority of this increase occurred post-drought (Fig.16). The cholla density on plots with high clay content (all greasewood plots and 4 shortgrass plots) had a higher rate of increase than those plots on sandy loam soils.

Figure 15. Cholla at plot sg61ug during the 2002 drought (top) and in 2010, after the drought (bottom). Cholla cover increased an average of 68% after the 2002 drought.

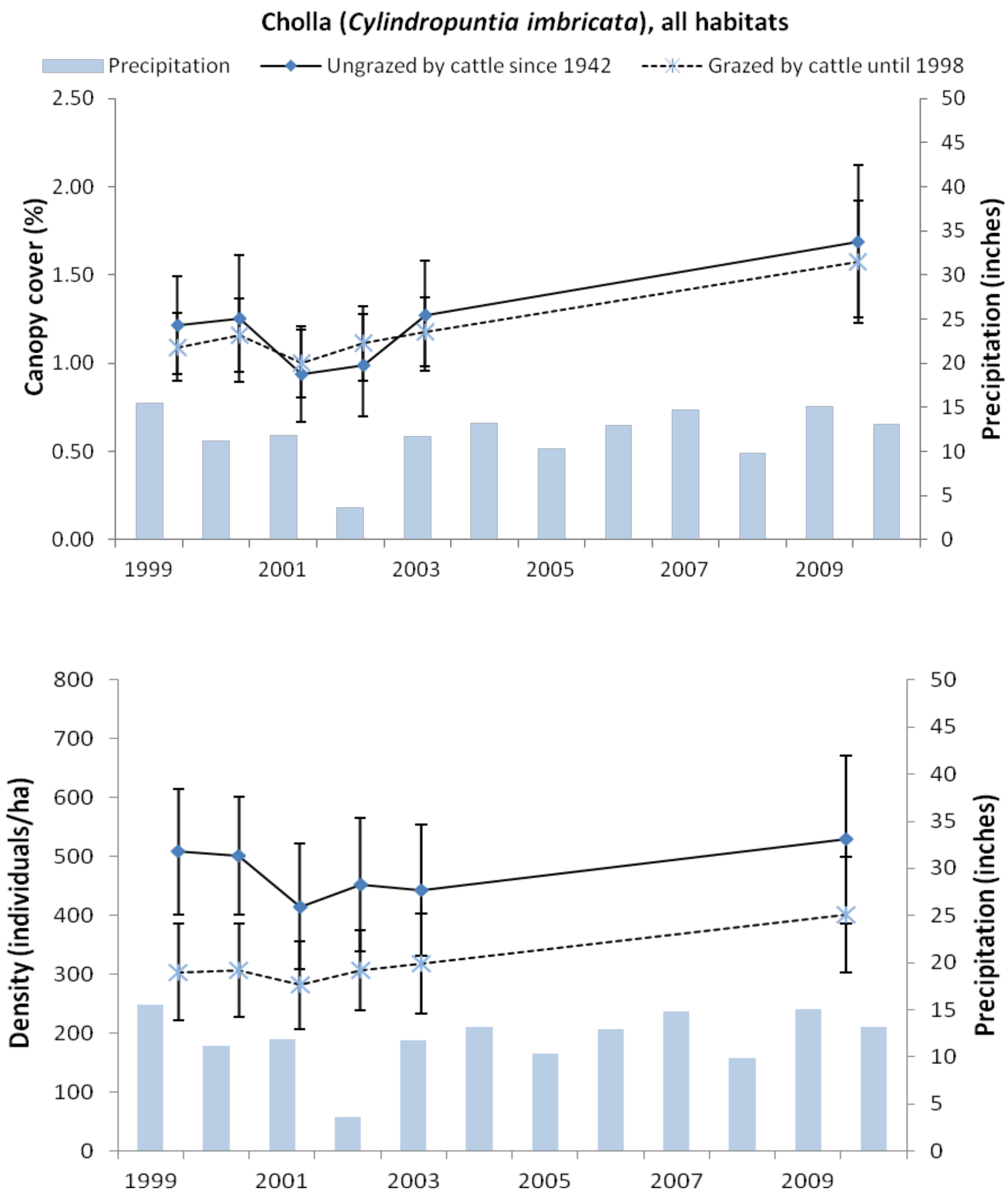


Figure 16. Cholla mean cover and density (± 1 SE) in all habitats combined, 1999-2010 (n=14 grazed and 9 ungrazed (1999-2000), 11 ungrazed (2001-2010)). Cholla exhibited no significant difference between grazed and ungrazed plots; however, there was a year effect as cover and density significantly increased (67% and 34%, respectively), after the 2002 drought.

Sandsage. At PCD, sandsage is primarily found in the sandsage shrublands where it is the signature species (Fig. 17). It is occasionally found in the greasewood habitat; however, it is never very abundant there. The following analysis only included the sandsage shrubland habitat. Sandsage did not exhibit a significant grazing treatment effect in either cover or density (P=0.08); however, the 1999 cover and density in grazed plots was higher than ungrazed (Table 2 and Figs. 18 and C-1). This difference was largely eliminated by 2010, as hypothesized for an increaser. Sandsage is the most drought sensitive of any of the PCD shrubs as it quickly declined in both cover and density during the 2002 drought (Figs. 17, 18, and C-1). Canopy cover decreased from 17% in 2001 to 8% in 2003 (post-drought). The density varied less than the cover, although plants were killed by the drought, losing an average of 1,500 individuals/ha, or a 17% loss; by 2010 the density had mostly recovered from the drought (Fig. 18).

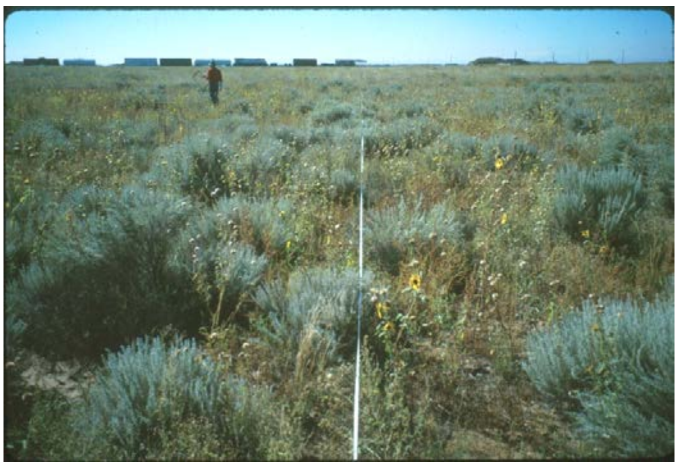


Figure 17. Sandsage shrubland plot ss08 in 1999 (top) and 2002, during the drought (bottom). Both photos were taken in August. There was 16% mortality in sandsage due to the drought.

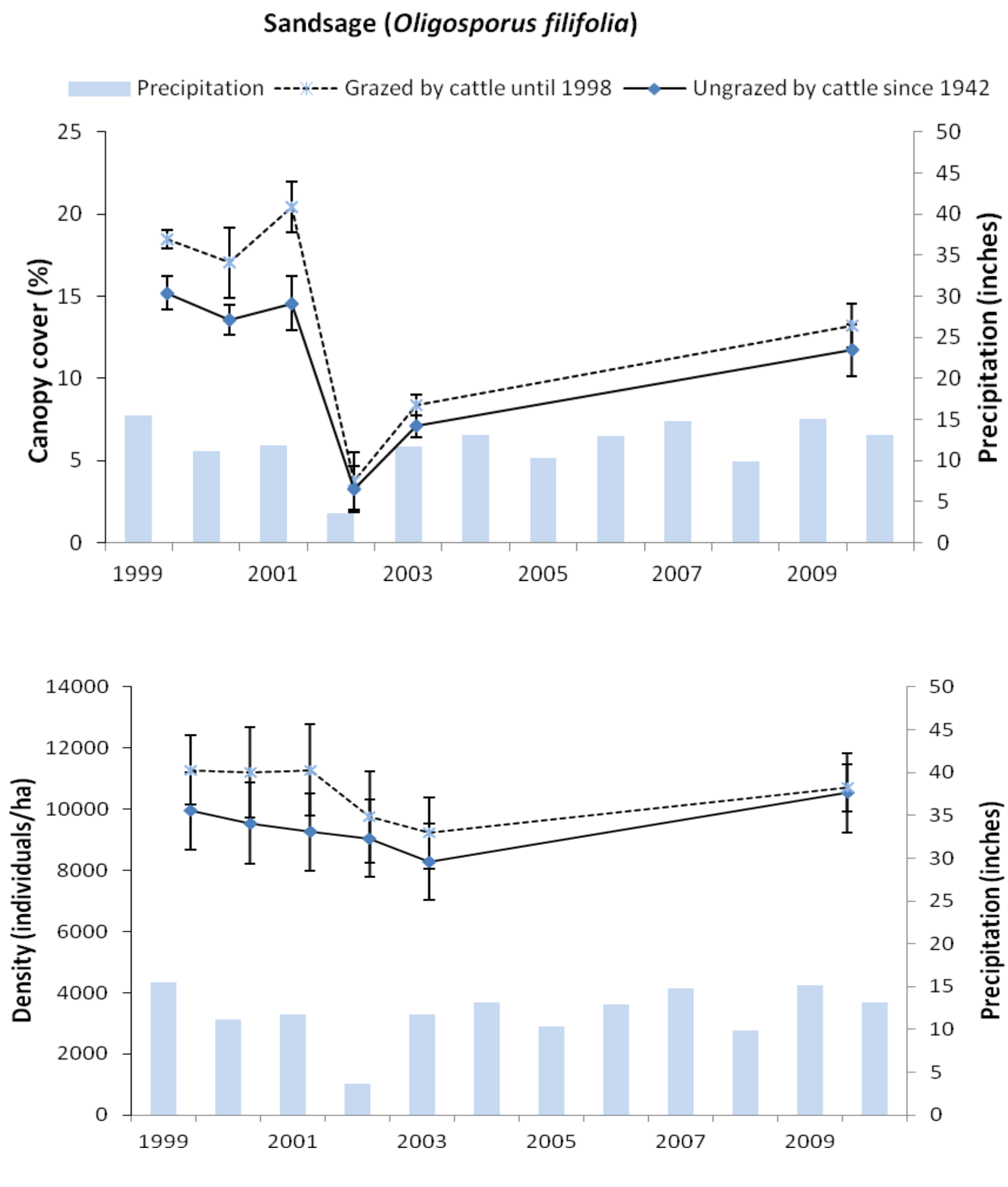


Figure 18. Sandsage mean cover and density (± 1 SE), 1999-2010 (n=5 grazed and 6 ungrazed). Sandsage exhibited a slight difference between grazed and ungrazed plots at the beginning of this study (P=0.08); the trend data also suggest that sandsage had a higher abundance in grazed vs ungrazed; however, it was not statistically significant. Sandsage is amazingly sensitive to annual precipitation. Density decreased with the 2002 drought but it had recovered by 2010.

Prickly pear. This prostrate cactus is relatively frequent in all habitat types, but cover is generally low (Figs. 19 and C-7). It has been considered an increaser with grazing by some authors and not an increaser by other authors. Within PCD, there was no grazing treatment effect in any of the habitat types and it averaged approximately 35% frequency overall (Table 2 and Fig. 19). Prickly pear had very little year to year variation and was one of the few species not impacted by the drought. Prickly pear in the greasewood habitat had a gradual increase from 1999-2004 but by 2010 some of this increase had been lost (Fig. C-7). In sandsage and shortgrass habitats, prickly pear abundance was stable throughout the study. Prickly pear is eaten by prairie dogs and there was a significant difference in density between on and off prairie dog towns (see prairie dog section for details).

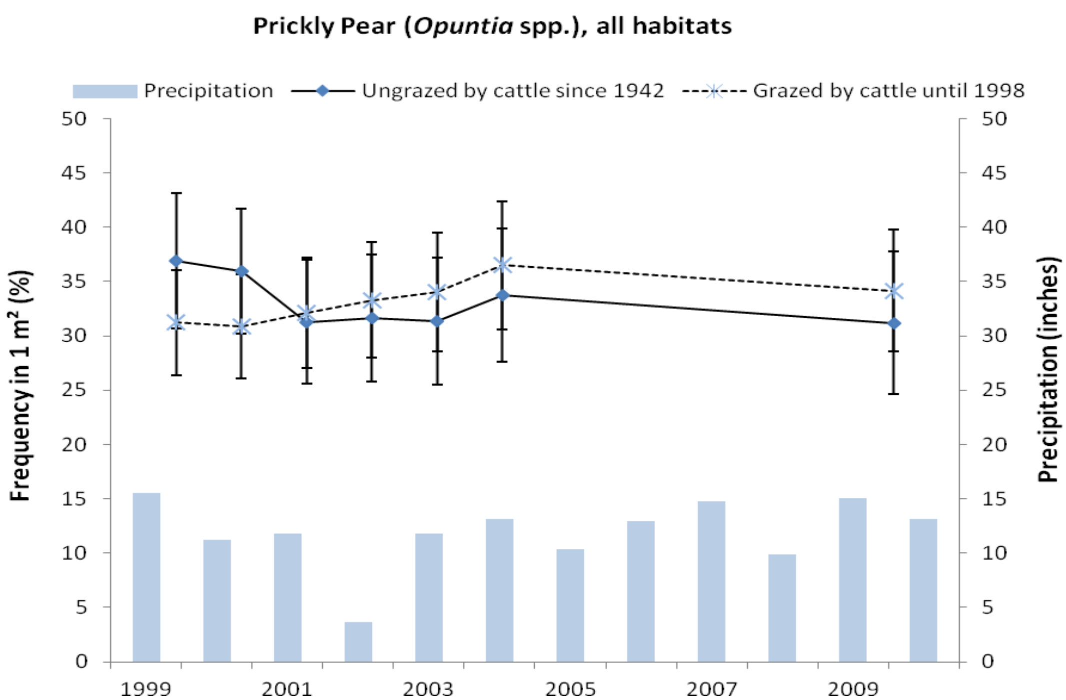


Figure 19. Prickly pear mean frequency (± 1 SE) in all habitats combined, 1999-2010 (n=19 grazed and 15 ungrazed (1999-2000), 17 ungrazed (2001-2010)). Prickly pear did not exhibit a difference between grazed and ungrazed plots. The prickly pear population was stable throughout the course of the study (the drop in ungrazed plots in 2001 was associated with an increased sample size).

Grasses and Grass Summary

The dominant grasses at PCD, ordered by dominance, are blue grama, alkali sacaton grass, galleta grass, three-awn grass, sand dropseed, and needle-and-thread grass. Table 3 summarizes these grasses for each habitat in 1999 and compares grazed plots to ungrazed plots. Alkali sacaton grass and blue grama did not exhibit any significant difference between grazed and ungrazed plots in any habitat type. Galleta grass, sand dropseed, three-awn grass, and needle-and-thread grass had a significant difference between grazed and ungrazed plots in at least one habitat.

The following results discuss each species and report on each habitat type as well as combining all habitats when a species occurs in more than one habitat type.

Blue grama. Blue grama is a shallow-rooted bunch grass that is extremely resistant to grazing pressures and fairly drought tolerant (Fig. 20). This species has the ability to grow with rainfall events as small as 5 mm, but seldom regenerates from seed. This is the only species that is dominant throughout all of the upland habitats at PCD (Table 3). It is also the dominant grass throughout much of the eastern plains of Colorado. Blue grama reached its highest abundance in pre-drought years; the shortgrass habitat had the highest abundance (30% average cover), followed by greasewood (22% average cover), and sandsage (10% average cover) (Fig. C-8). Regardless of habitat type, there was no effect from grazing treatment in either cover or frequency (Table 3, Figs. 21, C-8, and C-9). The 2002 drought was a significant event that had long-lasting effects that were apparently still evident in 2010 (Fig. 21). There was a year effect ($P \leq 0.001$) with a downward trend over time in both frequency and cover, with the highest abundance in the pre-drought years (1999-2001) and the lowest following the drought (2003-2010, Fig. 21). In the greasewood habitat, alkali sacaton grass was significantly less abundant than blue grama in 1999 (Fig. 22). However, by 2003 this difference was eliminated and blue grama and alkali sacaton grass were co-dominant and remained so in 2010 (Figs. 22 and C-9, Rondeau et al. 2013). Blue grama in the shortgrass prairie habitat had the largest mortality over time (35%), as it declined from an average of 78% frequency in 2000 to an

Table 3. **Mean cover and frequency (± 1 SE) of dominant grasses in greasewood, sandsage, and shortgrass habitats in 1999. Paired t-test or Mann-Whitney U-test were used to test for significance between grazed/ungrazed. Bolded entries exhibit significant contrasts between grazed and ungrazed (*P≤0.05, **P≤0.01).**

		Greasewood[1]		**Sandsage[2]**		**Shortgrass[3]**		**All habitats**		
Species	**Measurement**	**Grazed**	**Ungrazed**	**Grazed**	**Ungrazed**	**Grazed**	**Ungrazed**	**Grazed**	**Ungrazed**	**Sample size for all habitats**
Blue grama	*Cover*	20 ± 4	25 ± 3	10 ± 3	10 ± 3	27 ± 4	34 ± 8	20 ± 3	22 ± 4	n=19 grazed, 15 ungrazed
	Frequency (F3)	51 ± 9	62 ± 6	38 ± 8	40 ± 8	73 ± 8	79 ± 8	55 ± 6	58 ± 6	
Alkali sacaton grass	*Cover*	20 ± 5	12 ± 4					15 ± 4	12 ± 4	n=11 grazed, 5 ungrazed
	Frequency (F4)	66 ± 9	60 ± 12					61 ± 7	60 ± 12	
Galleta grass	*Cover*	**7 ± 2***	**13 ± 2***							
	Frequency (F4)	**41 ± 7***	**64 ± 9***					**33 ± 6***	**61 ± 8***	n=14 grazed, 6 ungrazed
Three-awn grass	*Cover*	1.2 ± 0.6	0.2 ± 0.2	4 ± 2	8 ± 3	3 ± 1	12 ± 6	4 ± 1	5 ± 2	n=18 grazed, 15 ungrazed
	Frequency (F4)	**8 ± 2***	**4 ± 1***	71 ± 13	41 ± 15	39 ± 14	61 ± 22	36 ± 8	34 ± 10	
Sand dropseed	*Cover*	3 ± 2	2 ± 0	**8 ± 1***	**5 ± 1***	1 ± 1	3 ± 1	4 ± 1	3 ± 1	n=19 grazed, 15 ungrazed
	Frequency (F4)	39 ± 12	34 ± 6	**96 ± 2****	**72 ± 6****	29 ± 12	50 ± 15	50 ± 9	53 ± 6	
Needle-and-thread grass	*Cover*			**1 ± 0***	**10 ± 4***					
	Frequency (F4) year 2000			**9 ± 5***	**61 ± 18***					

[1] n = 7 grazed; 5 ungrazed
[2] n = 5 grazed; 6 ungrazed
[3] n = 7 grazed; 4 ungrazed
F3 = 0.31 m x 0.31 m frequency plot size
F4 = 1 m x 1 m frequency plot size

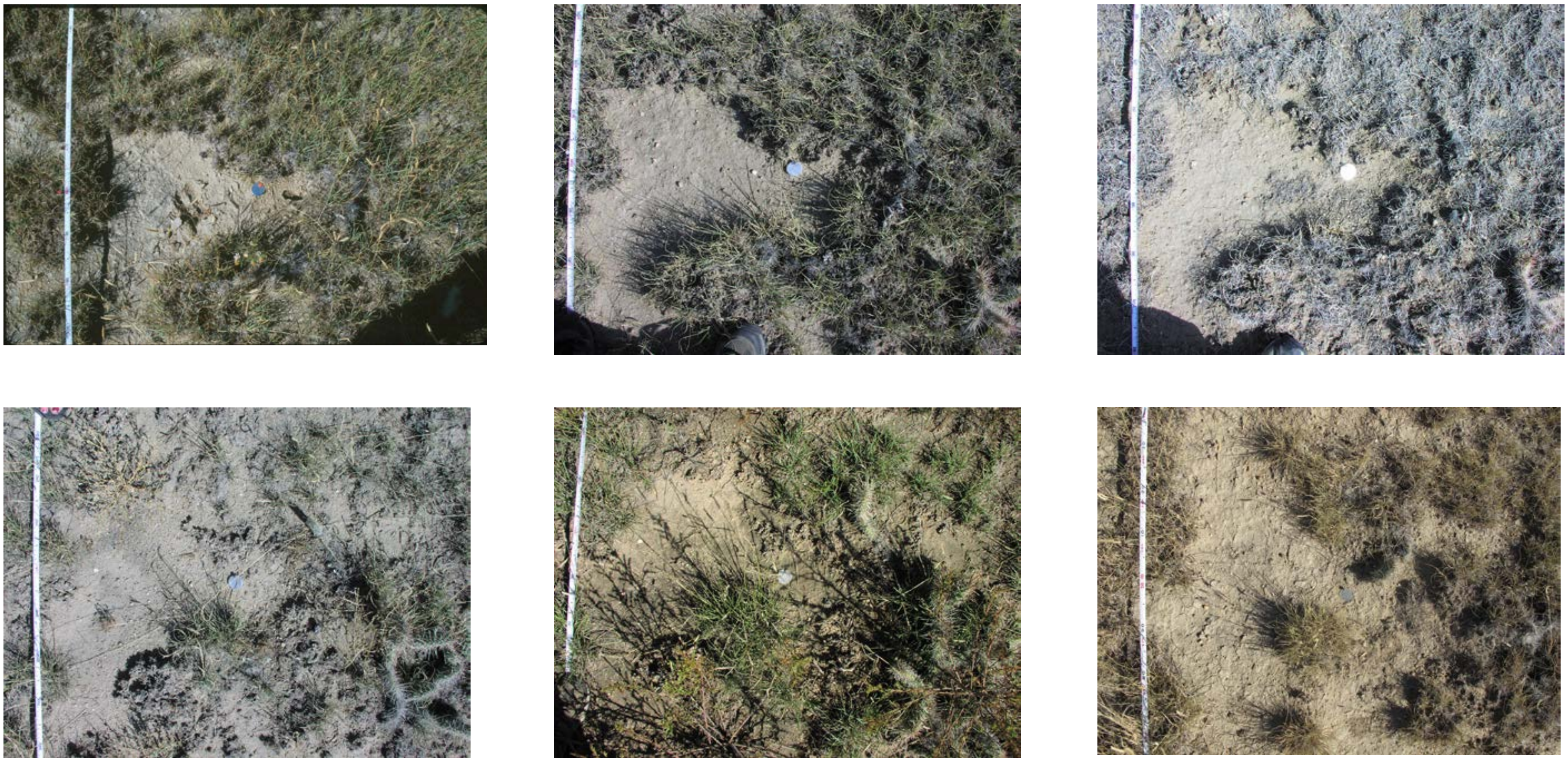


Figure 20. Microplot photos from shortgrass prairie plot sg68N, 1999, 2000, 2002 (top row), 2003, 2004, and 2010 (bottom row). The 2002 drought was the worst recorded drought in over 100 years and blue grama lost individuals and cover. Full recovery was still not evident eight years post-drought.

average of 51% in 2010. Blue grama in the greasewood habitat declined 25% as it went from an average frequency of 61% in 2001 to 46% post-drought. The blue grama in sandsage was less impacted from the drought exhibiting only a 16% difference in frequency as it declined from 45% in 2001 to 38% in 2003 and 40% in 2010.

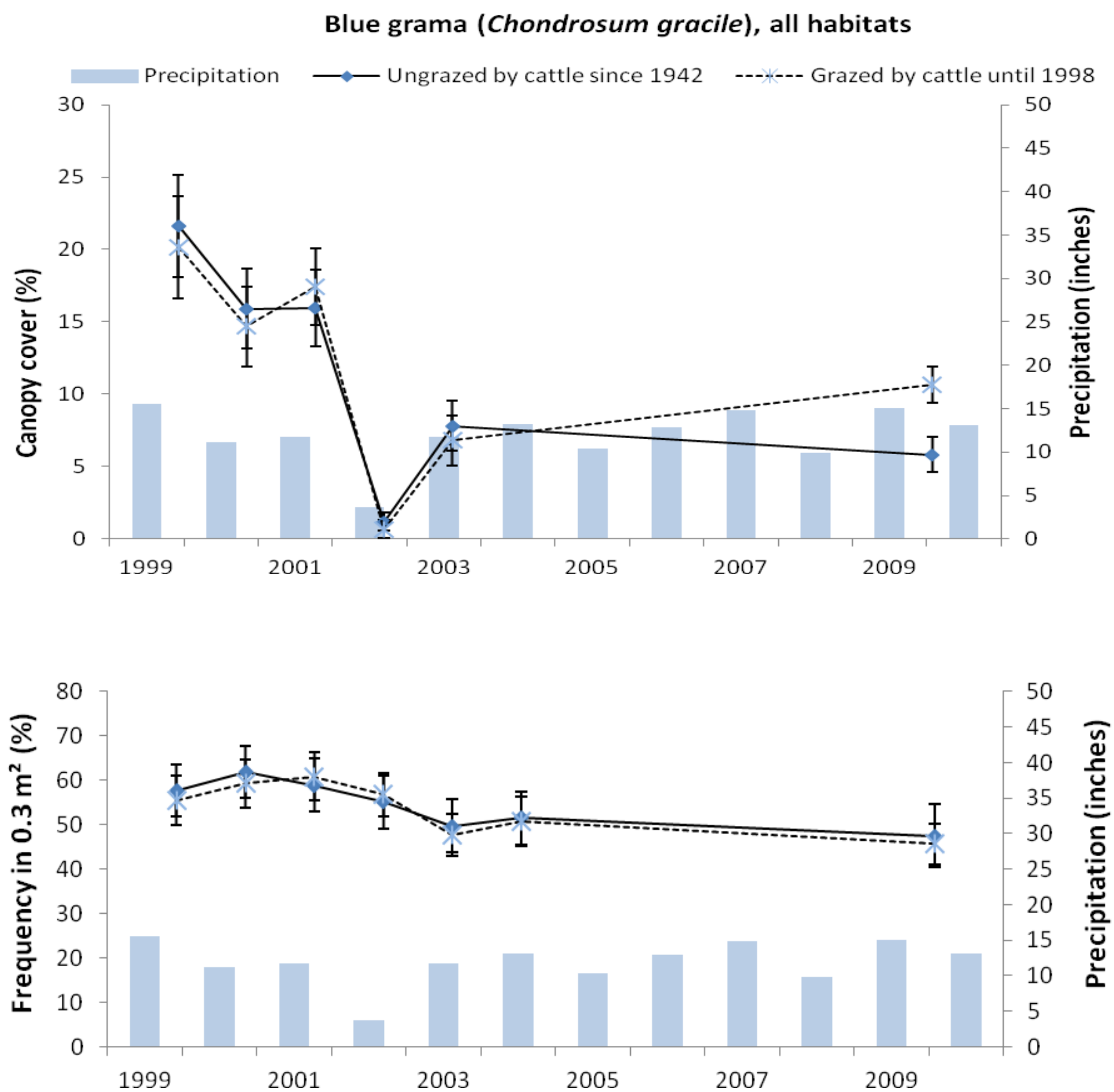


Figure 21. Blue grama mean cover and frequency (± 1 SE) in all habitats combined, 1999-2010 (n= 19 grazed and 15 ungrazed (1999-2000), 17 ungrazed (2001-2010)). There was no significant difference between grazed and ungrazed plots.

