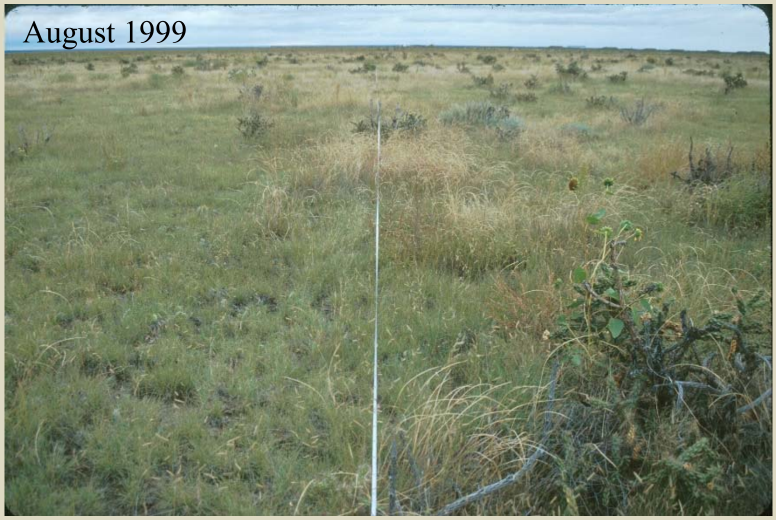
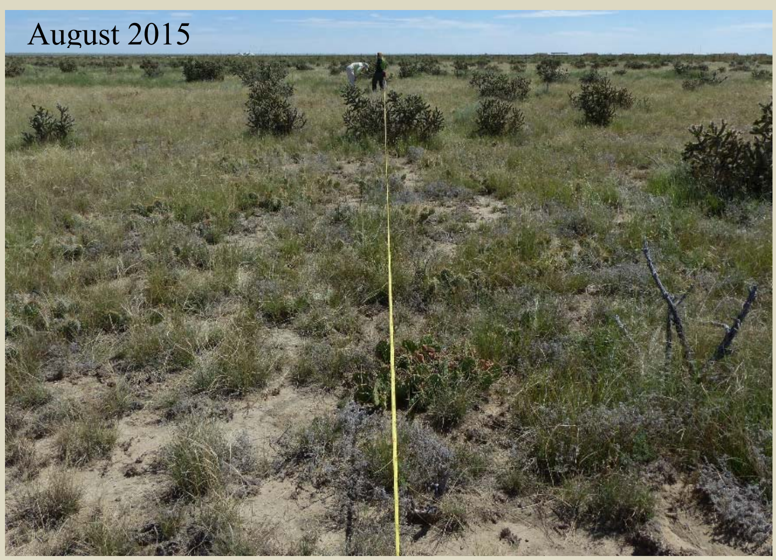
Vegetation Monitoring at Pueblo Chemical Depot: 1999-2015





COLORADO NATURAL HERITAGE PROGRAM

May 2016

Colorado State University

CNHP's mission is to preserve the natural diversity of life by contributing the essential scientific foundation that leads to lasting conservation of Colorado's biological wealth.

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Front Cover: Shortgrass prairie plot sg69, looking east from the plot center, in 1999 and 2015. Between 1999 and 2015, the cover of blue grama in the shortgrass prairie at Pueblo Chemical Depot decreased by 62% and the density of cholla increased by 47% between 1999 and 2015.

Vegetation Monitoring at Pueblo Chemical Depot: 1999-2015

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May 2016

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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. PCD makes up the southern portion of an important landscape conservation area – Chico Basin – and monitoring data collected here can be useful to PCD land managers as well as regional land managers. The PCD 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 the first two regimes are considered "grazed" and the latter two regimes "ungrazed." All further reference to the "grazed" regime refers to its historical use prior to 1998. During the 1999-2015 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, we 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, we added ten new plots though four existing plots were found to be disturbed and were subsequently dropped. In 2001, we added two additional plots on active prairie dog colonies. During 1999, 2000, 2001, 2002, 2003, 2010, and 2015, we re-sampled the plots between August 4 and September 22. This report eliminates the 1998 dataset due to incompleteness.

For greasewood shrubland we established 13 plots (7 grazed and 6 ungrazed), for sandsage shrubland we established 11 plots (5 grazed and 6 ungrazed), and in shortgrass prairie we established 13 plots (7 grazed and 6 ungrazed). Plot sg63ug in the shortgrass prairie still has pass-through cattle grazing and although we re-sampled the plot each year, it has been eliminated from this analysis. Eight of the shortgrass prairie plots were located within prairie dog towns. In the riparian area of Chico Creek we 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.

Though the project was originally conceived as a grazing study, the data also allowed analysis of vegetation changes due to drought and prairie dogs.

Differences between grazed and ungrazed plots and between plots with or without prairie dogs were evaluated by unpaired t-tests or non-parametric Mann Whitney U-tests. A mixed-effects model structured as a repeated measures analysis of variance (ANOVA) was used to test for significant year by grazing interactions to assess whether grazed and ungrazed plots remain different across the span of the study. The effects of extended drought between matched pairs of 1999 and 2015 plot observations were investigated by means of a Wilcoxon signed-rank test.

Grazed versus ungrazed. Species that decreased due to cattle grazing were cholla, needle-and-thread grass, and weeds (Russian thistle and kochia). Cholla density increased with the removal of grazing. Needle-and-thread grass, a palatable grass that cattle prefer, increased after the removal of grazing yet the extended drought slowed recovery. Weed frequency increased once cattle were removed, especially for Russian thistle. Species that increased from cattle grazing, thus a decrease was desired, were sandsage, three-awn grass, and sand dropseed. Of these, only sandsage responded as expected, that is, sandsage decreased in density and cover once cattle were removed and there is no longer a difference between the two grazing regimes. Three-awn grass and sand dropseed continue to have significant differences between grazed and ungrazed plots, with higher frequency in grazed plots. Greasewood, rabbitbrush, prickly pear, alkali sacaton grass, blue grama and galleta grass had no difference between grazed and ungrazed plots, thus we classify these species as neither an increaser nor a decreaser.

Extended Drought: Thirteen of the 17 years of this monitoring study (1999-2015) can be described as drought years or abnormally dry years. Drought indices indicate the most severe drought periods were 2002 and 2010 through 2012. Summers are getting hotter and temperature records indicate an increase in average growing season (April – September) temperature in the region of 1.2° F (0.6° C) over the last 120 years. Though 2015 was the highest precipitation year of the monitoring study (40% above average), just slightly higher than 1999, evidence of the extended drought was abundant.

The most significant decline is in blue grama, one of the dominant grasses of the Central Shortgrass Prairie ecoregion and the dominant grass at PCD. Blue grama, all habitats combined, decreased in cover and frequency by 47% and 38%, respectively, over the past 17 years. This decrease varied by habitat type, with the greatest losses in the shortgrass prairie habitat (62% cover and 45% frequency). The decline in blue grama has been relatively consistent throughout the monitoring study, however, over half of the decline occurred between the 2010 and 2015 sampling years. While the 2015 growing season precipitation was nearly identical to 1999, blue grama cover and frequency was still significantly lower, indicating that once blue grama individuals are lost the recovery rate is likely to be slow.

Other species showing significant declines over the study period include sandsage (50% mortality and 65% decrease in cover), three-awn grass (61% decrease in frequency), and needle-and-thread grass (50% decrease in frequency).

Shrubs and succulents that gained cover or density over the study period were rabbitbrush, greasewood, and cholla. Rabbitbrush and greasewood are deep-rooted shrubs that can access groundwater and, as such, are less susceptible to drought. Cholla, is a succulent that can easily withstand hot and dry conditions.

Sand dropseed, alkali sacaton grass, and galleta grass are likely to do well in future climate conditions. None of these grasses are as nutritious to cattle as blue grama. The slow recovery of blue grama 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.

Prairie dogs. The presence of prairie dogs in the shortgrass prairie influenced the plant composition. Prickly pear was less than half as abundant on prairie dog towns than off 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 indicating three-awn grass is increases with prairie dog grazing. Similarly, Russian thistle and kochia were more frequent on prairie dog plots than off.

Blue grama showed no difference with prairie dog grazing at the beginning of the study but showed greater losses on prairie dog plots than off in 2015. This indicates that the interaction of prairie dog grazing and extended drought is hard on blue grama.

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). PCD makes up the southern portion of an important landscape conservation area – Chico Basin – a large (>200,000 acre) intact prairie landscape. PCD and the larger Chico Basin are 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).

The PCD 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.

<u>Shortgrass prairie.</u> 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 20-50%.

<u>Sandsage shrubland.</u> 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 40% 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*).

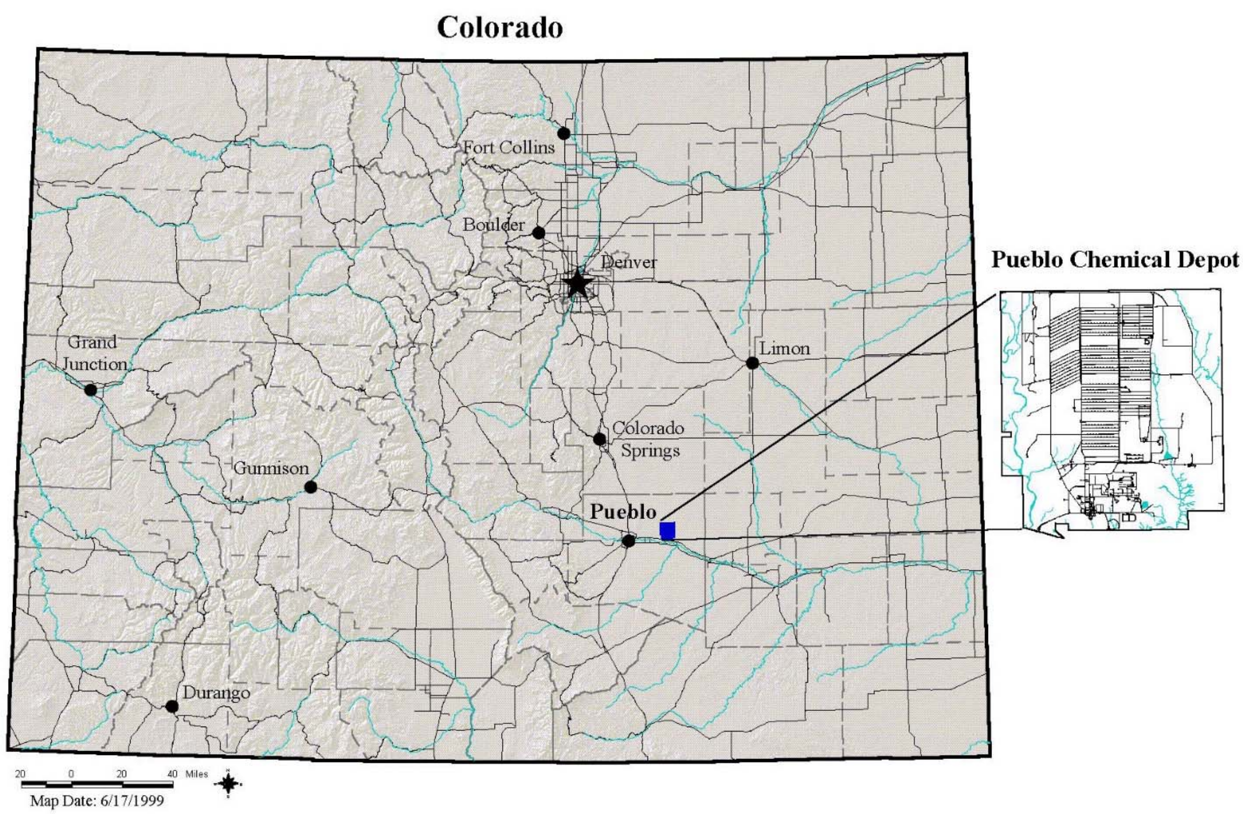

Figure 1. Location of Pueblo Chemical Depot.

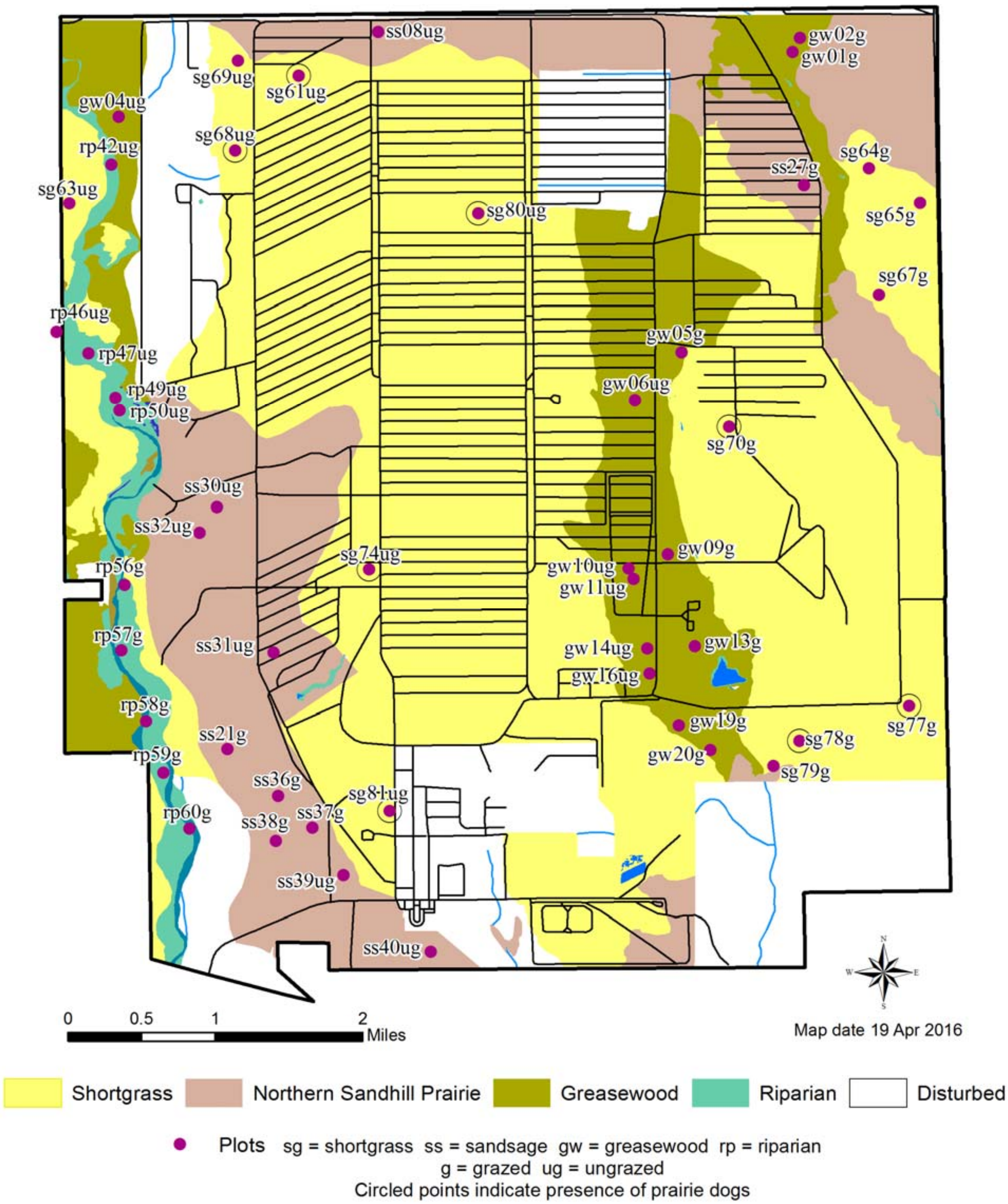

Figure 2. Vegetation types at PCD and locations of permanent vegetation sampling points.

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 (Martin and Szuter 1999, Sherrow 2001), 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, storage of mustard agent continued. An Explosive Destruction System was constructed at PCD and destruction of the remaining chemical munitions is ongoing.

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

At the Pueblo Airport (approximately 6 miles west 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) (1954 - 2015) (WRCC 2016). The historical average temperature during the growing season (April - September) in the Arkansas River drainage is shown on Figure 3 (NOAA 2016). The data show an increase of 0.1° F (0.06° C) per decade.

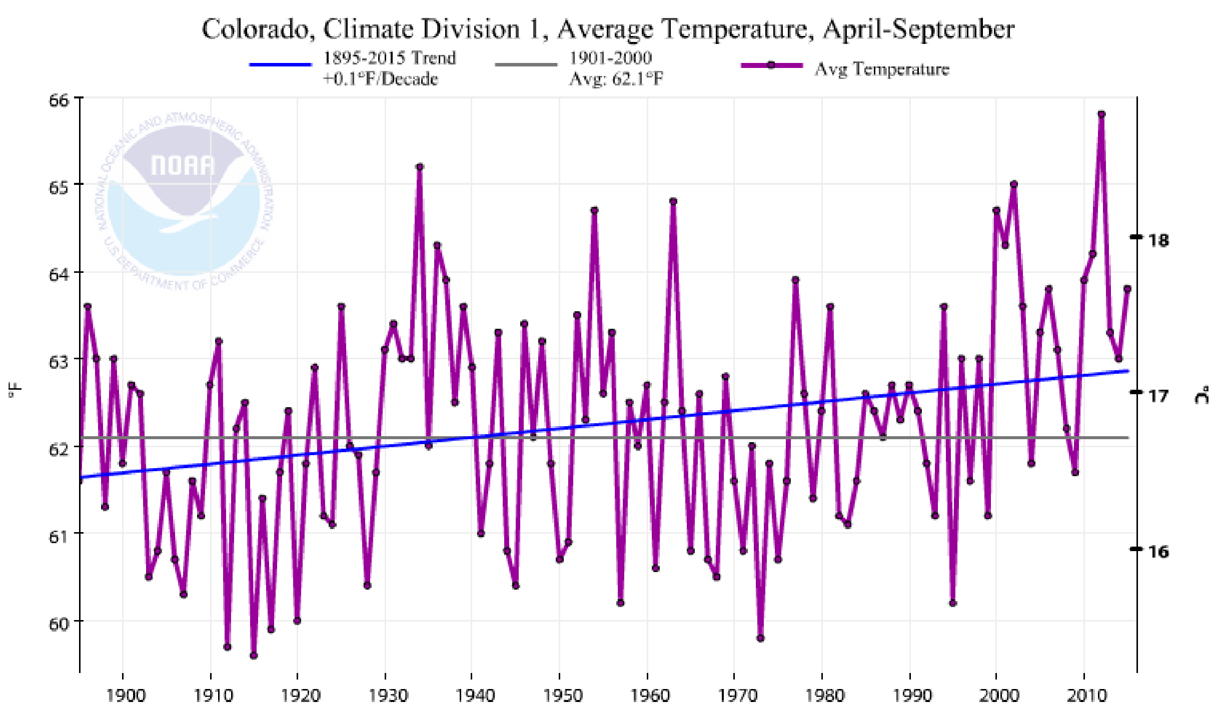

Figure 3. Historical average temperature within the Arkansas drainage, April-September (NOAA 2016).

From 1954 to 2015, yearly mean annual precipitation has been 11.8 inches (SD = 3.3 inches) (30 cm, SD = 8 cm), about 45% of which falls during July-August, the period of maximum plant production (Table 1, Fig. 4) (WRCC 2016). Annual precipitation varied over the years, from 69% below average in 2002 to 41% above average in 2015 (Fig. 5). On average, June experiences drought conditions with the average monthly precipitation falling below the average monthly temperature (Fig. 4).

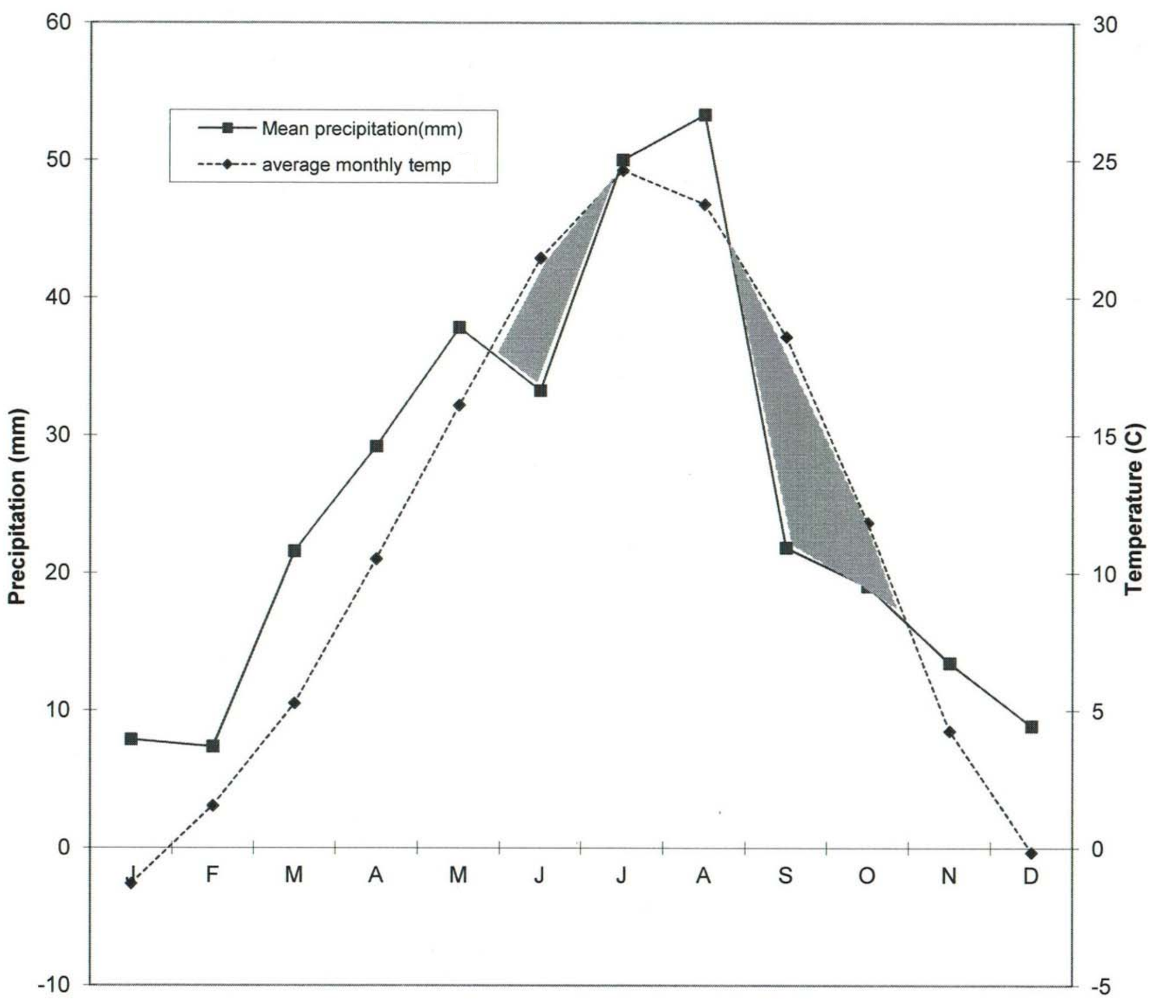

Figure 4. Mean monthly precipitation and temperature at the Pueblo Airport WSO. Shaded areas indicate where precipitation falls below temperature and represent drought conditions. Data are from 1955-2000.

Table 1. Annual precipitation (inches) for water year (October-September), 1998-2015. 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	1.07	1.20	5.39	2.71	0.95	15.11
2010	1.92	0.07	0.18	0.19	0.77	1.01	1.14	2.84	0.9	2.28	1.76	0.04	13.10
2011	0.03	0.20	0.44	0.29	0.58	0.65	0.30	0.61	0.80	2.35	0.79	0.46	7.50
2012	1.18	0.38	0.84	0.03	0.60	0.11	0.80	0.92	0.07	0.91	0.24	0.73	6.81
2013	0.29	0.00	0.30	0.21	0.48	0.21	0.30	0.73	0.27	1.68	3.92	1.27	9.66
2014	0.24	0.34	0.03	0.45	0.28	0.76	2.06	0.65	0.86	3.28	1.26	0.62	10.83
2015	0.91	0.46	0.24	0.25	1.13	0.57	1.42	5.55	1.22	0.64	4.24	0.03	16.66
Mean 1954-2015	0.76	0.46	0.34	0.31	0.32	0.79	1.20	1.49	1.26	1.95	2.09	0.80	11.81

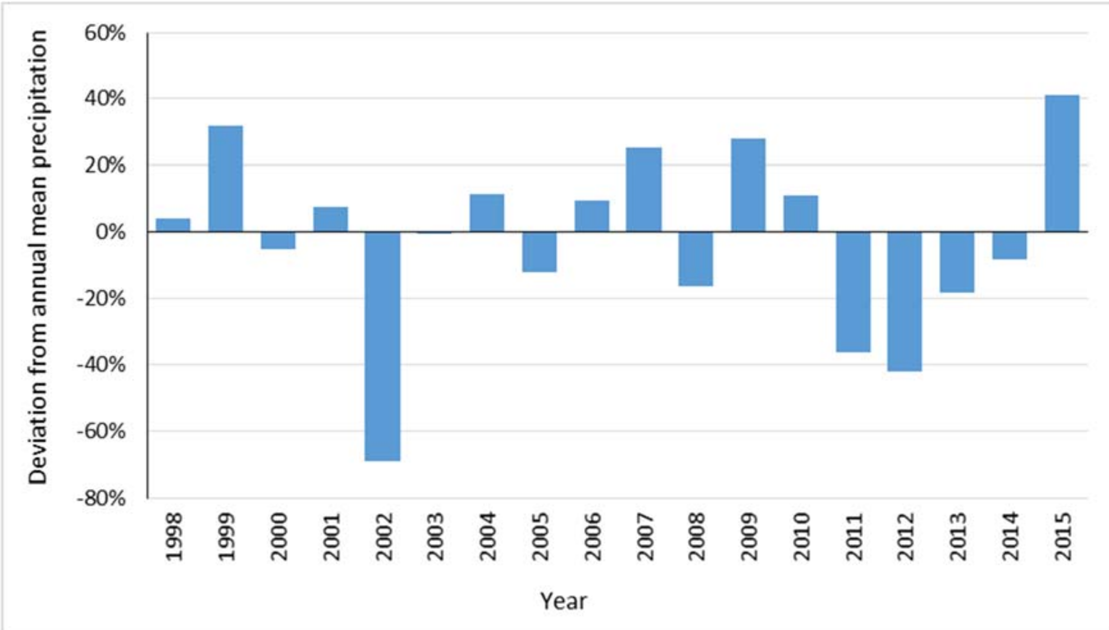

Figure 5. Deviation from mean annual precipitation at PCD (1998-2015). Water year (October-September) was used for calculating the mean. Pueblo WSO data. Mean is from 1955-2015.

A number of drought indices have been developed to assimilate climate variables such as rainfall, temperature, and evapotranspiration into an indicator of relative drought conditions. One of these indices is the evaporative demand drought index (EDDI) recently developed by Western Water Assessment (Rangwala et al. 2015, McEvoy et al. 2016). The EDDI takes into account the relationship between evaporative demand and actual loss of water at the land surface through evapotranspiration. The evaporative demand is the amount of water that would evaporate from the soil and be transpired by plants under well-watered conditions. The EDDI is calculated relative to 30 years of historical climate data. The EDDI for the upper Arkansas Watershed (including PCD) for the April through September growing season is shown on Figure 6.

The EDDI shows that many of the years of this monitoring study (1999-2015) can be described as drought years (positive drought index, shown below the zero line in Figure 6). The years with the highest drought index are 2002, 2010, 2011, and 2012.