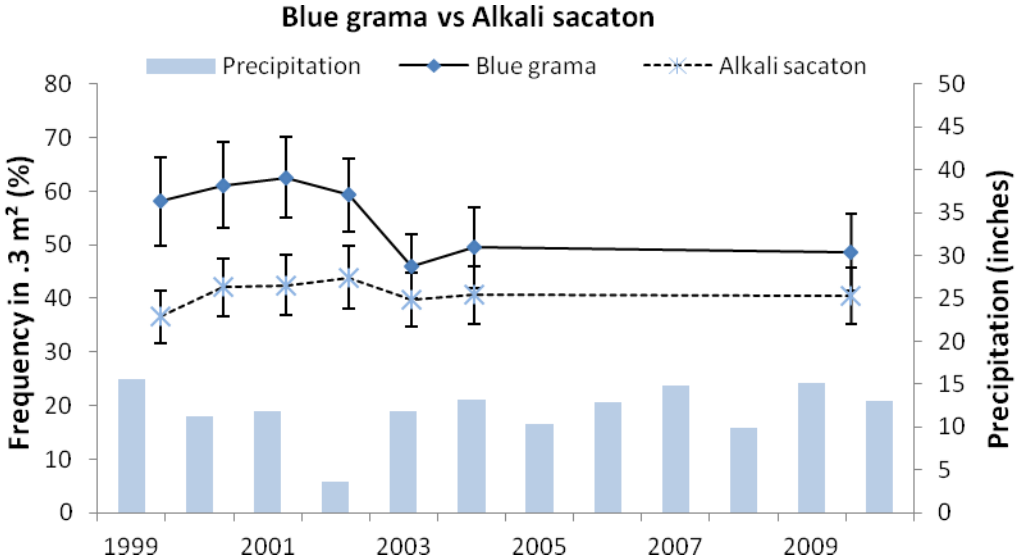


Figure 22. Blue grama and alkali sacaton grass mean frequency (± 1 SE) in all greasewood plots and all shortgrass plots with alkali sacaton grass, 1999-2010 (n=16). Blue grama had a significant reduction after the 2002 drought and there was still a 16% reduction in 2010 whereas alkali sacaton grass was stable over the same time period.

Alkali sacaton grass. This deep-rooted grass prefers the tighter and less porous alkaline soils with more clay and less sand; it occurs in the Razor clay, Arvada-Keyner, and Limon silty clay soils at PCD. It is abundant and often co-dominant with blue grama and primarily found in the greasewood habitat; however, the four shortgrass plots with Razor clay soil also had alkali sacaton grass. There appears to be an effect of grazing in shortgrass plots, with significantly higher cover of alkali sacaton grass in grazed plots; however, this is an erroneous contrast as there were no ungrazed shortgrass plots in soil types that support alkali sacaton grass. Therefore, the shortgrass habitat constituted an unbalanced design with an inadequate sample size. Greasewood plots did have an adequate sample size but exhibited no grazing treatment effect (Table 3). The drought had very little impact on alkali sacaton grass except for a drastic reduction in live cover during 2002 (Fig. C-10). When all of the greasewood plots and the four shortgrass plots with alkali sacaton grass were combined, there was an 11% increase in frequency from 1999 to 2010, whereas blue grama, in those same plots, decreased 16% (Figs. 23 and C-10).

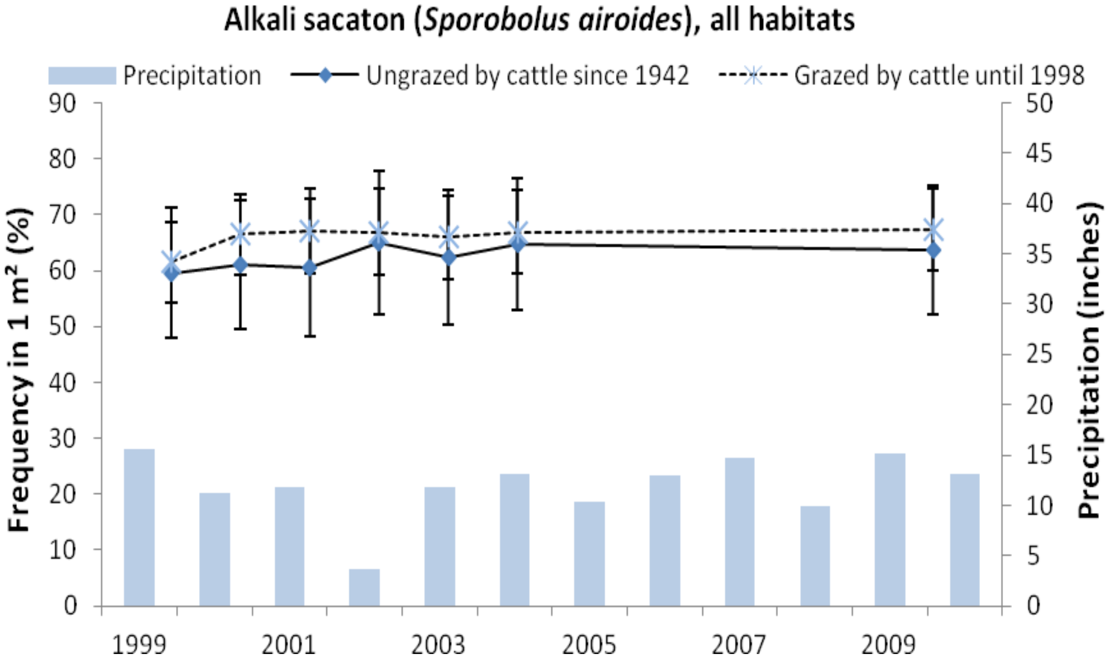


Figure 23. Alkali sacaton grass mean frequency (± 1 SE) in all greasewood plots and the four shortgrass plots that had the Razor clay soil type, 1999-2010 (n=11 grazed and 5 ungrazed). All shortgrass plots were grazed. There was no contrast between ungrazed and grazed and thus there was no interaction between year and grazing treatment.

Galleta grass. Galleta grass prefers silty clay loamy soils and was common in all greasewood plots and in 61% (8) of the shortgrass plots. It was described as a decreaser at the beginning of this study and it is trending in that direction, however slowly. In the greasewood habitat, there was a significantly higher cover ($P \leq 0.05$) and frequency ($P \leq 0.05$) in ungrazed plots verses grazed plots in 1999 (Table 3; Figs. C-11 and C-12). By 2010 there was no longer a significant difference. The picture is less clear in shortgrass since only one of the six ungrazed plots had galleta grass in abundance (>10% frequency). Therefore, I lumped all of the shortgrass plots (8) that had >10% frequency in with the greasewood plots (seven grazed and one ungrazed) and assessed the overall habitat with this sample. With this augmented sample, there was a significant difference ($P=0.02$) between grazed and ungrazed with grazed plots averaging 33% frequency and ungrazed plots averaging 61% frequency in 1999 (Table 3 and Fig. 24). The galleta grass increased 12% in frequency in grazed plots versus 3% in ungrazed plots over the course of the study. This trend hints at convergence for a "decreaser"; however, the grazing treatment by year interaction was not quite significant (P=0.1). The drought had very little impact on galleta grass, except for a drastic reduction in live cover during 2002 (Fig. C-11).

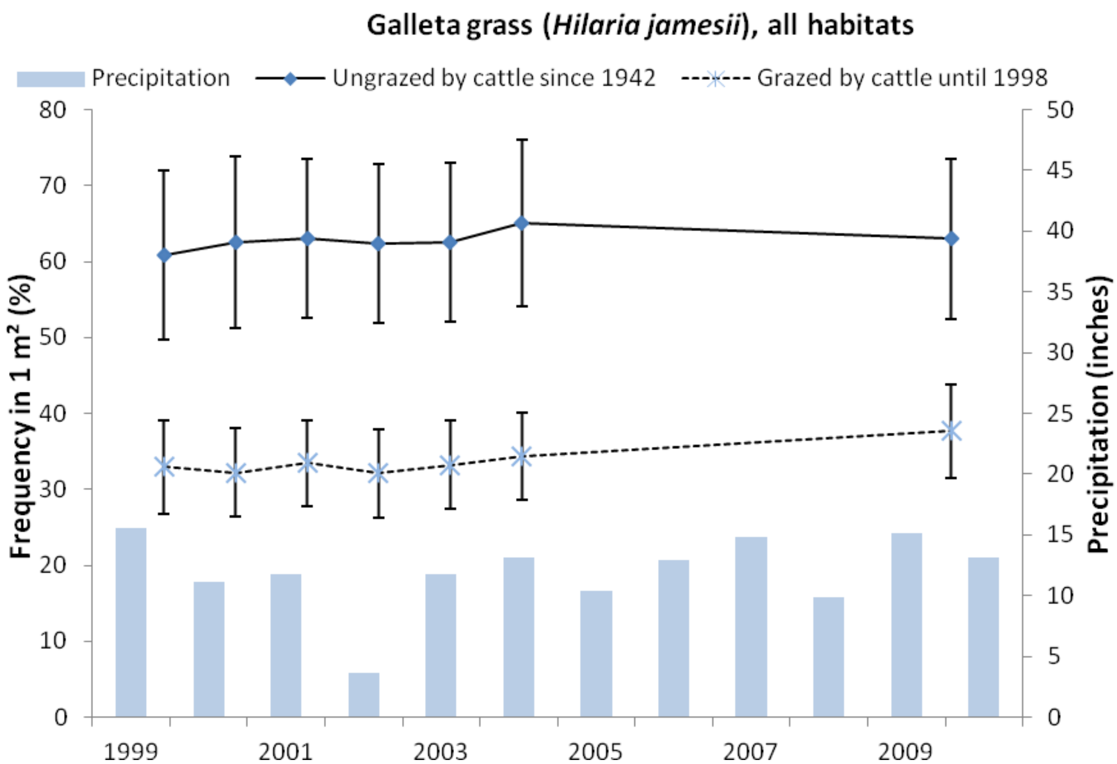


Figure 24. Galleta grass mean frequency (± 1 SE) in all greasewood plots (12) and 8 shortgrass plots, 1999-2010 (n=14 grazed and 6 ungrazed). Shortgrass plots that did not have > 10% frequency were eliminated, these were all grazed plots. There was a significant difference between grazed and ungrazed plots in 1999 (P=0.02) and this difference was not significant by 2010.

Three-awn grass. Three-awn grass is a short-lived perennial bunch grass that is not known for its palatability and is generally considered an increaser and an early successional plant after disturbance. It prefers the sandier soils. At PCD it is found in all habitat types; however, it is in low abundance in the greasewood habitat and reaches high abundance in both shortgrass and sandsage habitats. Although frequent in shortgrass and sandsage, it seldom reaches high cover except in sandsage (Figs. C-13 and C-14). The greasewood habitat was the only habitat that supported the "increaser" characterization as it had significantly higher frequency in grazed plots versus ungrazed (P≤0.05) and there was a grazing treatment by year interaction (P≤0.05). By 2010 there was no difference between the grazing conditions. Three-awn grass was uncommon in greasewood but it was present in all but one greasewood plot. In the sandsage habitat there was nearly a significant difference between grazed/ungrazed plots in 1999 (P=0.07) for frequency, with higher abundance in grazed plots, as expected (Table 3). In shortgrass there was no significant difference between grazed/ungrazed plots and the trend was in the opposite direction. That is, there was higher frequency in ungrazed plots than grazed. This anomaly may have been due to prairie dogs creating disturbed soils. There was significantly higher cover and frequency of three-awn grass in prairie dog towns than off prairie dog towns (see section on prairie dogs for more discussion). When all habitats were combined there was no significant difference in three-awn grass between grazed and ungrazed plots (Figs. 25, C-13, and C-14). Three-awn grass declined following the 2002 drought and was not fully recovered by 2010.

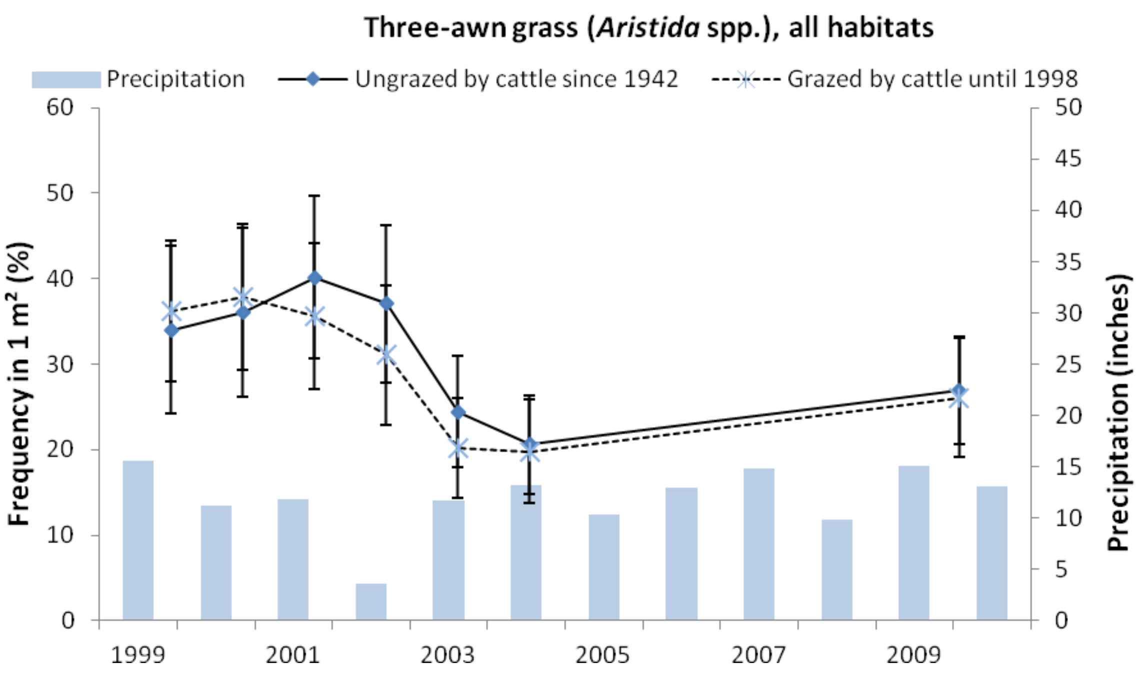


Figure 25. Three-awn grass mean frequency (± 1 SE) in all habitats combined, 1999-2010 (n=19 grazed and 15 ungrazed (1999-2000), 17 ungrazed (2001-2010)).

Sand dropseed. Sand dropseed is a short-lived perennial bunch grass. It was frequent in all habitat types but seldom reached high cover, except in sandsage habitat where it is nearly as common as three-awn grass and blue grama (Table 3, Fig. 26). The greasewood habitat had the lowest abundance and sandsage shrubland had the highest (Figs. C-15 and C-16). Sand dropseed is considered an increaser and is well suited to disturbance. The only habitat where sand dropseed was a notable increaser was in sandsage where grazed plots had significantly higher frequency (P≤0.001) and cover (P≤ 0.05) than in ungrazed plots (Fig. 26). There was not a grazing treatment by year interaction in the sandsage plots, (i.e., the grazed plots are not moving towards similarity with the ungrazed plots). In the shortgrass habitat there was not a significant difference in sand dropseed between grazed and ungrazed although it trended towards higher cover and frequency in the ungrazed plots, a condition not expected for an increaser. There was very little difference in sand dropseed between grazed and ungrazed in the greasewood habitat. When all habitats were combined there was no difference between grazed and ungrazed plots (Figs. 27, C-15, and C-16). The 2002 drought caused a decline in frequency and cover; however, by 2010 there was nearly a complete recovery from the drought (Figs. 26, 27, C-15, and C16).

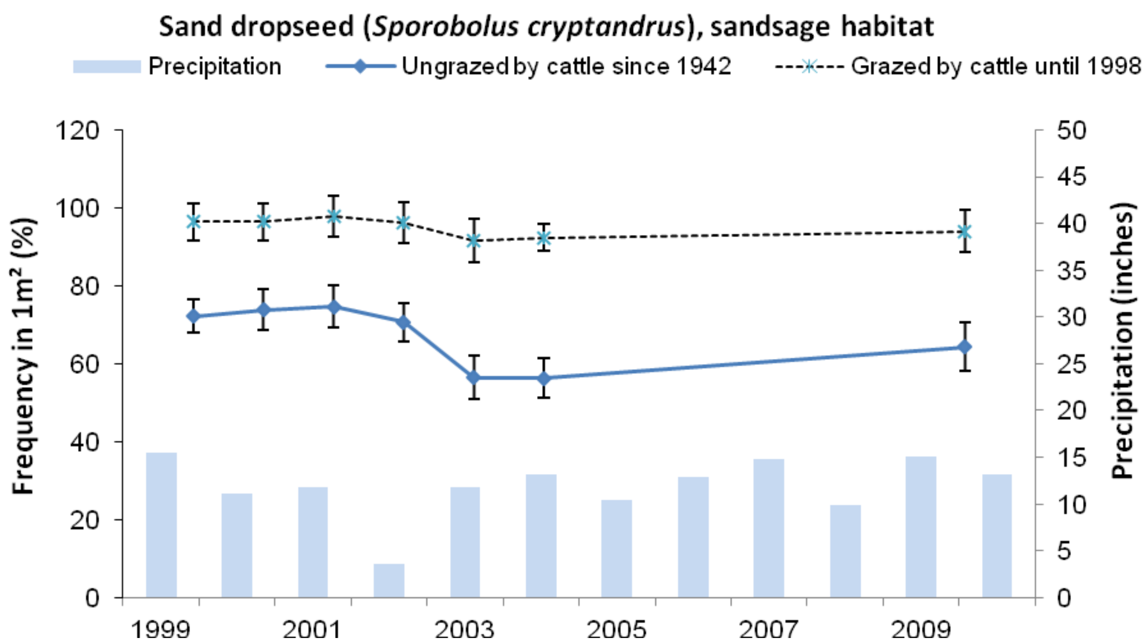


Figure 26. Sand dropseed mean frequency (± 1 SE) in sandsage habitat, 1999-2010 (n=5 grazed and 6 ungrazed). There was a significant difference between grazed and ungrazed at the beginning of the study (P=0.001) and this difference was still evident in 2010.

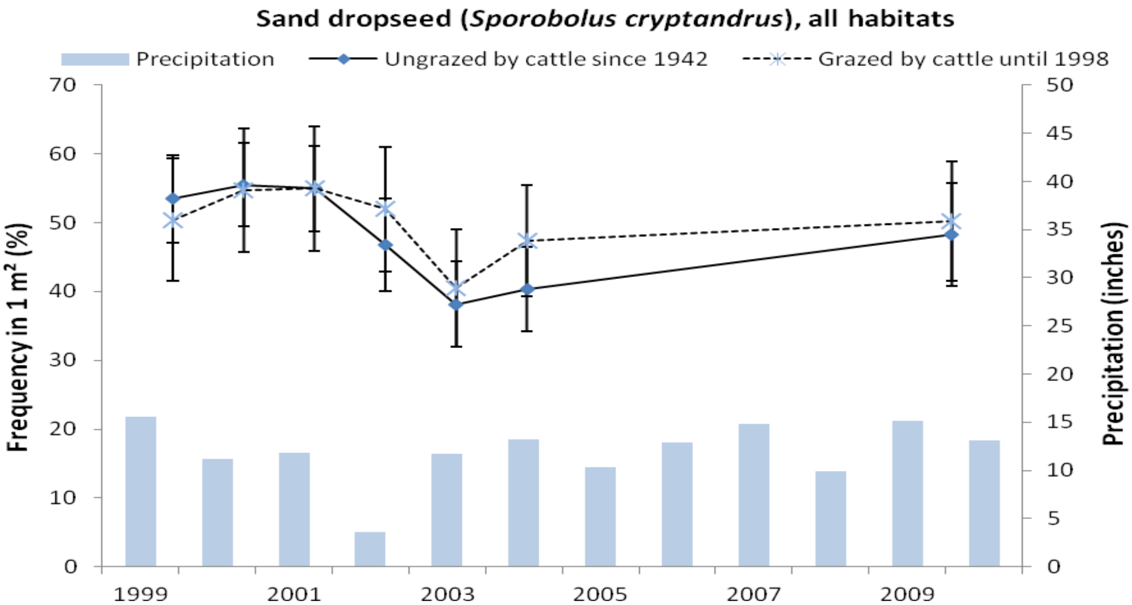


Figure 27. Sand dropseed mean frequency (± 1 SE) in all habitats combined, 1999-2010 (n=19 grazed and 17 ungrazed). There is no significant difference between grazed and ungrazed plots. The 2002 drought reduced the population size, however, by 2010 there was very little evidence of the drought.

Needle-and-thread grass. Needle-and-thread grass is a long-lived perennial bunch grass that is found only in the sandsage habitat at PCD (Table 3). It is considered a decreaser in association with heavy winter/early spring grazing (when it does not have seed heads); once it possesses seeds it is seldom grazed as the long stiff awns can cause problems to cattle gums. At PCD this plant fits the decreaser status. Both cover and frequency were significantly higher in ungrazed plots in 2000 ($P \leq 0.05$) (Fig. 28). Once cattle were removed, the grazed plots slowly gained cover and frequency; there was a significant year by grazing treatment interaction ($P \leq 0.01$, 0.05, respectively). The frequency in ungrazed plots remained nearly the same in 2010 as 2000, whereas the frequency in grazed plots more than doubled from an average of 9% in 1999 to 25% in 2010 (Fig. 28).

The 2002 drought reduced the cover and frequency of needle-and-thread grass, especially in the ungrazed plots, however, by 2010 there was complete recovery in the ungrazed plots and an increase in the grazed plots (Fig. 28).

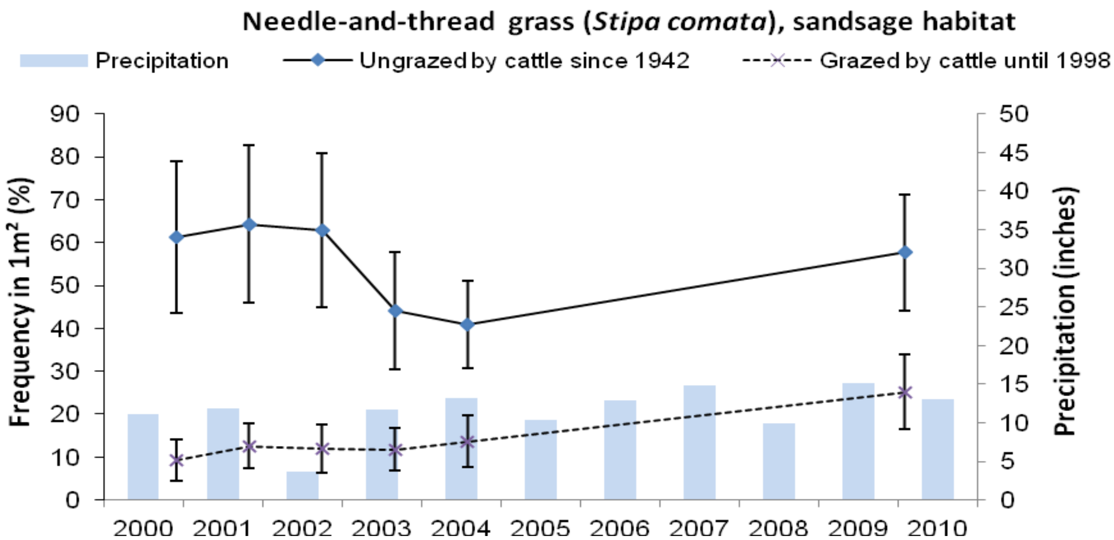
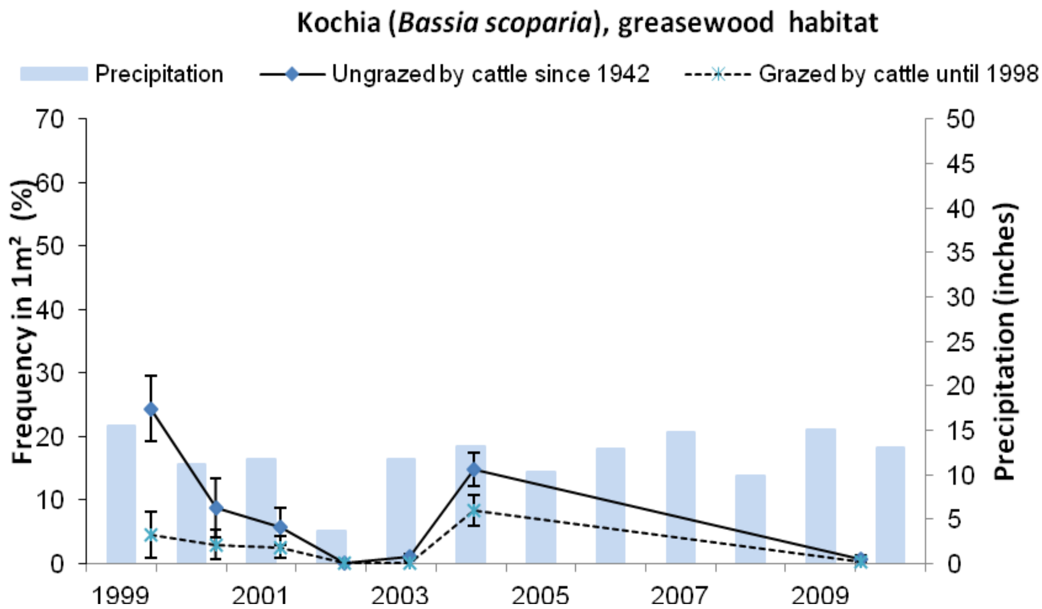


Figure 28. Needle-and-thread grass mean frequency (± 1 SE) in sandsage habitat, 2000-2010 (n=5 grazed and 6 ungrazed). There was a significant difference between grazed and ungrazed plots at the beginning of the study (P=0.03) and by 2010 this difference was diminished. The 2002 drought had an impact, especially in the ungrazed plots, however, by 2010 there was little evidence of the drought.

Weeds

Kochia. Kochia is a non-native annual forb that provides good forage to cattle if consumed in moderate amounts. At PCD, kochia is found in the greasewood and shortgrass habitats and is absent from the sandsage habitat. It was very responsive to precipitation events, with high abundance in 1999 and 2004 and virtually non-existent in 2010 (Figs. 29 and C-17). The following conclusions are based on the 1999-2004 timeframe since kochia was seldom detected in 2010. When all habitats were combined and a 2-way ANOVA test conducted, there was significantly higher abundance (P≤0.001) in ungrazed than grazed plots; abundance was ten times higher in ungrazed than grazed plots. In greasewood plots, kochia was also significantly higher in ungrazed plots in 1999 (P≤0.01) (Fig. 30), but by 2004 this difference was largely eliminated, primarily due to the kochia increasing more in grazed plots than ungrazed plots (Fig. 29). There was a year by grazing treatment interaction in the greasewood plots (P≤0.001); the ungrazed plots went from a mean frequency of 24% in 1999 down to 15% in 2004 while the grazed plots increased from 5% in 1999 to 8% in 2004. In the shortgrass habitat there was a disturbance in sg65 (grazed) in 2004 when a new power line and associated road bisected the plot. Prior to this disturbance, there was no kochia at the plot and following the disturbance, kochia significantly increased to 38%. None of the other grazed shortgrass plots exhibited this kind of an increase so the assumption is that the disturbance allowed kochia to increase, therefore I eliminated sg65 from the kochia analysis. In the shortgrass habitat, during 1999, kochia had significantly higher frequency (P≤0.01) in the ungrazed plots than in the grazed plots (20% vs 1%; Fig. 29). Therefore both greasewood and shortgrass plots had the same response, that is, grazed plots had less of this weed than the ungrazed plots and the grazed plots gained more than the ungrazed plots. The elimination of grazing caused an increase in weed abundance.



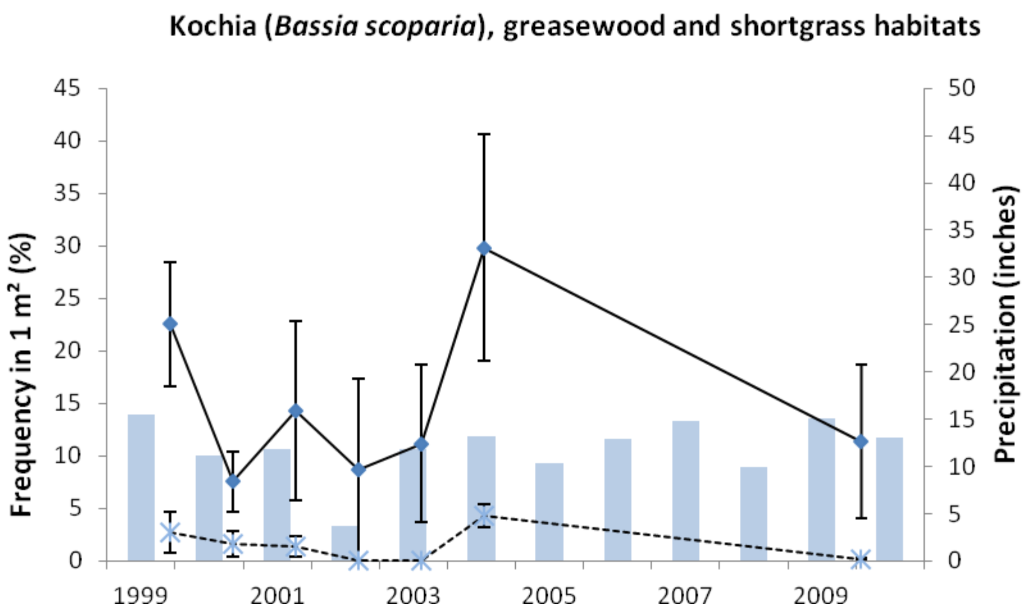


Figure 29. Kochia mean frequency (± 1 SE) in greasewood and shortgrass plots, 1999-2010 (n=13 grazed and 9 ungrazed (1999-2000), 11 ungrazed (2001-2010)). Sg65 was eliminated due to construction of a road in 2004.

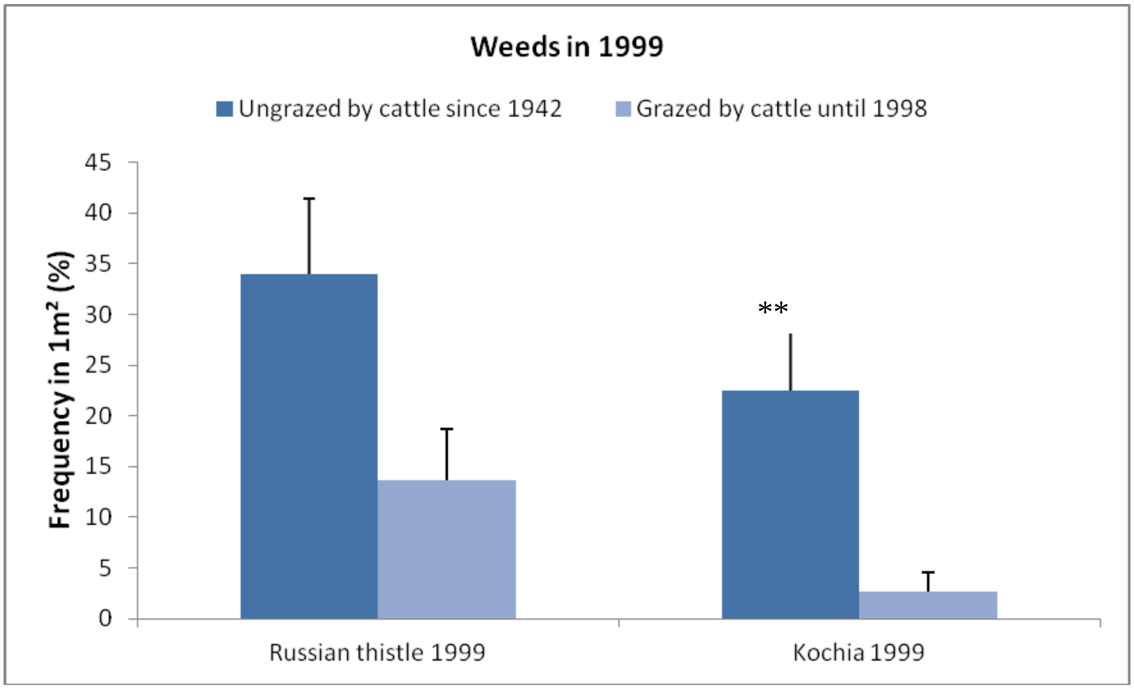
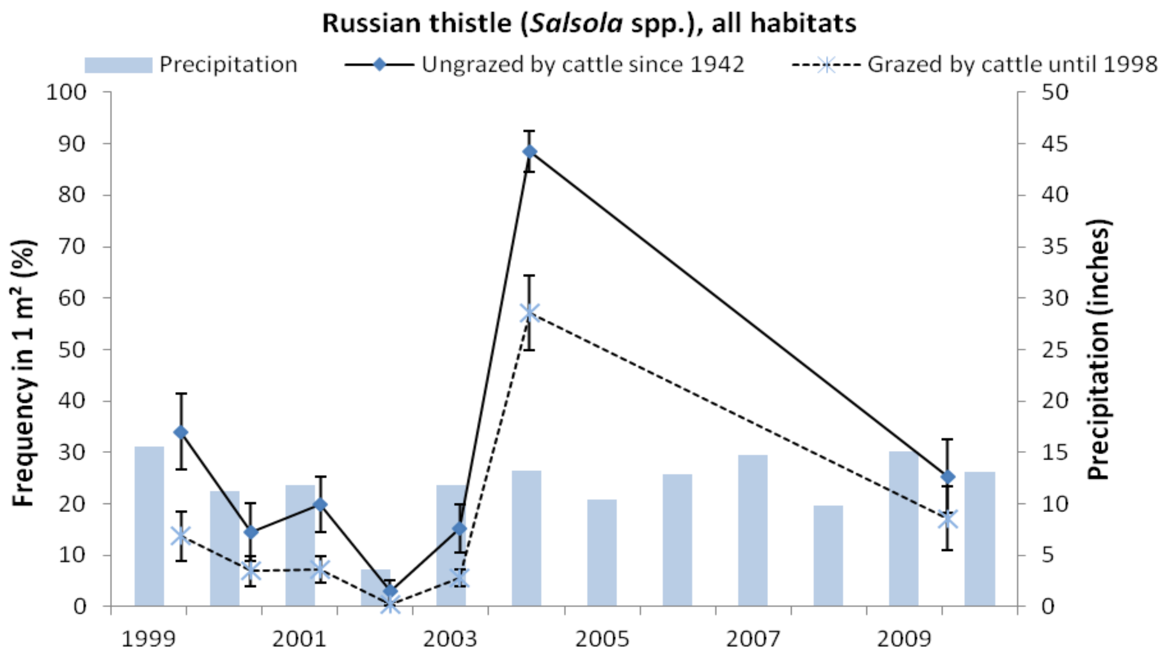


Figure 30. Russian thistle and kochia mean frequency (+ 1 SE) in 1999 (n=19 grazed and 15 ungrazed for Russian thistle; n= 13 grazed and 9 ungrazed for kochia). At the beginning of the study there was a near significant (P≤0.06) and significant (P≤0.001) difference for Russian thistle and kochia, respectively, between ungrazed and grazed plots.

Russian thistle. Russian thistle is another non-native annual weed that is utilized by cattle and, like kochia, is very sensitive to seasonal moisture. It is found in all of PCD habitat types and was not detected in 2002 and did extremely well in 2004 (Figs. 31 and C-18). There was significantly higher frequency of Russian thistle in greasewood ungrazed plots than grazed plots in 1999 (P≤0.01, Fig. 30). Neither sandsage nor shortgrass plots had a significant difference between grazed and ungrazed plots. When all habitats were combined, the 2-way ANOVA test was nearly significant (at P=0.06) with higher abundance in ungrazed plots than grazed (Fig. 31). In greasewood plots there was a grazing treatment by year interaction (P≤0.001) and Russian thistle increased in the grazed plots and thereby converged with the conditions prevailing in the ungrazed plots (Fig. 31). Looking at 2004, the peak year for Russian thistle, the frequency in ungrazed plots increased 3-fold from 2003 while the grazed plots increased 8-fold. When all habitats are combined there was a 2.5-fold increase in frequency in ungrazed plots and a 4-fold increase in grazed plots (Fig. 31), supporting the argument that cattle grazing had suppressed the annual weeds.



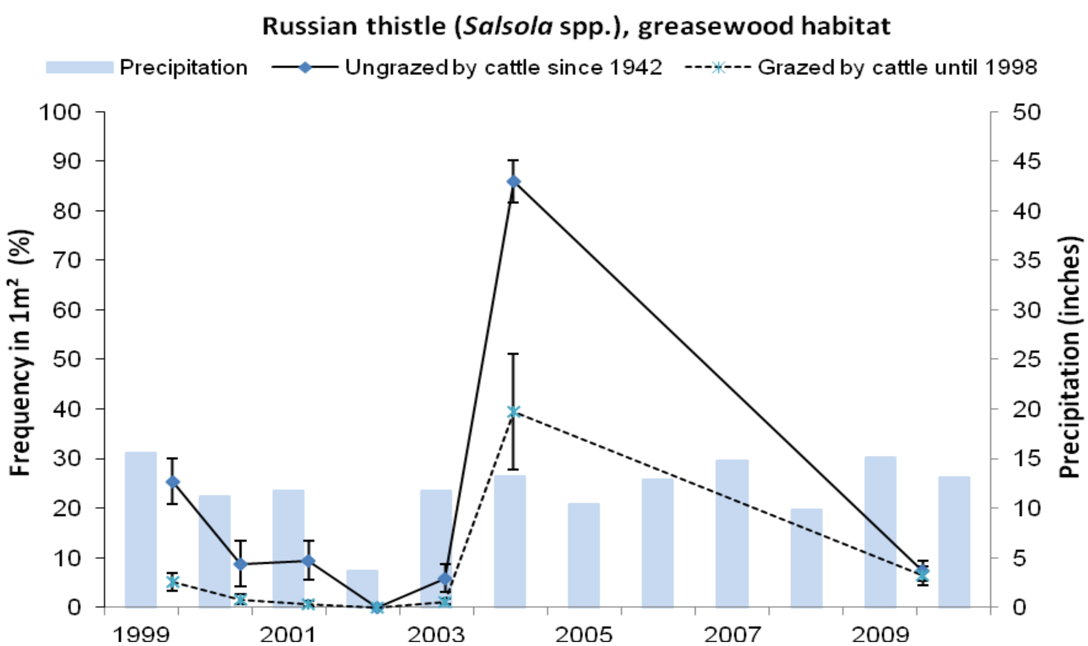


Figure 31. Russian thistle mean frequency (± 1 SE) in greasewood (top) and all habitats combined (bottom), 1999-2010 (n=19 grazed and 15 ungrazed (1999-2000), 17 ungrazed (2001-2010)). There was a nearly significant difference in 1999 (P=0.06) for all plots combined. This annual plant is very responsive to seasonal precipitation and 2004 was an exceptionally good year. Formerly grazed plots gained Russian thistle at a higher rate than the ungrazed plots.

Bare Ground. Bare ground is part of all habitats, however it was extremely hard to measure in sandsage habitat due to the ephemeral nature of litter (litter is easily blown off a sandsage site). Because of this, I report bare ground only for greasewood and shortgrass plots. Grazing is known to increase bare ground and PCD habitats were no exception. The bare ground in greasewood was significantly higher in grazed plots than ungrazed in 1999 ($p \leq 0.01$) (Fig. C-19). There was a grazing treatment by year interaction ($P \leq 0.05$) with grazed plots converging over time with the ungrazed plots. Bare ground in the shortgrass habitat exhibited a similar pattern as in the greasewood habitat with significantly more bare ground in grazed plots than ungrazed plots in 1999 ($P \leq 0.01$) (Fig. C-19). Unlike greasewood plots, however, there was not a significant grazing treatment by year interaction and there was still a significant difference between grazed and ungrazed plots in 2010. When greasewood and shortgrass plots are combined, the same trend as observed in the greasewood habitat was also evident (Fig. 32).

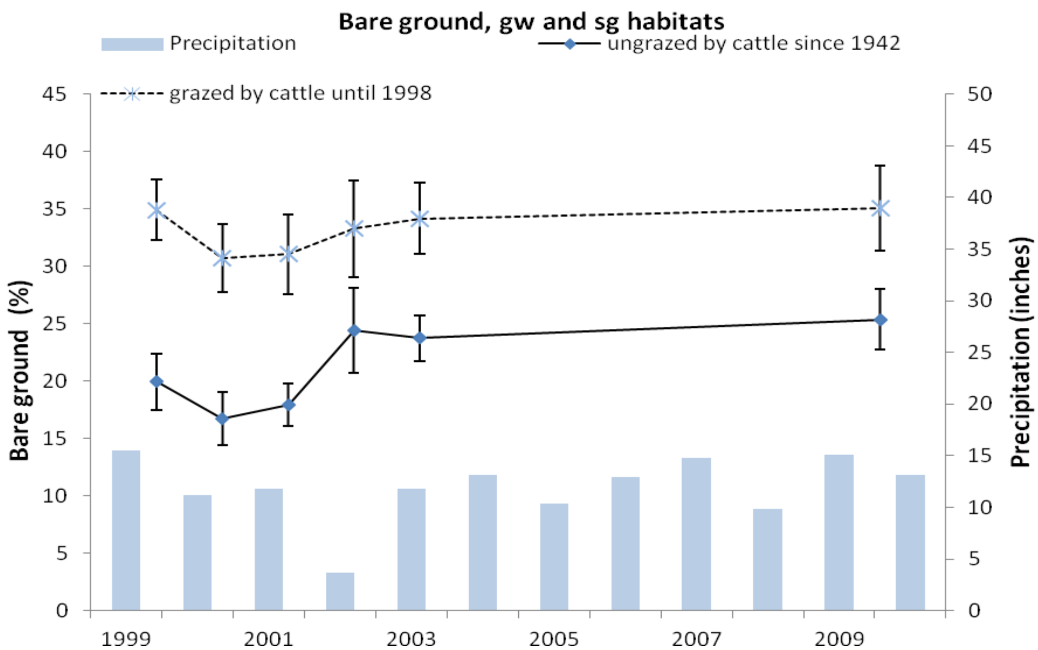


Figure 32. Bare ground mean cover (± 1 SE) in greasewood and shortgrass plots, 1999-2010 (n=14 grazed and n=9 ungrazed (1999-2000), 11 ungrazed (2001-2010)). There was a significant difference between grazed and ungrazed plots at the beginning of this study (P≤0.0001). This difference was much less by 2010, due to the formerly grazed plots becoming more vegetated.

Litter. Litter was measured by adding ground litter with standing dead litter and in retrospect this was not the best way to measure litter. Due to this I have eliminated litter from the analysis. In general, a good rule of thumb is that when there is more bare ground there is less litter (Fig. C-20).

Prairie Dog Treatment. Prairie dogs are a native rodent grazer that are common within the shortgrass habitat at PCD. They occur especially where there are Limon silty-clay loam soils. The shortgrass plots that never had prairie dogs throughout the course of this study were on Razor clay eroded soils or Otero gravelly sandy loam. There were nine plots on the Limon silty-clay loam soil type and all but one had prairie dogs at least one year during this study (Table 4). None of the towns were active throughout the entire study as sylvatic plague came through PCD multiple times; on average a town was active for 2 out of the 7 years and inactive for 4 out of the 7 years (Table 4). Although the original study was not designed to measure the effects of prairie dogs it was clear that prairie dogs should be considered and I added two plots, sg80 and 81 in 2001, both ungrazed by cattle. Sg81 was confined by bunkers on the north and south edges and the vegetation had been highly altered and was dominated by weeds. The vegetation at this plot was more altered by prairie dogs than any of the other plots, presumably because of the mobility constraint from the nearby bunkers.

The following results summarize the effect of prairie dogs versus no prairie dogs. The data are summarized below and in Figures C-21 through C-24 of Appendix C.

Blue grama, sand dropseed, galleta grass, kochia, and bare ground did not exhibit any difference in frequency or cover on or off of the prairie dog towns while three-awn grass, prickly pear, and Russian thistle were significantly different (Fig. 33). Three-awn grass and Russian thistle had significantly higher abundance on prairie dog towns than off prairie dog towns ($P \leq 0.05$; Fig. 33), while prickly pear had significantly lower abundance on prairie dog towns than off ($P \leq 0.01$).

Table 4. Prairie dog activity by year for each plot that had prairie dogs at some time during the study.

Plot	1999	2000	2001	2002	2003	2004	2010	years active	years inactive
sg61	inactive	inactive	inactive	active	inactive	active	inactive	2	5
sg68	inactive	inactive	inactive	inactive	inactive	inactive	active	1	6
sg70	inactive	inactive	inactive	inactive	inactive	active	active	2	5
sg74	inactive	inactive	inactive	inactive	inactive	inactive	active	1	6
sg77	inactive	active	active	active	inactive	inactive	active	4	3
sg78	inactive	inactive	inactive	inactive	inactive	active	active	2	5
sg80			active	active	inactive	inactive	inactive	2	3
sg81			active	active	active	inactive	active	4	1
Average								**2.3**	**4.3**

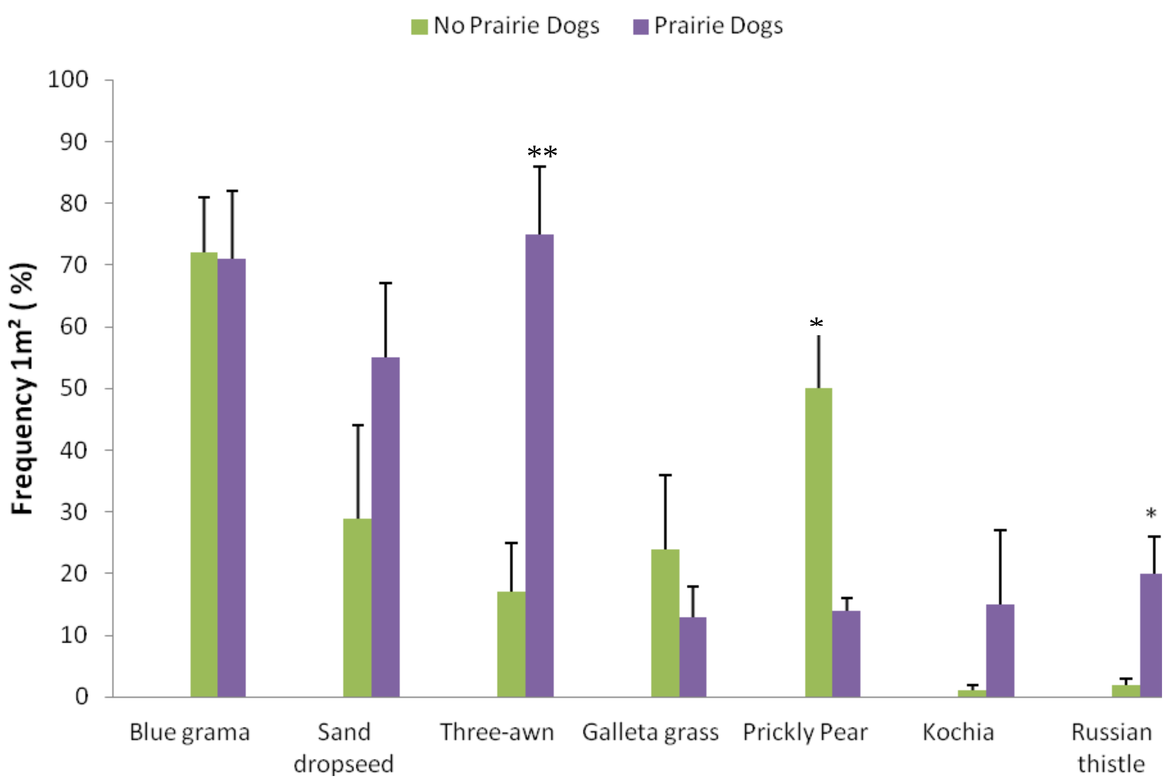


Figure 33. Mean frequency (± 1 SE) of dominant species on and off prairie dog towns for the year 2001 (n= 5 no prairie dogs, n=8 with prairie dogs). An * indicates significant differences *(P≤0.05) or **(P≤0.01).

Prickly pear was more than twice as abundant off of prairie dog towns as on (P≤0.01; Fig. 34) and all indications point towards prairie dogs eating prickly pear, for example, sg68 and sg74 did not have an active prairie dog town until the last sample year and in both instances the prickly pear declined after prairie dogs became established (Table 5).

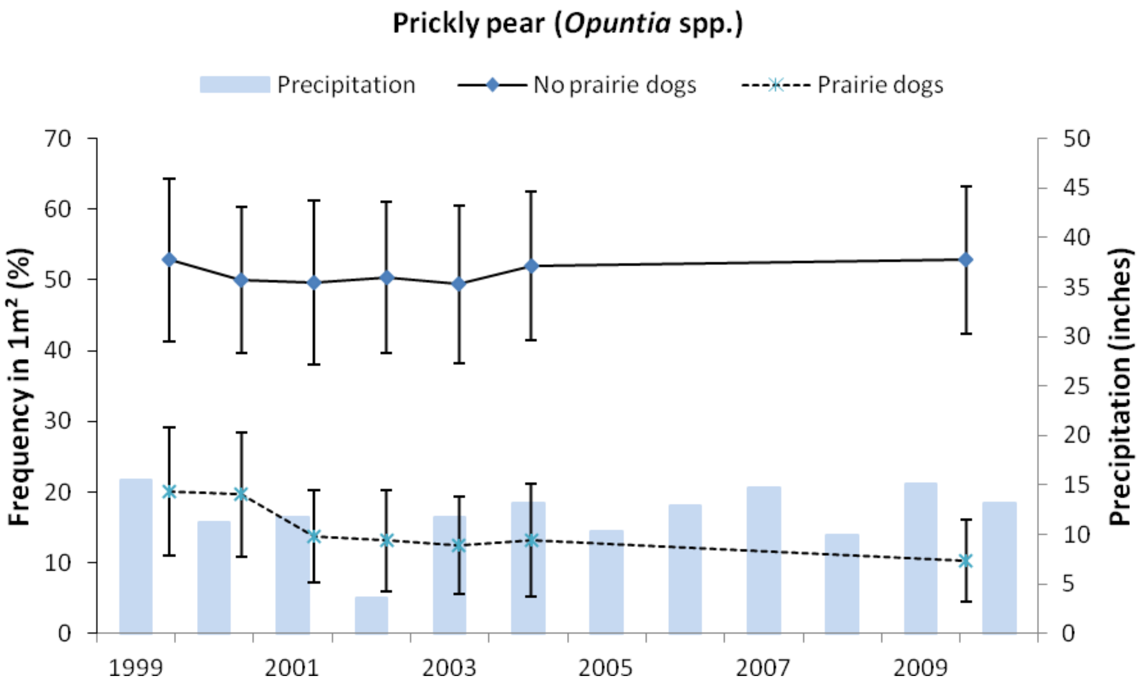


Figure 34. Prickly pear mean frequency (± 1 SE) on and off prairie dog towns, 1999-2010 (n=5 no prairie dogs, n=6 with prairie dogs (1999-2000), n=8 with prairie dogs (2001-2010)). There was significantly less prickly pear on prairie dog towns than off (P=0.01). The drop in prickly pear in 2001 was due to a change in sampled plots.

Table 5. Prickly pear mean frequency at plots that were free of prairie dogs until the end of the study. Prairie dogs became established between 2004 and 2010 and prickly pear noticeably decreased after the prairie dogs became established.

Plot	1999	2000	2001	2002	2003	2004	2010
sg68ug	59	57	51	56	53	64	49
sg74ug	33	32	32	31	32	28	11

Three-awn grass had approximately 2.5 times higher abundance on prairie dog towns than off (P≤0.01). Although the drought killed three-awn grass and recovery was not complete in 2010 there was still a difference between on/off prairie dog towns (Fig. 35).

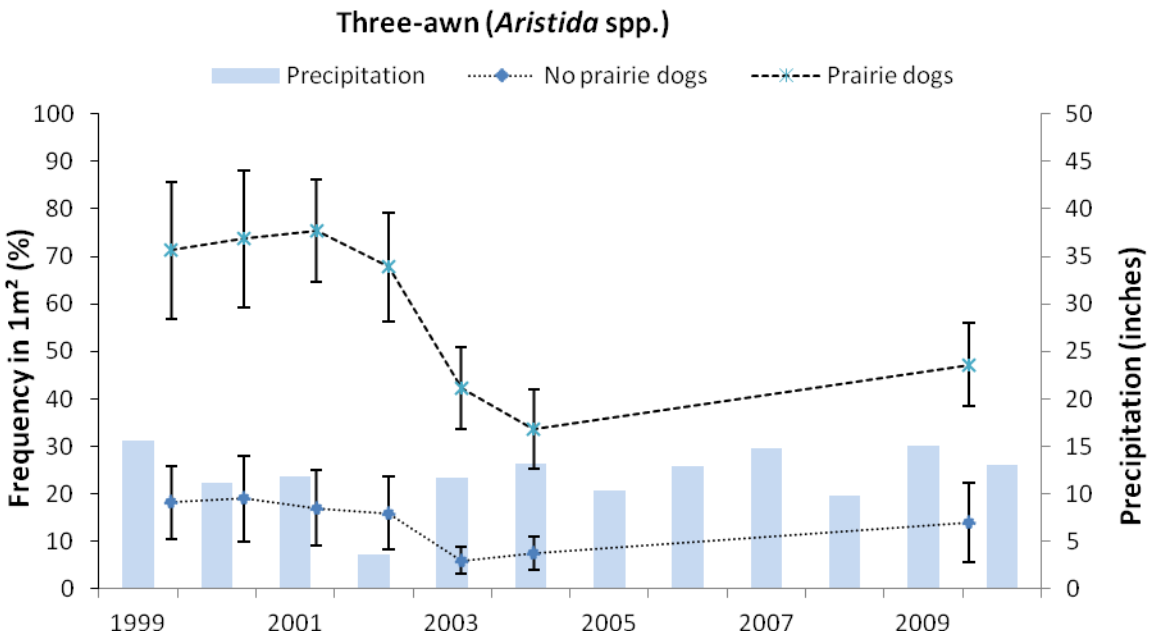


Figure 35. Three-awn grass mean frequency (± 1 SE) on and off prairie dog towns, 1999-2010 (n=5 no prairie dogs, n=6 with prairie dogs (1999-2000) and n=8 with prairie dogs (2001-2010)). Three-awn grass frequency was significantly higher on prairie dog towns than off (P=0.001). The drop in 2003 was associated with the 2002 drought.

Sand dropseed had insignificantly higher abundance on prairie dog towns than off. The drought had a relatively transient negative impact on sand dropseed, as it had reached pre-drought levels just two years after the drought (Fig. 36).

Kochia and Russian thistle had higher frequency on prairie dog towns than off however it was significant only in the year 2004 for Russian thistle (P≤0.05; Figs. 37 and 38).

Bare ground did not exhibit any difference on or off prairie dog towns (Fig. 39).

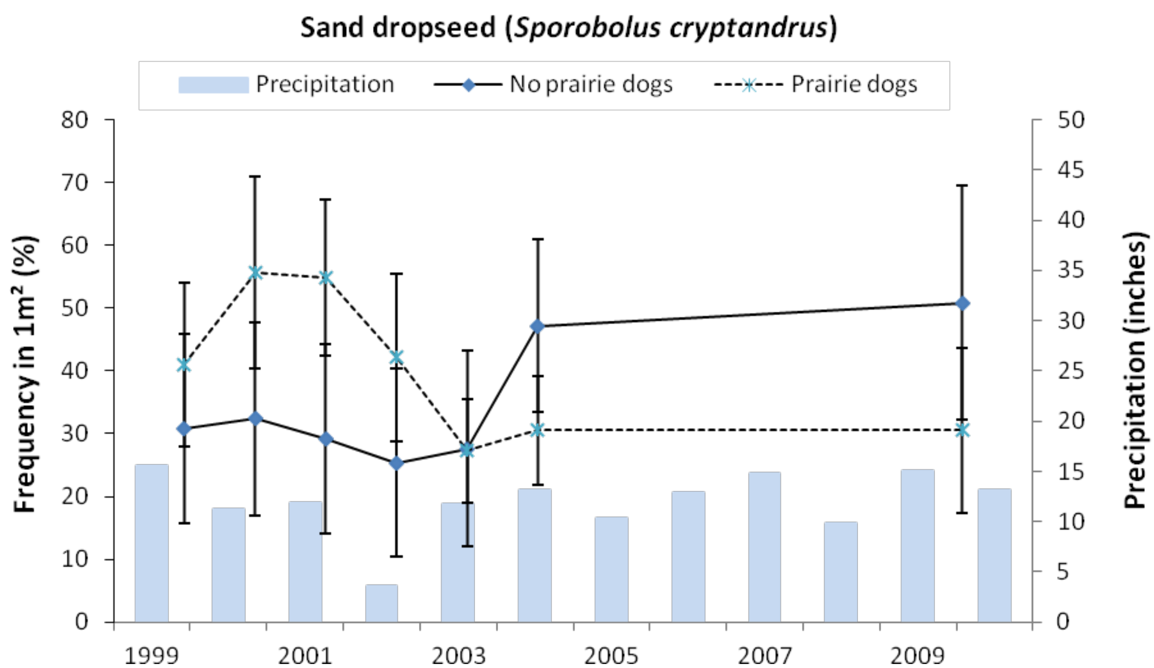


Figure 36. Sand dropseed mean frequency (± 1 SE) on and off prairie dog towns, 1999-2010 (n=5 no prairie dogs, n=6 with prairie dogs (1999-2000) and n=8 with prairie dogs (2001-2010)). Sand dropseed frequency did not differ between on or off prairie dog towns.