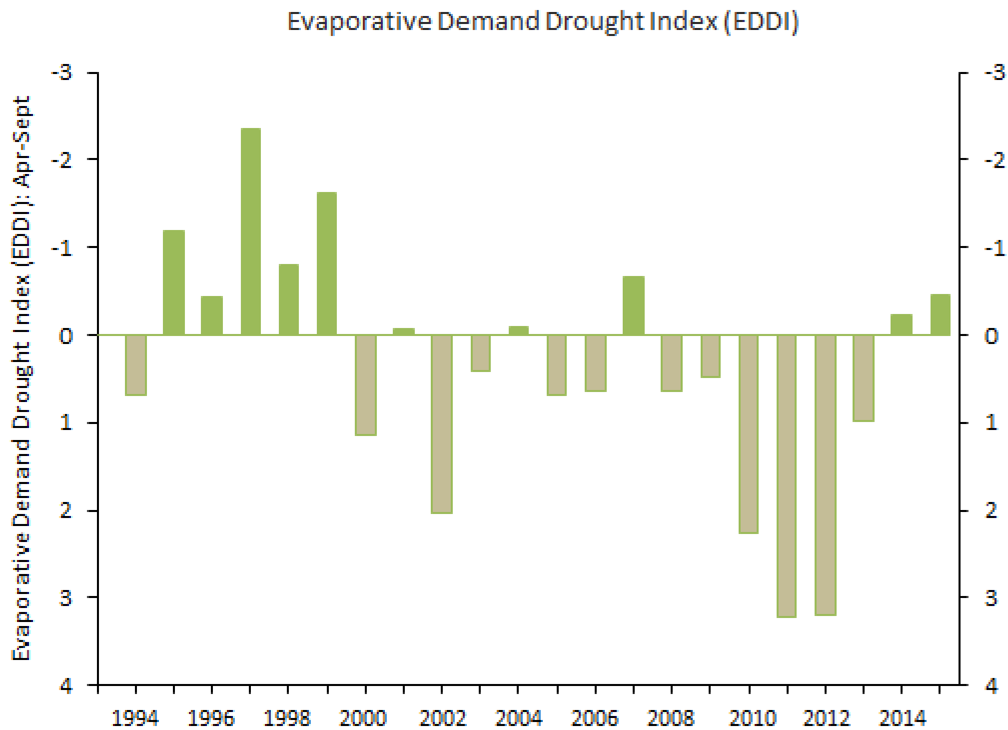

Figure 6. Evaporative Demand Drought Index for the growing season (April through September) at PCD (Rangwala et al. 2015).

Grazing History

PCD has experienced varied cattle grazing intensities, ranging from areas that have been ungrazed since 1942 (within the munitions storage area) to areas with year-round heavy grazing (Fig. 7). 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.

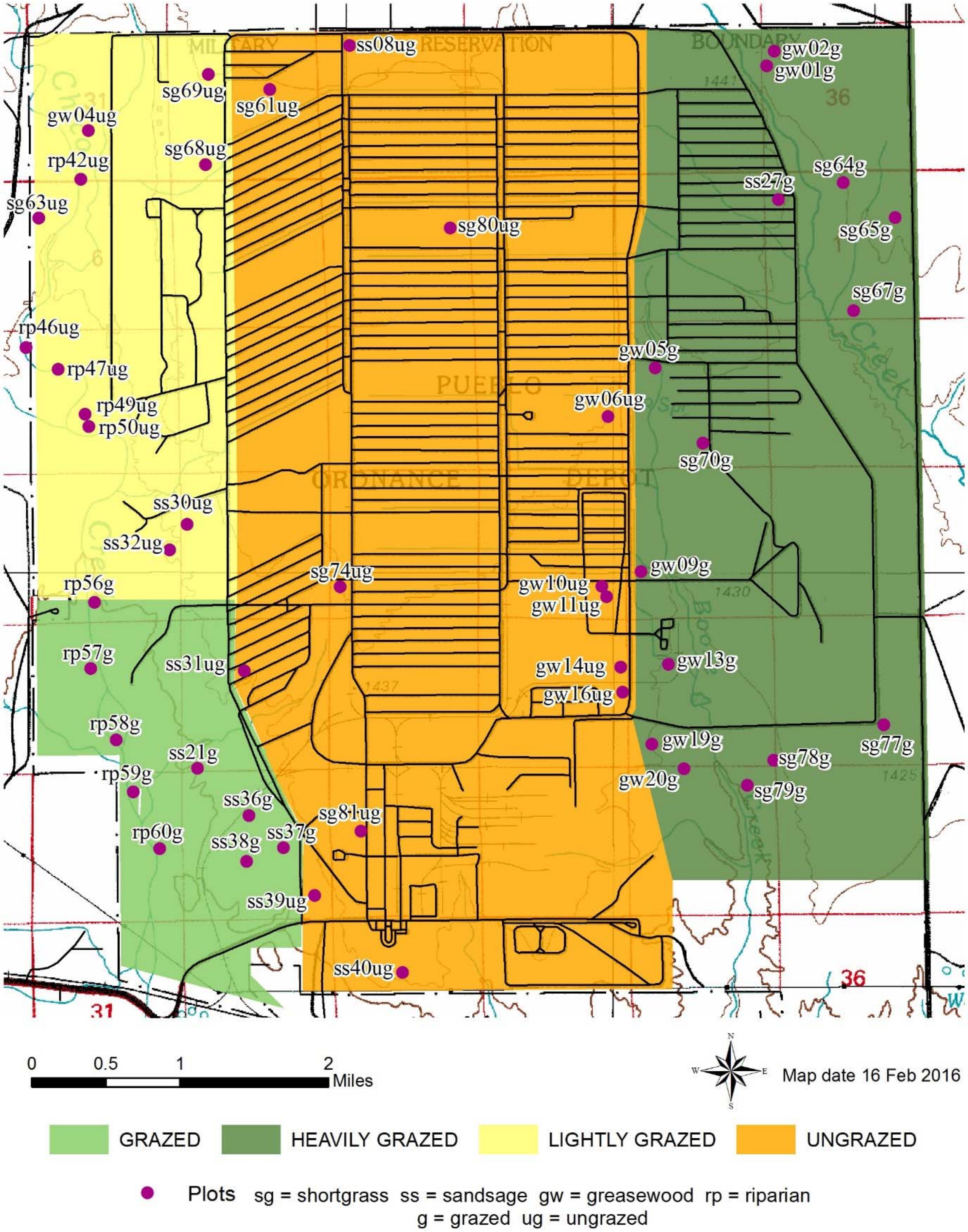

Figure 7. Grazing regimes at PCD with locations of permanent vegetation sampling points.

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 2015 the occupied area remained relatively constant (M. Canestorp, pers. comm., 2012); C. Jones, pers. comm., 2016).

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 (Fig. 8). 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. The soil types and their plant associations are briefly described below. The soil and plant composition descriptions are modified from the soil survey of the Pueblo area (USDA 1979).

Stoneham loam. This soil type is the dominant soil type for shortgrass prairie at PCD. 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.

Razor clay, eroded. This soil type also has shortgrass prairie vegetation but it occupies a smaller area than the Stoneham loam soils. In addition to shortgrass vegetation, some of these soils have greasewood shrubland. 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. There are four shortgrass plots on this soil type of which 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.

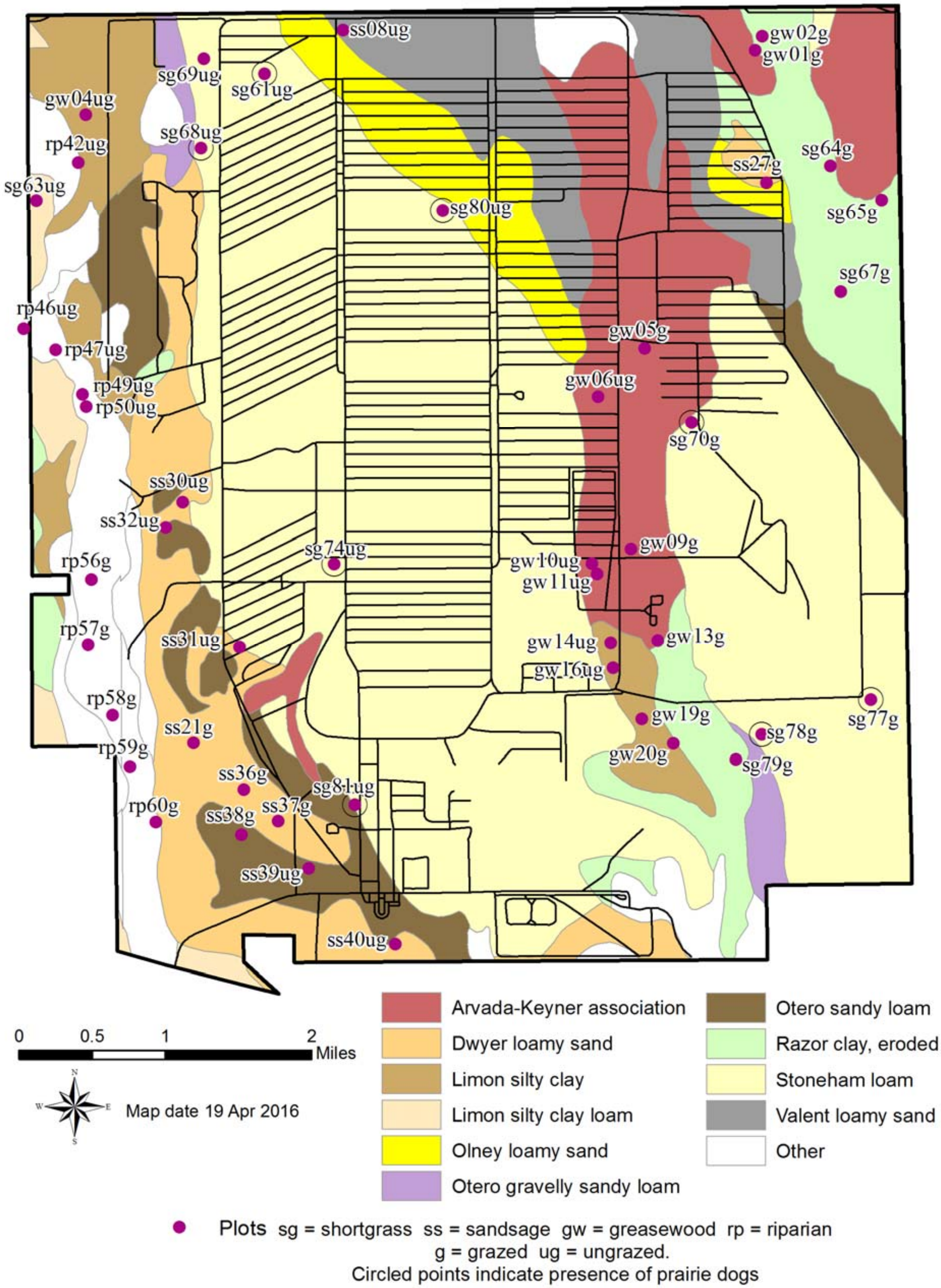

Figure 8. Soil types at PCD with the locations of permanent vegetation sampling points.

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. 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. 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. 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. 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 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 we developed sampling and management objectives. The 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. We were 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 previously reported (Rondeau and Kettler 1999; Rondeau 2001, 2003, 2013) 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 2015. *Increase* the average canopy cover and frequency of needle-and-thread grass in the **grazed** portion of the sandsage shrubland between 1998 and 2015.
>
> **Sampling objective 1**: We want to be 90% sure of detecting a 20% change in the absolute cover and frequency of needle-and-thread 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 2015.
>
> **Sampling objective 2**: We 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

Vegetation monitoring methods at PCD have been consistent throughout the study period (Rondeau and Kettler 1999, Rondeau 2001, 2003, 2013, Rondeau et al. 2013).

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, we established randomly chosen permanent vegetation monitoring plots in 1998 with an equal number in the grazed versus ungrazed treatments. After the 1998 field season, we 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 7 represent the placement of the plots relative to vegetation and grazing respectively. Figure 9 shows the placement of the plots as viewed with a 2015 aerial photo.

Complete sample years were 1999-2003, 2010, and 2015. Partial sampling was conducted in 2004 and 2005; in 2004 frequency data were collected from all plots (except gw04) and in 2005 frequency data were collected from shortgrass prairie plots. The plots were resampled between August 4 and September 22. We generally resampled the plots within two weeks of their original sample date. For greasewood shrubland we established 13 plots (7 grazed and 6 ungrazed), for sandsage shrubland we established 11 plots (5 grazed and 6 ungrazed), and for shortgrass prairie we established 13 plots (7 grazed and 6 ungrazed).

At the beginning of this study, three of the grazed (sg70g, sg77g, and sg78g) and one of the ungrazed (sg61ug) plots in the shortgrass prairie were located within prairie dog towns. In 2001, two additional shortgrass prairie plots were established in areas ungrazed by cattle but

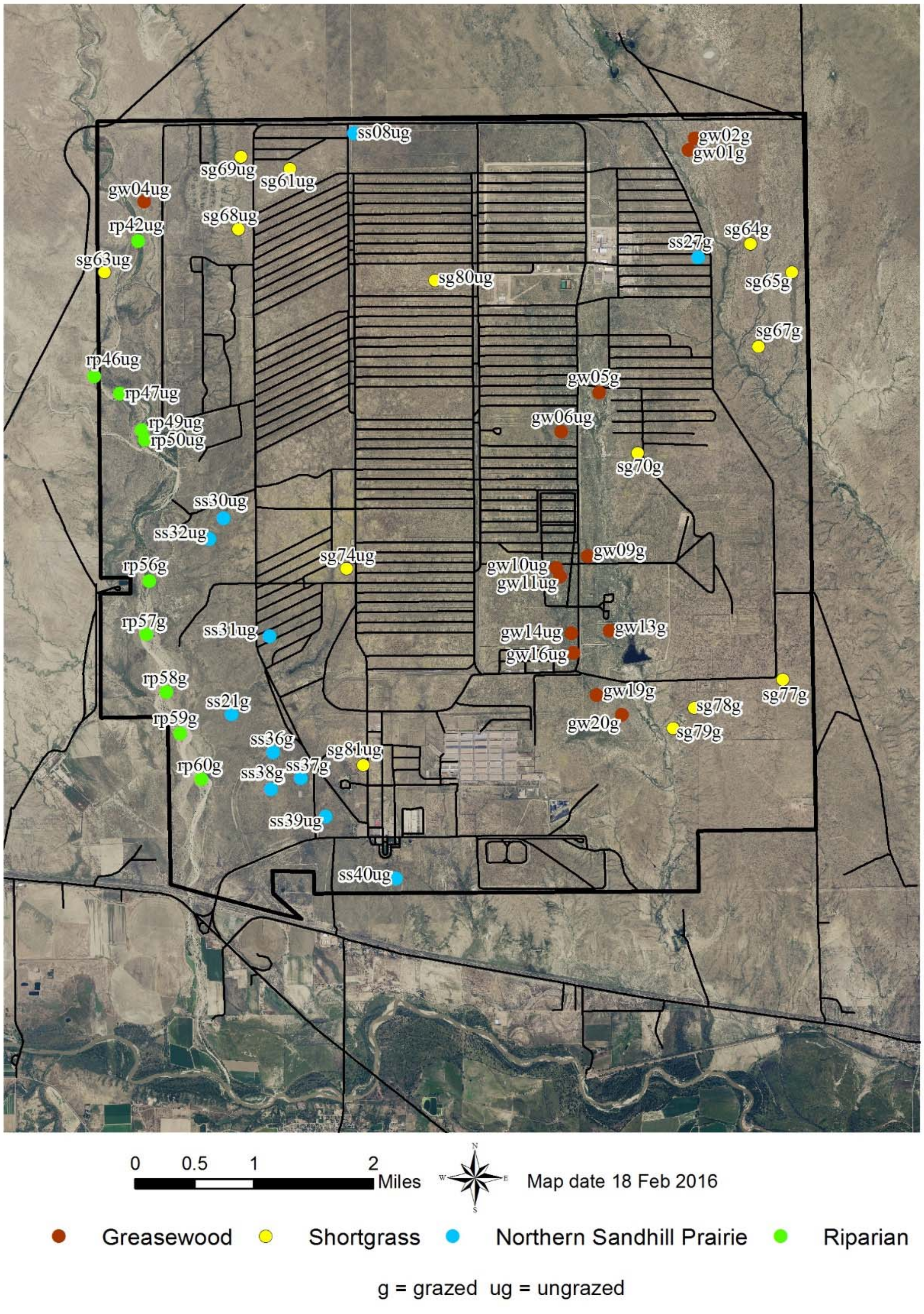

Figure 9. 2015 aerial photo of PCD with locations of permanent vegetation sampling points. As detailed in the grazing history section, plots labeled "grazed" were grazed by cattle until 1998 and plots labeled "ungrazed" have not been grazed by cattle since 1942.

within prairie dog towns (sg80ug and sg81ug). Prairie dogs moved into two additional ungrazed plots (sg68ug and sg74ug) sometime between 2005 and 2010. None of the towns were active throughout the entire study as plague came through PCD multiple times. On average a town was active during 3.5 out of 9 monitoring events.

Fires have also affected some plots. Shortgrass plot sg65g was burned by a lightning-induced fire in June 2000; sg70g was burned by a human-induced fire in November 2001; and sg80ug was burned in November 2002. The only shrubland plots that have burned during the study are greasewood plots gw19g and gw20g, which burned in March 2011.

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. 10).

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. 10). 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.

Standing dead vegetation (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

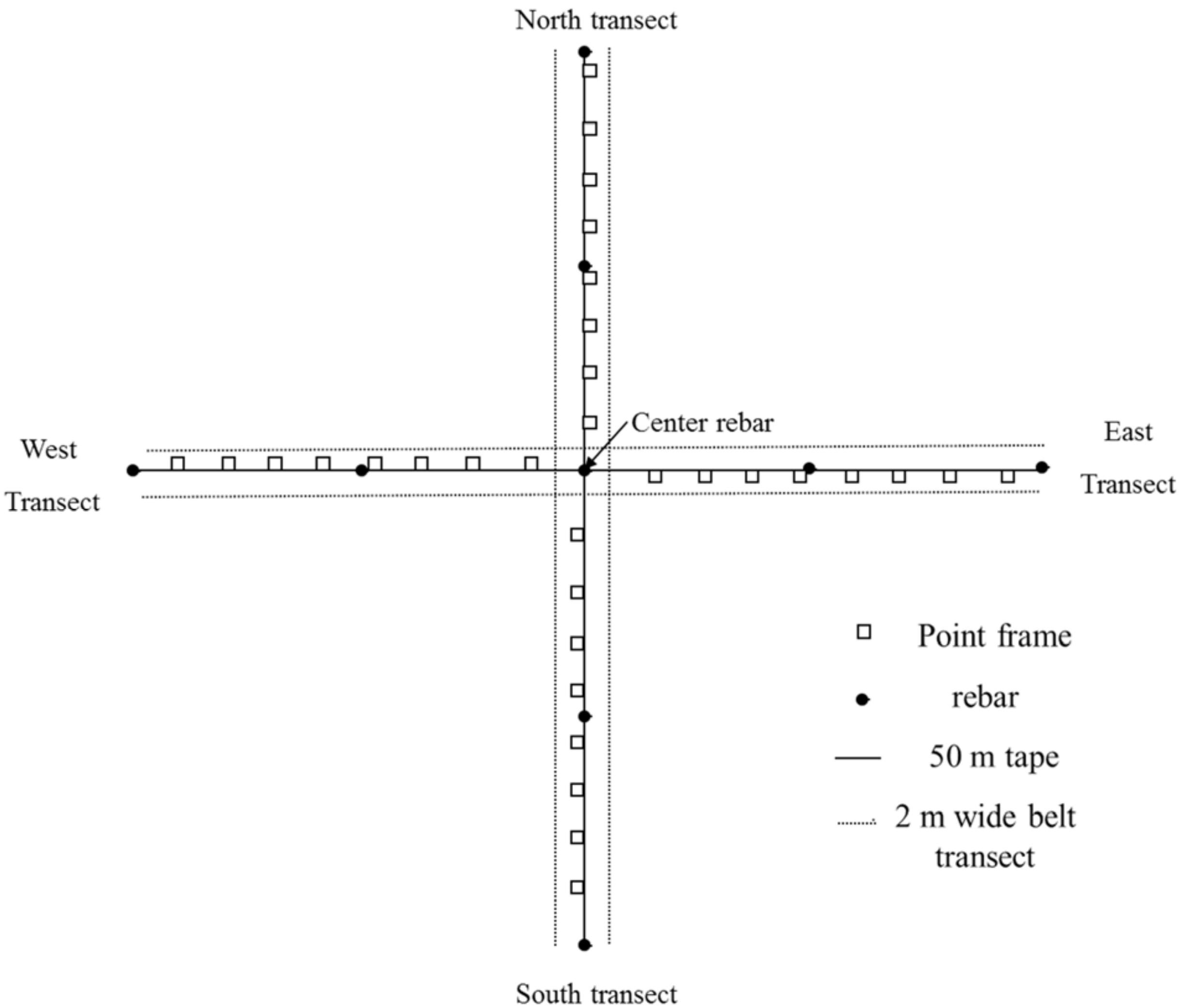

Figure 10. Configuration of an upland vegetation sampling site.

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. 10). 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. We 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). The UTM coordinates of the plots are listed in Appendix B.

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, we used a Nikon 2000 35-mm camera with a 35-80 mm lens set for 35 mm. In 2003, 2004, and 2010, we used an Olympus digital camera. In 2015, we used a Panasonic Lumix digital camera (12mp).

See Appendix C for sample field forms.

Riparian

For the grazed and ungrazed riparian areas we randomly selected five sites along Chico Creek (Fig. 7). During 1998, 1999, and 2000 we collected frequency data, but this proved to be of limited value and frequency monitoring was discontinued. Repeat photos are the only data currently collected from Chico Creek.

Statistical Analysis

Statistical analysis was performed using JMP Pro 12.0.1 (SAS Institute 2015). All data was checked for normality and a square root transformation was attempted for non-normal data. For normally distributed species, we 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, we used a Mann-Whitney *U*-test (implemented as the Wilcoxon Test in JMP). For the species that we did not consider increasers/decreasers we 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, we conducted a repeated measures ANOVA (Glantz 1992), implemented as a mixed model in JMP software to ascertain if there was detectable effect of grazing on difference in canopy cover, density, and frequency of dominant species among the years 1999-

2015. Frequency plot sizes used for the analyses were F3 for blue grama in all habitats, F3 for sand dropseed in the sandsage habitat, and F4 for the remaining species.

RESULTS

Changes in vegetation cover, density, and frequency through time were analyzed with respect to their response to cattle grazing, climate, and prairie dogs. Though the original intent of this study was to evaluate the difference between grazed and ungrazed plots, in an effort to understand the variability we see in the field and in the data, we included climate (extended drought in this case) and the presence or absence of prairie dogs in our evaluation. Additionally, we present data collected from two greasewood shrubland plots before and after a fire. Results are presented for shrubs/succulents, grasses, weeds, and bare ground.

Cattle Grazing

As described in the grazing history section of this report, plots that were grazed by cattle up until 1998 are considered "grazed" and plots that had not been grazed by cattle since 1942 are considered "ungrazed." Analysis of the 1999 shrub monitoring data showed a significant difference between grazed and ungrazed plots for cholla and a nearly significant difference between grazed and ungrazed plots for sandsage and rabbitbrush. Significant differences between grazed and ungrazed plots were also shown for some of the grass species, annual weeds, and bare ground. Tables 2 and 3 show the statistical analysis of the 1999 monitoring data for shrubs, grasses, weeds, and bare ground. In this section we discuss the species that had significant or nearly significant differences between grazed and ungrazed plots in 1999 and track those differences through time. Additionally, because prickly pear is generally considered a species that increases in abundance with grazing ("increaser"), we discuss this species as well.

Table 2. Mean cover, density, or frequency (± 1 SE) of shrubs 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. Density is individuals per hectare.

Species	1999 data		P-value	Expected change (grazed vs ungrazed)	Observed change (grazed vs ungrazed)	Notes
	Grazed (mean)	Ungrazed (mean)				
Sandsage—sandsage habitat						
Cover (%)	18	15	0.08	Increaser	Increaser	Sandsage cover and density were higher in grazed than ungrazed plots in 1999 suggesting that cattle grazing increased sandsage. There is no longer a difference between grazed/ungrazed.
Density	11,285	9,779	0.08	Increaser	Increaser	
n	5	6				
Greasewood—greasewood habitat						
Cover (%)	3	4	ns	Increaser	Neither	No difference observed between grazed/ungrazed.
Density	1,354	975	ns	Increaser	Neither	
n	7	5				
Rabbitbrush—greasewood and shortgrass habitats						
Cover (%)	1	3	0.07	Increaser	Probably neither	Difference between grazed/ungrazed still evident after 15 years of no grazing. Therefore, difference not likely attributable to grazing.
Density	917	1,433	ns	Increaser	Probably neither	
n	12	9				
Cholla—greasewood and shortgrass habitats						
Cover (%)	0.3	0.8	0.04	Increaser	Decreaser	Cholla density increased at a higher rate in grazed than ungrazed plots suggesting that cattle grazing suppressed cholla.
Density	215	508	0.015	Increaser	Decreaser	
n	12	9				
Prickly pear (F4)—all habitats						
Frequency (%)	31	37	ns	Increaser	Neither	No difference observed between grazed/ungrazed.
n	19	15				

n = number of plots
ns = not significant
F4 = 1 m x 1 m plot size

Table 3. Mean cover and frequency (± 1 SE) of grasses, weeds, and bare ground in greasewood, sandsage, and shortgrass habitats in 1999 (and 2015 for those that were significantly different). 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, ***P≤0.001).

		Greasewood[1]		Sandsage[2]		Shortgrass[3]		All habitats		
Species	**Measurement**	**Grazed**	**Ungrazed**	**Grazed**	**Ungrazed**	**Grazed**	**Ungrazed**	**Grazed**	**Ungrazed**	**Sample size for all habitats**
GRASSES										
Total grass	*Cover 1999*	52 ± 2	52 ± 1	27 ± 3	31 ± 4	41 ± 3	51 ± 4	41 ± 3	43 ± 3	n=19 grazed, 15 ungrazed
Blue grama	*Cover 1999*	20 ± 4	25 ± 3	10 ± 3	10 ± 3	28 ± 5	34 ± 8	20 ± 3	22 ± 4	n=19 grazed, 15 ungrazed
	Frequency 1999 (F3)	51 ± 9	62 ± 6	38 ± 8	40 ± 8	73 ± 8	79 ± 8	55 ± 6	58 ± 6	n=19 grazed, 15 ungrazed
Alkali sacaton grass	*Cover 1999*	20 ± 5	12 ± 4	---	---	---	---	15 ± 4	12 ± 4	n=19 grazed, 15 ungrazed
	Frequency 1999 (F4)	66 ± 9	60 ± 12	---	---	---	---	61 ± 7	60 ± 12	n=11 grazed, 5 ungrazed
Galleta grass	*Cover 1999 2015*	**7 ± 2*** 8 ± 2	**13 ± 2*** 13 ± 4	---	---	---	---	**5 ± 2*** 6 ± 1	**12 ± 2*** 12 ± 4	n=14 grazed, 6 ungrazed
	Frequency 1999 (F4) 2015	**41 ± 7*** 43 ± 6	**64 ± 9*** 64 ± 10	---	---	---	---	**33 ± 6*** 34 ± 6	**61 ± 8*** 56 ± 11	n=14 grazed, 6 ungrazed
Three-awn grass	*Cover 1999*	1.2 ± 0.6	0.2 ± 0.2	8 ± 3	4 ± 2	4 ± 2	12 ± 6	4 ± 1	5 ± 2	n=19 grazed, 15 ungrazed
	Frequency 1999 (F4) 2015	**8 ± 2*** 0.6± 0.6	**4 ± 1*** 0.2 ± 0.2	71 ± 13	41 ± 14	39± 14	61 ± 22	36 ± 8	34 ± 10	n=19 grazed, 15 ungrazed
Sand dropseed	*Cover 1999 2015*	3 ± 2	2 ± 0	**8 ± 1*** **21 ± 3**	**5 ± 1*** **12 ± 3**	1 ± 1	3 ± 1	5 ± 1	2 ± 1	n=19 grazed, 15 ungrazed
	Frequency 1999 2015	39 ± 12 (F4)	34 ± 6 (F4)	**54 ±5**** **81 ±6**** (F3)	**28 ± 4**** **50 ± 7**** (F3)	29 ±12 (F4)	50 ± 15 (F4)	50 ± 9 (F4)	53 ± 6 (F4)	n=19 grazed, 15 ungrazed
Needle-and-thread grass	*Cover 1999 2015*	---	---	**0.6±.3*** 2 ± 1	**11 ± 5*** 2 ± 1	---	---	---	---	
	Frequency 2000 (F4) 2015	---	---	**9 ± 5*** 11 ± 3	**61 ± 18*** 25 ± 12	---	---	---	---	

		Greasewood[1]		Sandsage[2]		Shortgrass[3]		All habitats		
Species	**Measurement**	**Grazed**	**Ungrazed**	**Grazed**	**Ungrazed**	**Grazed**	**Ungrazed**	**Grazed**	**Ungrazed**	**Sample size for all habitats**
WEEDS AND BARE GROUND										
Russian thistle	*Frequency 1999* *(F4) 2015*	**5 ±2***** 24 ± 11	**25 ± 5***** 4 ± 2	34± 15 55 ±15	44 ± 16 72 ± 9	**8 ± 4*** 79 ± 7	**30 ± 14*** 64 ± 12	**14 ± 5**** 52 ± 8	**34 ± 7**** 47 ± 9	n=19 grazed, 15 ungrazed
Kochia	*Frequency 1999* *(F4) 2015*	**5 ± 4*** 0.7 ±0.5	**24 ± 5*** 0 ± 0	---	---	**.4±.2**** 0.3 ±0.2	**20 ± 13**** 0 ± 0	**3 ± 2***** 0.5 ± 0.3	**23± 6***** 0 ± 0	n=14 grazed, 9 ungrazed
Bare ground	*Cover 1999* *2015*	**28 ±2**** **30 ± 2***	**17 ± 2**** **20 ± 4***	---	---	42±3** 41±6	24 ± 4** 38 ± 3	35±3*** 36 ± 3	20 ±2*** 28 ± 4	n=14 grazed, 9 ungrazed

[1] n = 7 grazed; 5 ungrazed (Note: plot gw04ug was excluded from this analysis because it receives pass through grazing in the spring.)
[2] n = 5 grazed; 6 ungrazed
[3] n = 7 grazed; 4 ungrazed (Note: plots sg80ug and sg81ug were excluded from this analysis because they were not included in the 1999 sample)
F3 = 0.31 m x 0.31 m frequency plot size
F4 = 1 m x 1 m frequency plot size

Shrubs and succulents

Sandsage grows on well-drained sands and is the signature species in the sandsage shrubland habitat. Sandsage cover and density were higher in ungrazed plots than grazed plots at a nearly significant level (P=0.08) (Table 2). This difference between grazed and ungrazed plots, and that the differences were largely eliminated by 2003, indicates that cattle grazing increased sandsage (Fig. 11). For cover, the significant (P<0.02) grazing treatment by year interaction[1] also indicates sandsage is an increaser.