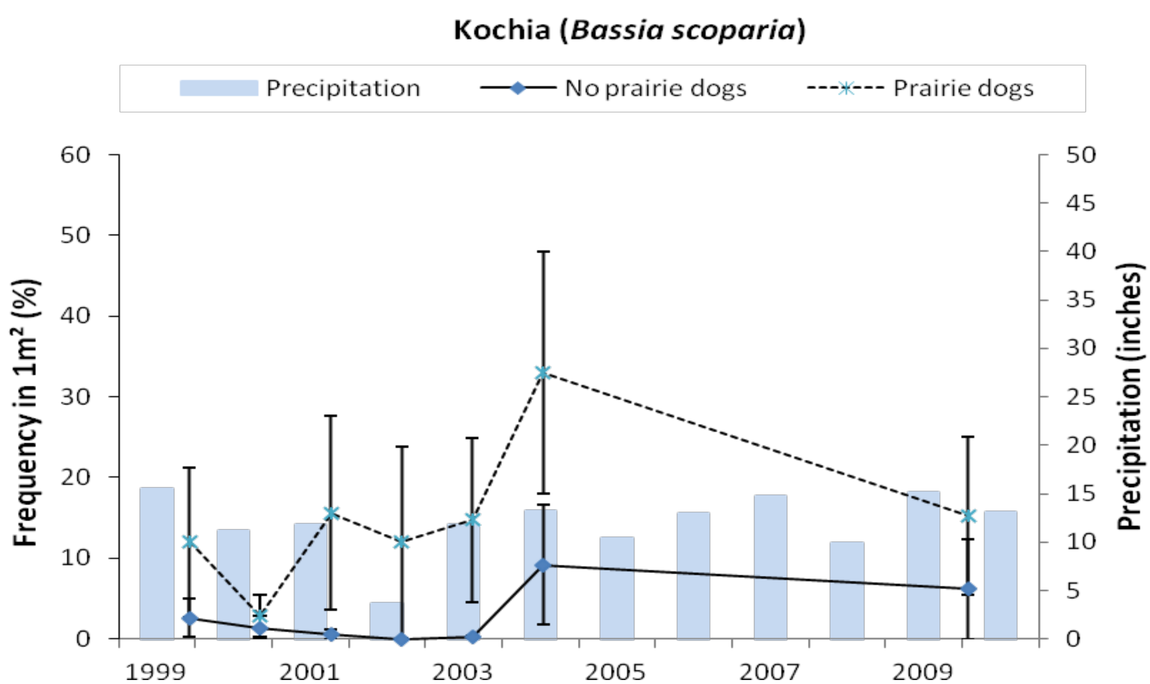


Figure 37. Kochia mean frequency (± 1 SE) on and off prairie dog towns, 1999-2010 (n=5 no prairie dogs, n=6 with prairie dogs (1999-2000) and n=8 with prairie dogs (2001-2010)). There was no significant difference between on and off prairie dog towns.

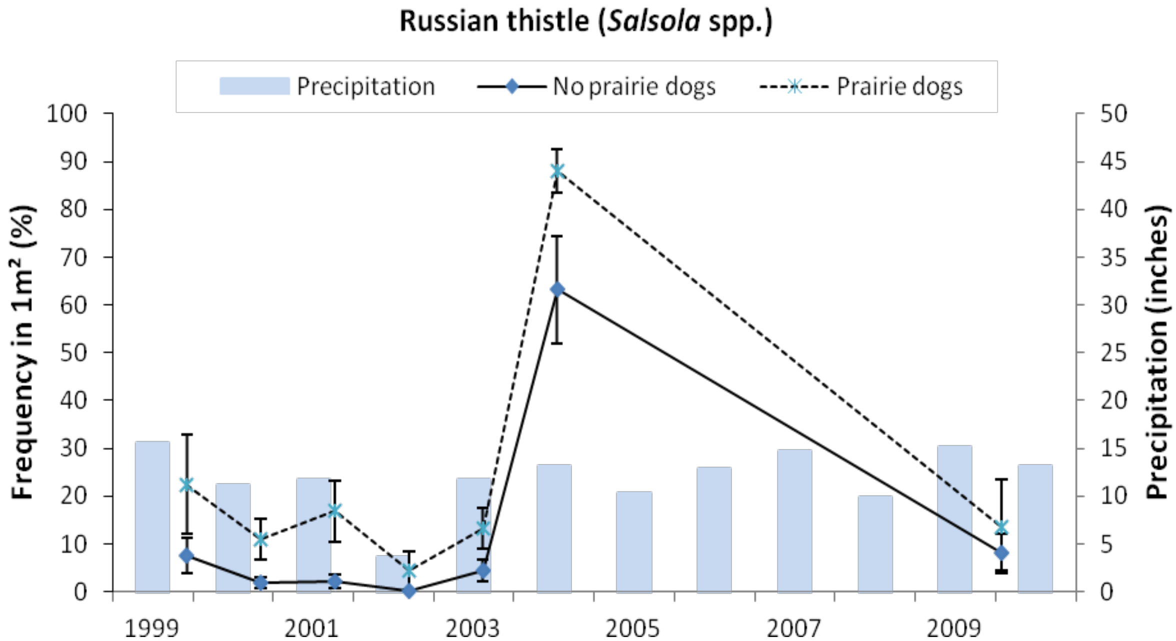


Figure 38. Russian thistle mean frequency (± 1 SE) on and off of prairie dog towns, 1999-2010 (n=5 no prairie dogs, n=6 with prairie dogs (1999-2000) and n=8 with prairie dogs (2001-2010)). Russian thistle frequency was higher on prairie dog towns than off in years 2000, 2001, and 2004.

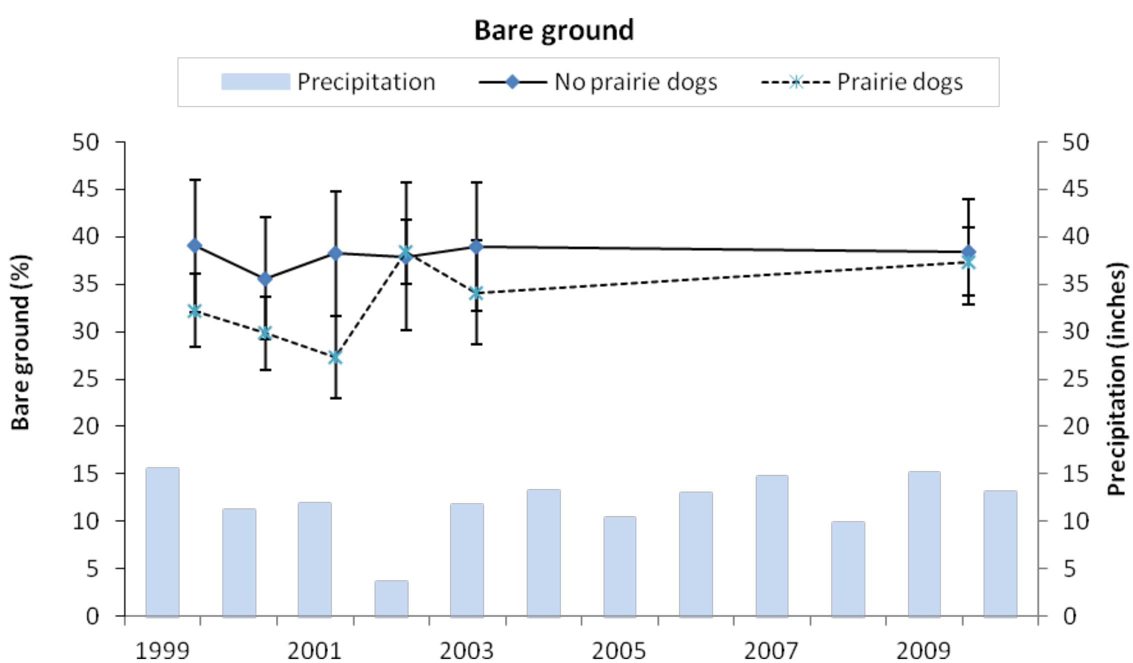


Figure 39. Bare ground mean cover (± 1 SE) on and off prairie dog towns, 1999-2010 (n=5 no prairie dogs, n=6 with prairie dogs (1999-2000) and n=8 with prairie dogs (2001-2010)). There was no significant difference exhibited on or off of prairie dog towns.

Discussion

Eleven years of monitoring at PCD has given us insight into the response of vegetation to the cessation of livestock grazing, drought conditions, and to the presence of prairie dogs in Colorado's eastern shortgrass prairie. These insights and results are important to future management at PCD as well as for the greater Chico Basin area. Although PCD is small, relative to a large landscape level, it makes up the southern portion of an important landscape level conservation area – Chico Basin. The Nature Conservancy, Colorado Natural Heritage Program, and Rocky Mountain Bird Observatory, have identified Chico Basin as a high priority conservation area for Colorado. The primary reason that all three organizations have identified Chico Basin as significant is that it is a large (>200,000 acre) intact prairie landscape that incorporates the mosaic of shortgrass prairie, sandsage prairie, greasewood flats, wetlands, and riparian areas. This intact landscape supports a suite of species of concern, including but not limited to mountain plover, burrowing owl (*Athene cunicularia*), ferruginous hawk (*Buteo regalis*), long-billed curlew (*Numenius americanus*), black-tailed prairie dog, swift fox (*Vulpes velox*), massasauga rattlesnake (*Sistrurus catenatus*), and Arkansas darter (*Etheostoma cragini*).

Results from this study are applicable to much of the Chico Basin Conservation Area and should help with management choices on both PCD and the greater Chico Basin.

Cessation of Grazing

The cessation of grazing at PCD was a decision made by Team Pueblo in 1998, following a preliminary recommendation from an environmental study (Rust 1999). My primary task was to document the changes that took place as a consequence of this major management decision. After eleven years of monitoring, I have documented that the effects from the cessation of cattle grazing were most readily noticed in sandsage, galleta grass, sand dropseed, needle-and-thread grass, bare ground, and weeds.

There were no native species within the shortgrass prairie that consistently indicated the presence of cattle, whereas greasewood and sandsage shrublands each had two indicator species. Galleta grass was the best indicator species of the greasewood shrubland, with generally more cover and frequency in ungrazed areas, although grazed areas still had a substantial amount of galleta grass. Three-awn grass was also an indicator in the greasewood shrubland with higher abundance in grazed plots, however three-awn grass had a very small presence in the greasewood habitat. The best indicator species for sandsage shrubland were sandsage, sand dropseed, and needle-and-thread grass; the grazed areas consistently had more sand dropseed and sandsage, and less needle-and-thread grass than the ungrazed areas (Table 3).

There were two non-native species that were good indicators of grazing: kochia and Russian thistle, especially in the greasewood and shortgrass habitats. Cattle grazing suppressed these weeds and with the cessation of cattle grazing at PCD, there has been an increase in both species of weeds. The annual weeds, Russian thistle and kochia, were tightly associated with precipitation events and although their presence indicated a lack of grazing, they were nearly absent in all plots during drought years. Thus annual weeds are useful indicators during wet years; the best indicators were consistent across years and sampling methods.

Bare ground was a good indicator of cattle grazing, especially in greasewood and shortgrass habitats. The cessation of grazing in the greasewood habitat decreased the amount of bare ground whereas the difference is still evident in the shortgrass habitat, 12 years after the cessation of grazing.

My overall impression of the upland habitat conditions at PCD is that the greasewood and shortgrass habitats had little to no shifts in species composition due to cattle grazing but the sandsage had a significant shift in species composition and although it is showing signs of recovering from past heavy grazing, it will take many more years to observe this shift.

Although the amount of bare ground is one of the best indicators of grazing regimes in the shortgrass prairie and greasewood shrubland, it is unclear what the desired amount should be. The desire for less bare ground in the shortgrass prairie may, at first glance, appear to be a positive outcome, in that less erosion will take place. Yet, on the other hand, our knowledge of the prairie fauna indicates that several shortgrass prairie species prefer areas with high levels of bare ground. The best example of a species with this preference is the mountain plover. This declining shortgrass prairie bird prefers areas that have over 30% bare ground and vegetation that is less than 3 inches high (Knopf and Miller 1996). The areas at PCD that have not been grazed since the 1940s, in general, do not meet these criteria, and therefore do not support nesting mountain plover, whereas the grazed areas, in general, do. Although, with the cessation of grazing, bare ground has decreased in grazed areas, there is still a noticeable difference between grazed and ungrazed treatments, even five years after the cessation of grazing, probably due to the continued presence of prairie dogs.

Numerous studies have linked the mountain plover to areas where both prairie dogs and cattle grazing occur (Knowles et al. 1982, Olson and Edge 1985, Olson-Edge and Edge 1987, Dinsmore 2001). This combination, most likely, closely represents the historic combination of bison and prairie dogs. Fires are another natural process that can control cover and structure of vegetation. If PCD wishes to maintain or increase nesting mountain plover populations, they may want to consider alternatives such as conducting late fall to early spring (March) controlled burns to maintain the structure that mountain plover needs. Another possibility would be to bring in cattle for a short time in early spring, prior to the arrival of mountain plover. Mountain plovers have been observed nesting in prairie dog colonies at PCD (M. Canestorp, per. com. 2012).

Of all the vegetation types at PCD, sandsage shrubland appears to have more undesirable impacts from cattle grazing than do the shortgrass prairie or greasewood shrubland. The species composition is more drastically altered in the sandsage shrubland than in the greasewood shrubland or shortgrass prairie. It is unclear how many years of rest from grazing would be necessary for the grazed and ungrazed plots to become similar.

Changes in plant composition do not happen quickly, especially in dry environments. Several studies have reported that even 100 years may not be adequate time for certain soils and plant communities to readjust to an impact (Webb and Wilshire 1980). At several sites in Arizona, the removal of livestock grazing for up to 20 years had not resulted in increased perennial grass cover (Valone 2002). Another Arizona site was ungrazed for 39 years and there was significantly higher perennial grass cover inside the exclusion fence than outside, and nearly all the increase had occurred over the past 20 years (Valone 2002). There may be significant time lags at PCD in the response of vegetation to the removal of livestock, especially with the perennial bunch grasses of the sandsage shrubland. I expect that with time, needle-and-thread grass will increase and sand dropseed will decrease in the grazed areas at PCD, but how much time is needed before this happens is unknown. The near absence of sand bluestem (*Andropogon hallii*) and prairie sandreed (*Calamovilfa longifolia*) at PCD is still a mystery as these species are present just north and south of PCD borders. Natural Resources Conservation Services (NRCS) considers these species indicators of a functioning sandsage habitat and perhaps restoration of these species would speed up the recovery process. Since needle-and-thread grass has responded relatively rapidly, there may be hope that these other grasses will become established on their own but since they are not present in the plots that have not been grazed since 1942, it appears that once these species are eliminated from an area it is extremely hard to re-establish them without human intervention.

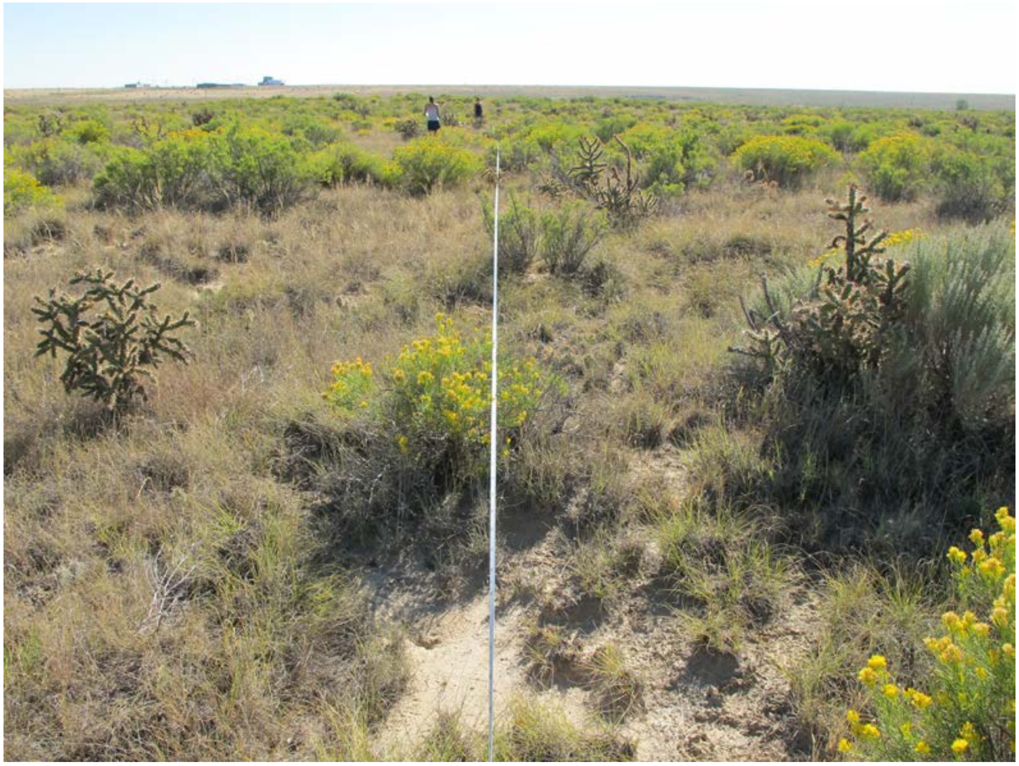
Impacts of Drought

The occurrence of drought is seldom a desired event, yet it is drought, coupled with grazing and fire, that has shaped the composition of the flora and fauna that denotes the central shortgrass prairie. The 2002 drought was the worst drought in over 100 years (Pielke et al. 2005). As the Intergovernmental Panel on Climate Change models depict more extreme drought events as the earth's climate warms (Ray et al. 2008), the results that were documented at PCD may be important in understanding the ecological impacts that more frequent and intense droughts will have. Most of the vegetation will lie dormant during extreme hot and dry conditions yet readily bounce back when the moisture returns. During extreme events, individuals may die, either during or just following a drought, resulting in a reduction in the population size for a few years. A study at the Central Plains Experimental Station, about 40 miles east of Fort Collins, reported a one-year lag time for changes in frequency for blue grama and three-awn grass (Hyder et al. 1975).

Warm season (C4) grasses, such as blue grama, are more responsive than cool season (C3) grasses, such as needle-and-thread grass, to additional water supplements (Skinner et al. 2002). Sala and Lauenroth (1982) reported that leaf water potential and leaf conductance to water in blue grama increased within 12 hours following a small (5 mm) precipitation event, and that improved leaf water relations lasted up to two days. This rapid response to rainfall would allow blue grama, with its dense, shallow root system (Bartos and Sims 1974, as cited in Skinner et al. 2002), to be highly competitive under fluctuating moisture conditions.

The effects of grazing intensity on plant responses to drought are species specific (Olson et al. 1985, as cited in Skinner et al. 2002), suggesting that the interaction between drought and grazing could significantly affect the botanical composition of rangelands. In one study, ungrazed plots were no less susceptible to drought than grazed plots (Skinner et al. 2002).

With just a bit over three inches of rain in 2002, all plots suffered from the drought and by 2003 it was evident that some species had a high rate of mortality while others were hardly impacted. By 2010, it was much easier to tell which species benefitted from the drought. Rabbitbrush and cholla were the two shrubs that significantly gained in cover or density after the 2002 drought, while greasewood had a short spike following the drought. However, by 2010 it had lost those gains. Climate had a larger impact on shrubs than grazing which is an observation that managers may be interested in. An increase in shrubs will change the flora and fauna of an area as well as reduce the amount of forage for cattle. Fires will reduce rabbitbrush and cholla and to some degree greasewood, and may be a good management tool if shrub encroachment occurs in areas where a manager does not want them. A fire occurred at PCD in 2011 and the two shrubland plots that were burned had a significant reduction in shrubs. Rabbitbrush had nearly 90% mortality and cholla individuals showed about 50% mortality (Fig. 40). Rabbitbrush and cholla will most likely repopulate this area but it is unclear how long this will take and it could be that full shrub recovery will happen in just a few years.



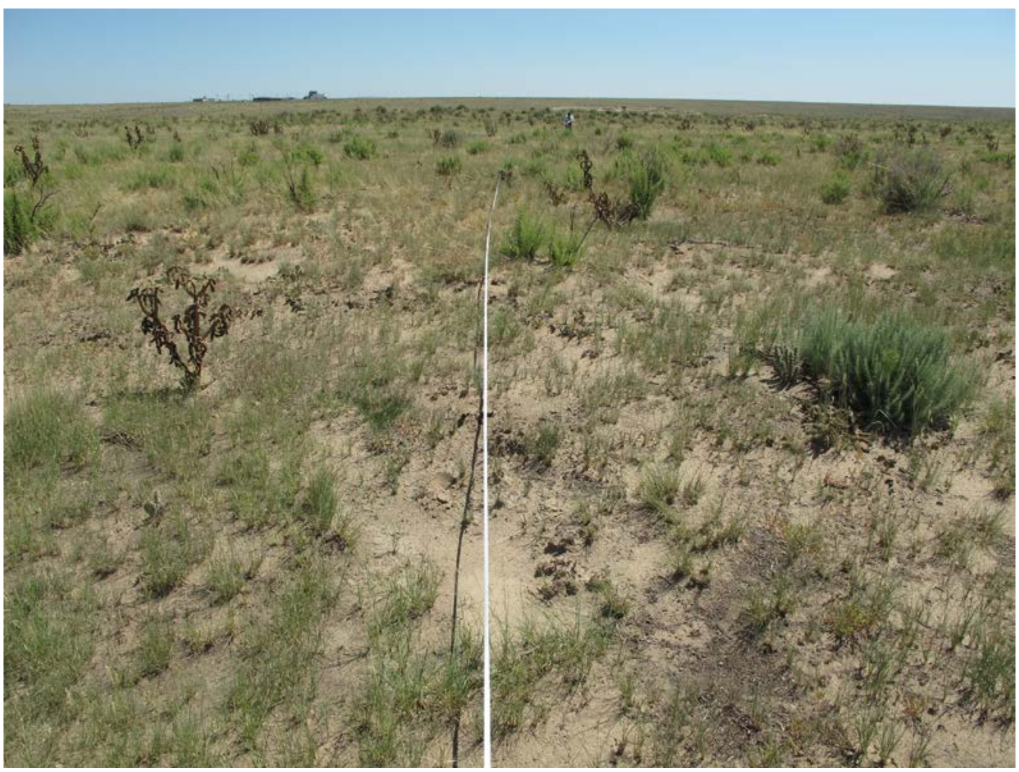
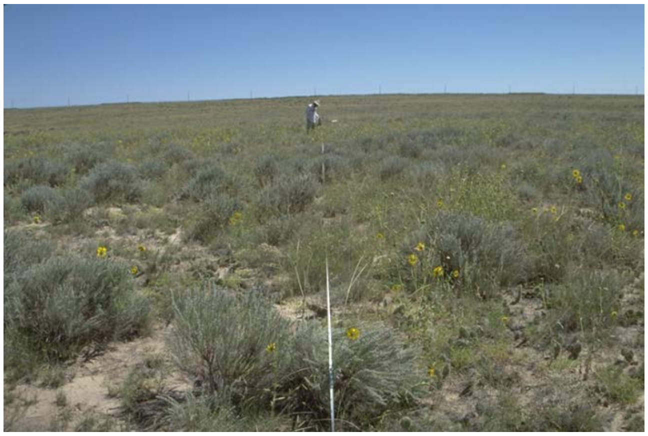


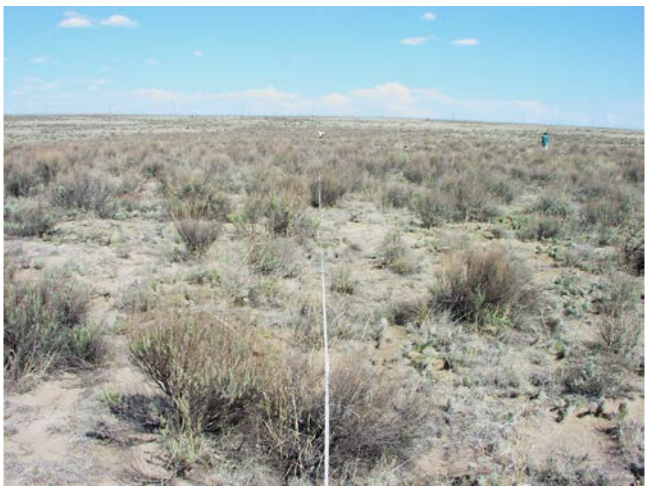
Figure 40. Greasewood shrubland plot gw20 in 2010 and 2011. Plot gw20 experienced a fire in 2011 and rabbitbrush was reduced by 90% and cholla by 50%. Top photo was taken Sep. 9, 2010 and bottom photo was taken Aug. 17, 2011. Most of the visible shrubs in 2011 are greasewood.

Sandsage had an ephemeral negative impact from the drought but by 2010 this effect had been negated (Fig. 41). Prickly pear, alkali sacaton grass, and galleta grass were hardly impacted by the drought while blue grama, three-awn grass, sand dropseed, and needle-and-thread grass were negatively impacted. Recovery of these species was varied with blue grama responding much slower than any other species. The fact that blue grama had still not recovered eight years after the drought may be important to cattle producers in eastern Colorado since blue grama is the primary forage in much of the rangelands. If droughts become more frequent and more intense and blue grama is severely impacted by intense droughts then forage production will be reduced. The reduction in a dominant high quality grass could impact the economics of ranching operations.

Drought effects were not limited to vegetation. Prairie dogs produced young but few of them survived (P. Young, pers. comm.). Some of the remaining prairie dogs were forced to venture onto new ground while others continued to chew down the remaining prickly pear and small remnants of grass. The existing prairie dog towns looked more like a desert than a shortgrass prairie (P. Young, pers. comm.). Even the chollas were wilted and girdled by prairie dogs. This 100-year event didn't even spare the grasshopper community that is normally quite prevalent. The grasshopper population plummeted, regardless of vegetation type (Sovell 2006.). About the only vertebrate life that appeared unaffected by the drought were some of the small mammals. For example, the Ord's kangaroo rat (*Dipodomys ordii*) populations have remained steady throughout (Sovell et al., 2004). One possible reason for this is the kangaroo rat strategy of storing seeds. They potentially have large enough caches to carry them through a large drought.

The annual weeds, Russian thistle and kochia, showed a response to annual variation in precipitation. Russian thistle and kochia had their highest frequency during 1999 (the wettest year) and were hardly present in 2002 and 2010.





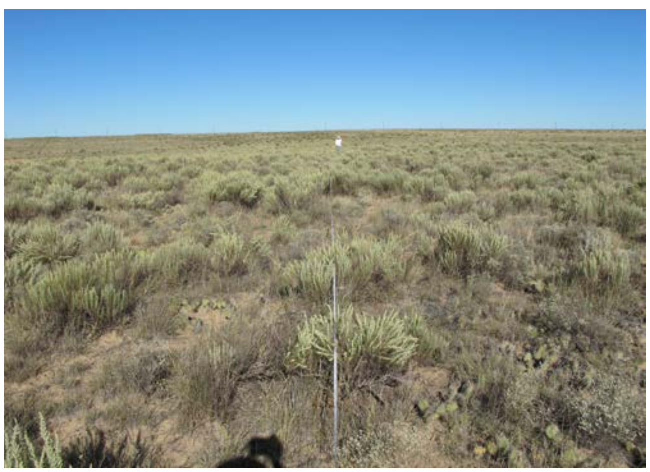


Figure 41. Sandsage shrubland plot ss32ug in 1998 (upper photo), 2002 (middle photo), and 2010 (lower photo). Photographs taken at end of west transect looking east.

Prairie Dogs

Although studying the impacts of prairie dogs on vegetation was not originally part of this study, it was hard to avoid. Because the sampling design required random samples, we inevitably placed monitoring plots within prairie dog colonies. In 1998, the first year of monitoring, we had four shortgrass prairie plots within prairie dog colonies; three were in the grazed regime and one was in the ungrazed regime. As the study progressed, it became clear that prairie dogs had a significant impact on the vegetation. In order to equalize our design, in 2001 we added two additional prairie dog plots in the ungrazed regime. The effect of the prairie dogs became even more complicated with the 1999 plague event that eliminated prairie dogs from two of the plots in the grazed treatment and one of the plots in the ungrazed treatment. Then add the 2002 drought event and November 2002 fire at sg80ug (within a prairie dog colony) and things get complicated very quickly. But, even with all these permutations, we can still observe certain vegetation parameters that are tightly associated with the presence of prairie dogs.