Rabbitbrush[2] is a long-lived and deep-rooted shrub and is generally considered to increase in cover with cattle grazing. It is primarily found as a co-dominant in the greasewood shrubland habitat and is occasionally found in shortgrass at low density and cover. Interestingly, the ungrazed plots show consistently higher cover and density of rabbitbrush than the grazed plots (Table 2, Fig. 12), the opposite of what would be predicted for an "increaser." Because the difference between grazed and ungrazed plots continues, 15 years after cessation of grazing, we assume that the difference cannot be attributed to grazing history.

Cholla[2] is found in both shortgrass and greasewood habitats and is generally absent from sandsage habitat as it has a preference for clay or loamy soils rather than sandy soils (Fig. 13). Cholla has been considered an increaser by some authors; however, our data show significantly higher cover and density of cholla in grazed plots than ungrazed plots (Table 2 and Fig. 13), indicating it is a decreaser. Cholla density increased by 56% in grazed areas vs. 13% in ungrazed areas, suggesting that cattle grazing suppressed cholla. It is possible that young cholla were eaten by cattle, thus the removal of cattle allowed cholla density to increase over time.

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[1] Grazing treatment by year interaction tests whether grazed plots are moving towards similarity with ungrazed plots.

[2] Plots gw19 and gw20 were excluded from the rabbitbrush and cholla analyses as a 2011 fire killed many of these shrubs in these plots. See section on fire for discussion.

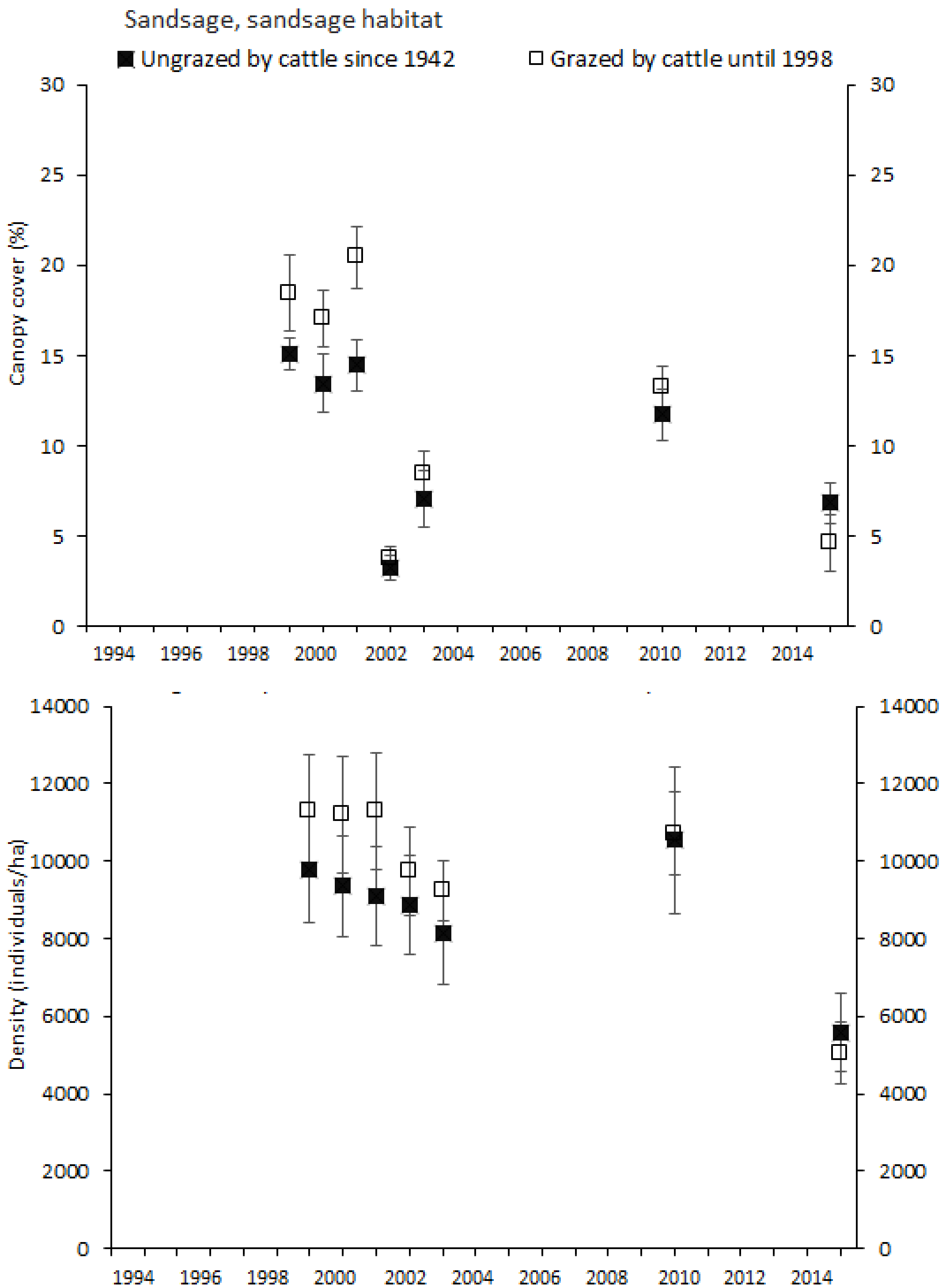

Figure 11. Sandsage mean cover and density (± 1 SE), grazed vs ungrazed, 1999-2015 (n=5 grazed and 6 ungrazed). Sandsage exhibited a slight difference between grazed and ungrazed plots at the beginning of this study (P=0.08); by 2010 there was no difference between grazed/ungrazed. The grazing by year interaction for cover was significant (P<0.02).

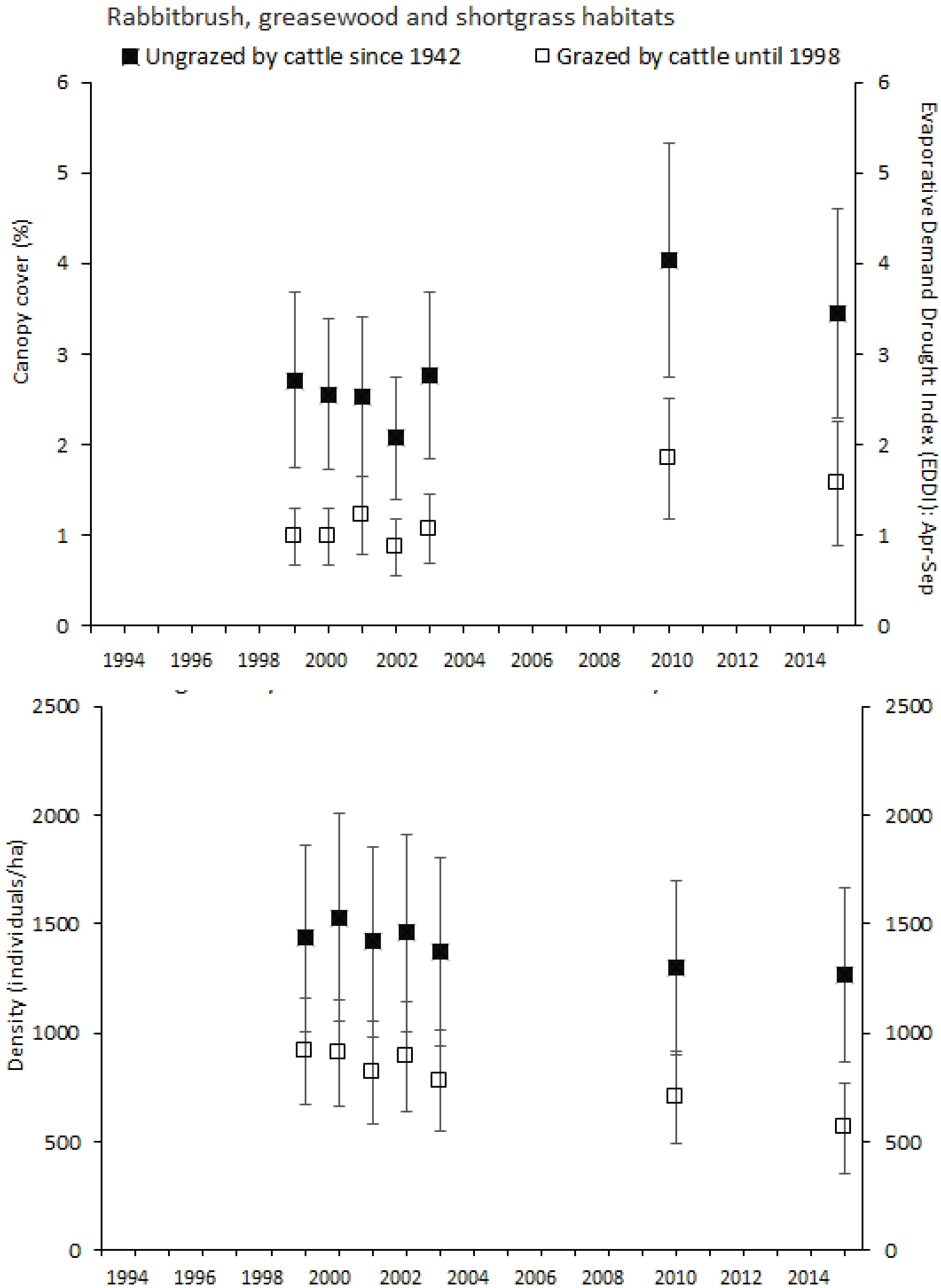

Figure 12. Rabbitbrush mean cover and density (± 1 SE) in greasewood and shortgrass habitats combined, grazed vs ungrazed, 1999-2015 (n=12 grazed and 9 ungrazed). Rabbitbrush cover showed a nearly significant difference between grazed and ungrazed plots in 1999.

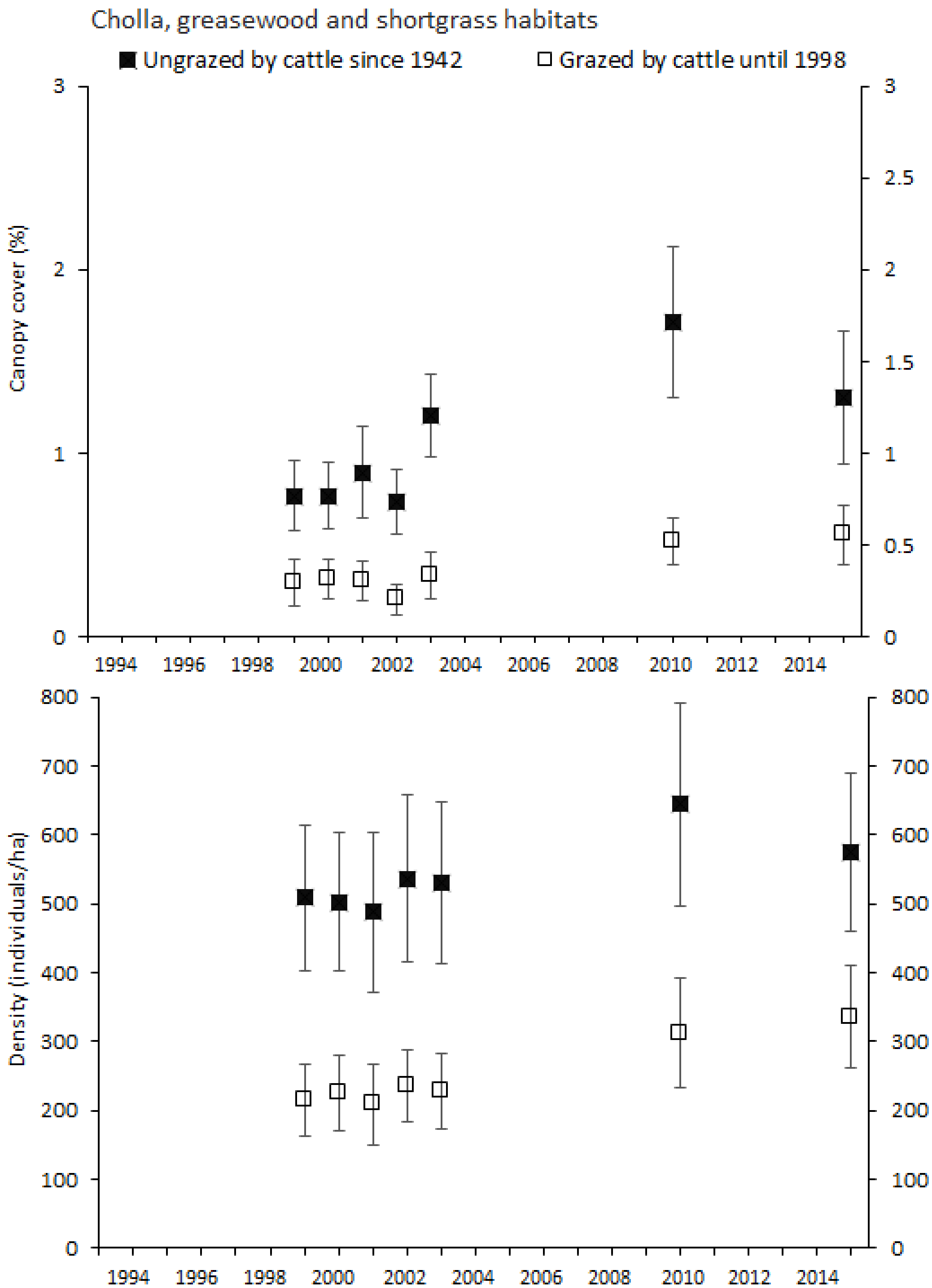

Figure 13. Cholla mean cover and density (± 1 SE) in greasewood and shortgrass habitats combined, grazed vs ungrazed, 1999-2015 (n=12 grazed and 9 ungrazed). Cholla showed significantly higher cover and density in ungrazed plots relative to grazed plots indicating that cattle grazing may have suppressed cholla.

Prickly pear cactus is relatively frequent in all habitat types, but cover is generally low (Fig. 14). It 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. 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. 14).

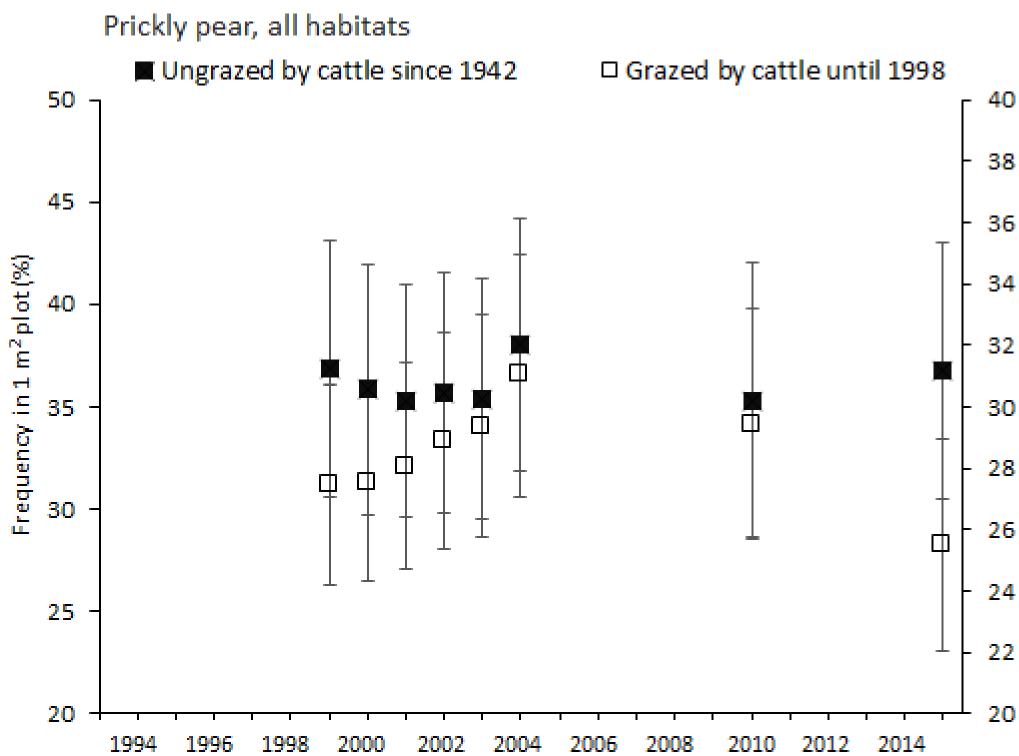

Figure 14. Prickly pear mean frequency (± 1 SE) in all habitats combined, grazed vs ungrazed, 1999-2015 (n=19 grazed and 15 ungrazed). Prickly pear did not exhibit a difference between grazed and ungrazed plots. The prickly pear population was relatively stable throughout the course of the study.

Grasses

The dominant grasses at PCD are blue grama, alkali sacaton grass, galleta grass, three-awn grass, sand dropseed, and needle-and-thread grass. Table 3 summarizes cover and frequency for these grasses for each habitat in 1999 and in some cases 2015, and compares grazed plots and ungrazed plots. Blue grama and alkali sacaton grass 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 species that had significant differences between grazed and ungrazed plots are discussed below.

Galleta grass. Galleta grass prefers silty clay loamy soils and was common in all greasewood plots and in 61% (8) of the shortgrass plots. The greasewood plots and 8 shortgrass plots combined had significantly higher galleta grass cover ($P \leq 0.05$) and frequency ($P \leq 0.05$) in ungrazed plots verses grazed plots in 1999 (Table 3 and Fig. 15). This indicates that galleta grass is a decreaser, that is, it decreases with grazing. However, the grazing treatment by year interaction was not significant and the 1999 and 2015 metrics are nearly identical indicating that galleta grass is not responding as a decreaser or an increaser.

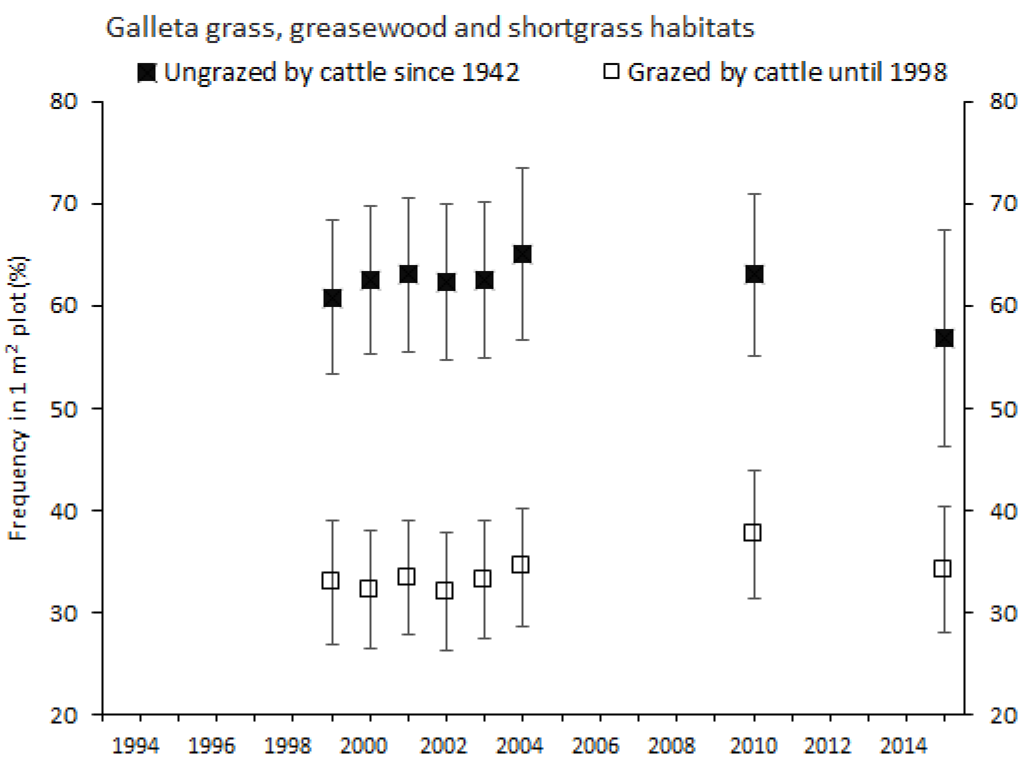

Figure 15. Galleta grass mean frequency (± 1 SE) in all greasewood plots (12) and 8 shortgrass plots, grazed vs ungrazed,1999-2015 (n=14 grazed and 6 ungrazed). Shortgrass plots that did not have >10% frequency were eliminated, these were all grazed plots. The difference between grazed and ungrazed plots in 1999 (P=0.02) continued through 2015.

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 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 (Table 3). The greasewood habitat was the only habitat that supported the "increaser" characterization as it had significantly higher frequency in grazed plots versus ungrazed ($P \leq 0.05$). Additionally, there was a grazing treatment by year interaction ($P \leq 0.05$) which indicates that the grazed plots were moving towards similarity with ungrazed plots (Fig. 16). 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, Fig. 17). Though there was no significant difference between grazed and ungrazed plots in the shortgrass habitat, when we analyze the same dataset using prairie dogs as the grazer we see significantly higher cover and frequency on vs off prairie dog towns (see prairie dog

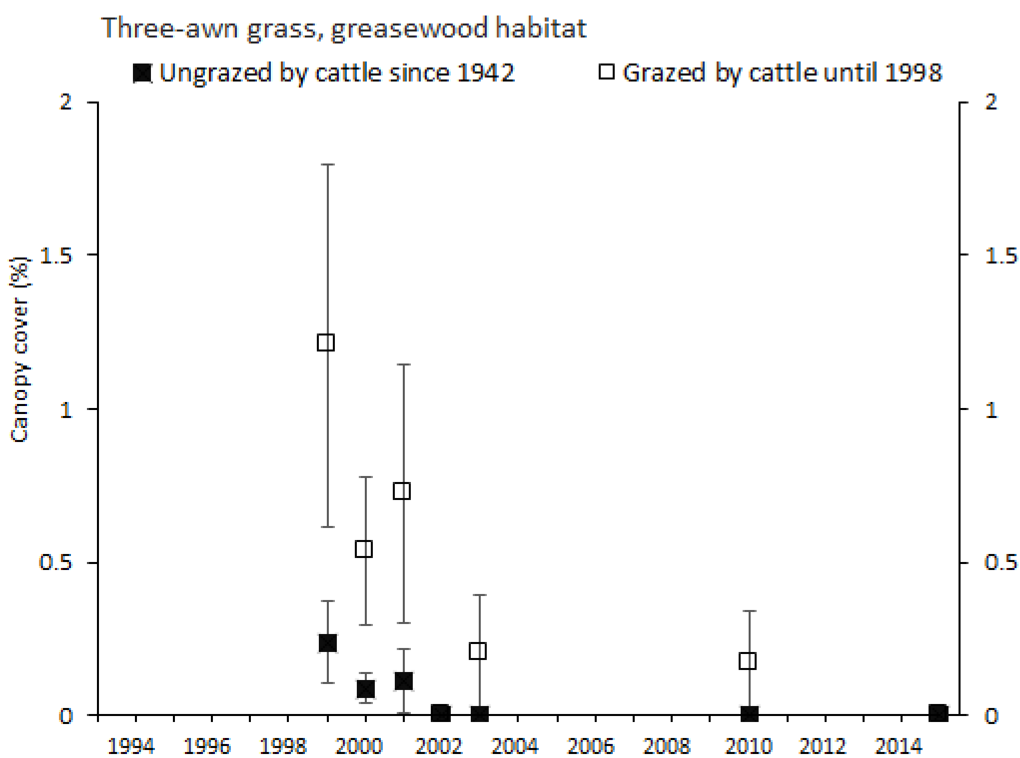

Figure 16. Three-awn grass mean frequency (± 1 SE) in greasewood habitat, grazed vs ungrazed, 1999-2015 (n=7 grazed and 5 ungrazed). The significant difference between grazed and ungrazed noted in 1999 was gone by 2003 and three-awn was almost absent in 2015.

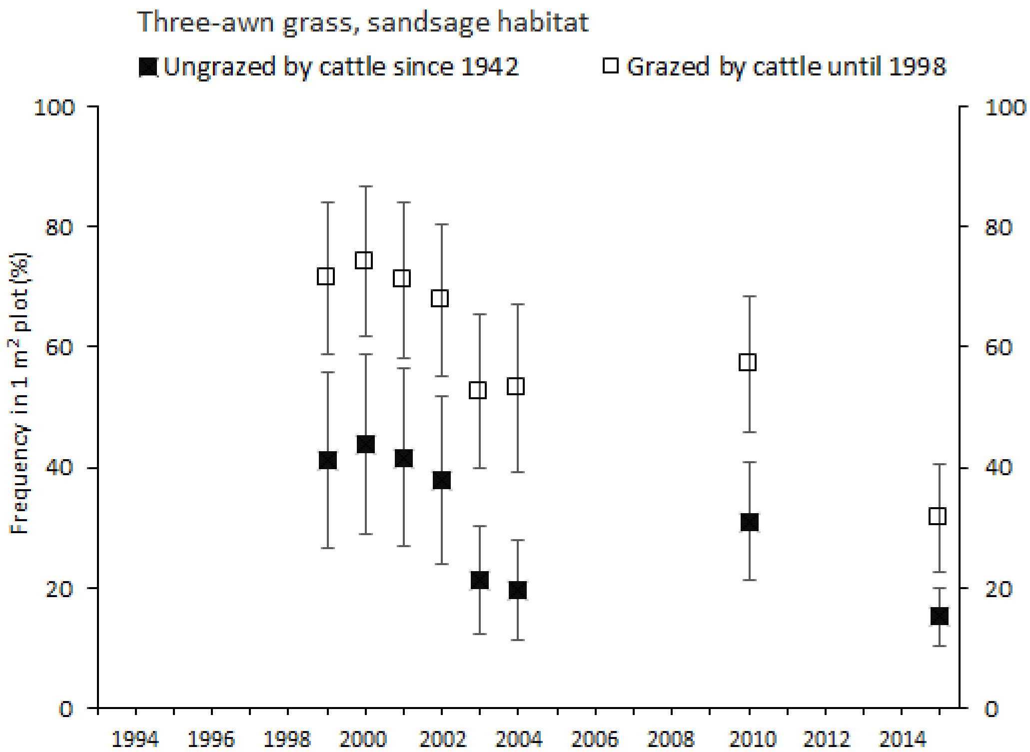

Figure 17. Three-awn grass mean frequency (± 1 SE) in sandsage habitat, grazed vs ungrazed, 1999-2015 (n=5 grazed and 6 ungrazed).

section). There was a marked downward trend in three-awn grass over time, regardless of grazing type, likely a result of extended drought conditions (see drought section).

Sand dropseed. Sand dropseed is a short-lived perennial bunch grass; it is considered an increaser and is well suited to disturbance. It is frequent in all habitat types but seldom reaches high cover, except in the sandsage habitat (Table 3, Fig. 18). The only habitat where sand dropseed was a notable increaser was in sandsage where grazed plots had significantly higher frequency ($P \leq 0.001$) and cover ($P \leq 0.05$) than ungrazed plots (Fig. 18). 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). When all habitats were combined there was no difference between grazed and ungrazed plots (Table 3, Fig. 19). The increase in cover and frequency in 2015 is likely related to climate conditions (very wet March 2015) and will be discussed in the extended drought section of this report.

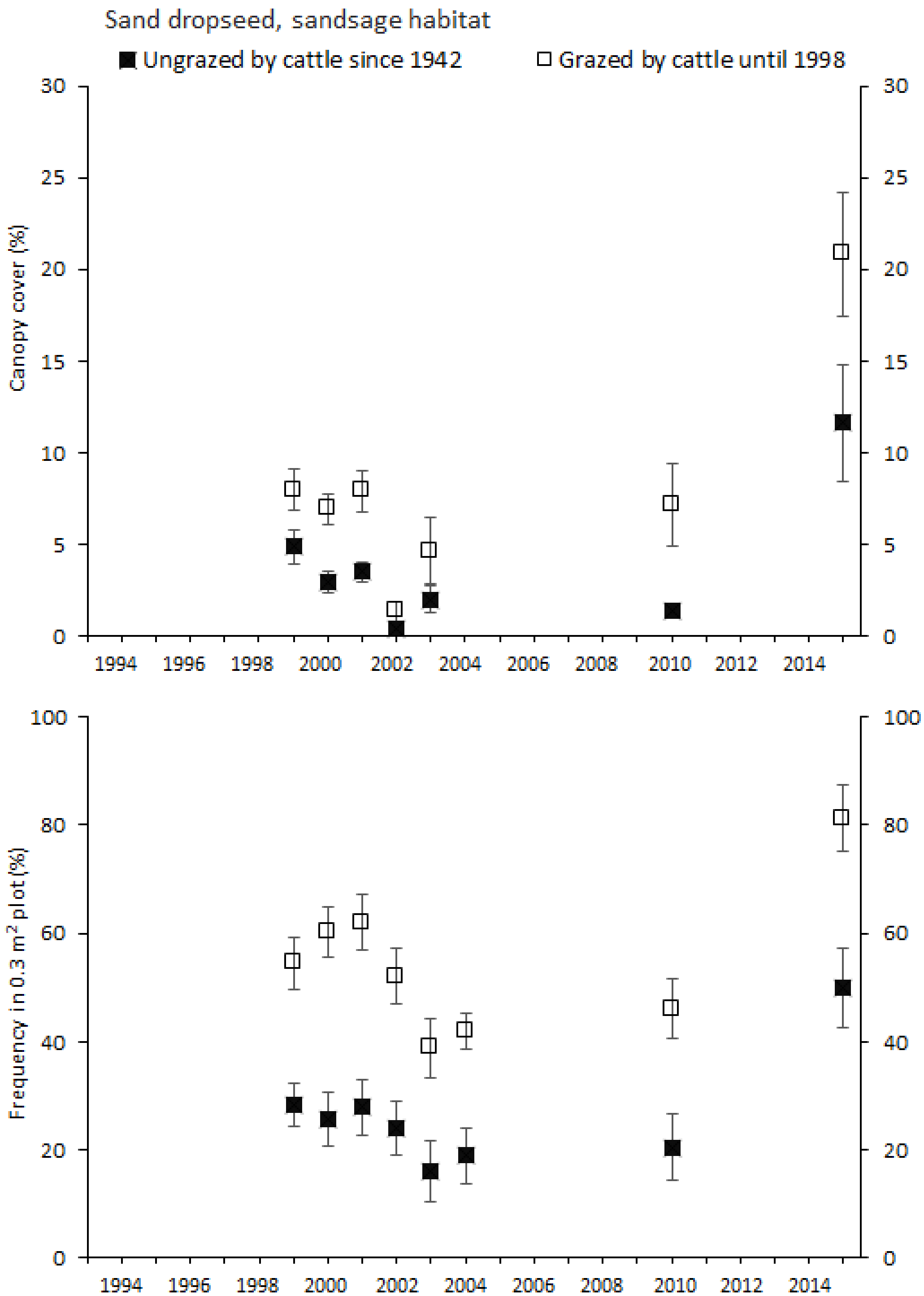

Figure 18. Sand dropseed mean cover and frequency (± 1 SE) in sandsage habitat, grazed vs ungrazed, 1999-2015 (n=5 grazed and 6 ungrazed). There was a significant difference between grazed and ungrazed at the beginning of the study and this difference was still evident in 2015 (in 2015 P=0.07 for cover and P=0.01 for F3 for grazed vs ungrazed *t*-test).

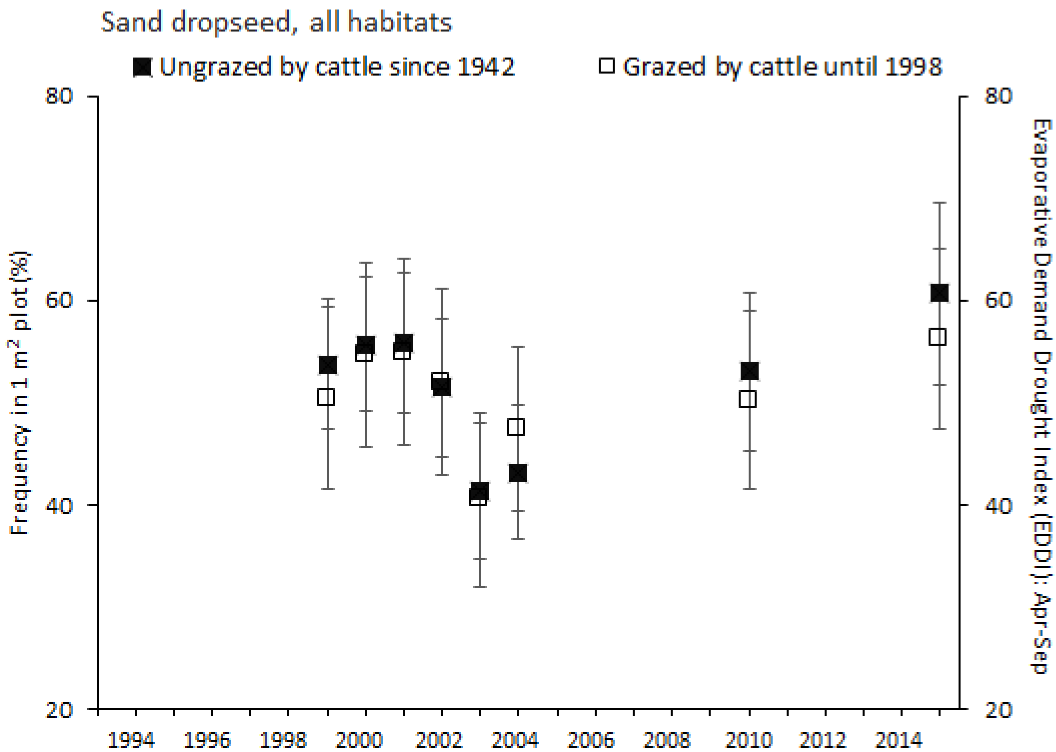

Figure 19. Sand dropseed frequency (± 1 SE) in all habitats combined, grazed vs ungrazed, 1999-2015 (n=19 grazed and 15 ungrazed). There was no significant difference between grazed and ungrazed plots.

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 ($P \leq 0.05$) (Table 3, Fig. 20). Once cattle were removed, the grazed plots slowly gained cover and frequency; there was a significant year by grazing treatment interaction ($P=0.003$, 0.003, 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 2000 to 25% in 2010 (Fig. 20). By 2015 the cover and frequency of needle-and-thread decreased dramatically, likely in response to extended drought.

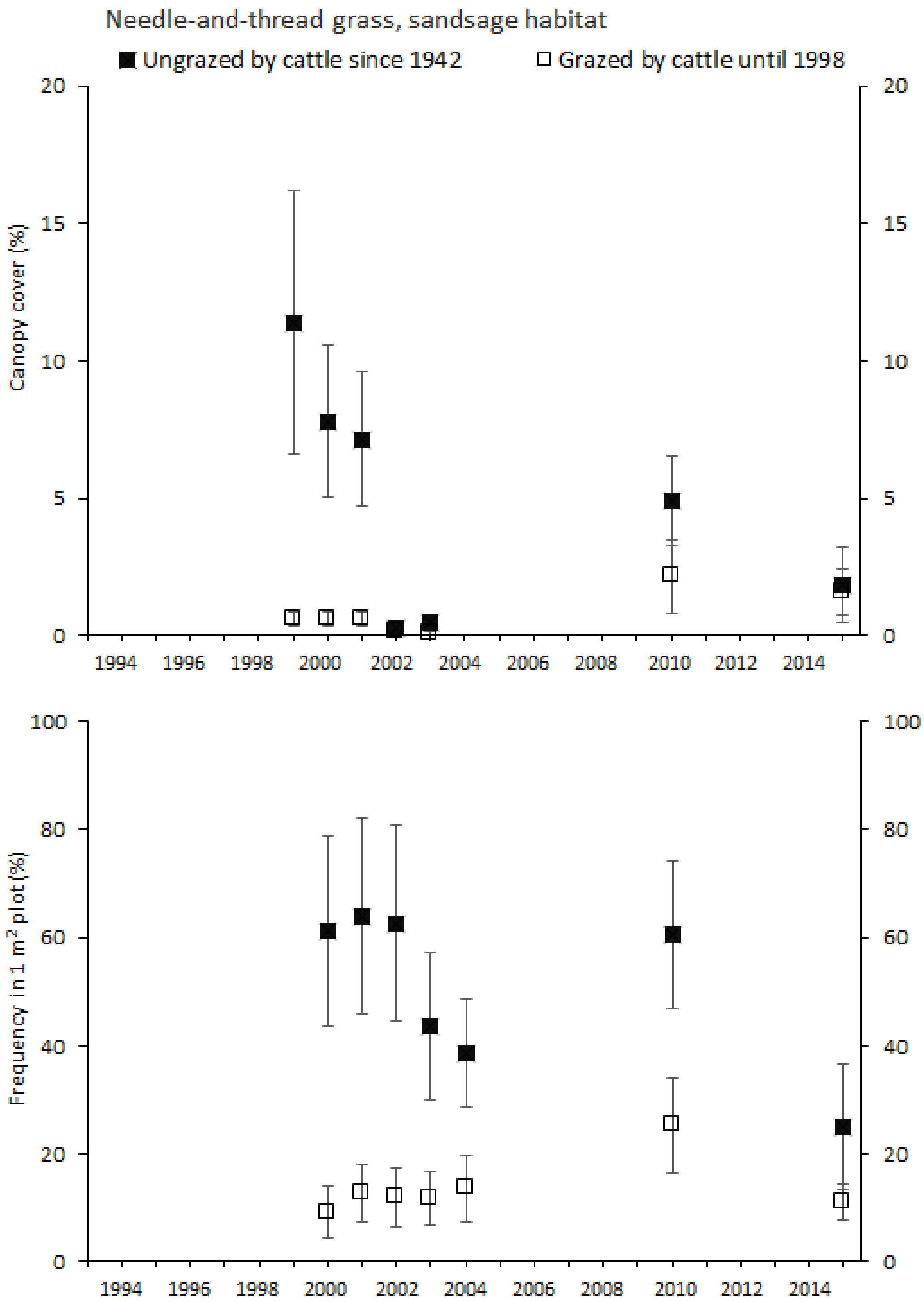

Figure 20. Needle-and-thread grass mean cover (1999-2015) and frequency (2000-2015) (± 1 SE) in sandsage habitat, grazed vs ungrazed, (n=5 grazed and 6 ungrazed). There was a significant difference between grazed and ungrazed plots at the beginning of the study (P=0.03) and by 2010 this difference was diminished. There was a grazing by year interaction (P=0.003).

Weeds

Kochia and Russian thistle are two non-native annual forbs monitored at PCD. In 1999, grazed plots had significantly lower frequency of kochia and Russian thistle than ungrazed plots (Fig. 21). These results indicate that grazing suppressed the weeds. Suppression of weeds by grazing was demonstrated in a study by Milchunas et al. (1992). They seeded kochia and Russian thistle on shortgrass prairie and found higher rates of seedling establishment and survival on long-term ungrazed sites relative to long-term grazed sites, with or without current year grazing.

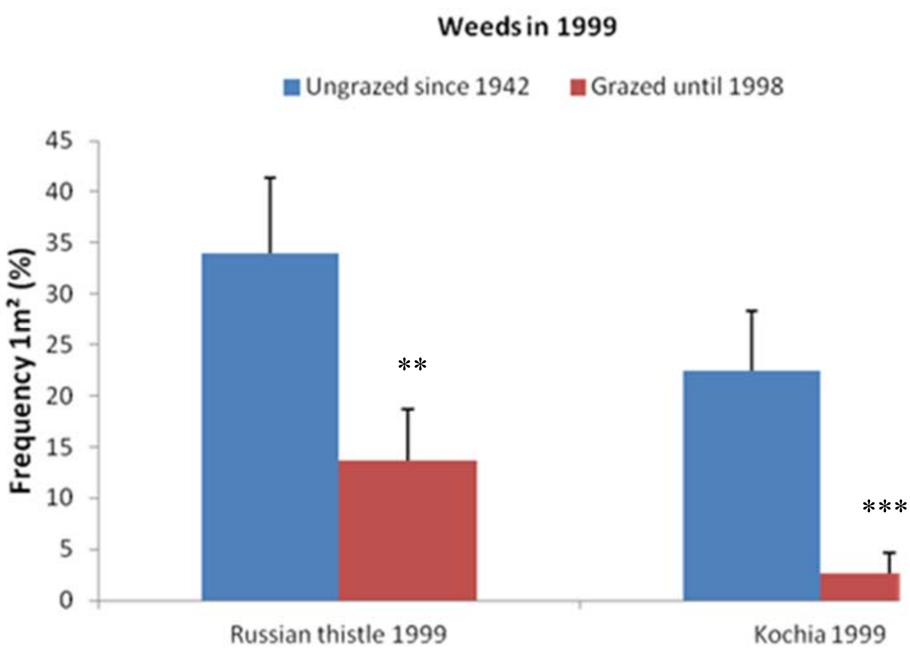

Figure 21. Russian thistle and kochia mean frequency (+ 1 SE) in 1999 (n=19 grazed and 15 ungrazed for Russian thistle; n= 14 grazed and 9 ungrazed for kochia). At the beginning of the study there was a significant difference for Russian thistle (P≤0.01) and and kochia (P≤0.001) between grazed and ungrazed plots. By 2015 there was no longer any significant difference between grazed/ungrazed plots.

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 (Fig. 22). Kochia was much less widespread in 2010 and was virtually non-existent in 2015.

In greasewood plots, frequency of kochia was significantly higher in ungrazed plots than grazed plots in 1999 ($P \leq 0.01$); this difference was still evident in 2004 ($P \leq 0.05$) (Fig 22). This pattern indicates kochia decreases with grazing. The ability to analyze kochia for grazed/ungrazed treatment within the shortgrass prairie is confounded by the presence/absence of prairie dogs (see prairie dog section). It is surprising that kochia was hardly present in 2015, given the wet spring.

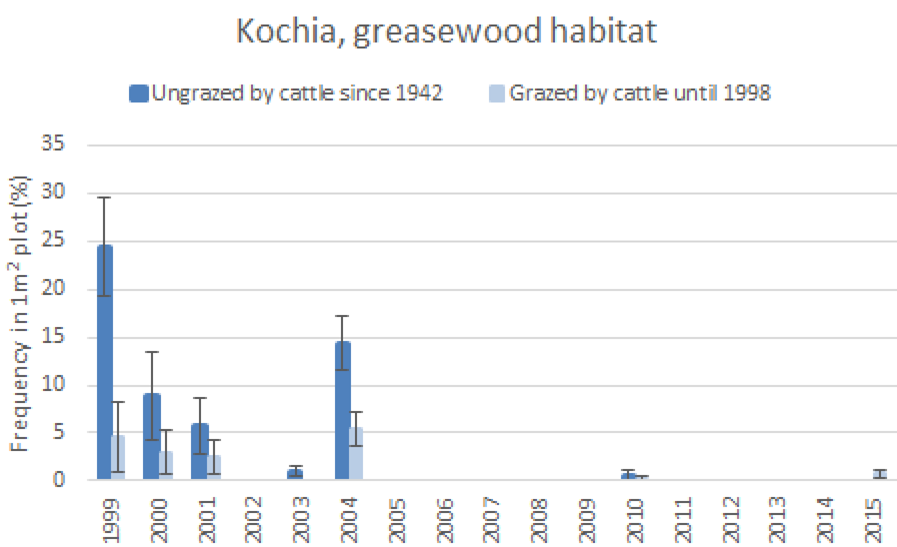

Figure 22. Kochia mean frequency (± 1 SE) in greasewood plots, grazed vs ungrazed, 1999-2015 (n=7 grazed and 5 ungrazed).

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 PCD habitat types. It was not detected in the extreme drought year 2002 but did extremely well in 2004 and 2015, the years with abundant spring precipitation (Fig. 23). There was significantly higher frequency of Russian thistle in ungrazed plots than grazed plots in 1999 ($P \leq 0.01$, Table 3), indicating Russian thistle decreases with cattle grazing. Due to the complicating factor of prairie dogs in the shortgrass prairie, we decided to remove shortgrass habitat from the trend analysis. Analysis of the greasewood and sandsage habitat data shows there was still a pronounced difference between grazed and ungrazed plots in 2004, however, by 2010 there was no longer a difference (Fig. 23).

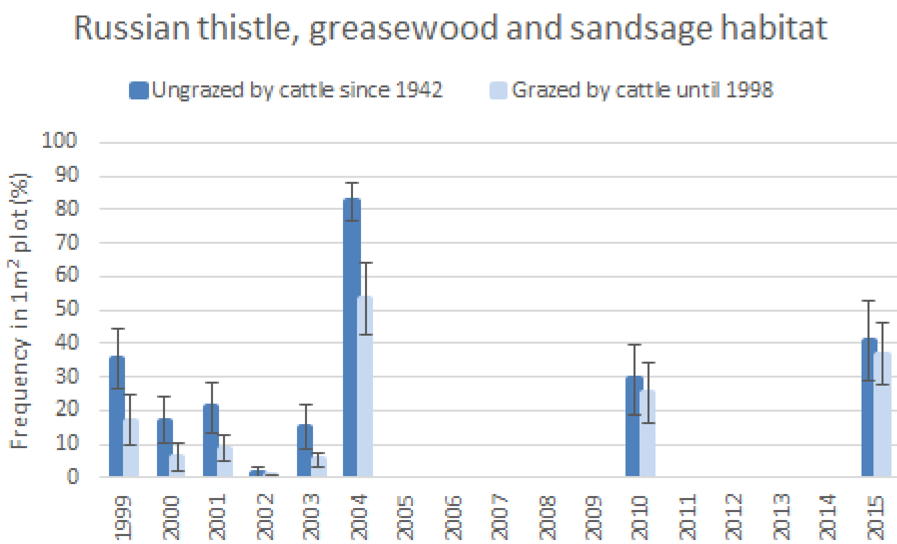

Figure 23. Russian thistle mean frequency (± 1 SE) in greasewood and sandsage habitats combined, grazed vs ungrazed, 1999-2015 (n=12 grazed and 11 ungrazed). Formerly grazed plots gained Russian thistle at a higher rate than the ungrazed plots.

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, bare ground is reported 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 ($P \le 0.01$) (Fig. 24). There was a grazing treatment by year interaction ($P \le 0.05$) 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 ($P \le 0.01$) (Fig. 24). Unlike the greasewood plots, there was no significant grazing treatment by year interaction in the shortgrass plots.

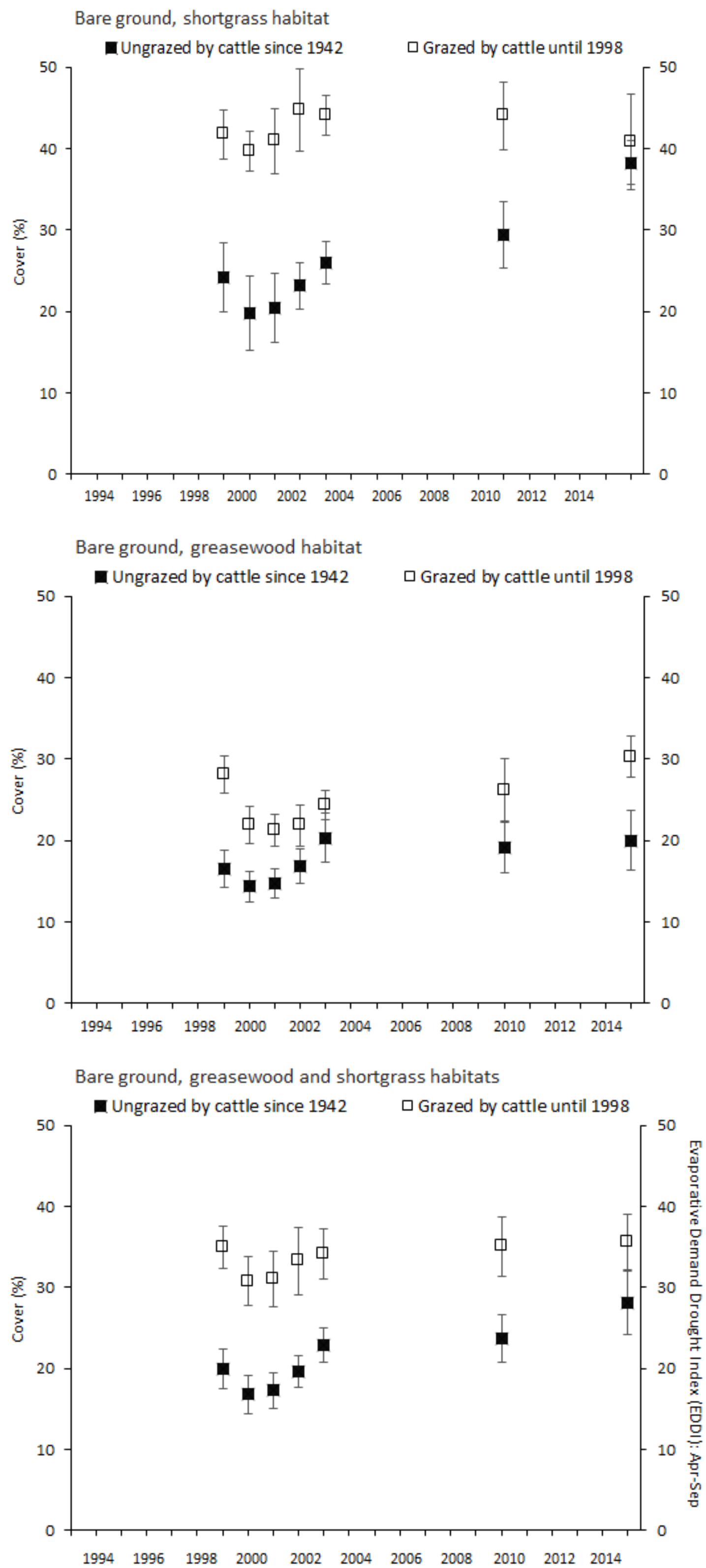

Figure 24. Bare ground mean cover (± 1 SE) in shortgrass (n=7g, 4 ug), greasewood (n=7g, 5ug), and greasewood and shortgrass plots, grazed vs ungrazed, 1999-2015 (n=14g, 9 ug). There was a significant difference between grazed and ungrazed plots at the beginning of this study (P≤0.001).

Extended Drought

Many of the years of this monitoring study (1999-2015) can be described as drought years or abnormally dry years. The evaporative demand drought index (EDDI) shows wet years from 1995 through 1999, moderate to high drought years for 2000 through 2013 (with the exception of 2007), and wet years for 2014 and 2015 (Fig. 6). Temperature records indicate the years 1934, 2002, and 2012 had the highest average growing season (April-September) temperature during the 120 year period of record for the lower Arkansas (Fig. 3). The temperatures at the Pueblo airport for our study period had 2012 as the hottest year (also 61% below average April-September precipitation), and the last 6 years 2010-2015 had above average temperatures (Fig. 25). In addition, the daily temperature variability over the past 60 years or so, has increased for the area (Pueblo airport data). Difference between daily low and high temperature are 1-2°F more now than in the period 1960-1990 (Fig. 26). Precipitation data show the years 2002, 2011, and 2012 as the lowest rainfall years (Fig. 25). The drought index, temperature, and precipitation data indicate 2002, and the general period of 2010 through 2012, as the most severe drought periods at PCD.

Other years stand out as wet years. During the period of monitoring, the years 1999 and 2015 had the highest annual precipitation (Fig. 5). In addition, the years 2004 and 2015 had exceptionally high spring precipitation. During April 2004, 4.4 inches of precipitation fell and during May 2015, 5.5 inches of precipitation fell; these amounts are about four times higher than the average monthly rainfall (Table 1).

In an effort to understand the connection between climate and what we see in the field we plotted the vegetation data simultaneously with the drought index (EDDI). Changes in vegetative cover, density, and frequency can be easily compared with the drought index. In this section we discuss all the monitored plant species with an emphasis on those showing a strong signal with climate.

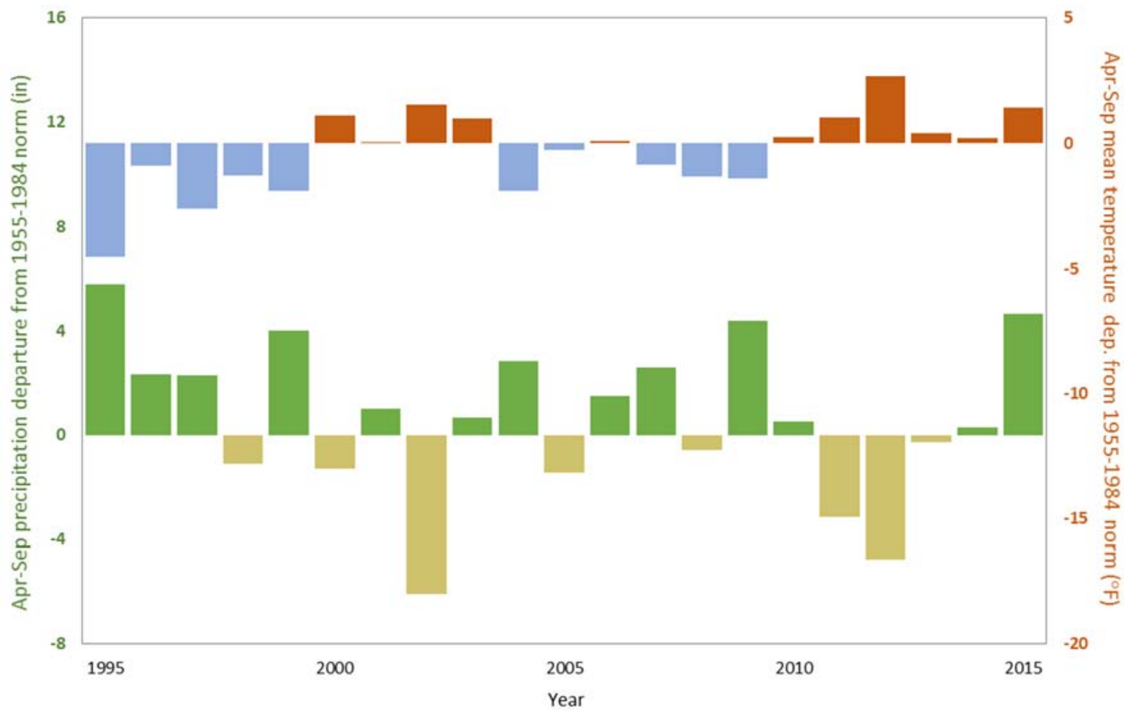

Figure 25. Departure from 1955-1884 average growing season (April-September) precipitation and temperature at Pueblo Airport WSO. The 30-year period (1955-1984) average temperature and precipitation are 66.7°F and 8.44 inches, respectively.