Three affected classes worthy of mention are three-awn grass, prickly pear, and bare ground. Three-awn grass is an indicator of heavy cattle grazing. At PCD, I found this grass to be a better indicator of the presence of prairie dogs than cattle grazing. There was no significant difference in cover or frequency of three-awn grass in cattle-grazed versus cattle-ungrazed areas (Table 3), yet there was a striking difference between prairie dog presence and absence (Fig. 35; Table 5). Prairie dog colonies had nearly three times as much cover and frequency of three-awn grass as areas without prairie dogs. Winter et al. (2002) had similar results, reporting 62% frequency for three-awn grass within prairie dog towns and 25% frequency outside of prairie dog towns; similarly, they reported 9% cover within prairie dog towns and 2% outside of prairie dog towns.

Rust (1999) stated that three-awn grass was an increaser with cattle grazing. We believe that Rust's sampling design did not take into account the variation in shortgrass prairie at PCD and had too small of a sample size and too few plots on prairie dog colonies to detect this important correlation.

Plot sg74ug was an ungrazed plot without prairie dogs, yet it had nearly 100% frequency of three-awn grass (Fig. 19). Returning to our original 1999 notes, when this plot was established, we noted that it had remnants of a few old prairie dog holes. Subsequent conversations with Max Canestorp (Fish and Wildlife Service) confirmed this observation. It is unclear how long the prairie dogs had been gone, but this may help explain why three-awn grass is so prevalent.

Prickly pear cactus is very noticeable even to the casual observer and was often mentioned by early explorers (prior to the introduction of cattle and horses) as they crossed the plains (Hart and Hart 1997). It has long been used as an indicator of poor cattle management (Whitson et al. 1992) and may still be a good indicator in certain areas, but our study at PCD does not support this view. For example, the grazed plots in the sandsage shrubland had an average of 21% frequency while the ungrazed plots had an average of 35% frequency (Fig. C-7); the difference was not statistically significant. The grazed plots in the greasewood shrubland had 42% frequency while the ungrazed had 34% frequency, again not a statistically significant difference. The shortgrass prairie had nearly equal frequency in grazed (29%) versus ungrazed (25%) plots. However, there was a striking difference with the presence or absence of prairie dogs (Fig. 34). Prickly pear was hardly present on plots with prairie dogs (average frequency of 5%) while plots without prairie dogs had an average frequency of 47%. Plots sg74ug and sg79g, both without prairie dogs, had a low frequency of prickly pear (Table 5). Both of these plots were observed to have old prairie dog holes when we established the plots, which may help explain the low frequency of prickly pear.

Prairie dogs include prickly pear in their diets, especially in the winter (Summers and Linder 1978); this may explain the dearth of prickly pear on prairie dog towns.

Prairie dog towns noticeably stand out from areas without prairie dogs. This easily noted difference is usually due to the short cropped nature of the vegetation, allowing one to observe more of the ground. We found that the amount of bare ground did not necessarily increase in the presence of prairie dogs despite the overall appearance. Bare ground averaged 27% cover on prairie dog towns and 35% cover off of prairie dog towns (difference not statistically significant), which goes against the casual observation (Fig. C-23). The amount of bare ground is more likely to be correlated with the presence of cattle grazing, with significantly higher cover (41%) in grazed areas than ungrazed areas (21%) (Fig. C-19).

An important point here is that the presence of prairie dogs alone (without cattle) may not provide adequate mountain plover nesting habitat, as mountain plover prefer greater than 30% bare ground as well as short vegetation (Knopf and Miller 1996). Therefore, the combination of grazing (cattle/bison) and prairie dogs that mimics historic disturbance may be important for some species. Winter and spring fire is another tool that can provide adequate bare ground and short vegetation.

PCD is part of a much larger functioning landscape that exhibits a diverse mosaic of grazing and fire intensity and frequency. The PCD monitoring program provides excellent baseline data that will be useful in understanding this subtle but diverse pattern.

Acknowledgments

This project would not have gotten off the ground without U.S. Fish and Wildlife Service and Pueblo Chemical Depot, especially Max Canestorp, Bruce Rosenlund, and Christine Hambric. Max and Christine provided endless assistance on all parts of this project. Thanks to PCD for providing housing adjacent to a cool swimming pool. Field work at PCD occurs at a season when temperatures reach the high 90s, making field work taxing at best. In spite of these extreme conditions, the field crews have always impressed me with their ability to be diligent and work extremely hard. The following people have assisted with field work: Clarissa Carlson, Chiara Brakeman, Dave Anderson, Diane Lee, Kelly Fischer, Donna Shorrock, Jodie Bell, Steve Kettler, John Sovell, Gordon Rodda, Georgia Doyle, Joe Stevens, Steve Thomas, Kim Fayette, Maureen DeCoursey, Kim Vincent, April Wasson, Rita Berberian, Phyllis Pineda, Kristen Person, and Lindsey Holms. Thanks to Ronnie Estelle, Richard Lancaster, and Sara Quinlivan for office assistance. Amy Lavender oversaw the GIS portion of this report and Mike Wunder provided valuable assistance with developing the randomly generated sampling points. The Nature Conservancy, especially Bob Unnasch, provided invaluable assistance with developing the monitoring design. Thanks to Max Canestorp, Denise Culver, John Sovell, and Jim Gionfriddo for reviewing this report. Special thanks to Georgia Doyle for greatly assisting me in developing this report. Tass Kelso, from Colorado College not only provided a summer intern but endless enthusiasm and encouragement for publishing the results. Finally, I thank Gordon Rodda for not only being the best husband one could ask for, but generously providing statistical assistance at all stages as well as reviewing the proposal and reports.

Literature Cited

Bartos, D. L., and P. L. Sims. 1974. Root dynamics of a shortgrass ecosystem. J. Range Management 27: 33-36.

Benedict, R. A., P. W. Freeman, and H. H. Genoway. 1996. Prairie legacies-mammals. Pages 149-166 in F. B. Samson and F. L. Knopf, eds., Prairie conservation: preserving North America's most endangered ecosystem. Island Press, Washington, D.C. 339 pp.

Bonham, C. D. 1989. Measurements for terrestrial vegetation. Wiley, New York. 338 pp.

Canestorp, M. 2012. Email communication re: PD info from Max Canestorp, U.S. Fish and Wildlife Service, Natural and Cultural Resource Manager, U.S. Army Pueblo Chemical Depot to R. Rondeau. July 30.

Dinsmore, S. J. 2001. Population biology of mountain plover in southern Phillips County, Montana. Ph.D. dissertation, Colorado State University, Fort Collins, CO.

Elzinga, C. L., D. W. Salzer, and J. W. Willoughby. 1998. Measuring and monitoring plant populations. BLM Technical Reference 1730--1. U.S.D.I. Bureau of Land Management, Denver, CO. 492 pp.

Evans, H. E. 1997. The natural history of the Long expedition to the Rocky Mountains. Oxford University Press, New York, New York. 268 pp.

Glantz, S. A. 1992. Primer of biostatistics. 3rd ed. McGraw-Hill, New York, N.Y.

Hart, R. H., and J. A. Hart. 1997. Rangelands of the Great Plains before European settlement. Rangelands 19(1): 4-11.

High Plains Regional Climate Center. 2010. http://www.hprcc.unl.edu/data/historical; data for Pueblo, WSO AP, Colorado.

Hornaday, W. T. 1889. The extermination of the American Bison, with a sketch of its discovery and life history. Pages 369-548 in Report of the National Museum, 1886-'87. Smithsonian Institution. United States National Museum, Washington, D.C.

Hyder, D. N., C. E. Conrad, P. T. Tueller, L. D. Calvin, C. E. Pulton, and F. A. Sneva. 1963. Frequency sampling in sagebrush-bunchgrass vegetation. Ecology 44: 740-746.

Hyder, D. N., R. E. Bement, E. E. Remmenga, and C. Terwilliger Jr. 1965. Frequency sampling of blue grama range. J. Range Management 18: 90-93.

Hyder, D. N., R. E. Bement, E. E. Remmenga, and D. F. Hervey. 1975. Ecological responses of native plants and guidelines for management of shortgrass range. Technical Bulletin No. 1503. U.S. Gov't Printing Office for USDA, Washington, D.C.

Knopf, F. L., and B. J. Miller. 1996. *Charadrius montanus*--montane, grassland, or bare-ground plover? Auk 111: 505-506.

Knopf, F. L., and J. R. Rupert. 1996. Reproduction and movements of mountain plovers breeding in Colorado. Wilson Bulletin 108: 28-35.

Knowles, C. J., C. J. Stoner, and S. P. Gieb. 1982. Selective use of black-tailed prairie dog towns by mountain plovers. Condor 84:71-74.

Martin, P. S., and C. Szuter. 1999. War zones and game sinks in Lewis and Clark's west. Conservation Biology 13(1): 36-45.

National Park Handbook 116. 1982. Exploring the American West, 1803-1879. U.S. Department of the Interior, Division of Publications, National Park Service, Washington, D.C. 128 pp.

Olson, S. L., and D. Edge. 1985. Nest site selection by mountain plovers in northcentral Montana. J. Range Management 38:280-282.

Olson, K. C., R. S. White, and B. W. Sindelar. 1985. Responses of vegetation of the Northern Great Plains to precipitation amount and grazing intensity. J. Range Management 38: 357-361.

Olson-Edge, S.L., and W.D. Edge. 1987. Density and distribution of the mountain plover on the Charles M. Russell National Wildlife Refuge. Prairie Naturalist 19:233-238.

Pielke, R. A., N. J. Doesken, O. Bliss, T. Green, C. Chaffin, J. D. Salas, C. A. Woodhouse, J. J. Lukas, and K. Wolter. 2005. Drought 2002 in Colorado: an unprecedented drought or a routine drought? Pure Appl. Geophys., 162: 1455-1479.

Ray, A. J., J. J. Barsugli, and K. B. Avert. 2008. Climate projection. Pp. 29-39 In: Climate change in Colorado. Colorado Water Conservation Board, University of Colorado, Boulder, CO.

Reading, R.P. and R. Matchett. 1997. Attributes of black-tailed prairie dog colonies in northcentral Montana. J. Wildl. Management 61(3): 664-673.

Rondeau, R. J. 2001. Vegetation monitoring at Pueblo Chemical Depot 1998-2000. Fort Collins, CO: Colorado Natural Heritage Program.

Rondeau, R. J. 2003. Vegetation monitoring at Pueblo Chemical Depot: 1998-2002. Fort Collins, CO: Colorado Natural Heritage Program.

Rondeau, R. J., and S. M. Kettler. 1999. Pueblo Chemical Depot vegetation monitoring: 1998 results. Fort Collins, CO: Colorado Natural Heritage Program.

Rondeau, R.J., K.T. Pearson, and S. Kelso. 2013. Vegetation response in a Colorado grassland-shrub community to extreme drought: 1999-2010. Am. Midland. Nat.

Rust Environment and Infrastructure, Inc. (Rust). 1999. Ecological surveys (Final, revision 1). Englewood, CO: Rust Environment and Infrastructure.

Sala, O. E., and W. K. Lauenroth. 1982. Small rainfall events: An ecological role in semiarid regions. Oecologia 53: 301-304.

Sherrow, J. 2001. The decline of the Great Plains bison herds. Environmental Review 8(2): 7-16.

Skinner, H. R., J. D. Hanson, G. L. Hutchinson, and G. E. Schuman. 2002. Response of C_3 and C_4 grasses to supplemental summer precipitation. J. Range Management 55: 517-522.

Sovell, J., B. Wunder, P. Lukacs, J. Gionfriddo, and J. Siemers. 2006. Population parameters and fat composition of small mammals on Pueblo Chemical Depot (2000-2003). Fort Collins, CO: Colorado Natural Heritage Program and Colorado State University.

Sovell, J. 2006. Grasshopper monitoring on Pueblo Chemical Depot (2001-2003). Fort Collins, CO: Colorado Natural Heritage Program.

Steranka, Patricia J. Personal communication to Rust in 1996.

Summers, C. A., and R. L. Linder. 1978. Food habits of the black-tailed prairie dog in western South Dakota. J. of Range Management 31: 134-136.

U.S. Department of Agriculture (USDA) Soil Conservation Service. 1979. Soil survey of Pueblo Area, Colorado: parts of Pueblo and Custer Counties. 92 pp.

U. S. Fish and Wildlife Service (USFWS). 1987. Fish and wildlife management plan, U.S. Army Pueblo Depot Activity, Pueblo, Colorado: U.S. Fish and Wildlife Service.

Valone, T. J. 2002. Timescale of perennial grass recovery in desertified arid grasslands following livestock removal. Conservation Biology 16(4): 995-1002.

Webb, R. H., and H. G. Wilshire. 1980. Recovery of soils and vegetation in a Mojave desert ghost town, Nevada, U.S.A. J. Arid Environments 3: 291-303.

Whitson, T. D., L. C. Burrill, S. A. Dewey, D. W. Cudney, B. E. Nelson, R. D. Lee, and R. Parker, eds. 1992. Weeds of the west. Western Society of Weed Science in cooperation with the Western United States Land Grant Universities Cooperative Extension Services, Jackson, WY. 630 pp.

Winter, S. L., J. F. Culley Jr., and J. S. Pontius. 2002. Vegetation of prairie dog colonies and non-colonized shortgrass prairie. J. Range Management 55: 502-508.

Appendix A. Species list with codes for plant species found in plots at PCD.

Forbs code	***Latin name***
Amaret	*Amaranthus retroflexus*
Ambfra	*Ambrosia fragrans*
Ambpsi	*Ambrosia psilostachya*
Asceng	*Asclepias engelmannii (or linear leaf Asc.)*
Asclin	*=Asceng*
Ascspe	*Asclepias speciosa*
Astmol	*Astragalus mollissimus*
Astpec	*Astragalus pectinatus*
Astsho	*Astragalus shortianus*
Astsp1	*Astragalus sp.*
Bassco	*Bassia scoparia*
Brieup	*Brickellia eupatorium*
Briros	*Brickellia rosmarinifolia*
Casjam	*Caesalpinia jamesii=Hoffmanseggia*
Chealb	*Chenopodium album*
Checyc	*Chenopodium cycloides*
Chesp.	*Chenopodium sp.*
Chesp1	*Chenopodium sp.*
Chesub	*Chenopodium subglabrum*
Cirarv	*Cirsium arvense*
Circan	*Cirsium canescens*
Cirsp.	*Cirsium sp.*
Cleser	*Cleome serrulata*
Concan	*Conyza canadensis*
Crotex	*Croton texensis*
Crysp	*Cryptantha sp.*

Forbs code	***Latin name***
Cypari	*Cyperus aristatus*
Cypsp	*Cyperus sp.*
Dalcyl	*Dalea cylindreceps*
Dalnan	*Dalea nana*
Dipfas	*=Schpan*
Dyspap	*Dyssodia papposa*
Erifla	*Erigeron flagellaris*
Eribel	*Erigeron bellidastrum*
Eriogsp	*Eriogonum sp.*
Eupden	*Euphorbia dentata*
Eupser	*Euphorbia serpyllifolia*
Eupsp	*Euphorbia sp.*
Evonut	*Evolvulus nuttalianus*
Gaucoc	*Gaura coccinea*
Galpin	*Gaillardia pinnatifida*
Gilopt	*see Ipolax (Ipomopsis laxiflora)*
Graind	*Grammica indecora*
Helann	*Helianthus annus*
Helpet	*Helianthus petiolaris*
Helpum	should be *Helpet*
Ipolax	*Ipomopsis laxiflora*
Ipolep	*Ipomoea leptophylla*
Iponut	see *Evonut*
Lactat	*Lactuca tatarica*
Latsp	*Lathryus sp.*
Lygjun	*Lygodesmia juncea*
Macpin	*Machaeranthera pinnitifida*
Mactan	*Machaeranthera tanacetifolia*

Forbs code	***Latin name***
Medsat	*Medicago sativa*
Melalb	*Melilotus alba*
Meloff	*Melilotus officinale*
Melsp	*Melilotus sp.*
Mennud	*Nuttalia (Mentzelia) nuda*
Nyctsp	*Nyctaginaceae sp.*
Oresp	*Oreocarya sp.*
Oxylin	*Oxybaphus linearis*
Oxysp	*Oxytropis sp.*
Pacsp	*Packera sp.*
Palsph	*Palifloxia sphaerlata*
Pecang	*Pectis angustifolia*
Porhal	*Portulaca halimoides*
Porole	*Portulaca oleracea*
Psoten	*Psoralidium tenuiflora*
Rattag	*Ratibida tagetes*
Salaus	*Salsola australis*
Senspa	*Senecio spartoides*
Solros	*Solanum rostratum*
Sphcoc	*Sphaeralcea coccinea*
Spurge	*see Euphorbia*
Suasp	*Suaeda sp.*
Syssp	*Sysimbrium sp.*
Talpar	*Talinum parviflorum*
Themeg	*Thelesperma megapotamicum*
Tradub	*Tragopogon dubius*
UNKFOR	*Unknown forb*
UNKSS30	*Unknown forb in ss30*

Forbs code	***Latin name***
UNKSS78	*Unknown forb in ss78*
Versp	*Verbena sp.*
Zingra	*Zinnia grandiflora*
Zyghex	*Zygophllidium hexagonum*

Graminoids code	***Latin name***
Andhal	*Andropogon hallii*
Aridiv	*Aristida divaricata*
Aripur	*Aristida purpurea*
Boucur	*Bouteloua curtipendula*
Bucdac	*Buchloe dactyloides*
Callon	*Calimovilfa longifolia*
Chogra	*Chondrosum gracile (Bouteloua gracilis)*
Chohir	*Chondrosum hirsuta (Bouteloua hirsutus)*
Cypacu	*Cyperus acuminatus*
Cypari	*Cyperus aristatus*
Dipfas	*see Schpan*
Disspi	*Distichlis spicata*
Elyely	*Elymus elymoides*
Hiljam	*Hilaria jamesii*
Lepfac	*see Schpan*
Muhtor	*Muhlenbergia torreyi*
Munsqu	*Munroa squarrosa*
Oryhym	*see Stihym*
Passmi	*Pascopyrum smithii*
Schpan	*Schedonnardus paniculatus*
Spoair	*Sporobolus airoides*
Spocry	*Sporobolus cryptandrus*

Forbs code	***Latin name***
Sticom	*Stipa comata*
Stihym	*Stipa hymenoides (Oyzopsis hymenoides)*
Vuloct	*Vulpia octoflora*

Shrubs & Cacti code	***Latin Name***
Atrcan	*Atriplex canescens*
Atrcon	*Atriplex confertiflora*
Atrgar	*Atriplex gardeneri*
Chrnau	*Chrysothamnus nauseosus*
Corviv	*Coryphantha vivipara*
Cylimb	*Cylindropuntia imbricata*
Echvir	*Echinocereus viridulus*
Erieff	*Eriogonum effusum*
Gutsar	*Gutierriezia sarothrae*
Hetvil	*Heterotheca villosa*
Ipolep	*Ipomoea lepotophylla*
Olifil	*Oligosporus (Artemisia) filifolius*
Opomac	*Opuntia macrorhiza*
Opopol	*Opuntia polyacantha*
Opupha	*Opuntia phaecantha*
Sarver	*Sarcobatus vermiculatus*
Yucgla	*Yucca glauca*

Appendix B. Example of field forms.

Transect #_____________

Site, Line-intercept, and Belt transect Data Form

Site name___________________________ Date (d/m/y)________/2001 Time _________ Page 1 of 1

Cardinal Direction: N S E W

Photo Roll# _____ Photo# Beginning____________ End__________ Aerial Photo Number_________________

Human disturbance signs? If so describe____

Prairie Dog Town? None Active Inactive

Comments or notes:_______________________________

Observers____

Begin at 1 m mark on the E and W lines for belt transect (to avoid double counting)

Gaps less than 10 cm are counted as canopy cover; plant does not have to be rooted in belt transect in order to count.

Species Code	**Species name**	**Tape measurements (cm)**	**Total (m)**	**% cover Total/50 (m)**	**Belt transect count/total #**
Chrnau	**Chrysothamnus nauseosus** Rabbitbrush				
Cylimb	**Cylindropuntia imbricata** Candelabra Cholla				
Gutsar	**Gutierrezia sarothrae** Snakeweed				

Ipolep	**Ipomoea leptophylla** Bush morning glory				
Olifil	**Oligosporus filifolius** Sand sagebrush				
Sarver	**Sarcobatus vermiculatus** Greasewood				
Yucgla	**Yucca glauca** Yucca				

Transect #__________________

Microplot cover data form

Site name________________________ Date (d/m/y)_____/2001 Time _________ Page 1 of 2

Cardinal Direction: N S E W

Photo Roll# _____ Photo# 3rd___________ 5th _________

Observers:________________________________

The first microplot is selected randomly between 0 and 10 m. Thereafter every microplot is 5 m from the previous. Plot is always on right side of line (as looking from 0 to 50 m) and short axis centered at mark. Microplots are permanent and usually with aluminum round tag in middle of 3rd and 5th plot. Over 100% total cover is possible, e.g. Erieff plus Chogra underneath.

Species Code	**Species name**	**Plot ___ m**	**% Cover Total/50**	**Plot ___ m**	**% Cover**	**Plot ___ m**	**% Cover**	**Plot ___ m**	**% Cover**
Erieff	*Eriogonum effusum*								
Arispp	*Aristida* spp. Three-awn grass								
Chogra	*Chondrosum gracile* Blue grama								
Spoair	*Sporobolus airoides* Alkali sacaton grass								
Spocry	*Sporobolus cryptandrus*								

	Sand dropseed								
Sticom	*Stipa comata* Needle-and-thread grass								
Bassco	*Bassia scoparia*								
Eupspp	*Euphorbia* spp.								
Salaus	*Salsola australis* Russian thistle								
Bare ground									
Litter									

Transect #_______________

Nested Frequency Plot form for Uplands

Page 1 of 2

Date_______________1999 Comments:____

Observers:_____________________

Along each 50 m transect a nested frequency plot is placed every two meters starting at the 2 m mark. All plots are on left side of line (looking from 0 m towards 50 m) with .1 x .1 m plot in lower left corner. Plant must be partially rooted in plot in order to count or for Opuntia spp. any pad whether rooted or not counts as in. Score is 0 = none, 1 = point, 2 = .1 x.1, 3 = .31 x .31 and 4 = 1 x 1 m.

Species include: Erieff, Opuspp, Arispp., Chogra, Hiljam, Spoair, Spocry, Schpan, Bassie, Salaus.

North	-	-	-	**-**	-	-	-	-	-	-	**South**	-	-	-	-	-	-	-	-	-	-
1											26										
2											27										
3											28										
4											29										
5											30										
6											31										
7											32										
8											33										
9											34										
10											35										
11											36										

12											37										
13											38										
14											39										
15											40										
16											41										
17											42										
18											43										
19											44										
20											45										
21											46										
22											47										
23											48										
24											49										
25											50										

Appendix C. Graphs for species, bare ground, and litter for each habitat type.

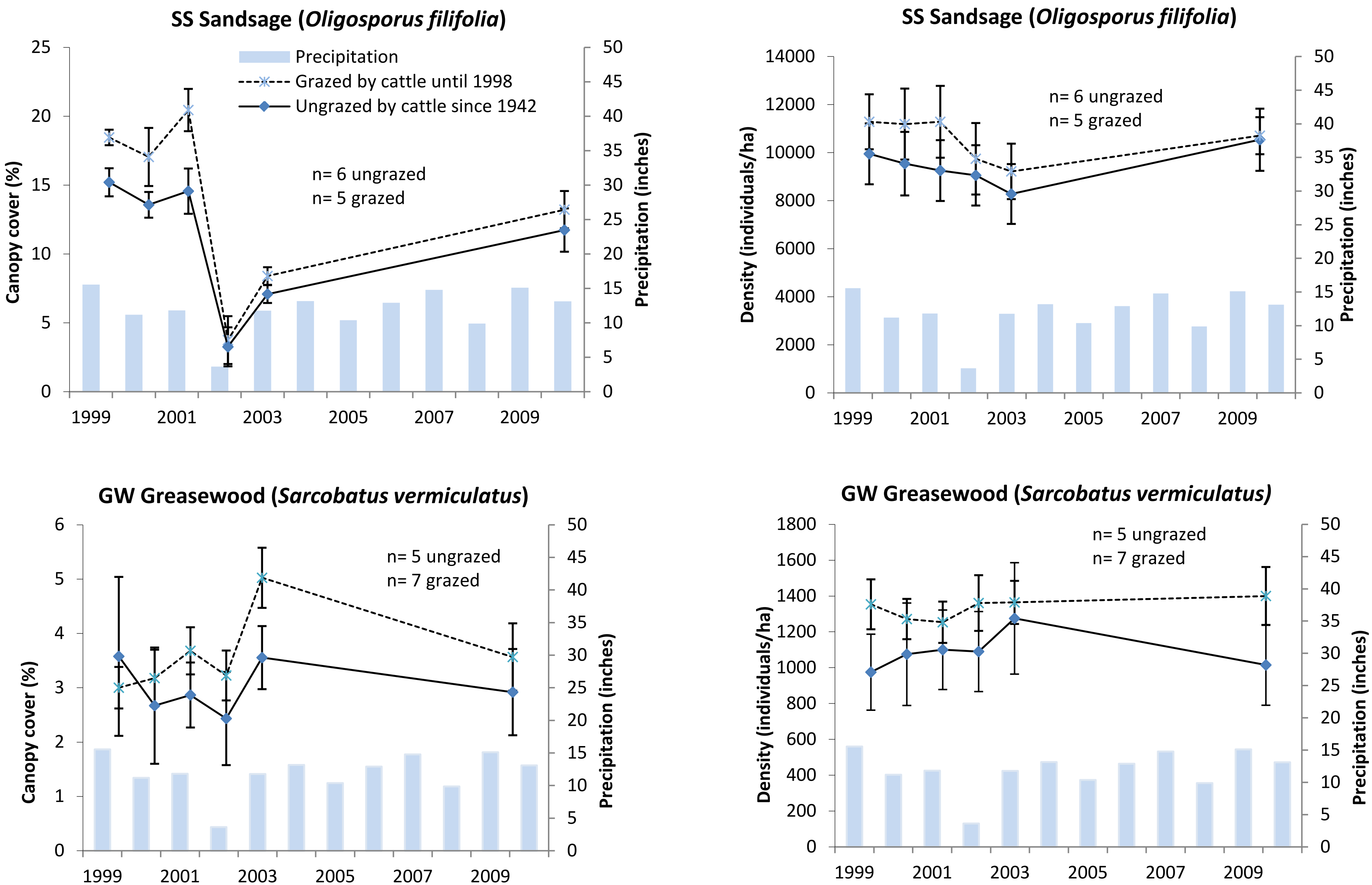


Figure C-1. Greasewood and sandsage mean **cover and density** (± 1 SE) for greasewood (GW) and sandsage (SS) habitats.