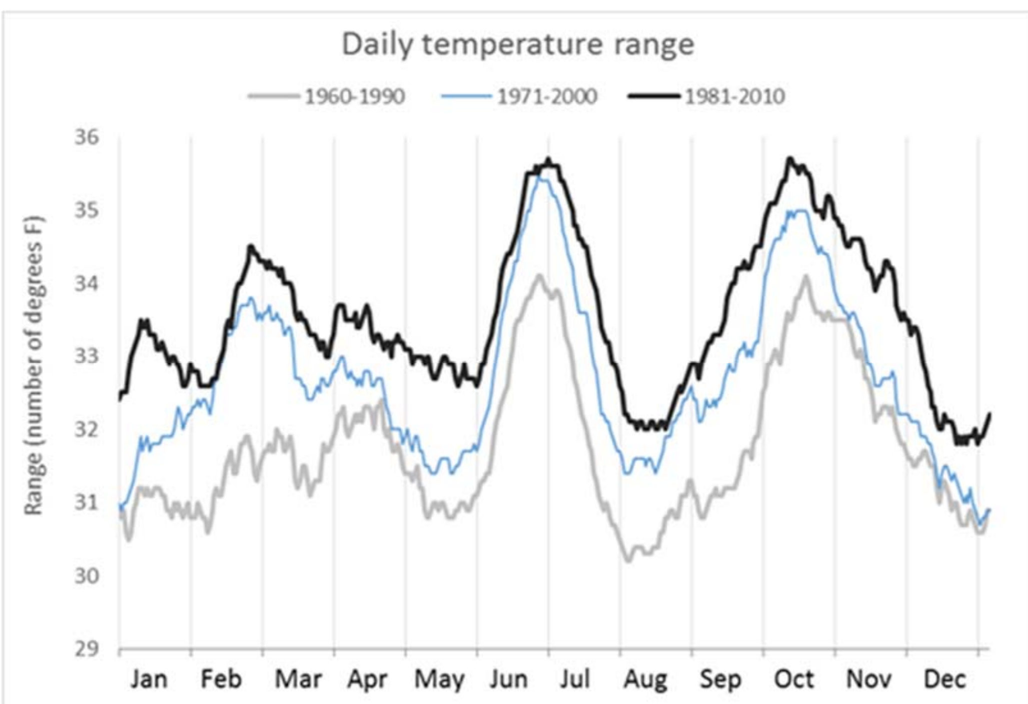

Figure 26. Daily temperature range at the Pueblo Airport WSO. Differences are due to cooler nights in most seasons and a tendency for warmer daytime temperatures.

Shrubs and succulents

Greasewood, rabbitbrush, cholla, sandsage, and prickly pear are the dominant shrubs and succulents at PCD. Over the course of the study total shrub cover has ranged from about 7 to 11% in the greasewood habitat, (Figs. 27 and D-1) and 3 to 17% in the sandsage habitat (Fig D-2), and has remained less than 1% in the shortgrass habitat (Figs. D-3 and D-5).

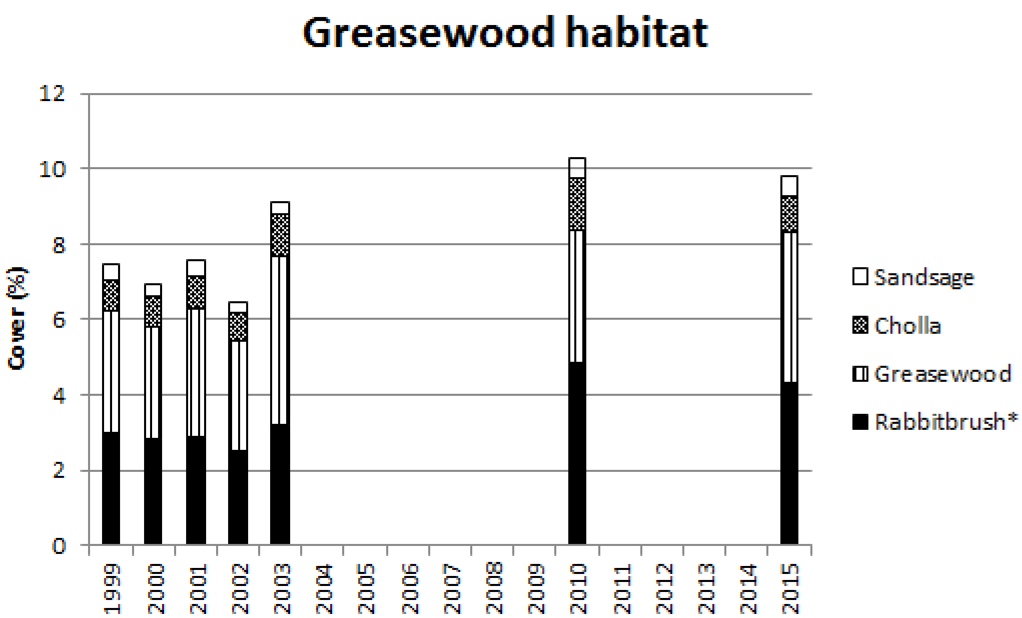

Figure 27. Total shrub cover in greasewood plots, 1999-2015 (n=11). Consistent trends among plots in slope for the period 1999-2015 were tested against a null hypothesis of equal ranks of negative and positive slopes using a Wilcoxon signed-ranked test; *P<0.05.

Changes over time are summarized in Table 4.

Table 4. Mean cover, density, and frequency (± 1 SE) of shrubs and non-shrubs in greasewood, sandsage, and shortgrass habitats in 1999 and 2015. Wilcoxon sign-ranked tests were used to test for significance of trend through years. Bolded entries exhibit significant trend from 1999 to 2015 (*P≤0.05, **P≤0.01, ***P≤0.001).

		Greasewood[1]		Sandsage[2]		Shortgrass[3]		All habitats		
Species	**Measurement**	**1999**	**2015**	**1999**	**2015**	**1999**	**2015**	**1999**	**2015**	**Sample size for all habitats**
SHRUBS AND SUCCULENTS										
Total shrubs	*Cover (%)*	8 ± 0.9	10 ± 1	---	---	**0.6 ± 0.3***	**1 ± 0.3***	---	---	
	Density (#/ha)	3600 ± 350	3700 ± 450	---	---	680 ± 210	440 ± 93	---	---	
Greasewood	*Cover (%)*	3 ± 0.5	4 ± 0.6	---	---	---	---	---	---	
	Density (#/ha)	**1200 ± 120***	**1400 ± 140***	---	---	---	---	---	---	
Rabbitbrush	*Cover (%)*	**3 ± 0.7***	**4 ± 0.9***	---	---	0.4 ± 0.2	0.3 ± 0.2	1.7± 0.5	2.3 ± 0.6	n=22
	Density (#/ha)	**1800 ± 280***	**1500 ± 290***	---	---	**450 ± 210****	**170 ± 90****	**1100 ± 220****	**840 ± 200****	n=22
Cholla	*Cover (%)*	0.8 ± 0.2	1 ± 0.2	---	---	0.2 ±0.08	0.9 ± 0.3	**0.5 ± 0.1***	**0.9 ± 0.2***	n=22
	Density (#/ha)	500 ± 85	620 ± 94	---	---	190 ± 50	280 ± 60	**350 ± 60***	**450 ± 70***	n=22
Sandsage	*Cover (%)*	0.4 ± 0.2	0.5 ± 0.3	**17 ± 1 *****	**6 ± 1*****	---	---	---	---	
	Density (#/ha)	130 ± 58	290 ± 130	**10000 ± 980 *****	**5300 ± 620*****	---	---	---	---	
Prickly pear	*Frequency (%) (F4)*	38 ± 5	35 ± 4	30 ± 7	37 ± 9	**35 ± 9****	**25 ± 7****	34 ± 4	32 ± 4	n=35

		Greasewood[1]		Sandsage[2]		Shortgrass[3]		All habitats		
Species	**Measurement**	**1999**	**2015**	**1999**	**2015**	**1999**	**2015**	**1999**	**2015**	**Sample size for all habitats**
GRASSES										
Total grass	*Cover (%)*	**52 ± 1***	**43 ± 2***	29 ± 3	28 ± 3	**45 ± 3***	**24 ± 4***	**42 ± 2***	**32 ±2***	n=35
Blue grama	*Cover (%)*	**24 ± 3***	**14 ± 2***	10 ± 2	9 ± 2	**30 ± 4**	**12 ± 3**	**22 ± 2***	**11 ± 1***	n=35
	Frequency (%) (F3)	**56 ± 5***	**38 ± 5***	**39 ± 5**	**27 ± 5**	**75 ± 5***	**41 ± 5***	**57 ± 4***	**35 ± 3***	n=35
Alkali sacaton grass	*Cover (%)*	16 ± 3	18 ± 3	---	---	3 ± 2	5 ± 2	14 ± 3	16 ± 3	n=17
	Frequency (%) (F4)	62 ± 6	68 ± 7	---	---	20 ± 9	22 ± 10	60 ± 6	66 ± 6	n=17
Galleta grass	*Cover (%)*	9 ± 2	9 ± 2	---	---	3 ± 1	4 ± 1	7 ± 1	8 ± 2	n=21
	Frequency (%) (F4)	47 ± 7	48 ± 7	---	---	20 ± 7	18 ± 7	39 ± 6	39 ± 6	n=21
Three-awn grass	*Cover (%)*	**0.7 ± 0.3***	**0 ± 0***	**6 ± 2**	**2 ± 0.7**	**7 ± 3**	**2 ± 1**	**4 ± 1***	**1 ± 0.4***	n=35
	Frequency (%) (F4)	**6 ± 1**	**0.5 ±0.3**	**55 ± 10**	**23 ± 5**	**47 ± 12***	**18 ± 9***	**34 ± 6***	**13 ± 3***	n=35
Sand dropseed	*Cover (%)*	2 ± 0.9	2 ± 0.8	6 ± 0.9	16 ± 3	2 ± 0.7	3 ± 0.9	4 ± 0.8	7 ± 1	n=35
	Frequency (%)	34 ± 7 (F4)	33 ± 7 (F4)	40 ± 5 (F3)	64 ± 7 (F3)	36 ± 9 (F4)	50 ± 11 (F4)	50 ± 6 (F4)	57 ± 6 (F4)	n=35
Needle-and-thread grass	*Cover (%)*	---	---	6 ± 3	2 ± 0.8	---	---	---	---	
	Frequency (%) (F4)	---	---	38 ± 13 (year 2000)	19 ± 7	---	---	---	---	

		Greasewood[1]		Sandsage[2]		Shortgrass[3]		All habitats		
Species	**Measurement**	**1999**	**2015**	**1999**	**2015**	**1999**	**2015**	**1999**	**2015**	**Sample size for all habitats**
WEEDS AND BARE GROUND										
Russian thistle	*Frequency (%) (F4)*	13 ± 3	15 ± 6	40 ± 11	64 ± 8	16 ± 6	73 ± 6	22 ± 5	51 ± 6	n=35
Kochia	*Frequency (%) (F4)*	13 ± 4	0.4 ± 0.3	---	---	8 ± 5	0.2 ± 0.1	11 ± 3	7 ± 5	n=24
Bare ground	*Cover (%)*	25 ± 2	26 ± 2	---	---	35 ± 4	40 ± 4	30 ± 2	33 ± 2	n=24

[1] n = 13 for all species except total shrubs, rabbitbrush, and cholla. n=11 for total shrubs, rabbitbrush, and cholla (gw19 and gw20 excluded due to shrub losses related to 2011 fire)
[2] n = 11
[3] n = 11 (Note: sg80 and sg81 were excluded from this analysis because they were not included in the 1999 sample)
F3 = 0.31 m x 0.31 m frequency plot size
F4 = 1 m x 1 m frequency plot size
--- = not analyzed or species does not occur within habitat

Greasewood. Greasewood is a long-lived and deep-rooted shrub that prefers swales with access to groundwater (Fig. 28). At PCD it is primarily found along Boone Creek and it is often co-dominant with rabbitbrush. Greasewood apparently tolerates drought quite well as it has maintained its cover and density through the course of the study (Fig. 29). It reached its highest cover in 2003, one year after the extreme drought, and reached its highest density in 2015. Plants affected by drought would be expected to lose cover and density, especially following successive years with high drought index values, such as 2010-2012 (Fig 29).

Figure 28. Greasewood at plot gw10, 2015.

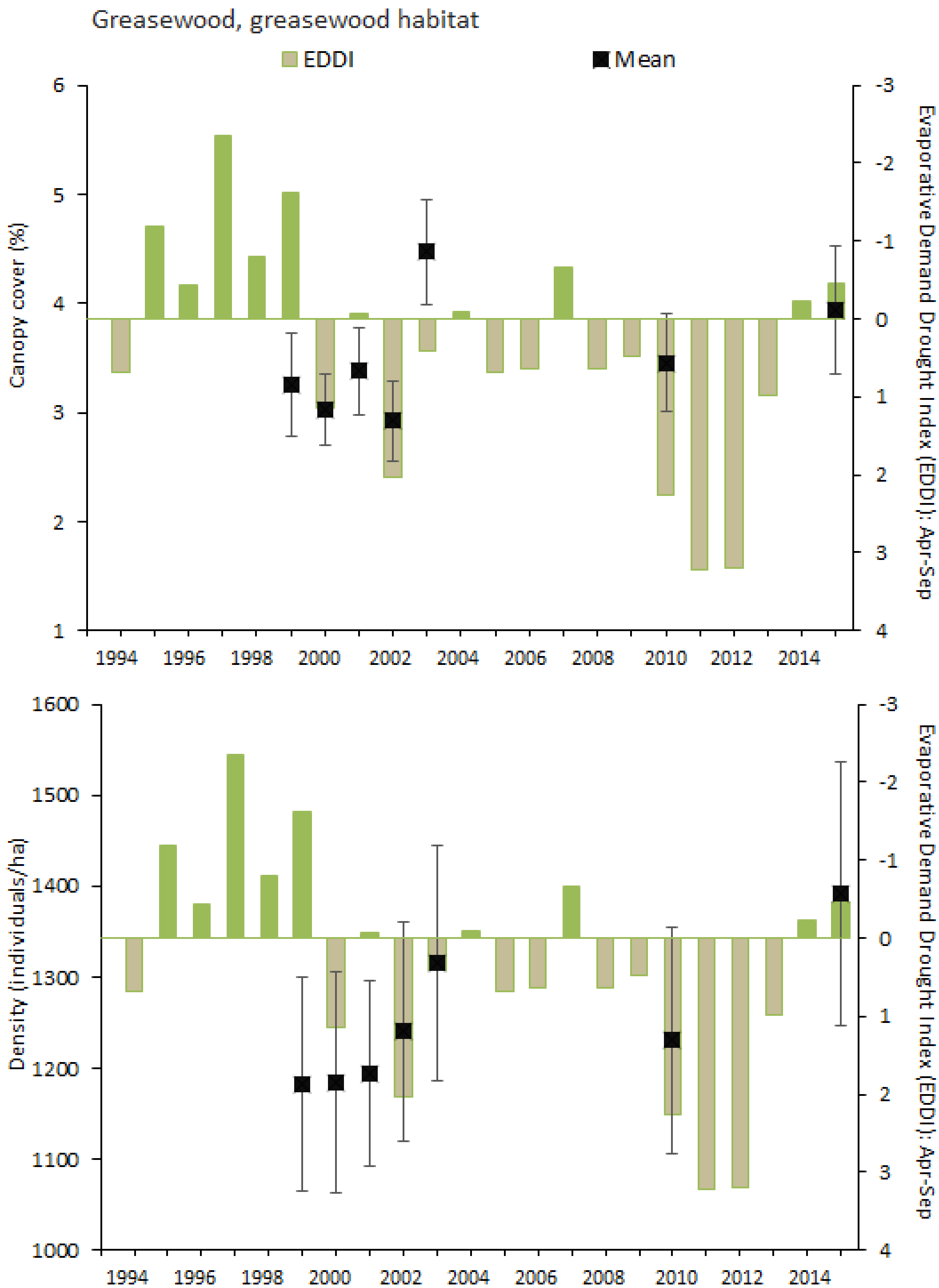

Figure 29. Greasewood mean cover and density (± 1 SE), 1999-2015 (n=13). The highest cover was in 2003, one year after the extreme drought year 2002. The increase in density between 1999 and 2015 was statistically significant (P≤0.05).

Rabbitbrush. Rabbitbrush is also a long-lived and deeply-rooted shrub; it grows in clay and loam soils at PCD (Fig. 30). It is primarily found as a co-dominant in the greasewood shrubland habitat and is occasionally found in shortgrass at low density and cover. The rabbitbrush cover in greasewood habitat increased from 3.0% to 4.3% (P≤0.05) between 1999 and 2015. For shortgrass and greasewood habitats combined the cover increased by 40% from 1.7% to 2.3%. The density slightly decreased in both greasewood (P≤0.05) and shortgrass (P≤0.01) habitats between 1999 and 2015 (Fig. 31). This combination indicates that drought most likely killed some individuals and that other plants have enlarged; well-established plants may access moisture effectively enough to grow during droughts. Greasewood plots gw19 and gw20 burned in 2011 and were removed from this drought analysis as there was a high mortality rate of rabbitbrush and cholla, and very little recovery as of 2015 (see fire section for more discussion).

Figure 30. Rabbitbrush at plot gw05, 2002 (top) and 2015 (bottom). Rabbitbrush cover at gw05 increased from 3% to 6% between 2002 and 2015 while density remained constant.

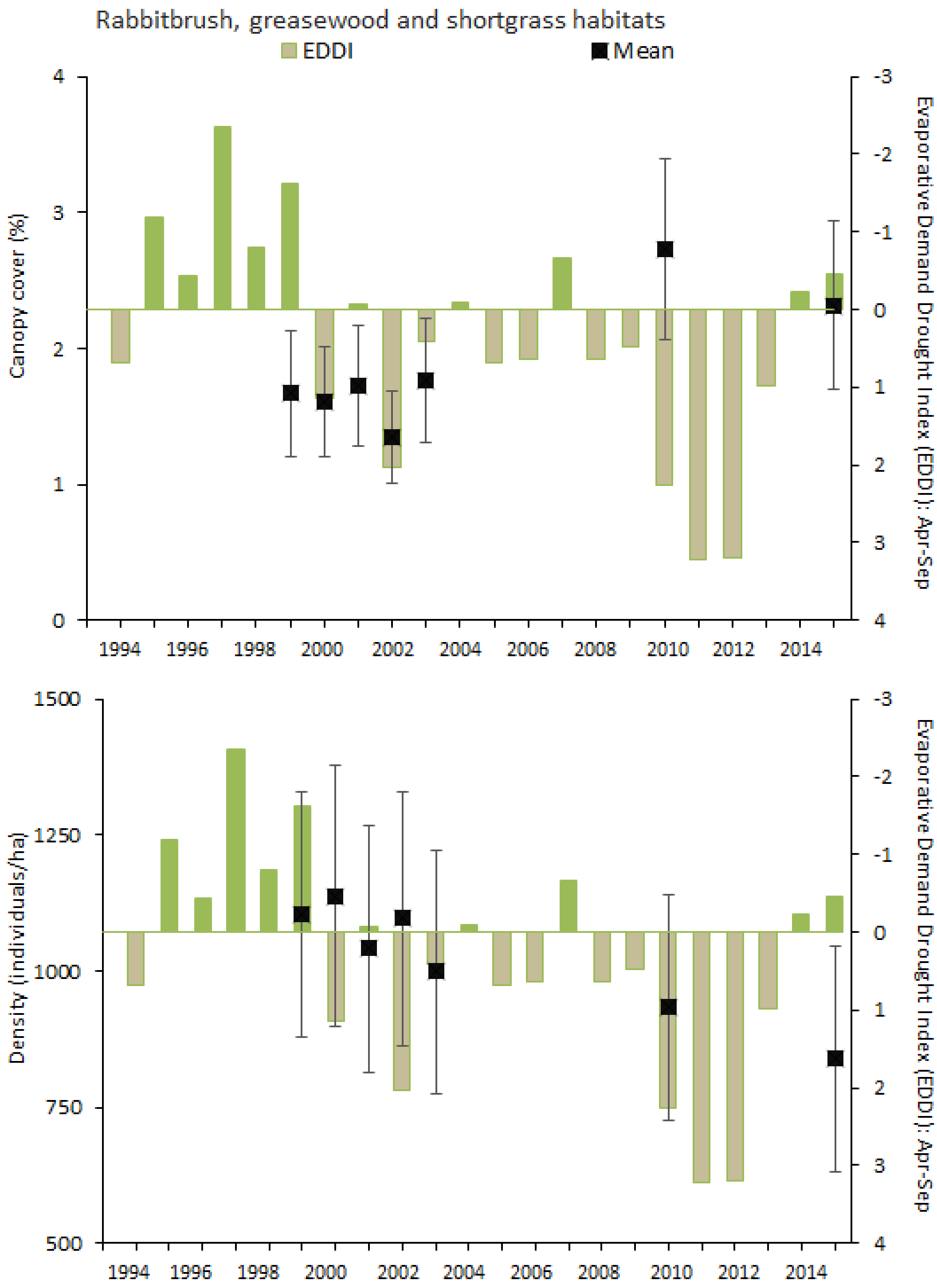

Figure 31. Rabbitbrush mean cover and density (± 1 SE) in all habitats combined, 1999-2015 (n=20). Rabbitbrush cover has increased by about 40% relative to 1999 and density has declined by about 20%.

Cholla. Cholla is found in shortgrass and greasewood habitats and is generally absent from sandsage habitat as it has a preference for clay or loamy soils rather than sandy soils (Fig. 32). At PCD, cholla was more abundant in greasewood habitat than in shortgrass habitat (Figs. D-5 and D-6). Cholla cover and density increased in the greasewood and shortgrass habitats over the 1999 measurements. The fire in greasewood plots gw19 and gw20 in 2011 caused cholla mortality thus we removed gw19 and gw20 from this analysis (see fire discussion). In the shortgrass habitat, while cholla cover and density are relatively low the trend is strongly upward (Fig. 33). Though the increases in cholla cover and density in the shortgrass and greasewood habitats individually were not statistically significant, when the habitats are combined the increases are significant ($P \leq 0.05$). These increases indicate high drought tolerance for cholla at PCD.

Figure 32. Cholla at plot sg61ug in 1999 (left) and 2015 (right). Cholla cover in plot sg61ug increased by a factor of four between 1999 and 2015.

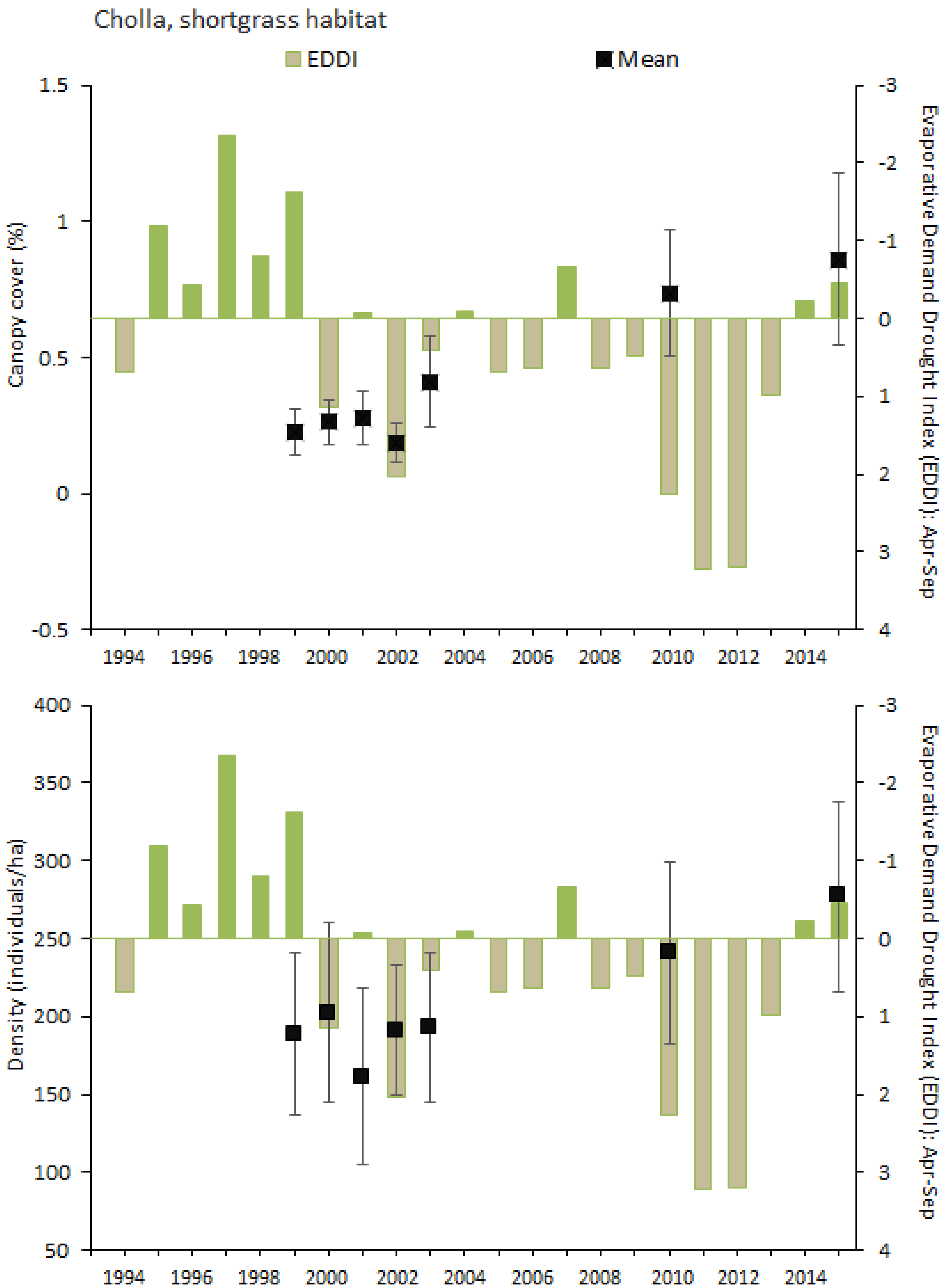

Figure 33. Cholla mean cover and density (± 1 SE) in shortgrass habitat, 1999-2015 (n=11). The increase in cover and density over time indicate high drought tolerance of cholla at PCD.

Sandsage. At PCD, sandsage is primarily found in the sandsage shrublands where it is the signature species (Figs. 34 and 35). It is occasionally found in the greasewood habitat, however, it is never very abundant there. The following analysis only included the sandsage shrubland habitat. Note that sandsage cover and density had a near significant difference between grazing treatments, which was eliminated by 2010 (see grazing section). Sandsage is the most drought sensitive of any of the PCD shrubs and has declined markedly in both cover and density since 2001 ($P \leq 0.001$ for cover and density; Fig. 36). Canopy cover decreased from 17% in 1999 to 6% in 2015, a 65% decrease. Over the same period the density decreased by 50%, or a loss of 5,100 individuals/ha (Fig. 36). Due to this high loss of sandsage abundance many of the areas appear more like a sand prairie than a shrub steppe.

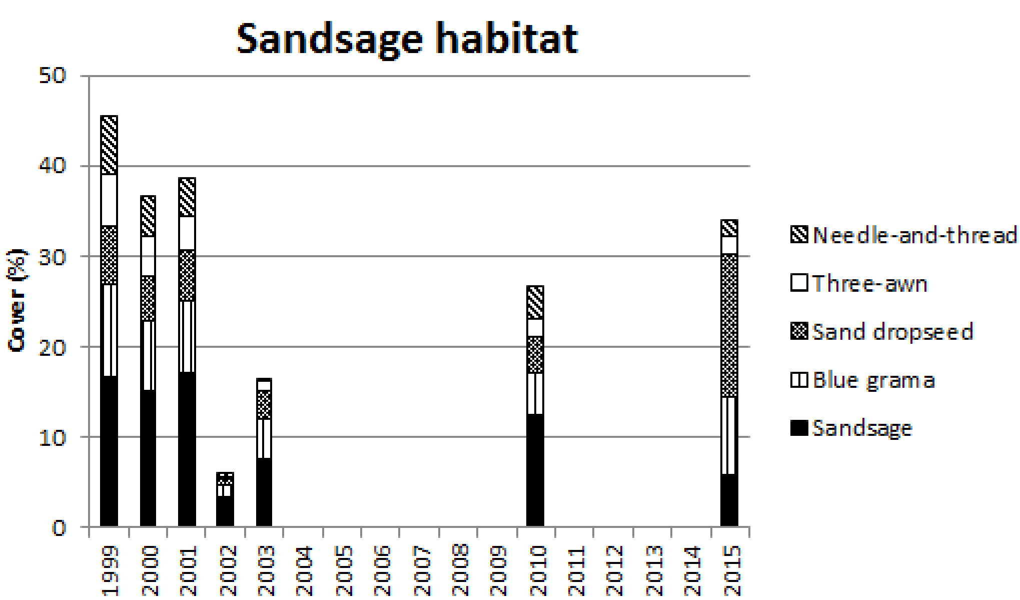

Figure 34. Sandsage and dominant grasses cover, 1999-2015 (n=11), showing the relative decrease in sandsage cover over time.