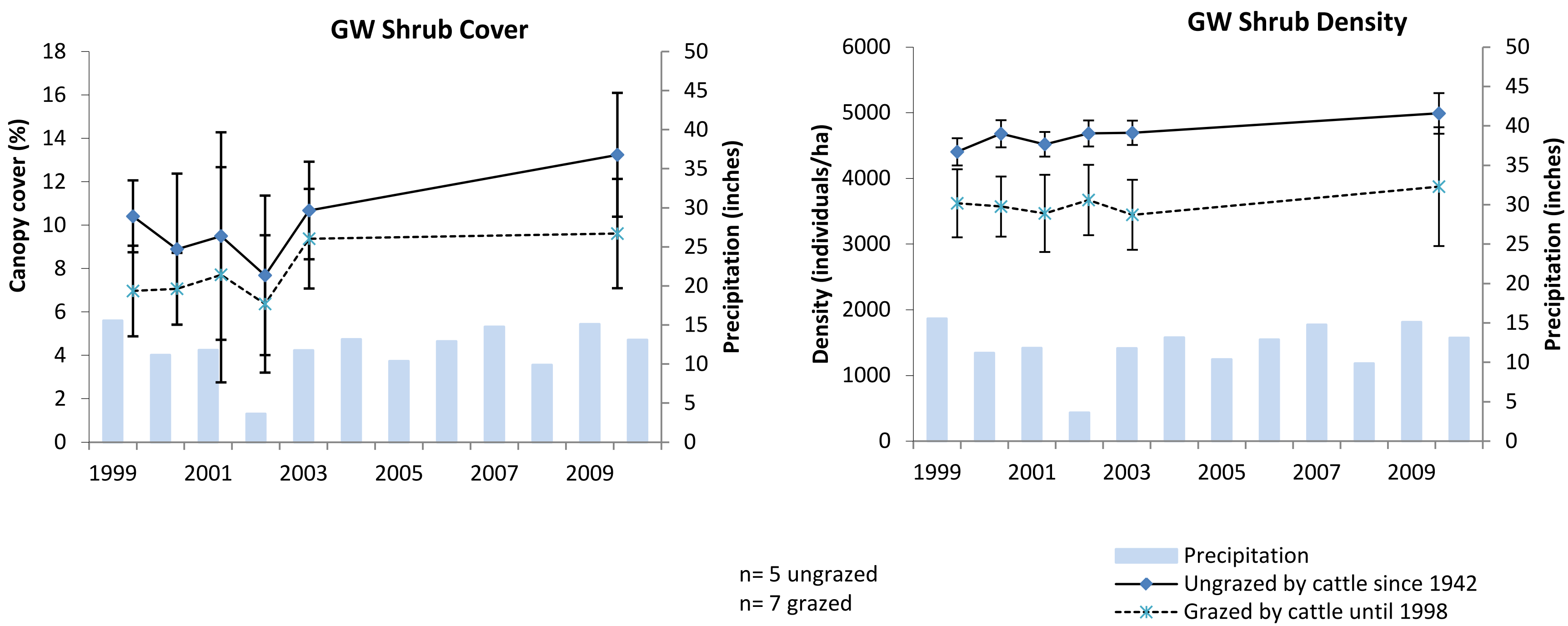


Figure C-2. Shrub summary for mean **cover and density** (± 1 SE) for greasewood habitat.

Rabbitbrush (*Chrysothamnus nauseousus*)

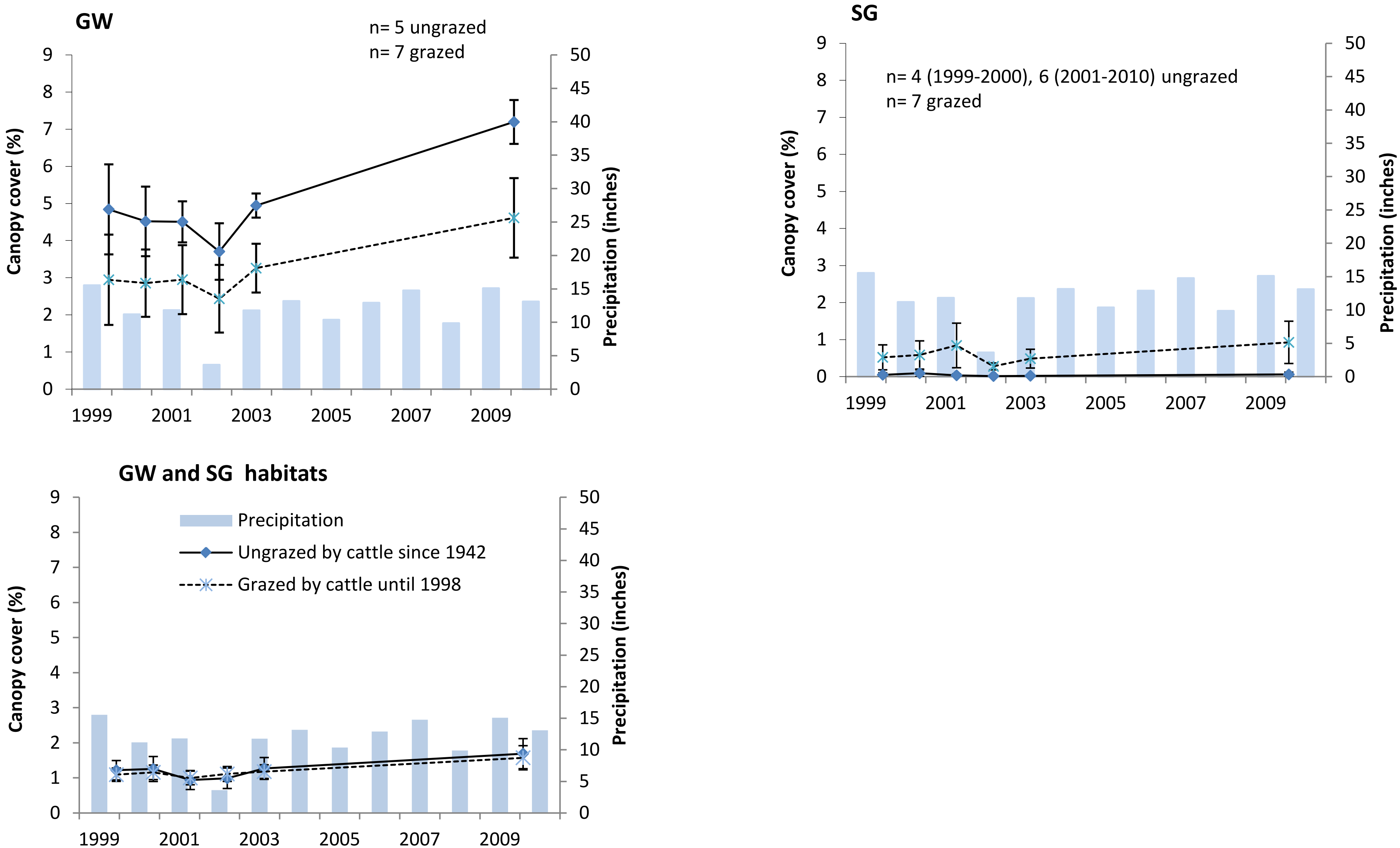


Figure C-3. Rabbitbrush mean **cover** (± 1 SE) for greasewood (GW), shortgrass (SG), and all habitats combined.

Rabbitbrush (*Chrysothamnus nauseousus*)

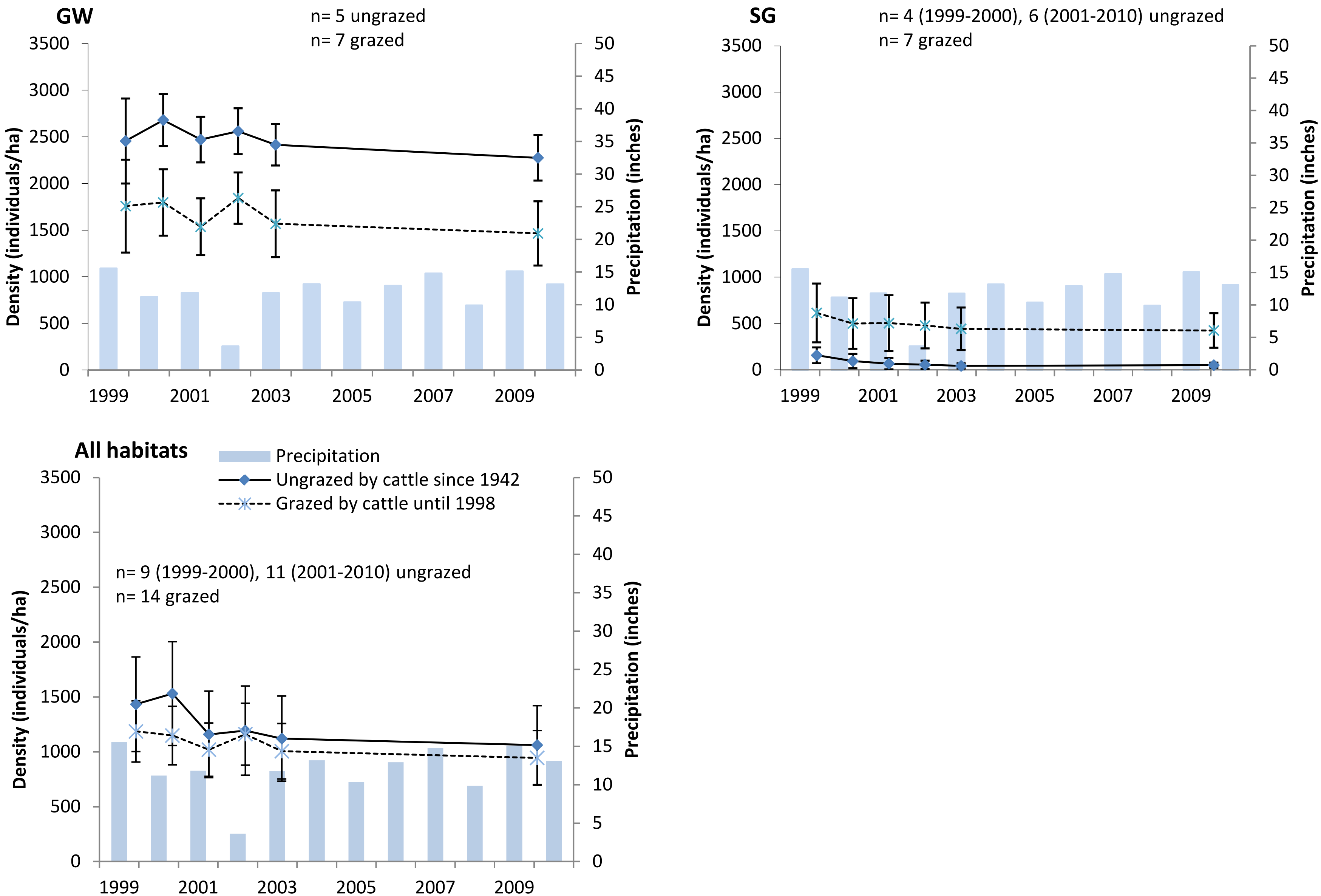


Figure C-4. Rabbitbrush mean **density** (± 1 SE) for greasewood (GW), shortgrass (SG), and all habitats combined.

Cholla (*Cylindropuntia imbricata*)

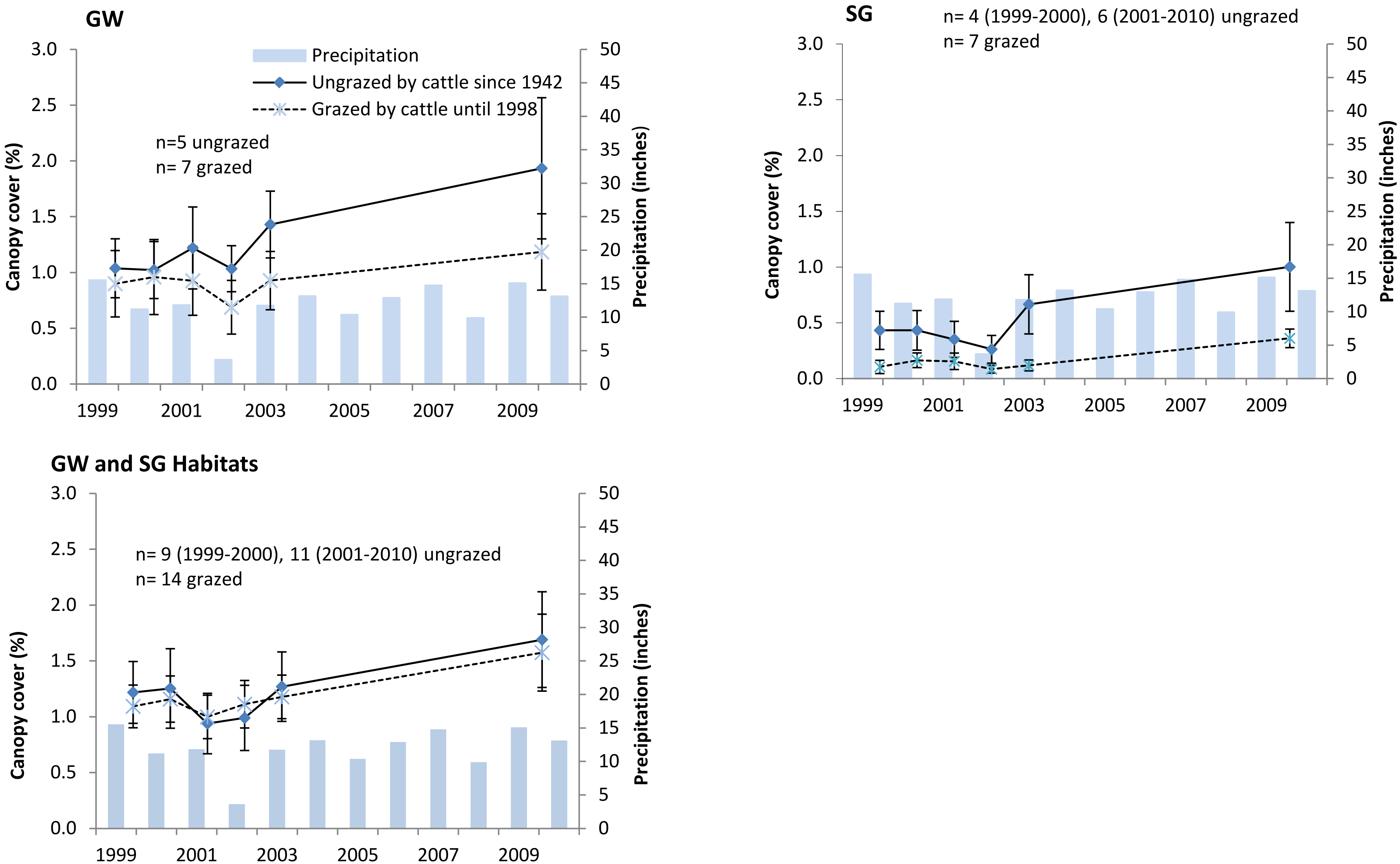


Figure C-5. Cholla mean **cover and density** (± 1 SE) for greasewood (GW), shortgrass (SG), and both habitats combined.

Cholla (*Cylindropuntia imbricata*)

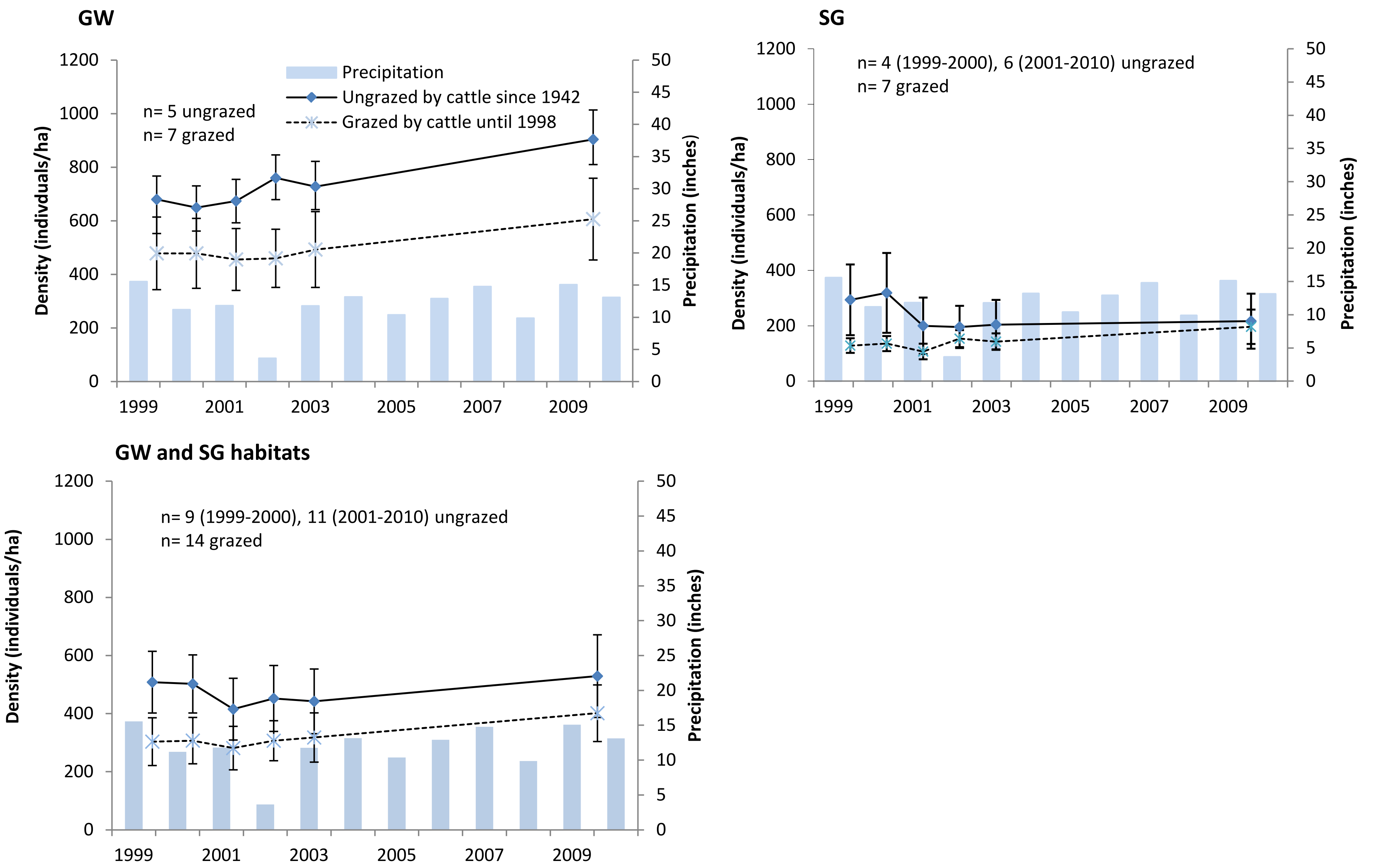


Figure C-6. Cholla mean **cover and density** (± 1 SE) for for greasewood (GW), shortgrass (SG), and both habitats combined.

Prickly pear (*Opuntia* spp.)

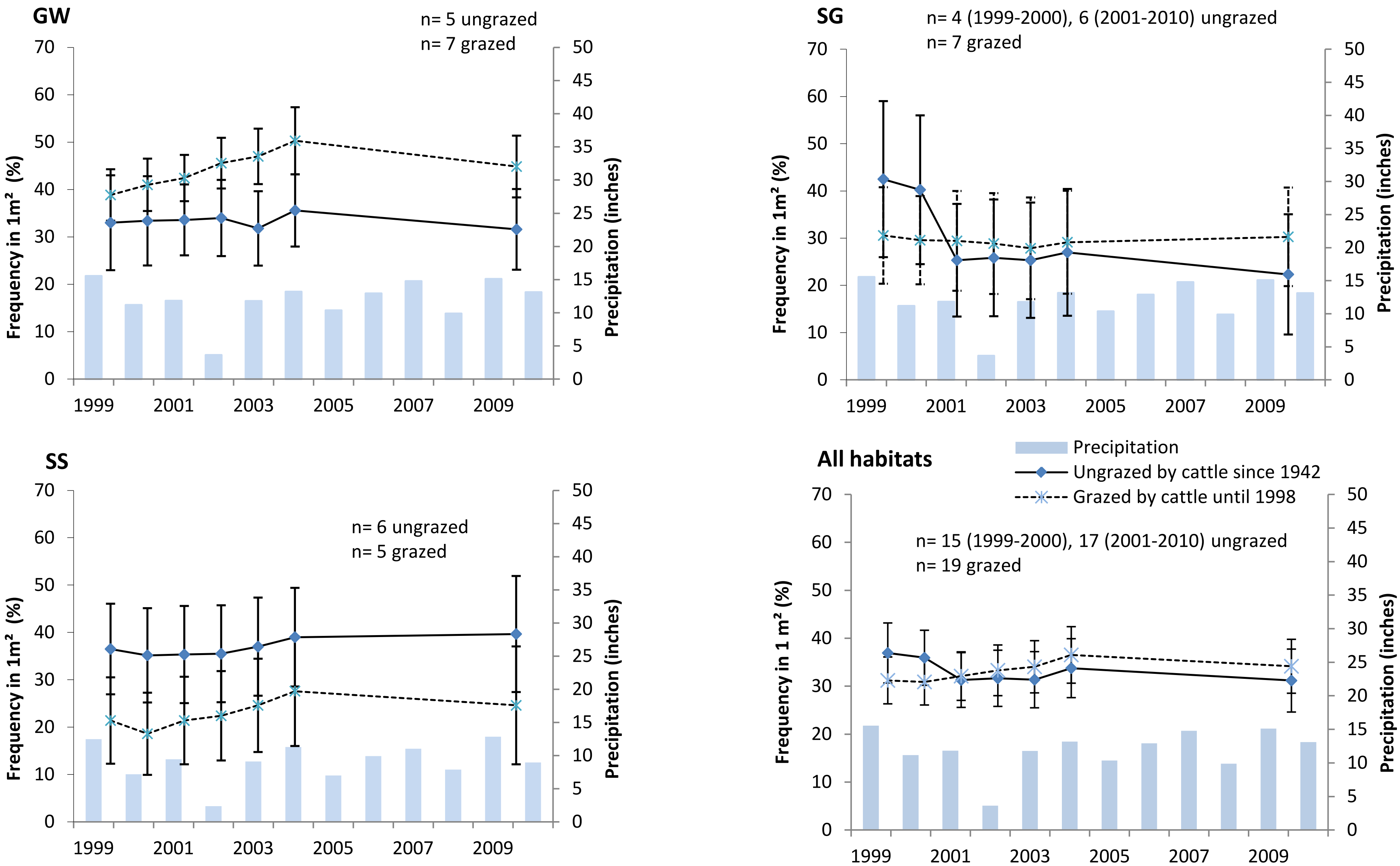


Figure C-7. Prickly pear mean **frequency** (± 1 SE) for greasewood (GW), shortgrass (SG), sandsage (SS), and all habitats combined.

Blue grama (*Chondrosum gracile*)

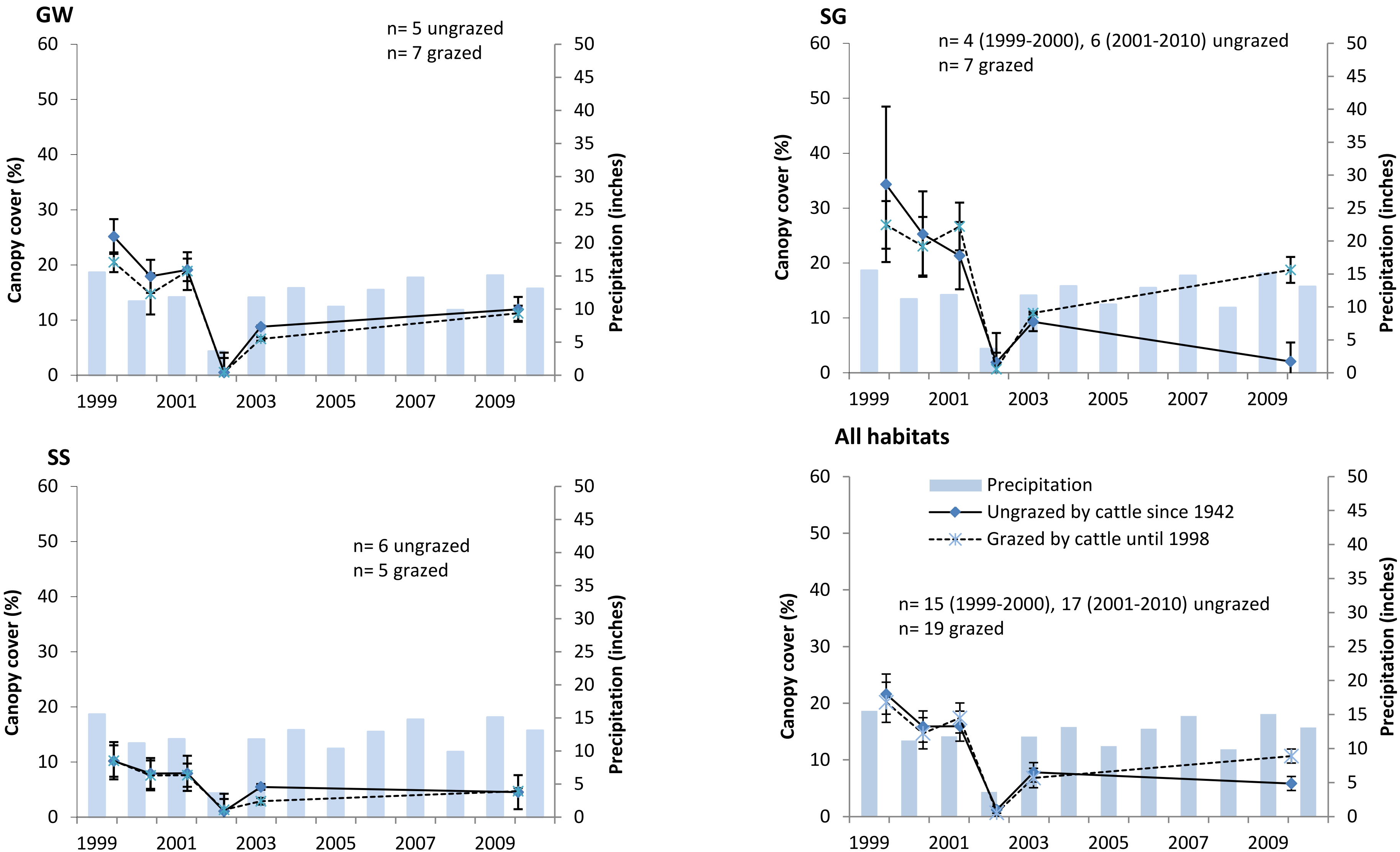


Figure C-8. Blue grama mean **cover** (± 1 SE) for greasewood (GW), shortgrass (SG), sandsage (SS), and all habitats combined.

Blue grama (*Chondrosum gracile*)

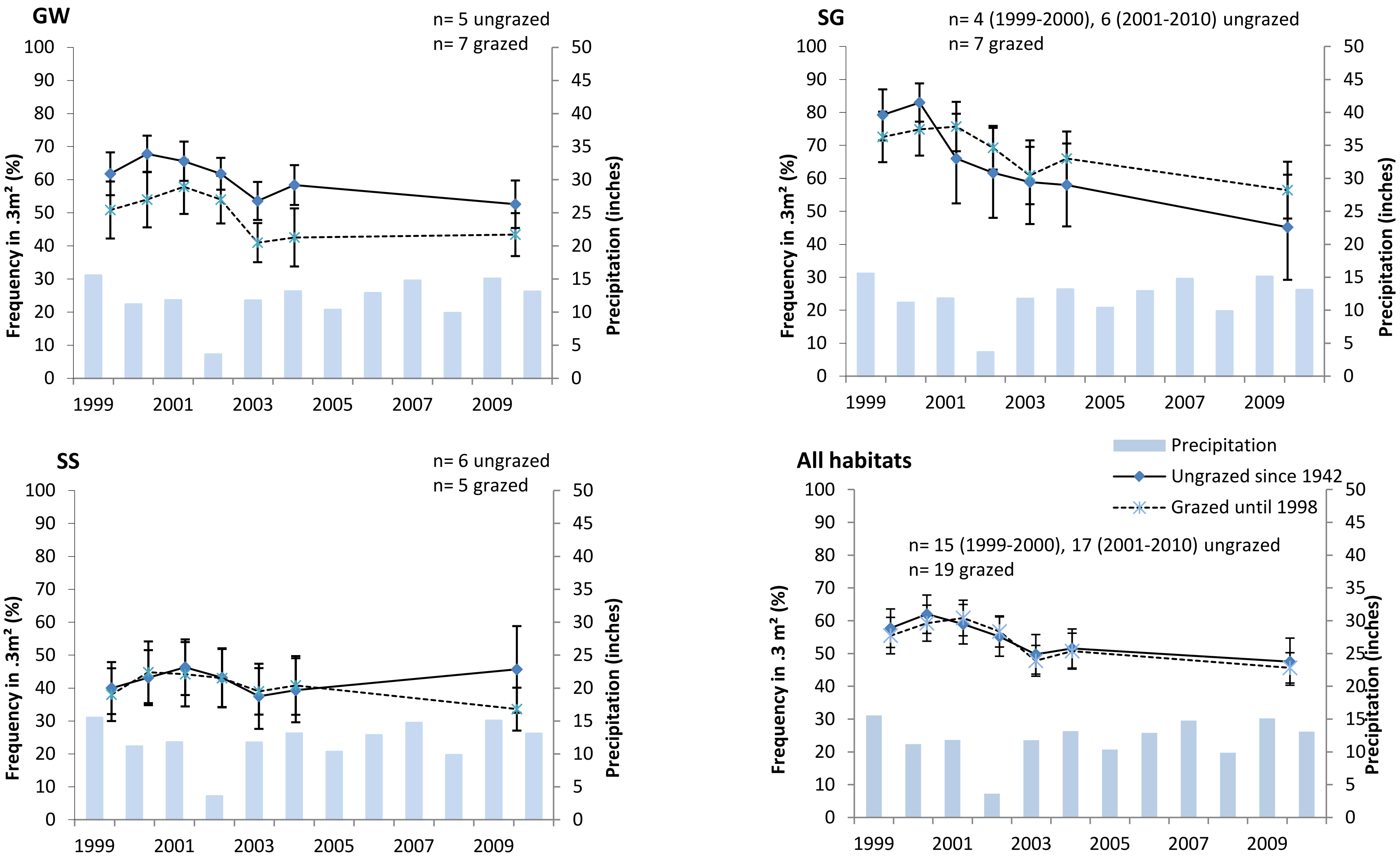


Figure C-9. Blue grama mean **frequency** (± 1 SE) for greasewood (GW), shortgrass (SG), sandsage (SS), and all habitats combined.

Alkali sacaton grass (*Sporobolus airoides*)

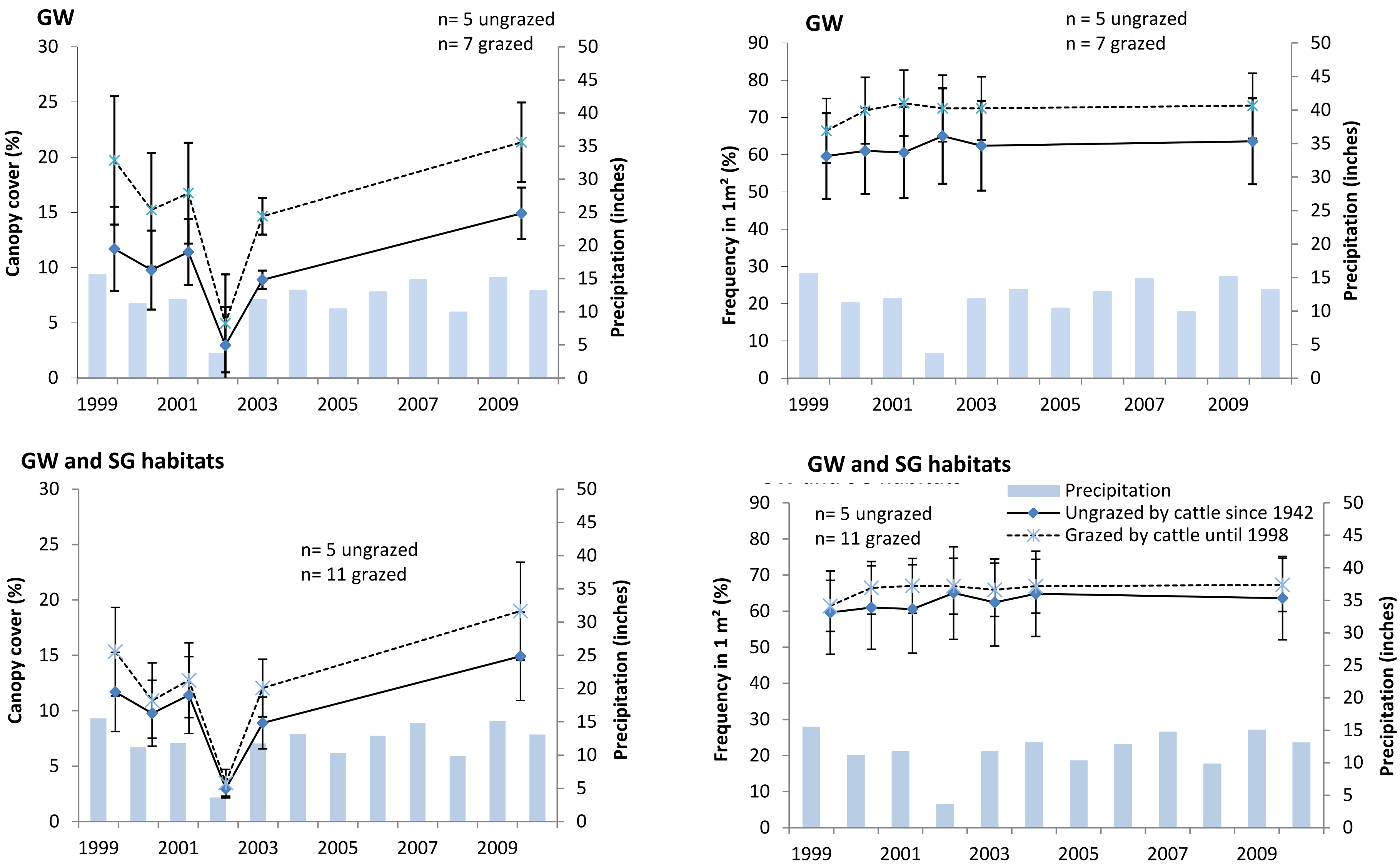


Figure C-10. Alkali sacaton grass mean **cover and frequency** (± 1 SE) for greasewood (GW) and GW and SG habitats combined.

Galleta grass (*Hilaria jamesii*)

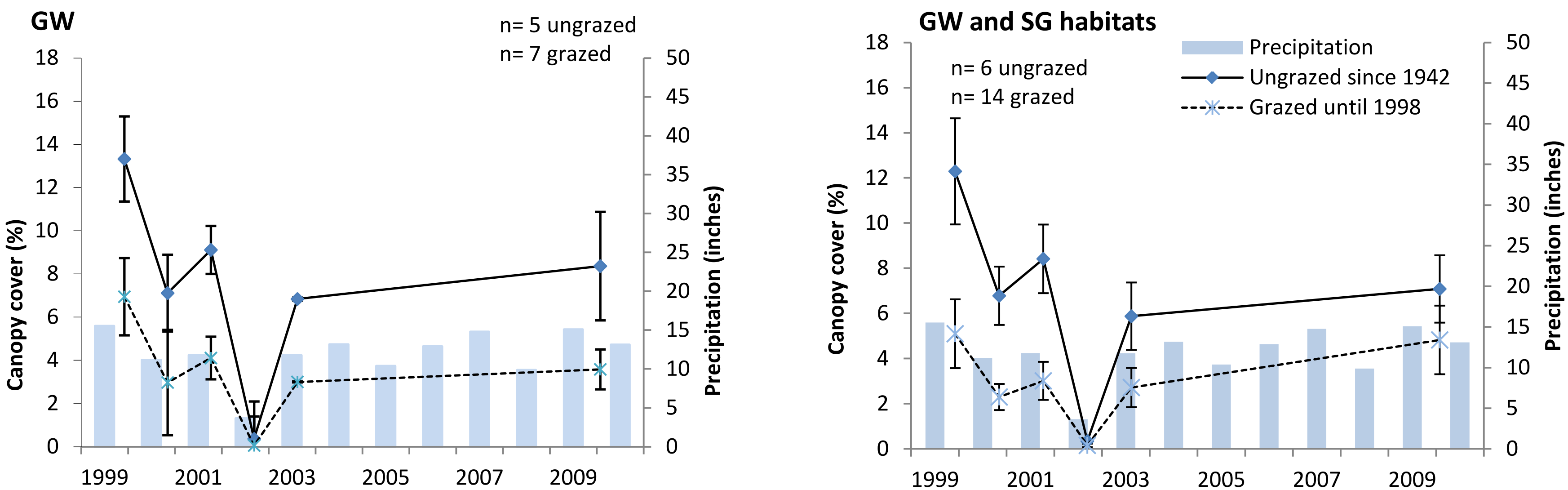


Figure C-11. Galleta grass mean **cover** (± 1 SE) in all greasewood plots (12) and 8 shortgrass plots. Shortgrass plots that did not have > 10% frequency were eliminated, these were all grazed plots.

Galleta grass (*Hilaria jamesii*)

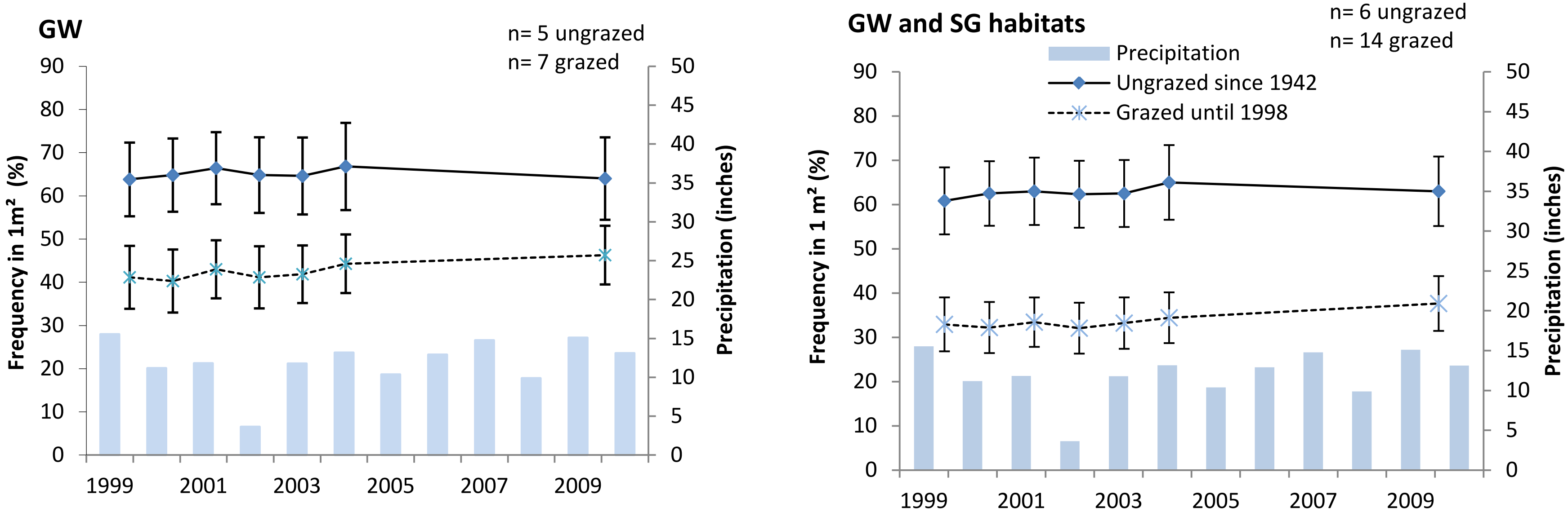


Figure C-12. Galleta grass mean **frequency** (± 1 SE) in all greasewood plots (12) and 8 shortgrass plots, 1999-2010 (n=14 grazed and 6 ungrazed). Shortgrass plots that did not have > 10% frequency were eliminated, these were all grazed plots.

Three-awn grass (*Aristida* spp.)

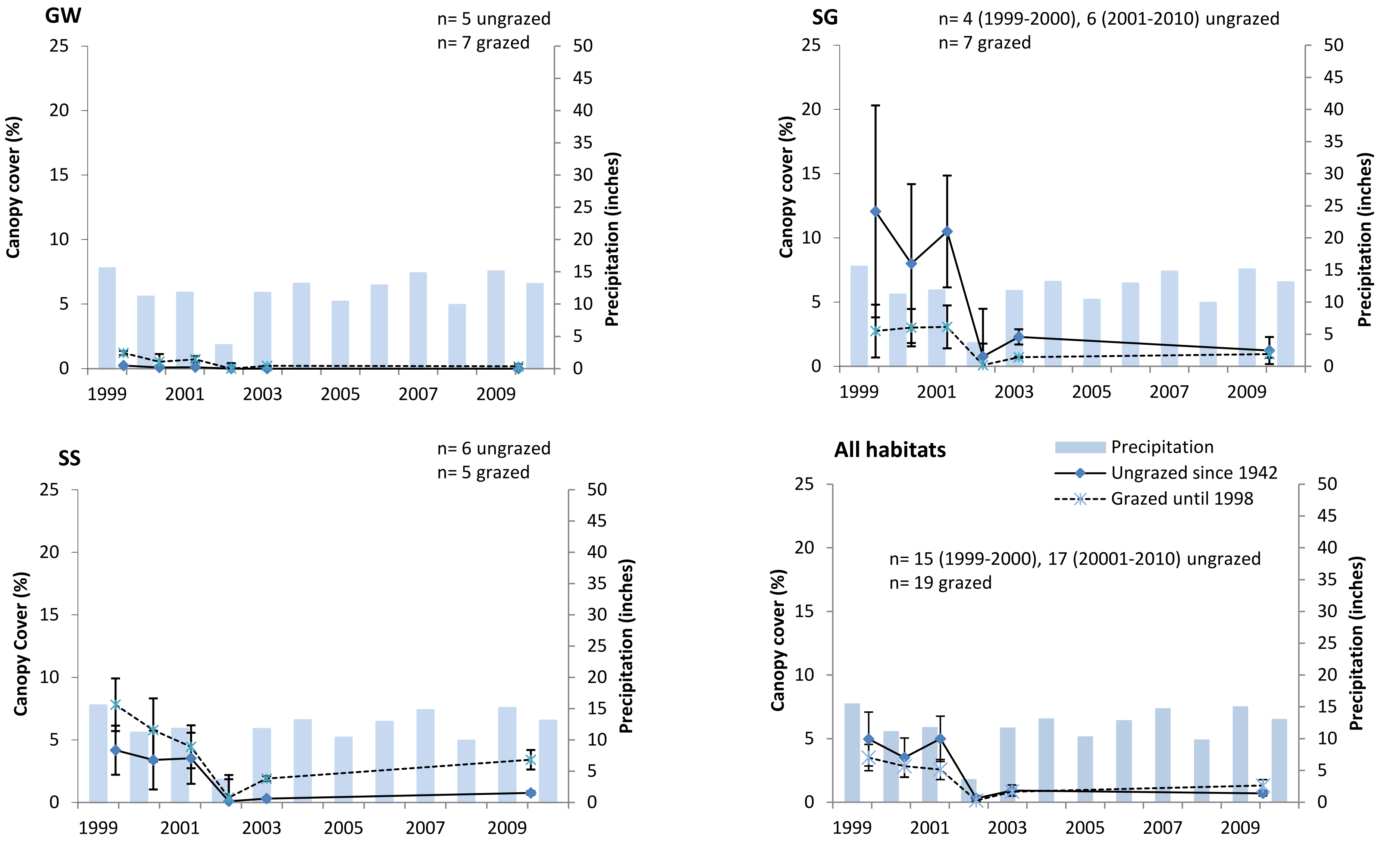


Figure C-13. Three-awn grass mean **cover** (± 1 SE) for greasewood (GW), shortgrass (SG), sandsage (SS), and all habitats combined.

Three-awn grass (*Aristida* spp.)

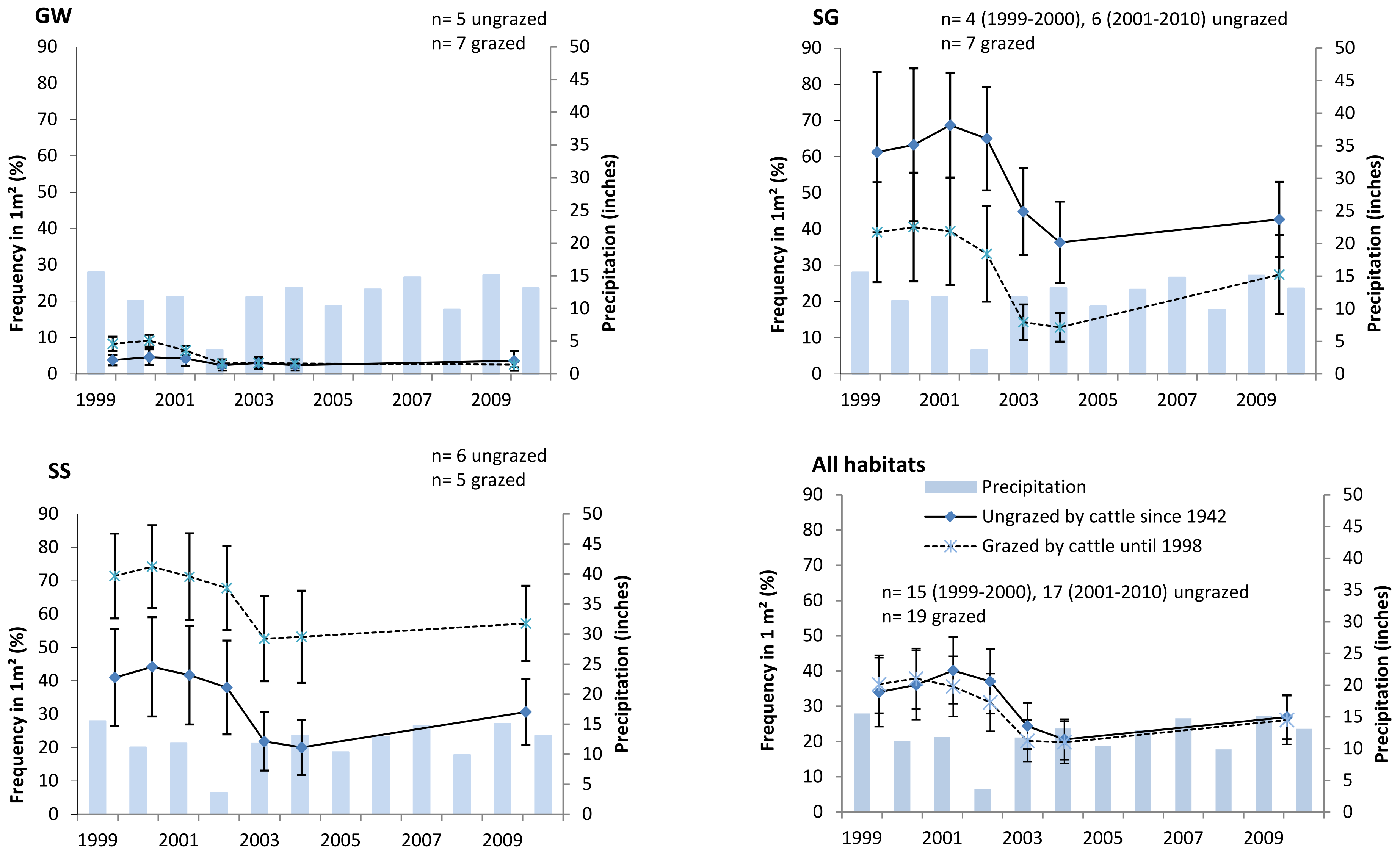


Figure C-14. Three-awn grass mean **frequency** (± 1 SE) for greasewood (GW), shortgrass (SG), sandsage (SS), and all habitats combined.

Sand dropseed (*Sporobolus cryptandrus*)

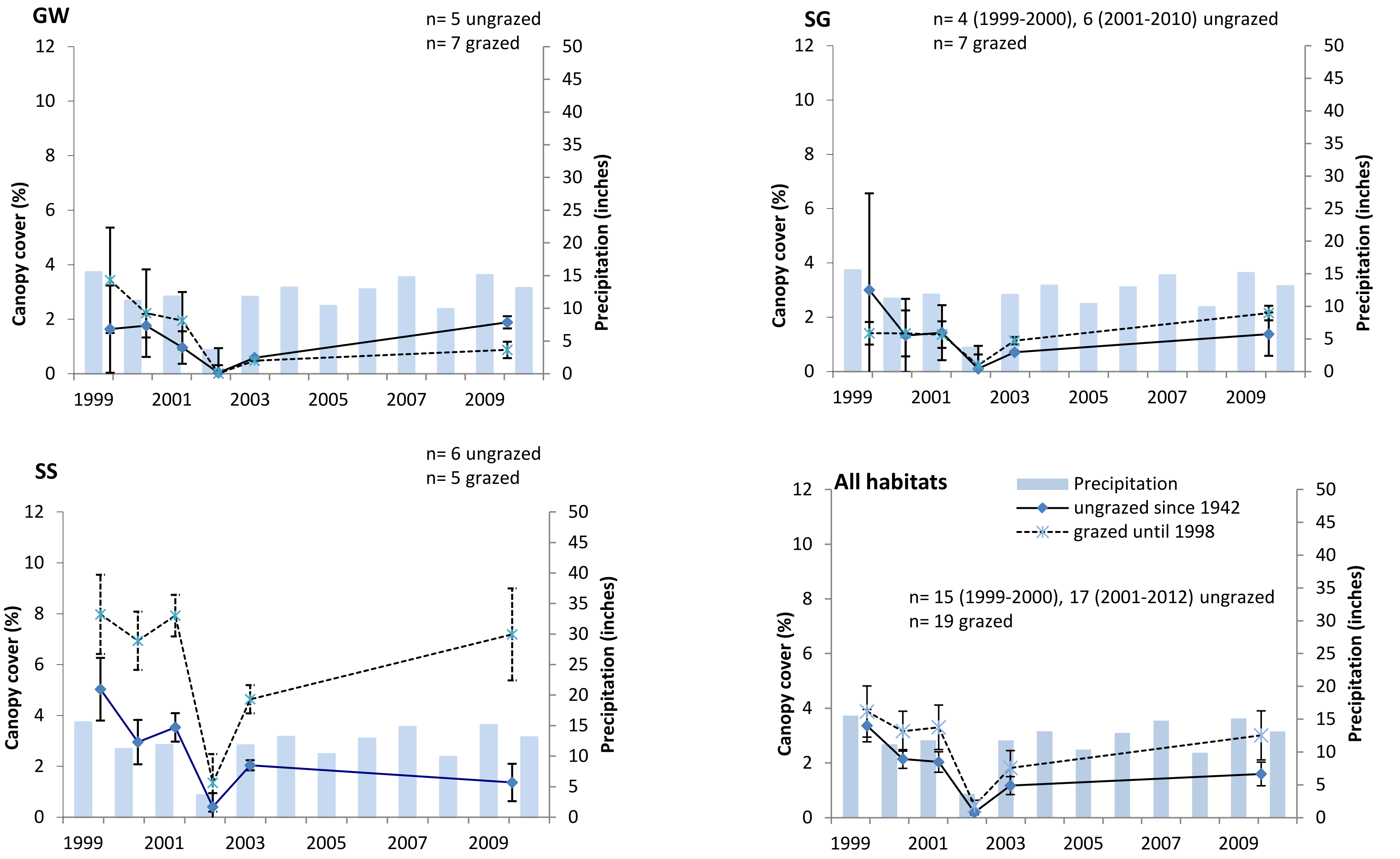


Figure C-15. Sand dropseed mean **cover** (± 1 SE) for greasewood (GW), shortgrass (SG), sandsage (SS), and all habitats combined.

Sand dropseed (*Sporobolus cryptandrus*)

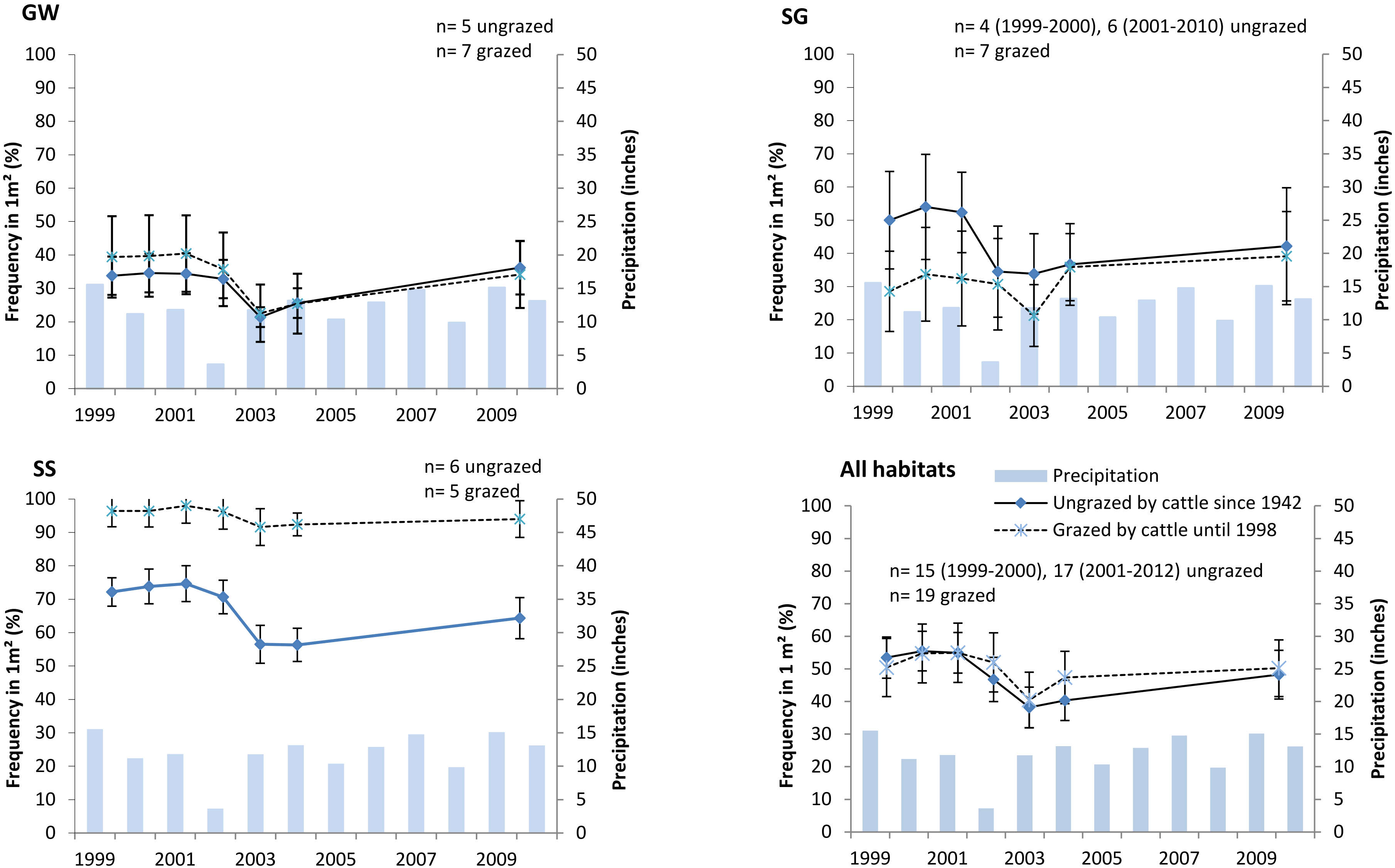
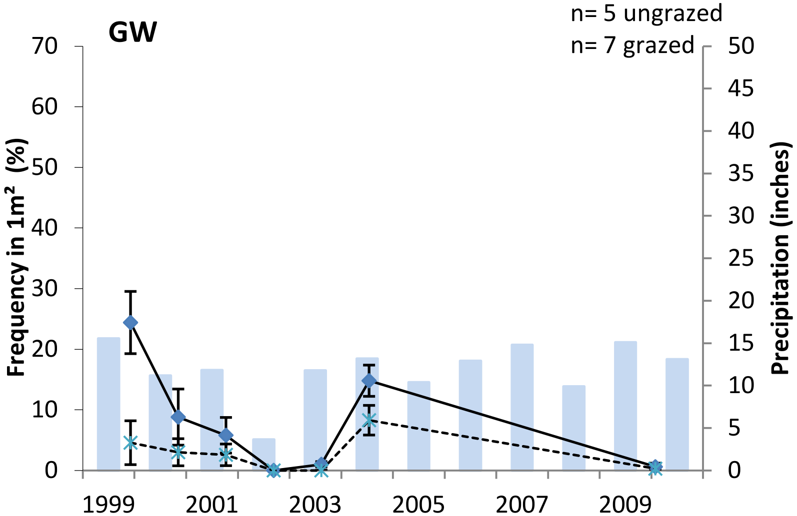
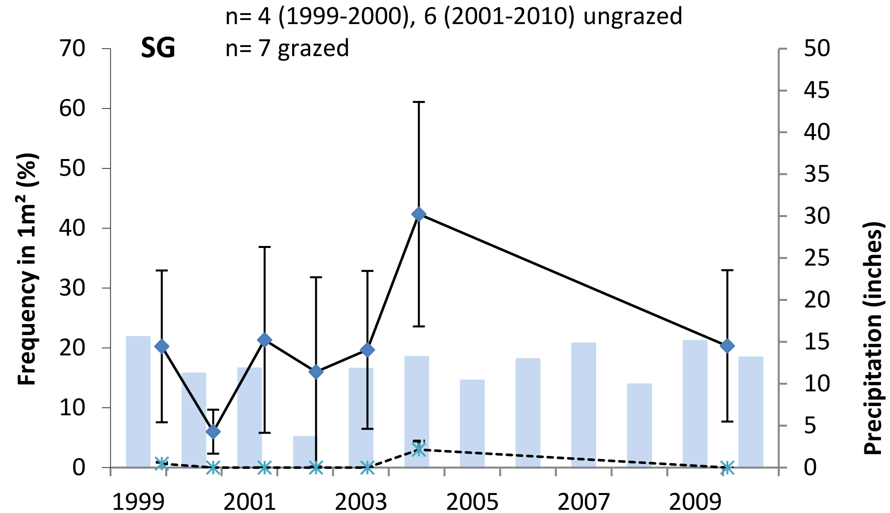


Figure C-16. Sand dropseed mean **frequency** (±1 SE) for greasewood (GW), shortgrass (SG), sandsage (SS), and all habitats combined.