Figure 35. Sandsage shrubland plot ss08 in 1999 (top), 2002 (middle), and 2015 (bottom). All photos were taken in August. There has been 50% mortality in sandsage between 1999 and 2015.

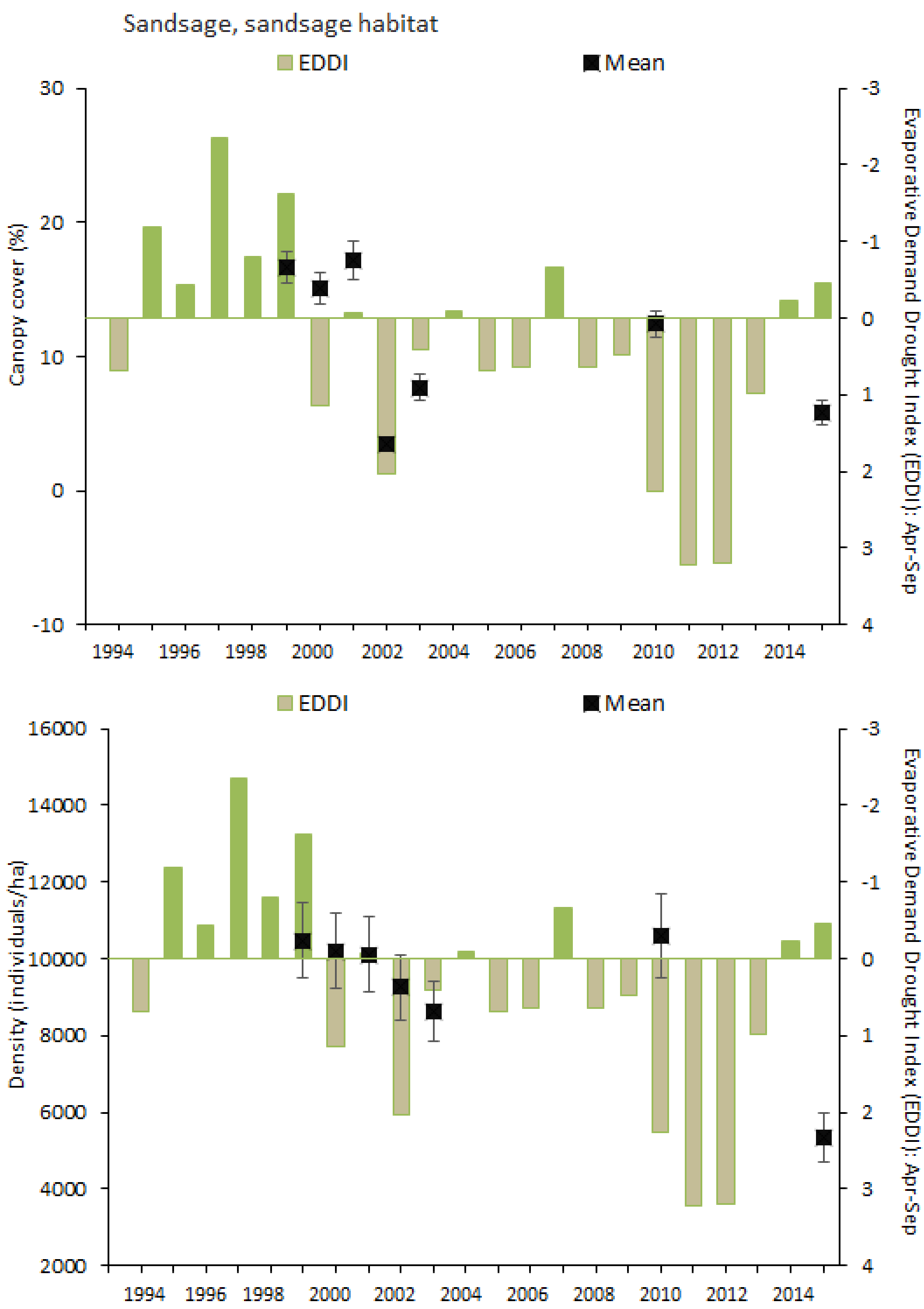

Figure 36. Sandsage mean cover and density (± 1 SE), 1999-2015 (n=11). Sandsage is amazingly sensitive to annual precipitation. Density decreased with the 2002 drought but it had recovered by 2010 and dropped again by 2015. The decreases in cover and density were significant (P≤0.001 for both metrics).

Prickly pear. This prostrate cactus is relatively frequent in all habitat types, but cover is generally low (Figs. 37 and D-7). Prickly pear had very little year to year variation and was one of the few species not impacted by the drought. In 2015, prickly pear reached its lowest frequency values in the greasewood and shortgrass habitats and its highest value in the sandsage habitat (Fig D-7). However, taking into account the standard error the values are relatively consistent year to year. 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).

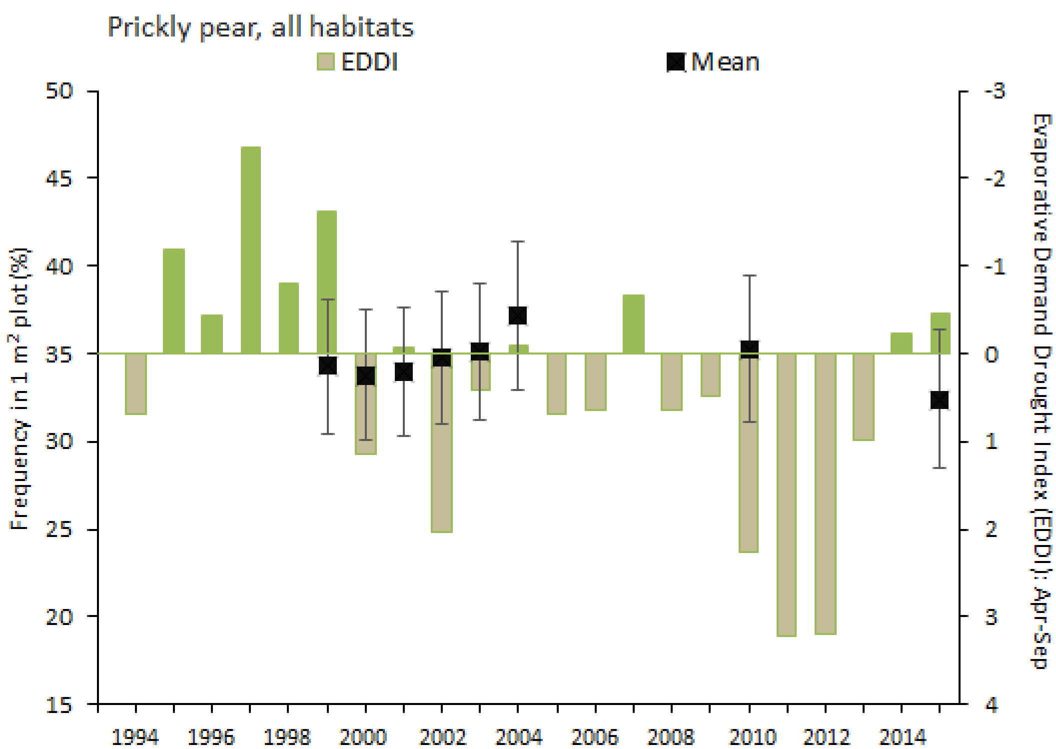

Figure 37. Prickly pear mean frequency (± 1 SE) in all habitats combined, 1999-2015 (n=35). The prickly pear population was relatively stable throughout the course of the study.

Grasses

The dominant grasses at PCD are blue grama, alkali sacaton grass, galleta grass, three-awn grass, sand dropseed, and needle-and-thread grass. Figure 38 shows grass cover by species, and total grass cover over time, in each habitat type. Shortgrass and greasewood habitats had the highest grass cover in 1999 and greasewood and sandsage had the highest grass cover by 2015 (Fig. 38). Total grass cover in all habitats combined went from 42% to 32%, a decrease of about 25% ($P \leq 0.001$). Most of this decline was within the shortgrass (47%, $P \leq 0.001$), followed by greasewood habitat (17%, $P \leq 0.001$) (Table 4). Total grass cover in the sandsage habitat remained relatively constant throughout the study. Most of the change is due to a decline in the abundance of blue grama, the signature species of the shortgrass prairie. Blue grama cover declined by 62% (from 30% to 12%, $P \leq 0.01$) in the shortgrass habitat and by 41% (from 24% to 14%, $P \leq 0.001$) in the greasewood habitat. Regardless of habitat type, three-awn grass also declined ($P \leq 0.001$). Sand dropseed increased in sandsage habitat and became the dominant grass, replacing blue grama's dominance (Fig. 38). Alkali sacaton grass became the dominant grass in greasewood, replacing blue grama's dominance. We discuss each species below.

Blue grama. Blue grama, the dominant grass throughout much of the eastern plains of Colorado, is a warm season, shallow-rooted bunch grass that is extremely resistant to grazing pressures and fairly drought tolerant (e.g., Epstein et al. 1996, Anderson 2003) (Fig. 39). This species has the ability to grow with rainfall events as small as 5 mm (Sala and Lauenroth 1982), but seldom regenerates from seed (Lauenroth et al. 1994). Growing season moisture (approx. April-September) is very important for blue grama growth; during extreme drought years, such as 2002, blue grama did not grow and some plants actually perished (however, a one-year lag effect was required to observe the actual mortality). Frequency and cover of blue grama in all habitats combined show a strong downward trend over the length of this study ($P \leq 0.001$) (Fig. 40). If we regard frequency as a surrogate for density (number of plants/area), we could say that the density of blue grama in the shortgrass habitat declined by 50% from 1999 to 2015 (Table 4 and Fig. D-9). While 2015 was an above average precipitation year and growing season (the highest of any of our sample years), blue grama cover in the shortgrass habitat was still 62% below 1999 levels (1999 and 2015 had nearly identical April-September precipitation as

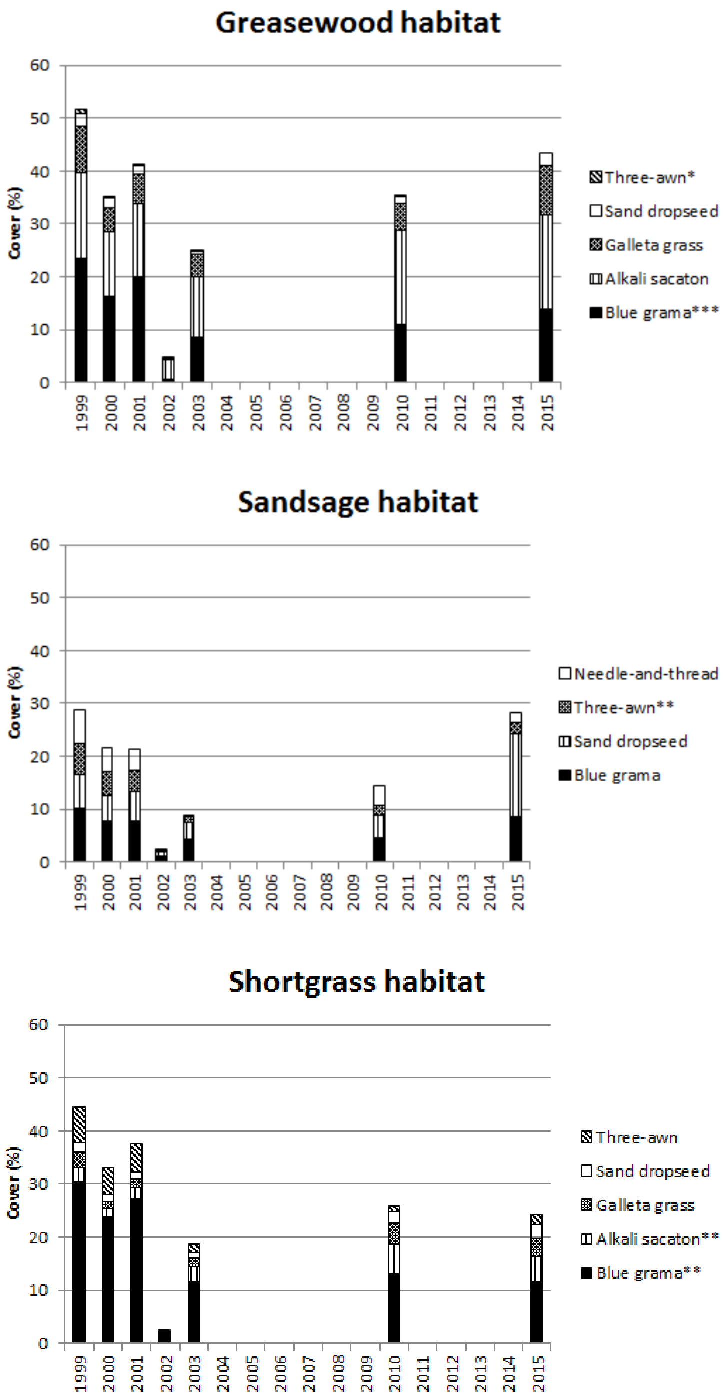

Figure 38. Total grass cover in greasewood, sandsage, and shortgrass habitats, 1999-2015 (n=13; 11; 11, respectively). The years 2002 and 2003 were the strongest drought episode in over 100 years. Consistent trends among plots in slope for the period 1999-2015 were tested against a null hypothesis of equal ranks of negative and positive slopes using a Wilcoxon signed-ranked test; *P≤0.05,P≤0.01, ***P≤0.001. Total grass cover in shortgrass and greasewood habitats combined significantly decreased over time (P≤0.001).**

well as annual precipitation) (Figs. 38 and D-8). A couple of good precipitation years, such as 2014 and 2015, were not enough to make up for the 13 years of drought.

The cover of blue grama appears more stable in the sandsage and had less of a loss in greasewood habitat (Figs. 38 and D-8); however, these habitats also show a significant decrease in blue grama frequency (Fig. D-9). A decrease in frequency signifies the loss of individual plants, which are likely killed by extended drought conditions. There was a year effect ($P \leq 0.001$) with a downward trend over time in frequency for all habitats combined (Fig. 40). Blue grama in the shortgrass prairie habitat had the largest mortality over time (45%, $P \leq 0.001$), as it declined from an average of 75% frequency in 1999 to an average of 41% in 2015. Blue grama in the greasewood habitat declined from an average frequency of 60% in 1999 to 38% in 2015, a 37% loss ($P \leq 0.001$). Blue grama in sandsage declined from 39% in 1999 to 27% in 2015, a 31% loss ($P \leq 0.01$).

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. The drought had very little impact on alkali sacaton grass except for a drastic reduction in live cover during 2002 (Figs. 41 and D-10). Within the shortgrass plots that had alkali sacaton grass, the cover increased 53% between 1999 and 2015, while the blue grama cover decreased by 52% in those same plots.

Galleta grass. Galleta grass prefers silty clay loamy soils and was common in all greasewood plots and in 61% (8) of the shortgrass plots. The drought had very little impact on galleta grass, except for a drastic reduction in live cover during 2002 (Figs. 42 and D-11).

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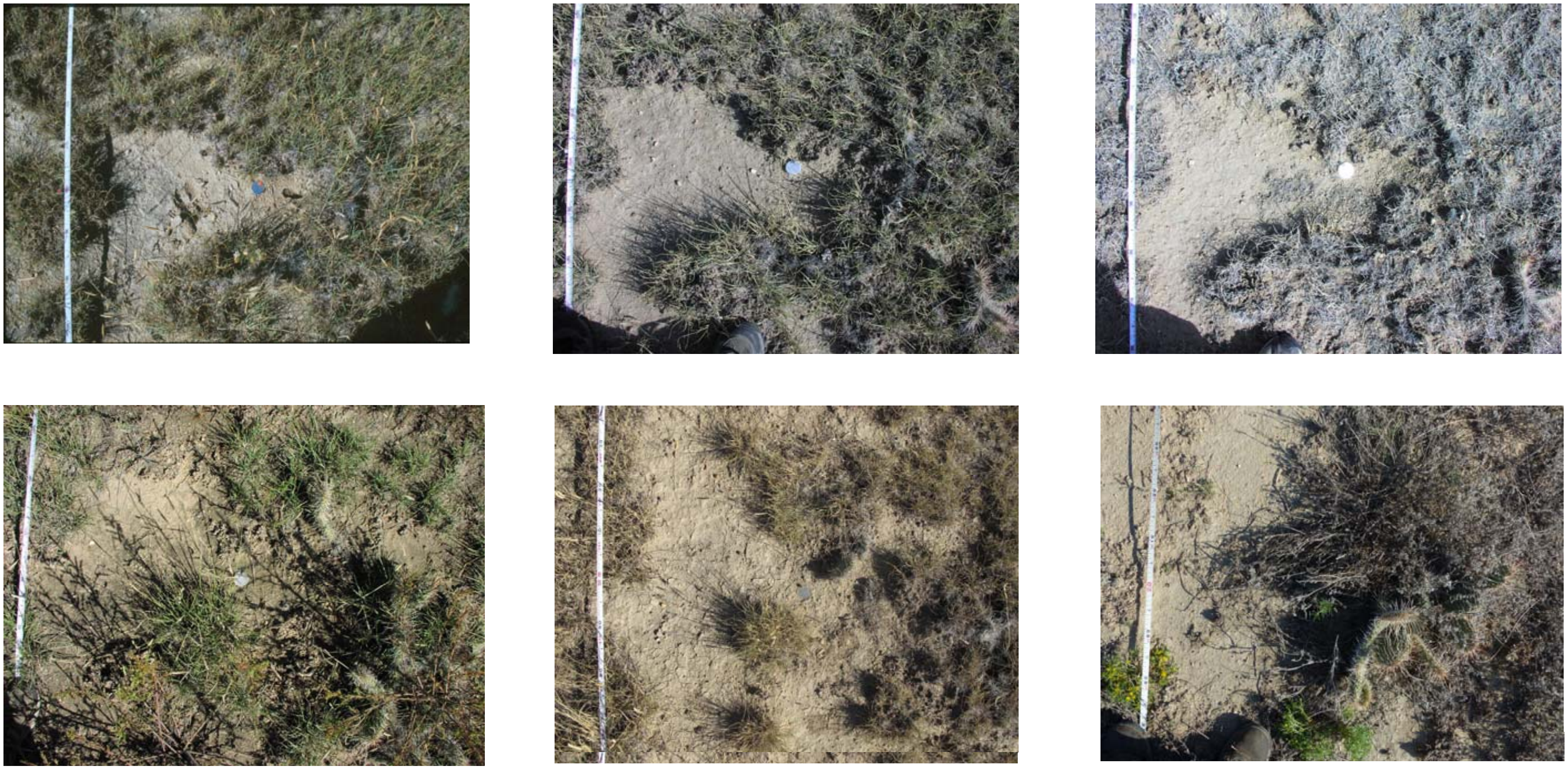


Figure 39. Microplot photos from shortgrass prairie plot sg68N, 1999, 2000, 2002 (top row), 2004, 2010, and 2015 (bottom row). The 2002 drought was the worst recorded drought in over 100 years and blue grama lost individuals and cover. Blue grama continued to lose cover and individuals through 2015.

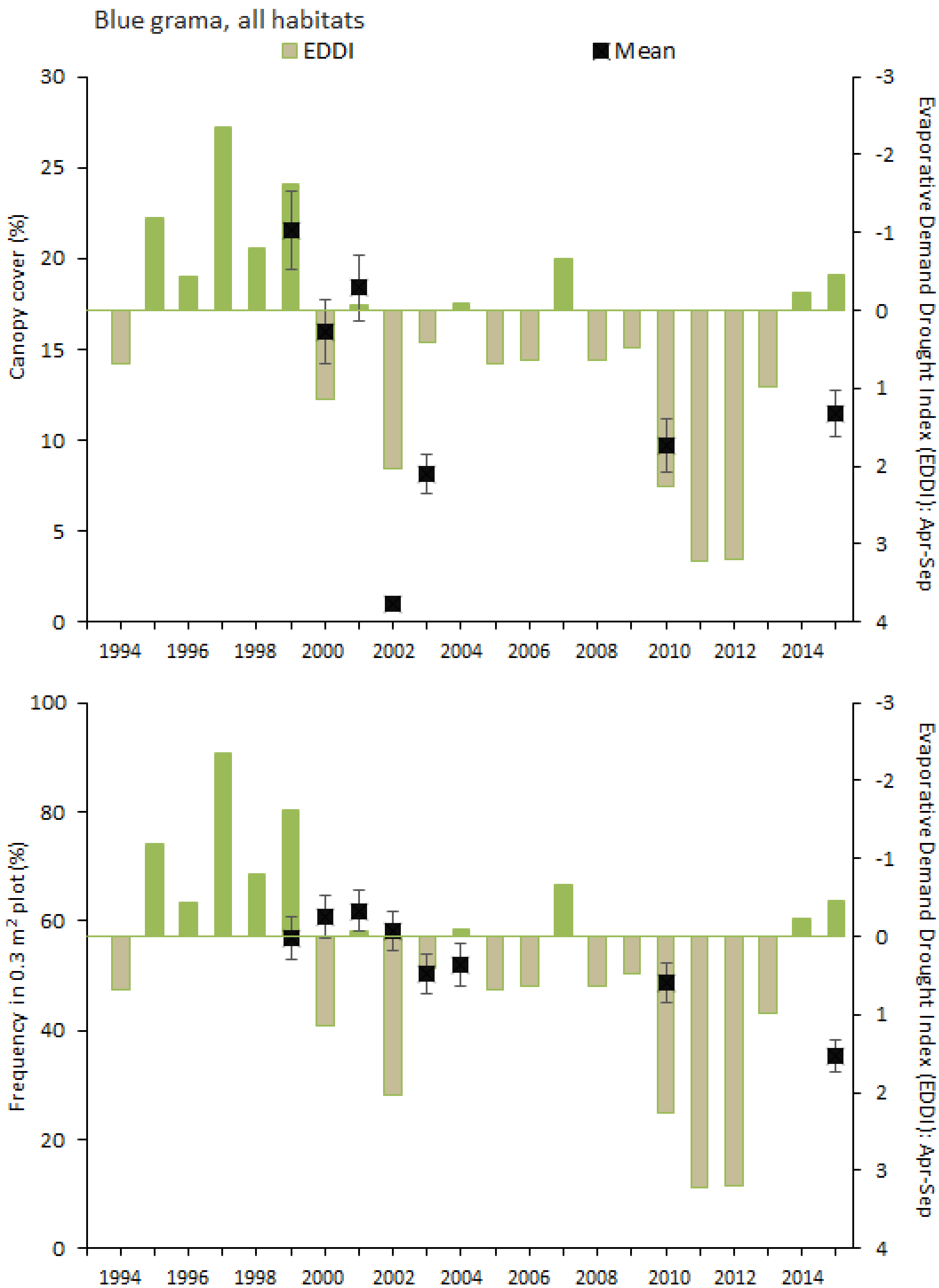


Figure 40. Blue grama mean cover and frequency (± 1 SE) in all habitats combined, 1999-2015 (n= 35). The decrease in cover and frequency over time was signficant (P≤ 0.001 for both metrics).

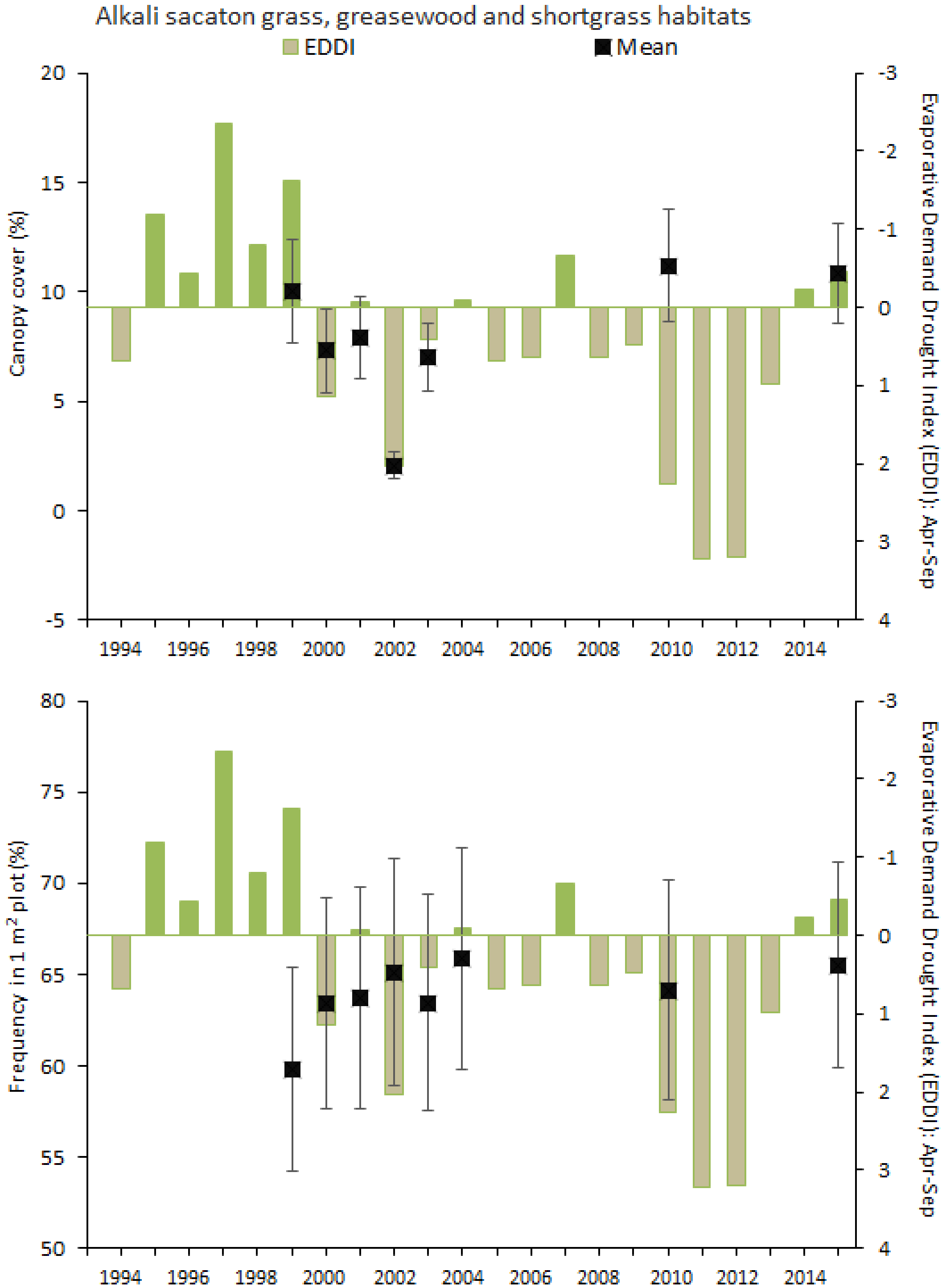


Figure 41. Alkali sacaton grass mean frequency (± 1 SE) in all greasewood plots and the four shortgrass plots that had the Razor clay soil type, 1999-2015 (n=17).

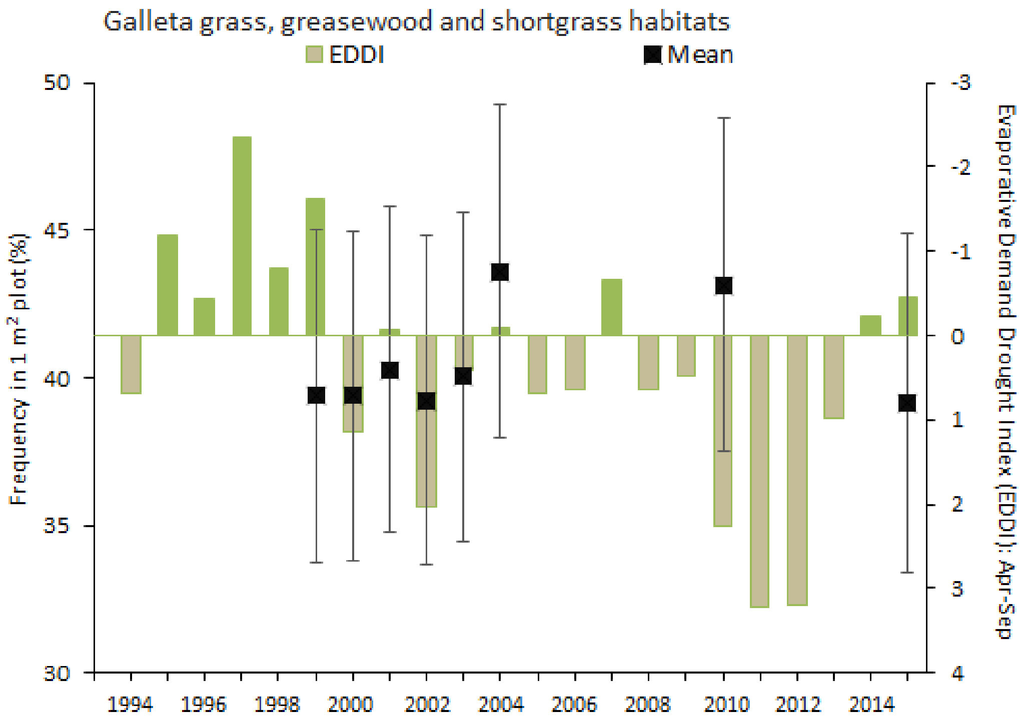


Figure 42. Galleta grass mean frequency (± 1 SE) in all greasewood plots (13) and 8 shortgrass plots, 1999-2015. Shortgrass plots that did not have > 10% frequency were eliminated.