Kochia (*Bassia* spp.)





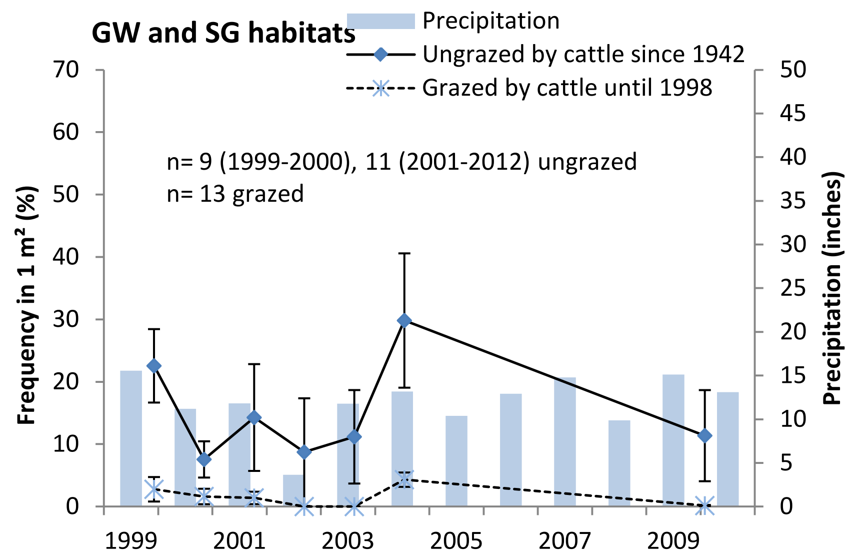


Figure C-17. Kochia mean **frequency** (± 1 SE) for greasewood (GW), shortgrass (SG), and both habitats combined.

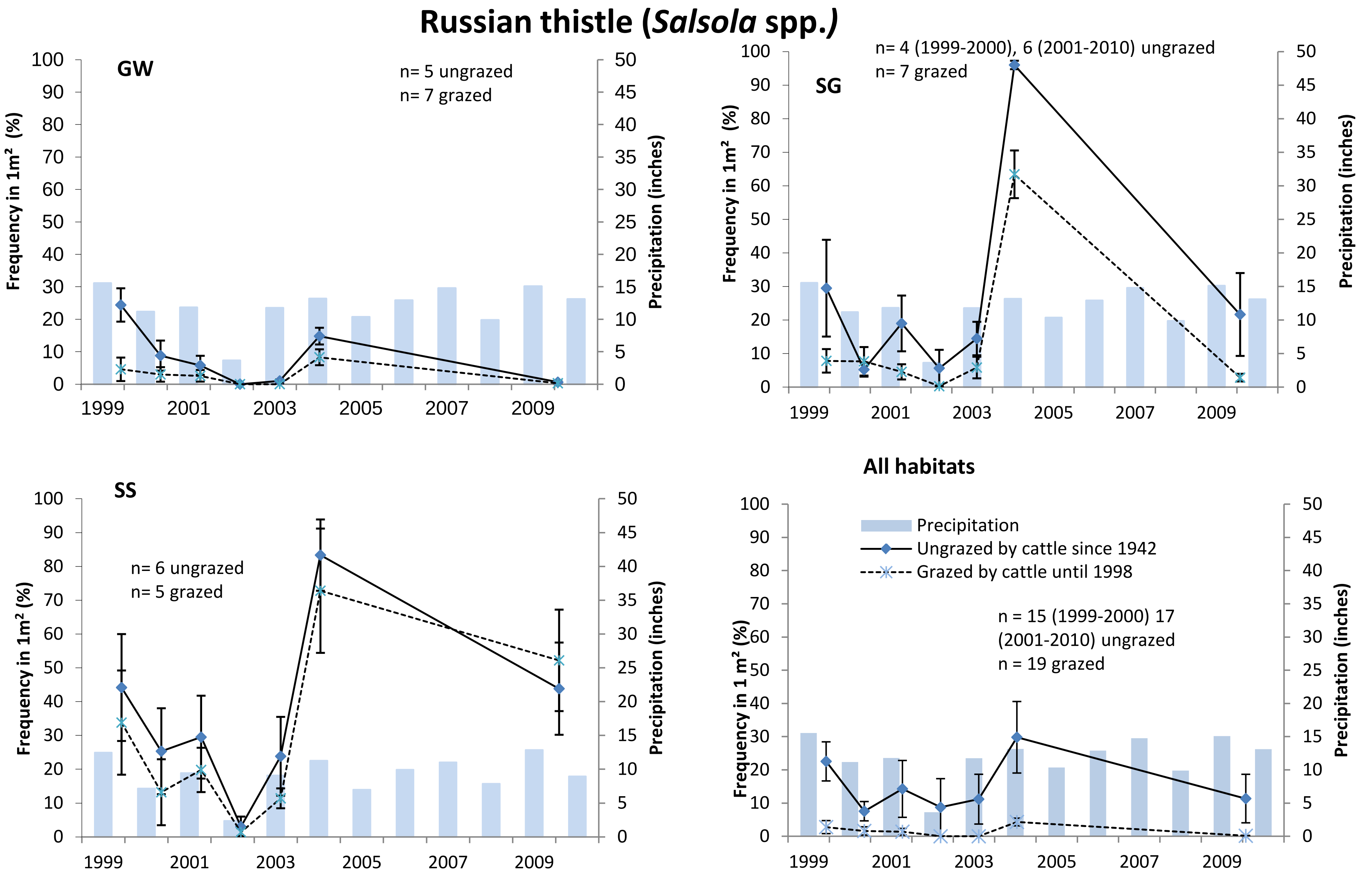


Figure C-18. Russian thistle mean **frequency** (± 1 SE) for greasewood (GW), shortgrass (SG), sandsage (SS), and all habitats combined.

Bare ground

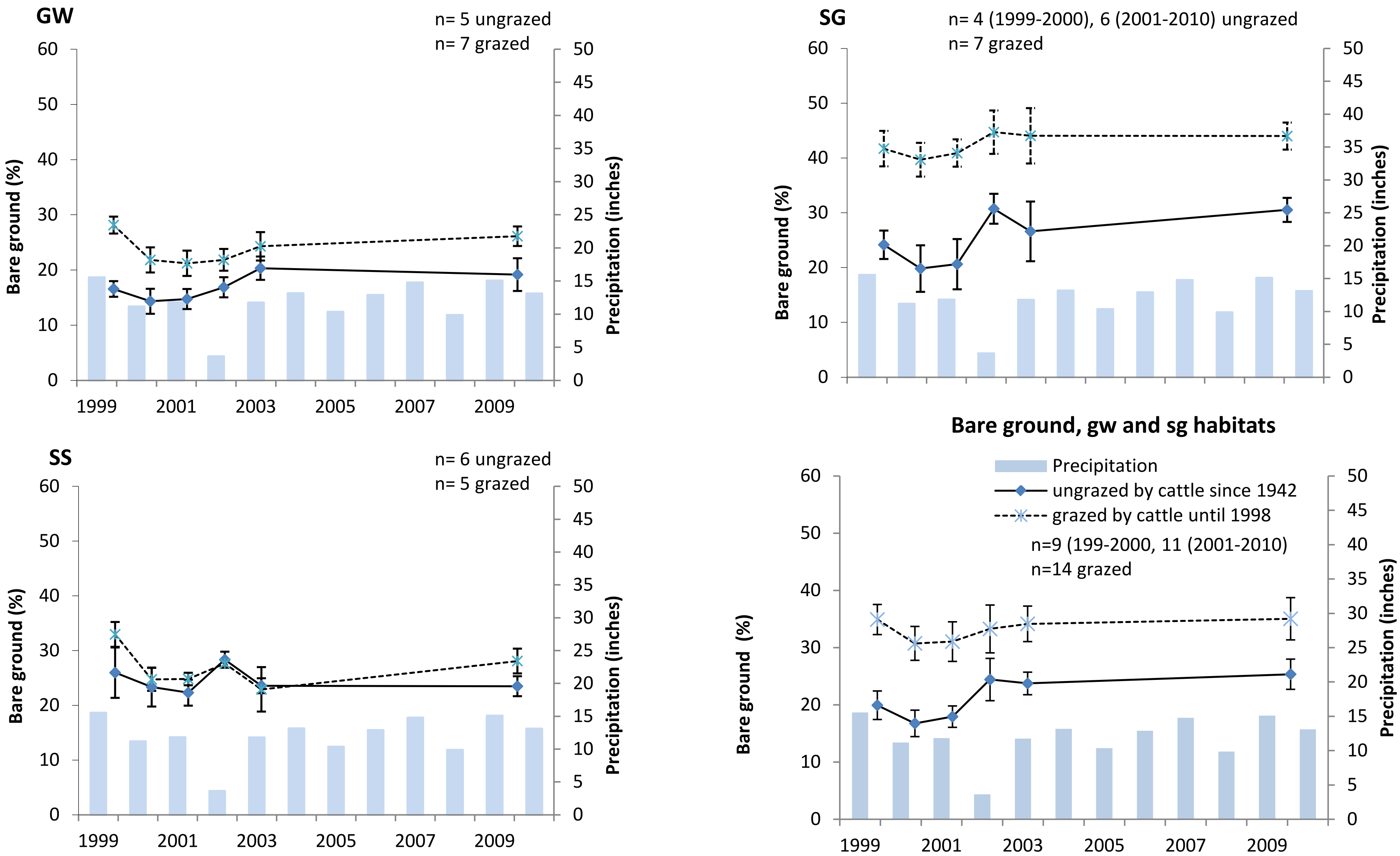


Figure C-19. Bare ground mean **cover** (± 1 SE) for greasewood (GW), shortgrass (SG), sandsage (SS), and GW and SG habitats combined. Bare ground and litter are much more ephemeral and not as easily measured in SS.

Litter

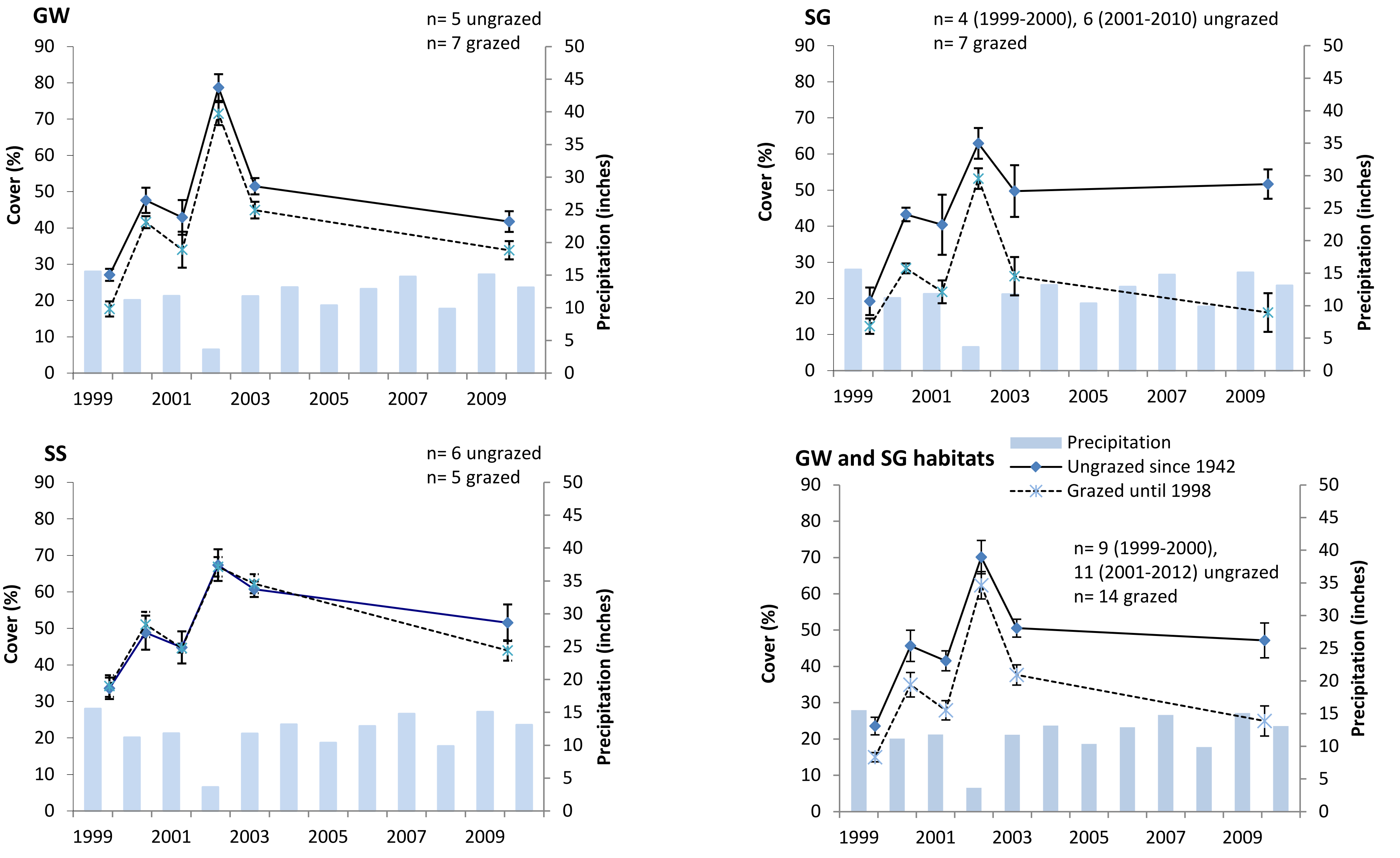


Figure C-20. Litter mean **cover** (± 1 SE) for greasewood (GW), shortgrass (SG), sandsage (SS), and GW and SG habitats combined. Litter is ephemeral in SS and not easily measured in SS.

Shortgrass Prairie Dog Plots

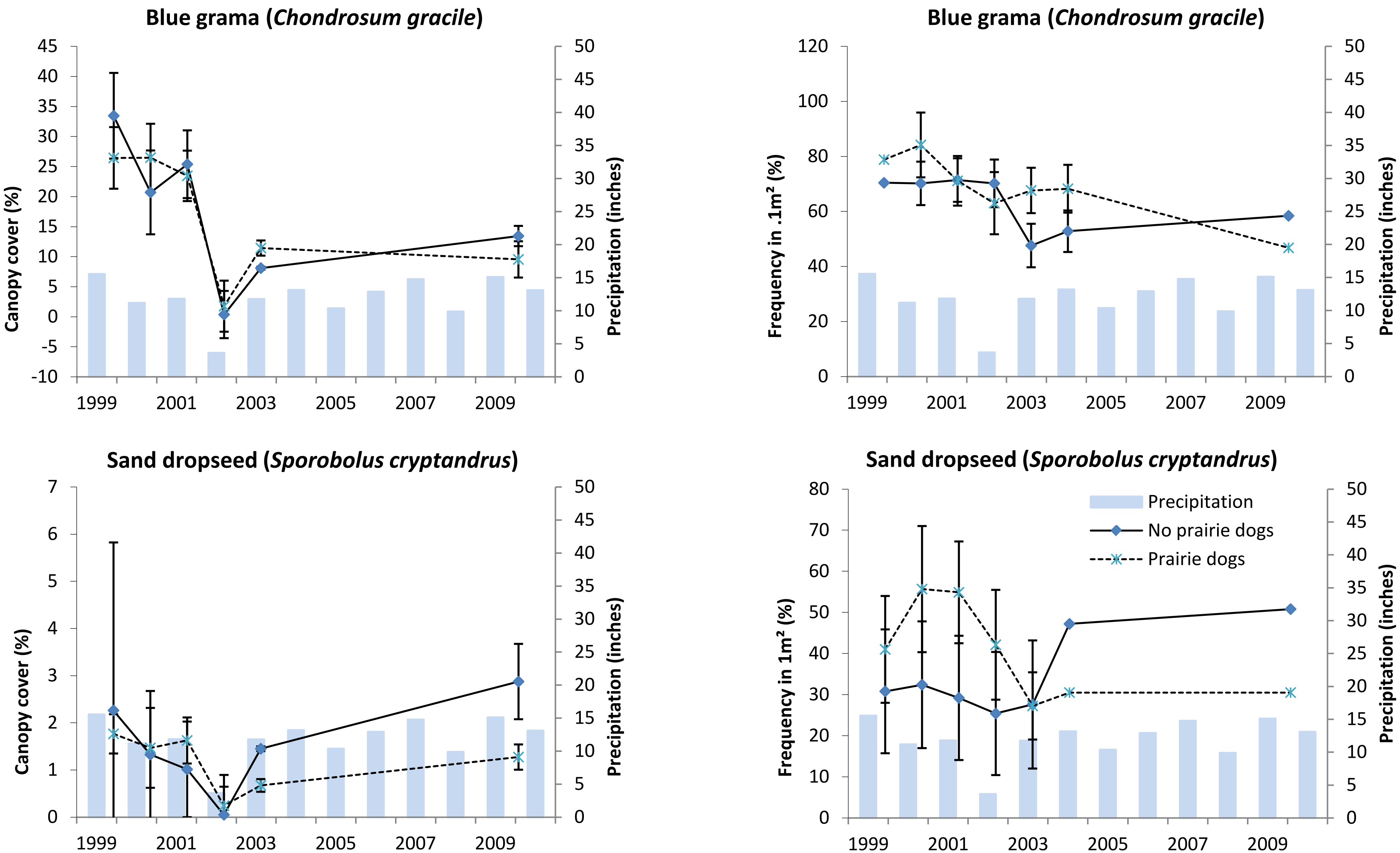


Figure C-21. Blue grama and sand dropseed mean **cover and frequency** (± 1 SE) in shortgrass plots with and without prairie dogs (n=5 no prairie dogs; n=6 (1999-2000), 8 (2001-2010) prairie dogs).

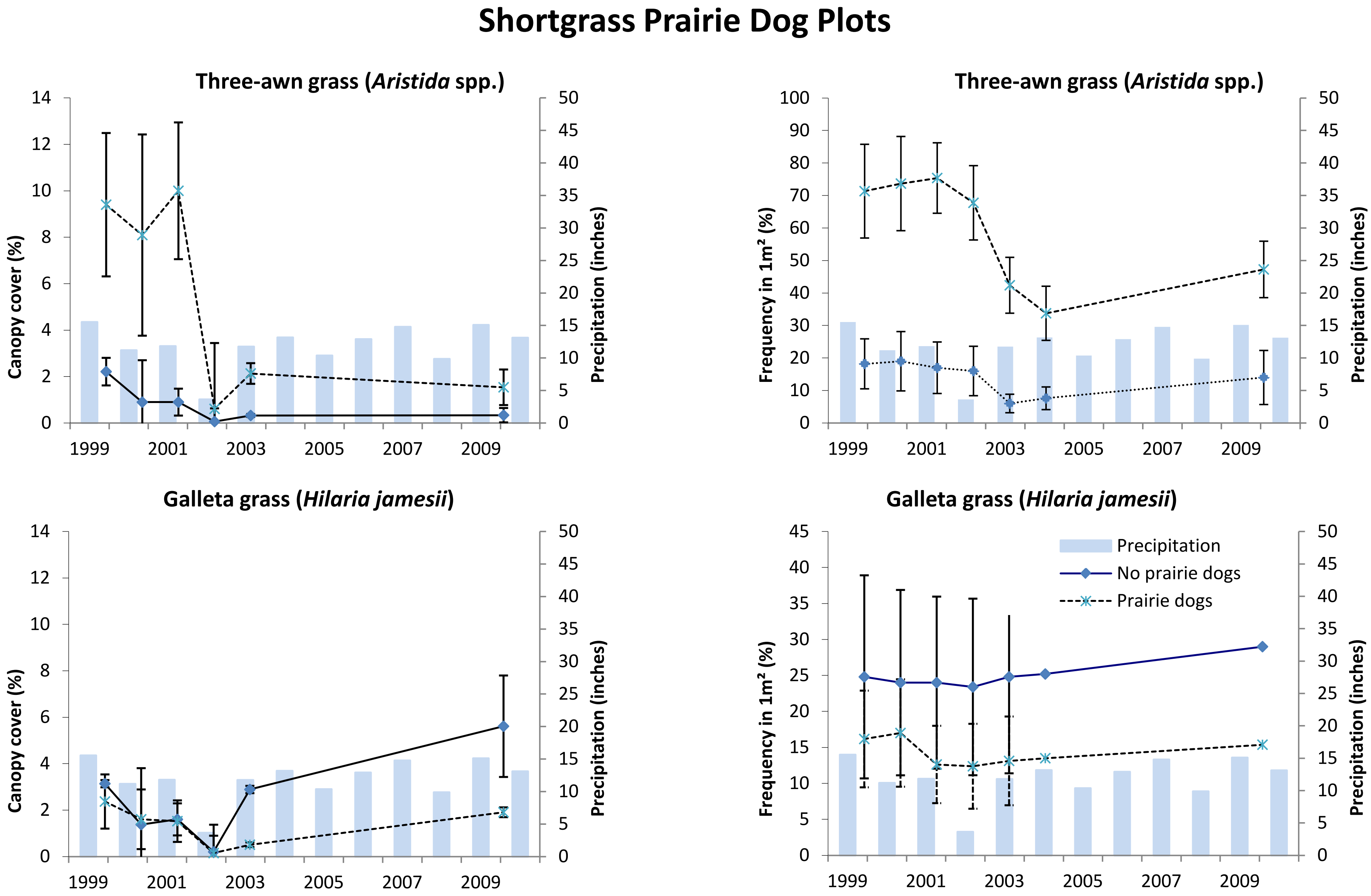


Figure C-22. Blue grama and sand dropseed mean **cover and frequency** (± 1 SE) in shortgrass plots with and without prairie dogs(n=5 no prairie dogs; n=6 (1999-2000), 8 (2001-2010) prairie dogs).

Shortgrass Prairie Dog Plots

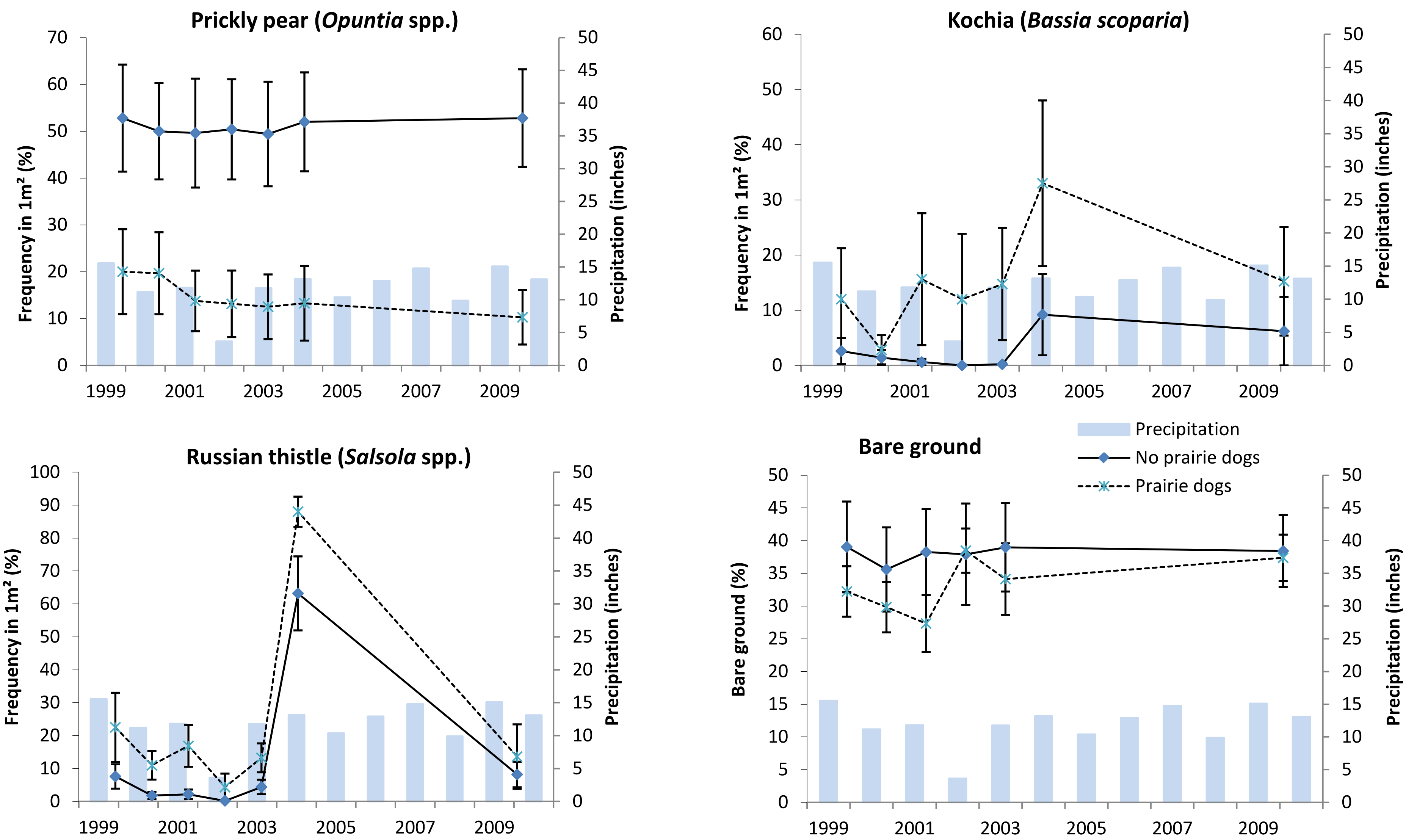


Figure C-23. Prickly pear, kochia, and Russian thistle mean **frequency** (± 1 SE) and bare ground mean **cover** (± 1SE) in shortgrass plots with and without prairie dogs(n=5 no prairie dogs; n=6 (1999-2000), 8 (2001-2010) prairie dogs).

Shortgrass Prairie Dog Plots

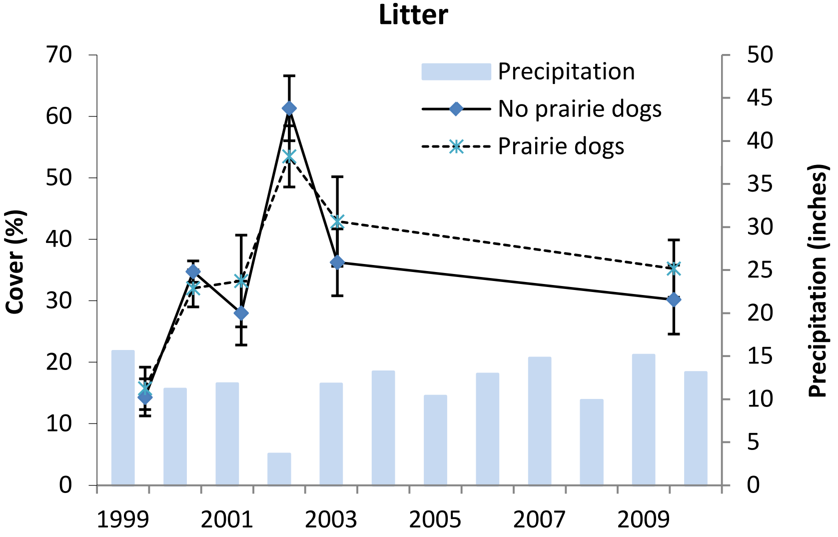


Figure C-24. Litter mean **cover** (± 1 SE) in shortgrass plots with and without prairie dogs(n=5 no prairie dogs; n=6 (1999-2000), 8 (2001-2010) prairie dogs).