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 (Figs. 43, D-12, and D-13) and had significantly higher cover and frequency on prairie dog towns than off towns (see prairie dog section). Three-awn grass declined following the 2002 drought and by 2015 was essentially absent from the greasewood habitat and was at low frequency and cover in the shortgrass and sandsage habitats. The overall frequency of three-awn decreased from 34% in 1999 to 13% in 2015, a decrease of 62% ($P \leq 0.001$). This decrease is likely a result of extended drought.

Sand dropseed. Sand dropseed is a short-lived perennial bunch grass. It was frequent in all habitat types but seldom reached high cover (Figs. 38, 44, D-14, and D-15). Sand dropseed is considered an increaser and is well suited to disturbance. Sand dropseed showed a marked

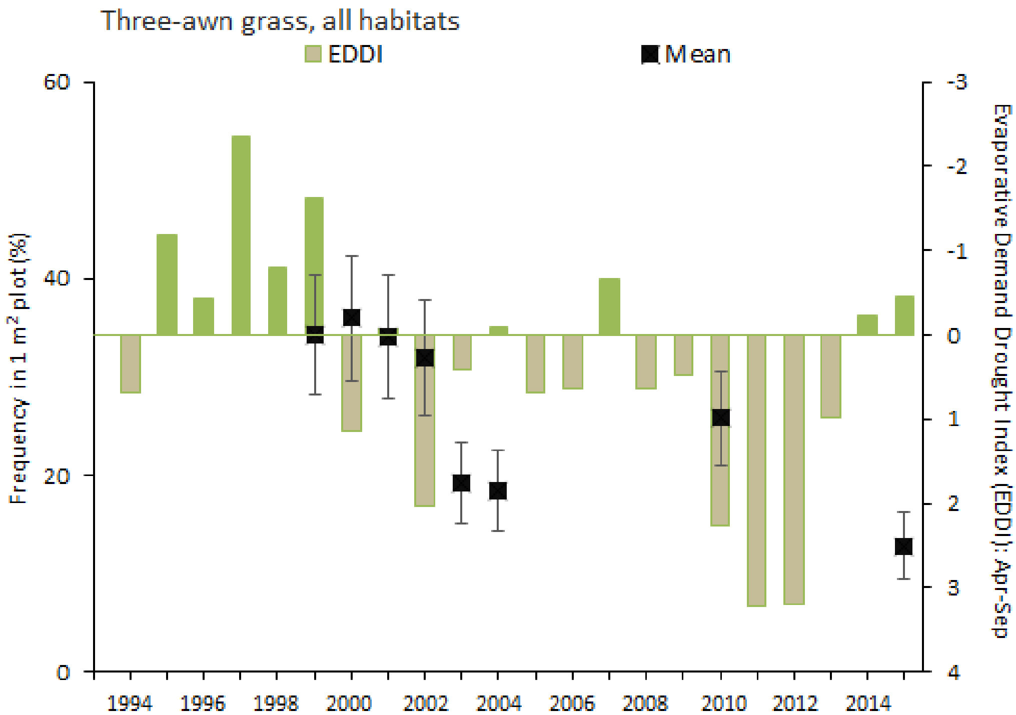


Figure 43. Three-awn grass mean frequency (± 1 SE) in all habitats combined, 1999-2015 (n=35). The frequency decreased by 62% between 1999 and 2015 (P≤ 0.001).

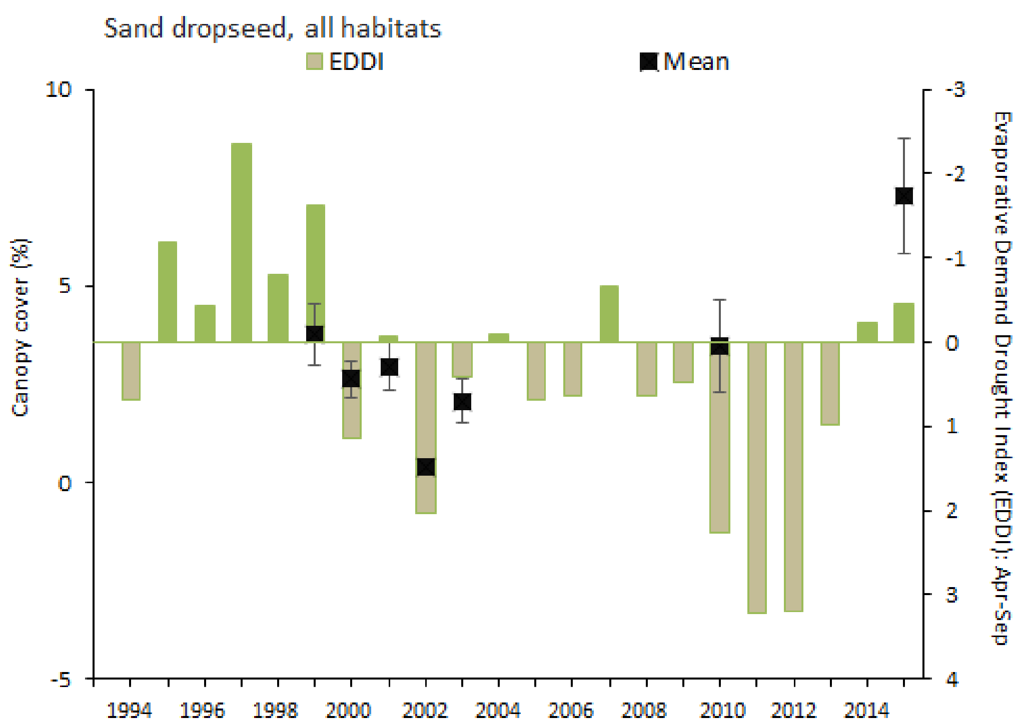


Figure 44. Sand dropseed mean frequency (± 1 SE) in all habitats combined, 1999-2015 (n=35).

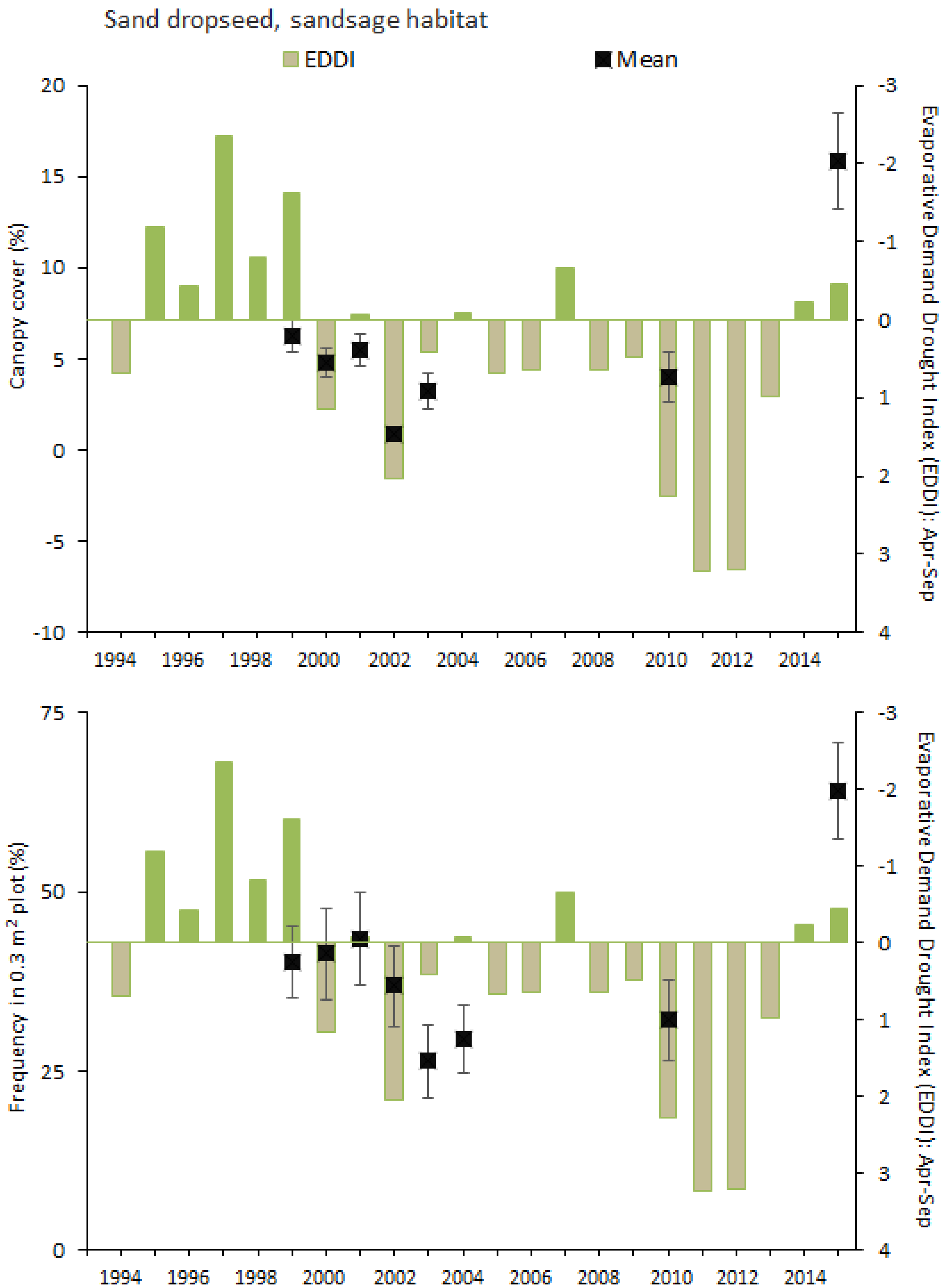


Figure 45. Sand dropseed mean frequency (± 1 SE) in sandsage habitat, 1999-2015 (n=11). The large increase in abundance and cover of sand dropseed in 2015 may be a result of the extremely wet spring combined with a large seedbank.

increase in the sandsage habitat in 2015, the only year in which it greatly exceeded blue grama cover (Fig. 45). The average cover in the sandsage habitat increased from 6% to 16% between 1999 and 2015 and the average frequency increased from 40% to 64%. These are increases of 160% and 38%, respectively. The reason for this increase may be the combination of high rainfall in May 2015 and a large seedbank in the sandsage habitat. Sand dropseed also increased in cover (32% increase) and frequency (37% increase) in the shortgrass habitat between 2010 and 2015 (Figs. D-14 and D-15). Many seedling sand dropseed plants were noted at PCD in 2015.

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 (Fig. 38). It is considered a decreaser in association with heavy winter/early spring grazing (when it does not have seed heads). Needle-and-thread grass dropped to its lowest frequency in 2015 (Fig. 46), likely in response to extended drought.

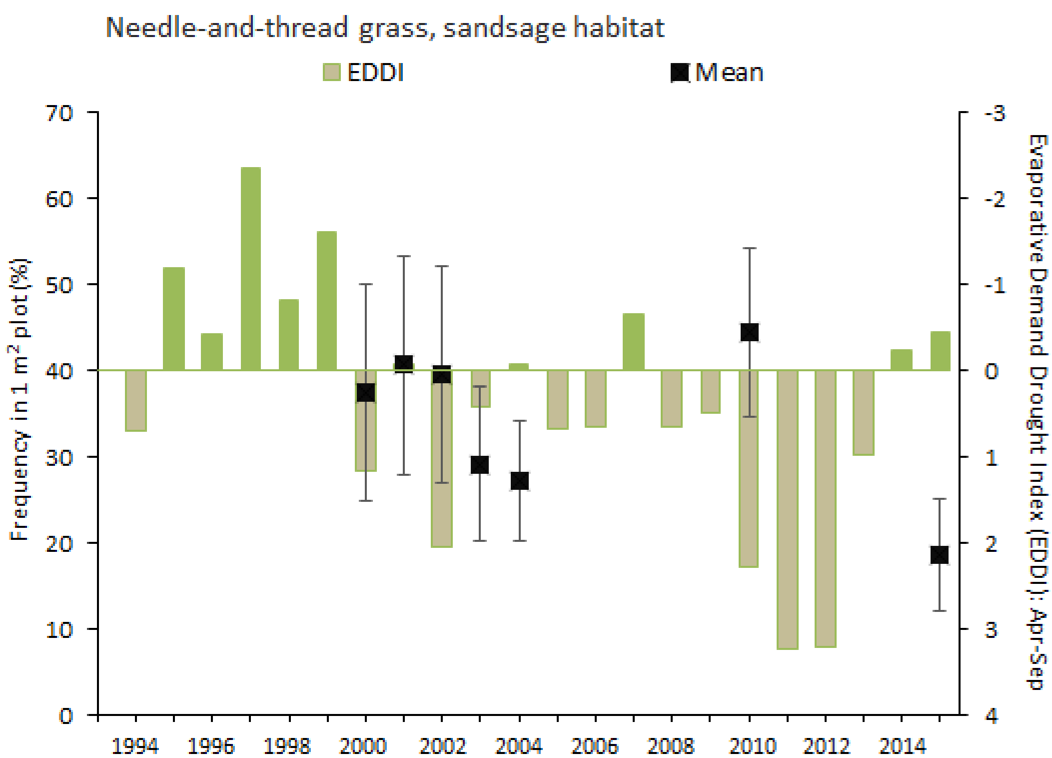


Figure 46. Needle-and-thread grass mean frequency (± 1 SE) in sandsage habitat, 2000-2015 (n=11). The recovery after the 2002 drought was not sustained; frequency reached its lowest value in 2015.

Weeds

Kochia. As mentioned earlier, kochia is a non-native annual forb. It, along with Russian thistle, form "tumbleweeds" of the prairie. At PCD, kochia is found in the greasewood and shortgrass habitats and is absent from the sandsage habitat. It is very responsive to precipitation events, with high abundance in 1999 and 2004 and virtually non-existent in 2010 (Figs. 47 and D-16). Though 2015 was a high spring rainfall year, kochia was also virtually non-existent in 2015.

Russian thistle. Russian thistle, like kochia, is a non-native annual weed that is very sensitive to seasonal moisture. It is found in all of PCD habitat types. It was not detected in 2002, the extreme drought year, and did extremely well in 2004 and 2015, years with high spring rainfall (Figs. 48 and D-17). In 2004, the year with the highest frequency of Russian thistle, almost 5 inches of rain fell in April, this is over four times higher than the average April rainfall (Table 1). Similarly, in 2015, 5.5 inches of rain fell in May, almost four times higher than the average May rainfall (Table 1).

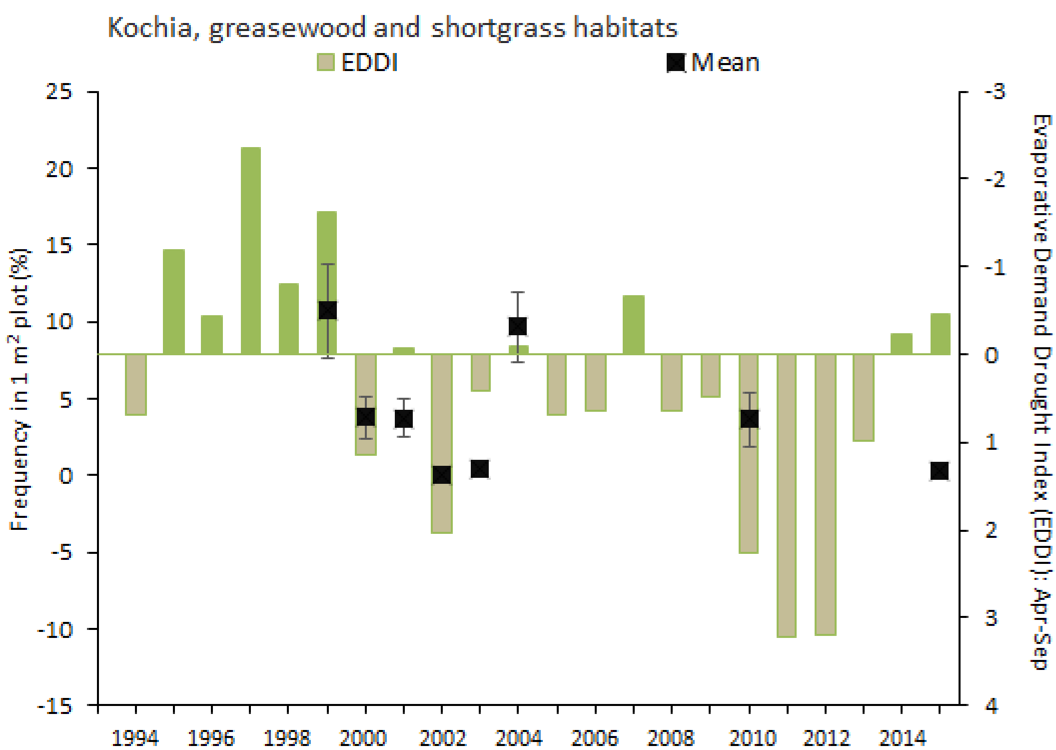


Figure 47. Kochia mean frequency (± 1 SE) in greasewood and shortgrass plots, 1999-2015 (n=24).

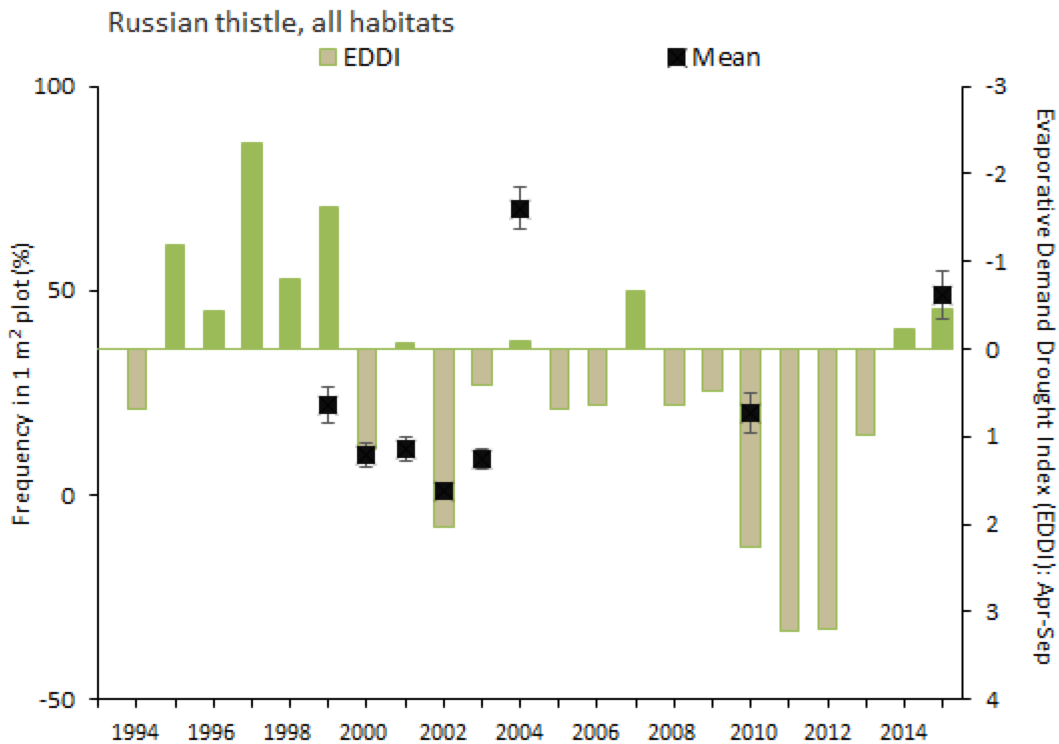


Figure 48. Russian thistle mean frequency (± 1 SE) in all habitats combined, 1999-2015 (n=35). This annual plant is very responsive to seasonal precipitation and 2004 and 2015 were exceptionally wet springs.

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, bare ground is reported only for greasewood and shortgrass plots. Bare ground averages higher in the shortgrass habitat (32% to 40%) than in the greasewood habitat (19% to 26%) (Figs. 49 and D-18). Average annual bare ground has ranged from 25% to 32% over the course of the study.

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 litter has been eliminated from the analysis. In general, a good rule of thumb is that when there is more bare ground there is less litter (Fig. D-19).

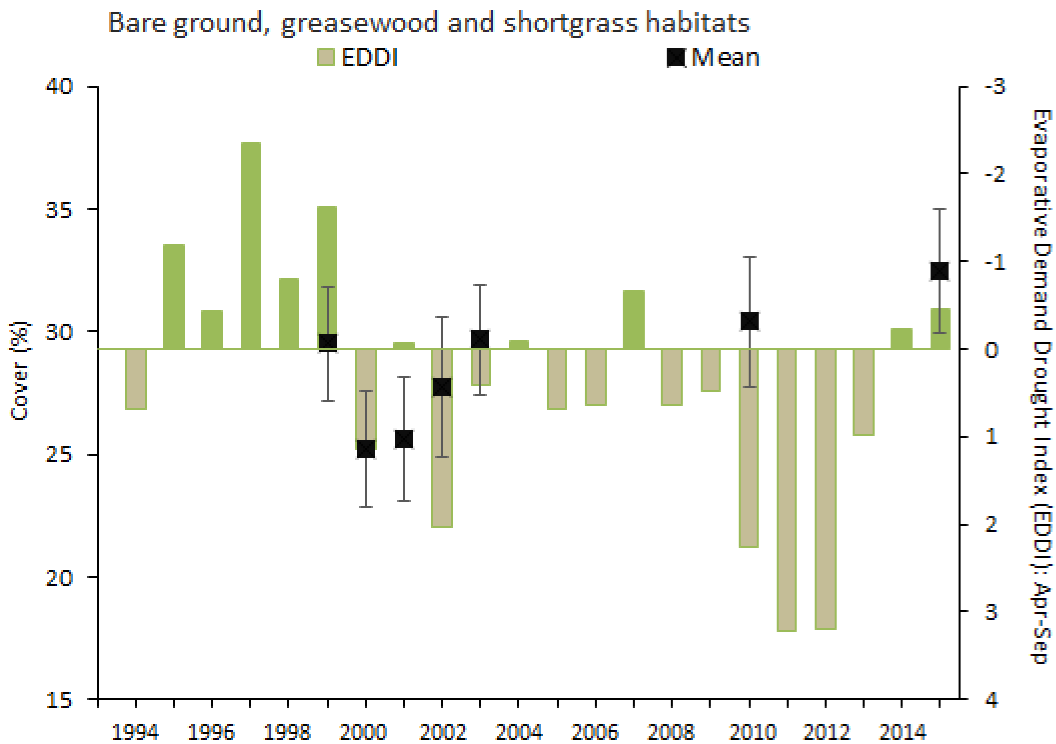


Figure 49. Bare ground mean cover (± 1 SE) in greasewood and shortgrass plots, 1999-2015 (n=24). Bare ground has remained at about 30% throughout the study.

Prairie Dogs

Prairie dogs are a native rodent grazer that are common within the shortgrass habitat at PCD. They occur especially where there are Stoneham loam soils. Eight of the nine plots on the Stoneham loam soil type had prairie dogs at least one year during this study (Table 5 and Fig. 8). Other shortgrass plots that never had prairie dogs throughout the course of this study were on Razor clay eroded soils or Limon silty clay loam. 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 3.5 out of the 9 sampling years (Table 5). Although the original study was not designed to measure the effects of prairie dogs it was clear that prairie dogs should be considered and two plots, sg80 and sg81, were added in 2001, both ungrazed by cattle. Sg80 was confined by bunkers on the north and south edges and the vegetation had been highly altered; it included virtually no blue grama 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. Sg81, on the other hand, had 60% frequency (F3) of blue grama in 2001 and by 2010 all of the blue grama was gone. The following results summarize the effect of prairie dogs versus no prairie dogs. The data are summarized below, in Figure 50, and in Figures D-20 through D-22 of Appendix D.

There was no significant difference in blue grama cover or frequency on/off prairie dog towns in 2001 but blue grama frequency (F3) was significantly lower on prairie dog plots than off in 2015 ($P \leq 0.05$). Blue grama frequency declined an average of 63% on prairie dog plots while it declined 31% on non-prairie dog plots between 2001 and 2015 (Figs. 50, 51, and D-20). One plot, sg61, was one of the only prairie dog plots where blue grama remained relatively unchanged; it had prairie dogs in two sample years, but not in 2010 or 2015.

Table 5. Prairie dog activity by year for each plot that had prairie dogs at some time during the study (n=inactive).

Plot	1999	2000	2001	2002	2003	2004	2005	2010	2015	years active	years inactive
sg61	n	n	n	active	n	active	n	n	n	2	7
sg68	n	n	n	n	n	n	active	active	active	3	6
sg70	n	n	n	n	n	active	active	active	n	3	6
sg74	n	n	n	n	n	n	active	active	active	3	6
sg77	n	active	active	active	n	n	active	active	n	5	4
sg78	n	n	n	n	n	active	active	active	n	3	6
sg80			active	active	n	n	n	n	n	2	5
sg81			active	active	active	n	n	active	active	5	2
Average										**3.5**	**5.5**

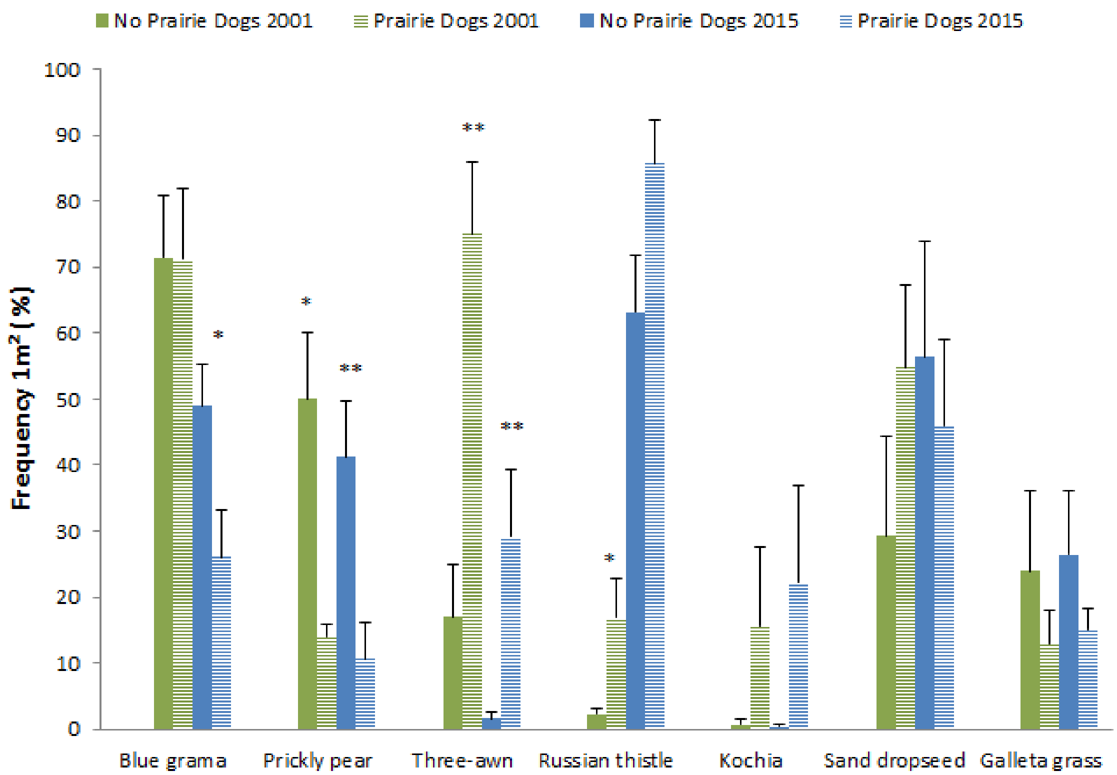


Figure 50. Mean frequency (± 1 SE) of dominant species on and off prairie dog towns for the years 2001 and 2015 (n= 5 no prairie dogs, n=8 with prairie dogs). An * indicates significant differences *(P≤0.05) or **(P≤0.01). (Note: Blue grama frequency shown is for 0.3 m^2 plot.)

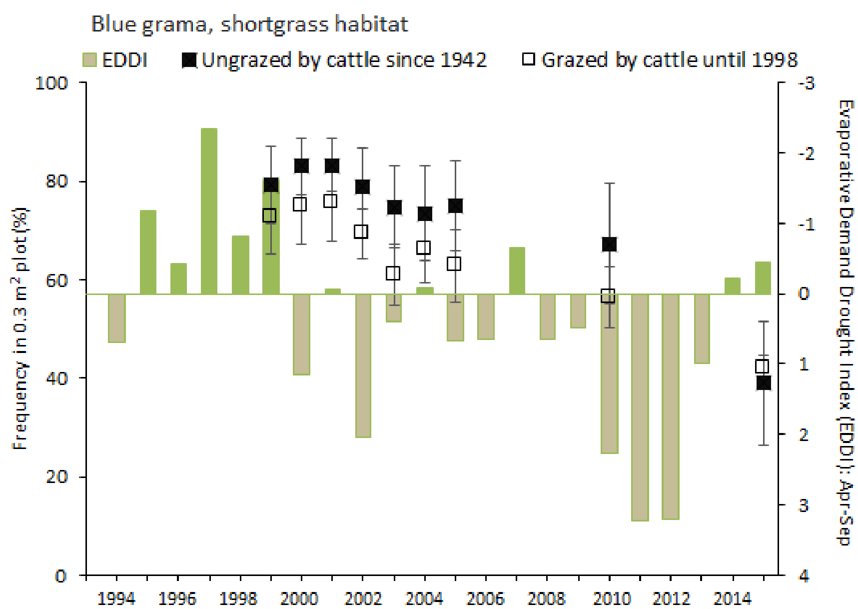


Figure 51. Blue grama mean frequency (± 1 SE) on and off prairie dog towns, 1999-2015 (n=5 no prairie dogs, n=6 with prairie dogs (1999-2000), n=8 with prairie dogs (2001-2015)). There was significantly less blue grama on prairie dog towns than off in 2015 (P≤0.05).

Prickly pear was more than twice as abundant off of prairie dog towns as on throughout the study period (P≤0.01; Fig. 52) and all indications point towards prairie dogs eating prickly pear. For example, sg68 and sg74 did not have an active prairie dog town until year 2010 and in both instances the prickly pear declined after prairie dogs became established (Table 6).

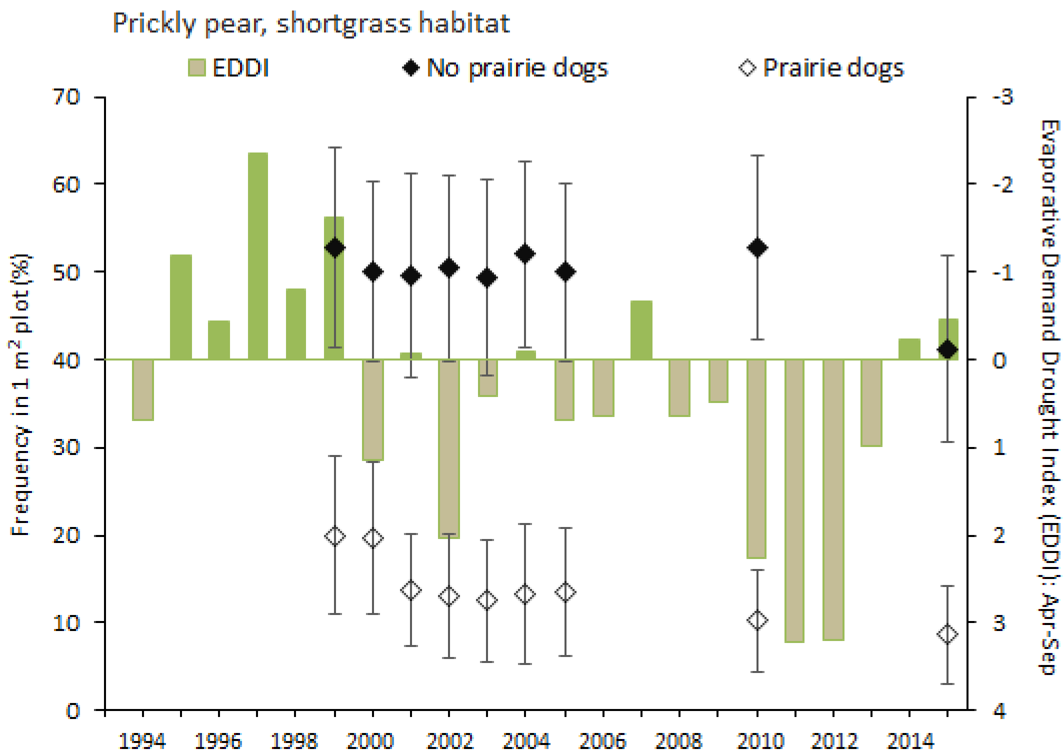


Figure 52. Prickly pear mean frequency (± 1 SE) on and off prairie dog towns, 1999-2015 (n=5 no prairie dogs, n=6 with prairie dogs (1999-2000), n=8 with prairie dogs (2001-2015)). There was significantly less prickly pear on prairie dog towns than off (P≤0.01). The drop in prickly pear in 2001 was due to a change in sampled plots.

Table 6. Prickly pear mean frequency at plots that were free of prairie dogs until toward the end of the study. Prairie dogs became established between 2005 and 2010 and prickly pear noticeably decreased after the prairie dogs became established.

Plot	1999	2000	2001	2002	2003	2004	2005	2010	2015
sg68ug	59	57	51	56	53	64	54	49	45
sg74ug	33	32	32	31	32	28	38	11	16

Three-awn grass had approximately 2.5 times higher abundance on prairie dog towns than off in 2001 (P≤0.01) indicating it increases with prairie dog grazing. Although drought has killed three-awn grass there is still a significant difference (P≤0.01) between on/off prairie dog towns (Fig. 53).

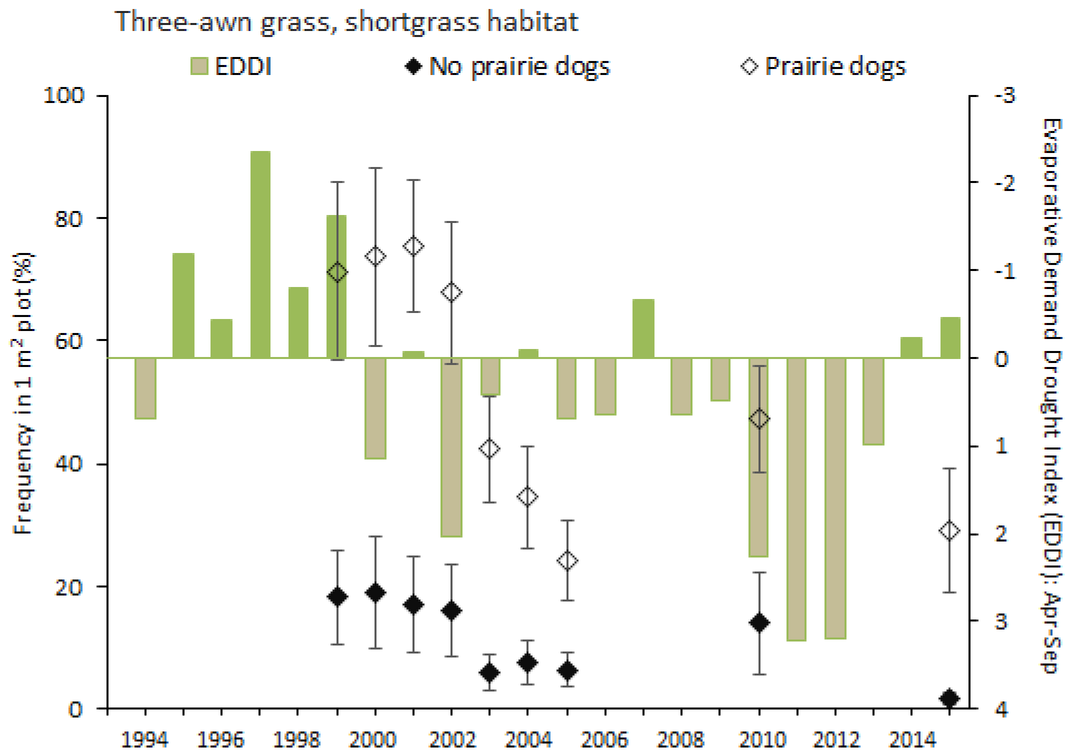


Figure 53. Three-awn grass mean frequency (± 1 SE) on and off prairie dog towns, 1999-2015 (n=5 no prairie dogs, n=6 with prairie dogs (1999-2000) and n=8 with prairie dogs (2001-2015)). Three-awn grass frequency was significantly higher on prairie dog towns than off (P≤0.001). The drop in 2003 is associated with the 2002 drought and the drop in 2015 is likely due to extended drought.

Kochia and Russian thistle had higher frequency on prairie dog towns than off, however, the difference was not significant for kochia and not consistently significant for Russian thistle (P≤0.05; Figs. 54 and 55).

Sand dropseed, galleta grass, and bare ground did not exhibit any difference between on or off prairie dog towns (Fig. 56, D-20, and D-21).

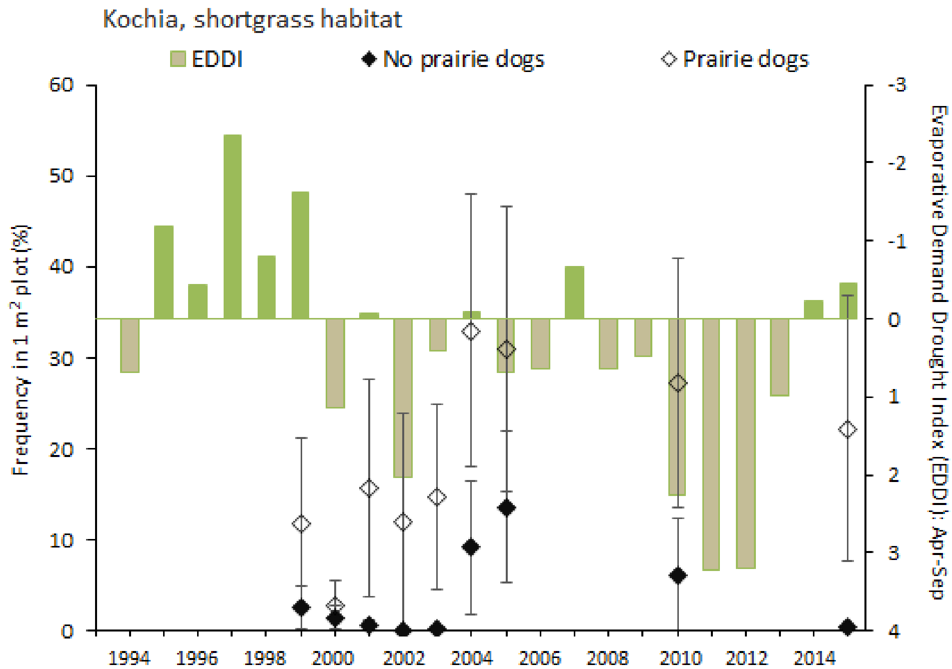


Figure 54. Kochia mean frequency (± 1 SE) on and off prairie dog towns, 1999-2015 (n=5 no prairie dogs, n=6 with prairie dogs (1999-2000) and n=8 with prairie dogs (2001-2015)). There was no significant difference between on and off prairie dog towns.

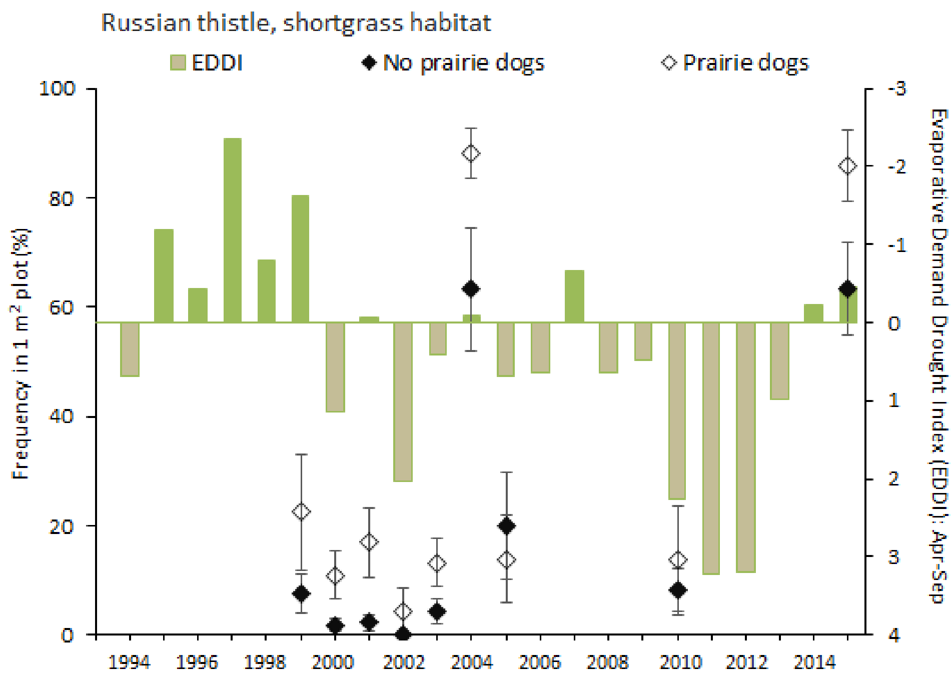


Figure 55. Russian thistle mean frequency (± 1 SE) on and off of prairie dog towns, 1999-2015 (n=5 no prairie dogs, n=6 with prairie dogs (1999-2000) and n=8 with prairie dogs (2001-2015)). Russian thistle frequency was higher on prairie dog towns than off in years 2000, 2001, 2004. Years 2004 and 2015 had significant April/May precipitation which likely contributes to the high frequency in those years.

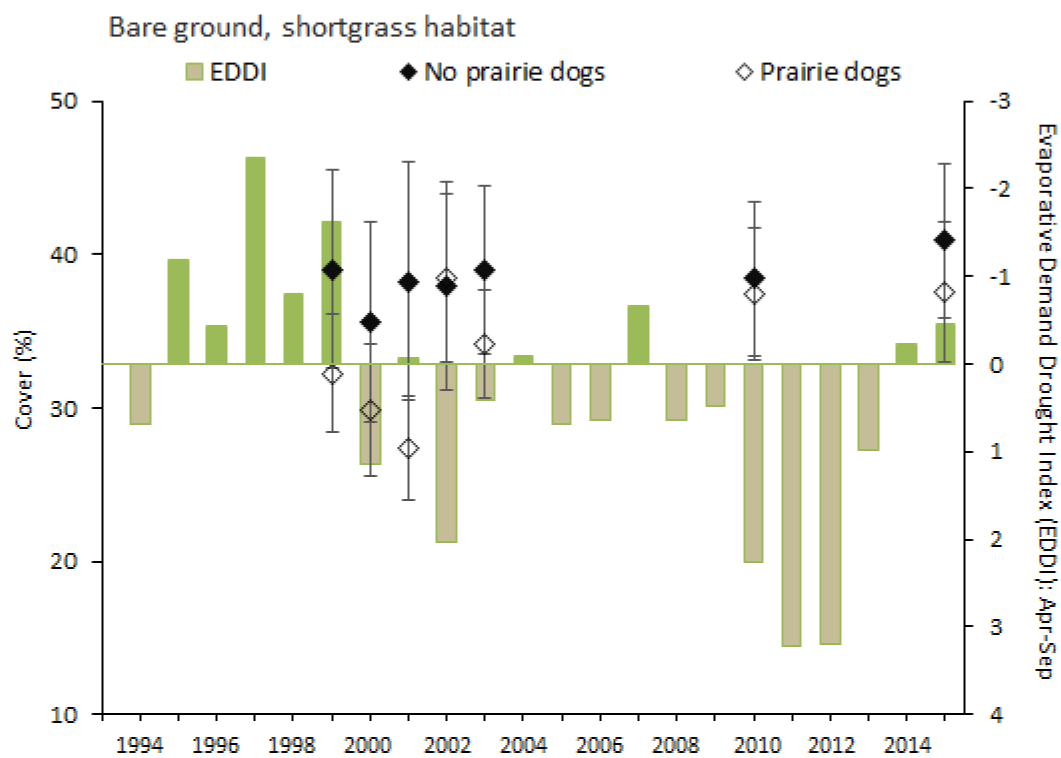


Figure 56. Bare ground mean cover (± 1 SE) on and off prairie dog towns, 1999-2015 (n=5 no prairie dogs, n=6 with prairie dogs (1999-2000) and n=8 with prairie dogs (2001-2015)). There was no significant difference exhibited on or off of prairie dog towns.

Fire

At least five of the plots at PCD have burned since monitoring began. These fires were not part of the experimental design and no long-term monitoring specifically related to fire has been conducted. Three of the plots were in the shortgrass habitat and two in the greasewood habitat. Shortgrass plot sg65 was burned by a lightning-induced fire in June 2000; sg70g was burned by a human-induced fire in November 2001; and sg80ug was burned in November 2002. Though no specific post-fire monitoring was conducted on the three shortgrass plots, the routine monitoring conducted the year following the fires did not show any noticeable long-term effect.

The two greasewood habitat plots burned as part of a 5,000-acre fire on a very windy day in March 2011. The two plots, gw19g and gw20g, are located in the Boone Creek drainage in the southeast portion of PCD. These plots, typical of the greasewood habitat, were dominated by greasewood, rabbitbrush, and cholla shrubs with a dense understory of blue grama and alkali sacaton grasses, and secondary grasses including sand dropseed and three-awn grass.

On August 16 and 17, 2011, Renée Rondeau and Tass Kelso (Colorado College) collected vegetation measurements and took many repeat photos of the two plots (Table 7). Fire effects were striking in that the fairly dense shrubland transformed into a grassland with sparse shrubs (Fig. 57). Rabbitbrush was hit hard with nearly 90% mortality. Cholla individuals showed about 50% mortality; the remaining live chollas were either stump sprouting from completely charred tops or intact ones with a weakened look of minimal green coloration and stem damage that looked like they might die over the next year. On the other side of the sensitivity spectrum, greasewood had done surprisingly well; although all of the greasewood had burned to the ground, most were successfully stump sprouting and had vigorous lush green growth.

Grasses were also negatively impacted by the fire and lost density; numerous culms were completely burned with no evidence of grass remains. The grasses that did survive appeared healthy with many inflorescences. Blue grama lost at least 25% of the plants, while alkali sacaton grass lost 38%. Sand dropseed was nearly eliminated with 75% of the population not visible.

Litter was completely burned and bare ground greatly increased going from 24% cover in 2010 to 70% in 2011. Due to all of these changes, the landscape had a very different appearance.

The decreases in rabbitbrush and cholla noted in 2011 still persist four years later. Rabbitbrush density is about 80% lower than pre-fire density and cholla density is about 45% lower than pre-fire density. Some regrowth is occurring but most of the shrubs killed by the fire have not been replaced. The grasses, on the other hand, don’t show any long-term effects from the fire. The changes in grass abundance and cover are likely related to climate as they track the changes seen at the rest of the plots.

Figure 57. Greasewood shrubland plot gw20 in 2010, 2011, and 2015. Plot gw20 burned in March 2011 and rabbitbrush was reduced by 80% and cholla by 45%. From top to bottom, photos were taken Sep. 9, 2010, Aug. 17, 2011, and bottom Sep. 3, 2015. Most of the visible shrubs in 2011 and 2015 are greasewood.

Table 7. Vegetation monitoring results before and after March 2011 fire at gw19 and gw20.

Species	gw19			gw20		
	2010	2011	2015	2010	2011	2015
Greasewood						
Cover (%)	1.7	0.77	2.1	2.4	2.5	4.2
Density (per ha)	1400	1125	1625	1525	1400	1800
Rabbitbrush						
Cover	12	0.57	2.1	5	0.03	0.2
Density (per ha)	2900	350	425	1900	225	425
Cholla						
Cover (%)	2.6	0.47	1.3	2.0	0.17	0.6
Density (per ha)	1275	600	700	600	325	350
Blue grama						
Cover (%)	4	5	7	3	5	10
Frequency (F3) (%)	41	32	24	29	25	19
Alkali sacaton						
Cover (%)	16	12	23	16	12	21
Frequency (F3) (%)	50	49	43	68	57	48
Sand dropseed						
Frequency (F4) (%)	54	26	66	36	7	f45

Discussion

Seventeen years of monitoring at PCD has given us insight into the response of vegetation to the previous livestock grazing, periodic drought conditions, occasional fire, and 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 conservation area – Chico Basin. The Nature Conservancy, Colorado Natural Heritage Program, and Bird Conservancy of the Rockies (formerly 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*), and massasauga rattlesnake (*Sistrurus catenatus*), as well as the state endangered southern redbelly dace (*Phoxinus erythrogaster*) and the state threatened 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). CNHP's primary task was to document the changes that took place as a consequence of this major management decision. After 17 years of monitoring, we have documented that the effects from the cessation of cattle grazing were most readily noticed in sandsage, cholla, three-awn grass, sand dropseed, needle-and-thread grass, bare ground, and weeds. Table 8 classifies the effect of cattle grazing on these species.

Table 8. Species response to cattle grazing.

Decreaser	**Increaser**	**Neither increaser or decreaser**
Cholla	Sandsage	Greasewood
Needle-and-thread	Three-awn grass	Rabbitbrush
Kochia	Sand dropseed	Prickly pear
Russian thistle		Alkali sacaton grass
		Blue grama
		Galleta grass

Our 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. The sandsage habitat, however, had a significant shift in species composition and, although it is showing signs of recovering from past heavy grazing, it will likely take many more years and favorable precipitation to observe a complete recovery.

There were two non-native species that were good indicators of grazing in 1999: kochia and Russian thistle, especially in the greasewood and shortgrass habitats. Cattle grazing suppressed these weeds. With the cessation of cattle grazing at PCD, there is now more similarity between grazed and ungrazed plots. These annual weeds are tightly associated with precipitation events and were abundant in wet years and nearly absent in drought years.

Bare ground was a good indicator of cattle grazing in greasewood and shortgrass habitats in 1999. The cessation of grazing in the greasewood habitat initially decreased the amount of bare ground in grazed plots but bare ground has been increasing in all plots lately, likely an effect of drought. In the shortgrass habitat, bare ground has been relatively constant at about 40% in the grazed plots throughout the study while bare ground in the ungrazed plots has increased to 35%. This increase in bare ground is likely drought related.

Although high levels of bare ground can be considered detrimental in that more erosion is possible, 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). During favorable moisture conditions, grazing can be managed to maintain high levels of bare ground and desired vegetation height. During drought conditions, it appears that high levels of bare ground occur with or without grazing.

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 management 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; C. Jones, per. com. 2015).

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. We expect that with time and favorable moisture, 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. It appears that once these species are eliminated from an area it is extremely hard to re-establish them without human intervention.

Impacts of Extended 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 characterizes the central shortgrass prairie. Current climate projections indicate that the prairie region can expect extreme and extended droughts coupled with high temperatures in the future (Ray et al. 2008, Cook et al. 2015). With warmer temperatures, an increase of 14-17% in annual precipitation might be required to maintain similar levels of moisture availability as in the past (suggested by models of the Colorado River Basin (Nash and Gleick 1991) and Great Plains wetlands (Poiani et al. 1995). Pueblo Chemical Depot, located at the warmer, drier margin of the current shortgrass distribution, serves as a window into potential future conditions for shortgrass prairie.

Drought indices, temperature records, and precipitation records for the region indicate that most years of the monitoring study can be classified as drought or abnormally dry years. The most severe drought periods were 2002 and 2010 through 2012. The 2002 drought has been classified as a 100-year event (Pielke et al. 2005), however the 2012 drought index is even more severe than 2002, probably due to the prolonged nature of the drought and even warmer temperature.

Most perennial vegetation will lie dormant during extreme hot and dry conditions yet bounce back when moisture returns. During extreme events, individuals may die, either during or the year following a drought, resulting in a reduction in the population (Chapline and Cooperrider 1941). Evans et al. (2011) found that 11 years of an experimental drought in northern Colorado prairie resulted in large reductions in blue grama cover that became evident after the 8th year of the drought. By the 11th year blue grama cover was 30% lower than in the control. Our study had a 62% decline in blue grama cover (30% to 12%) within the shortgrass prairie from 1999 to 2015, of which 11 years were drought years. The real sign of extended drought is a drop in abundance of plants. At PCD, we documented drought-related decreases in abundance of blue grama, three-awn grass, needle-and-thread grass, and sandsage (Table 9).

Table 9. Species response to extended drought.

Gained	**Declined**	**Negligible Change**
Rabbitbrush (cover)	Rabbitbrush (density)	Greasewood (cover)
Greasewood (density)	Sandsage	Prickly pear
Cholla	Blue grama	Alkali sacaton grass
	Three-awn grass	Galleta grass
	Needle-and-thread	Sand dropseed
		Weeds

The most significant decline is a 47% overall decrease in the cover of blue grama over the past 17 years, throughout PCD. This decrease varied by habitat type, with the shortgrass and greasewood losing significant cover (62% and 41%, respectively) and sandsage remaining stable. Our frequency metric can be used as a surrogate for density. Regardless of habitat type, blue grama density decreased by 38%, with the largest loss in shortgrass (45%), followed by greasewood and sandsage (32% and 31%, respectively), The decline in blue grama has been relatively consistent throughout the monitoring study, however, over half of the decline occurred between the 2010 and 2015 sampling years. It is interesting that blue grama in the sandsage lost individuals but did not lose cover, however, sandsage habitat has the lowest blue grama cover of all the habitats. While the 2015 growing season precipitation was nearly identical to 1999, blue grama cover was still significantly lower, thus denoting that once blue grama individuals are lost in the shortgrass and greasewood habitats, the recovery rate is likely to be slow (Coffin et al. 1996)

The significance of the decline in blue grama cover and density and its slow recovery rate has ramifications to the conservation value, economics, and carbon sequestration potential of the shortgrass prairie region. Wildlife and livestock that rely on blue grama are likely to be impacted by prolonged droughts that reduce the abundance of blue grama. In addition, carbon sequestration programs that may be used to mitigate climate change will need to incorporate the impacts of long-term droughts into their calculations.

Though blue grama abundance was at its lowest in 2015, tall growth from the thinned stand made the grasslands appear superficially recovered. The tall growth was due to the wet spring. Chapline and Cooperrider (1941) warn of prompt restocking of livestock on tall growth from thinned stands as this regrowth is needed to renew the weakened root systems and general vigor of the plants. Chapline (1936) summarizes this warning as follows:

> “The stand of perennial grasses is less dense in the year following a drought than during the drought year itself. When unusually favorable rainfall follows a drought year, as is sometimes the case, the reduced stand of vegetation makes an exceptional height growth and appears to be abundant. This often leads to prompt restocking. Too many livestock at that time may so closely utilize the forage as to seriously affect recovery from drought.” (Chapline 1936 as quoted in Johnson 1981).

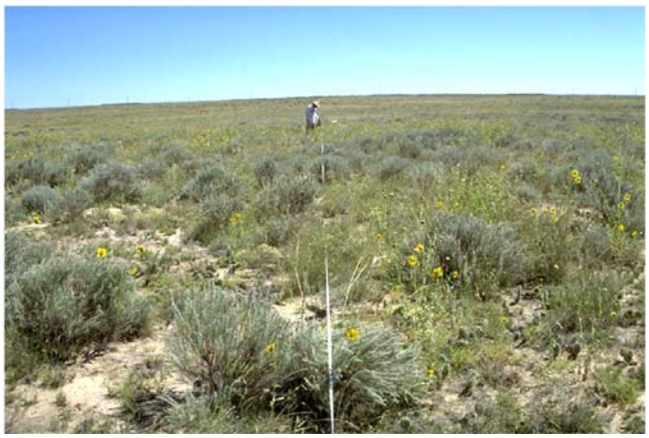
Warm season (C4) grasses, such as blue grama and three-awn grass, are more responsive than cool season (C3) grasses, such as needle-and-thread grass, to additional water supplements (Skinner et al. 2002). Sala and Lauenroth (1982) reported that leaf water potential and leaf conductance to water in blue 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. 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) and Evans et al. (2011) reported an 8 year time lag in cover. Other studies show recovery after 2 to 5 years of favorable rainfall (Johnson 1981; Paulsen and Ares 1962).

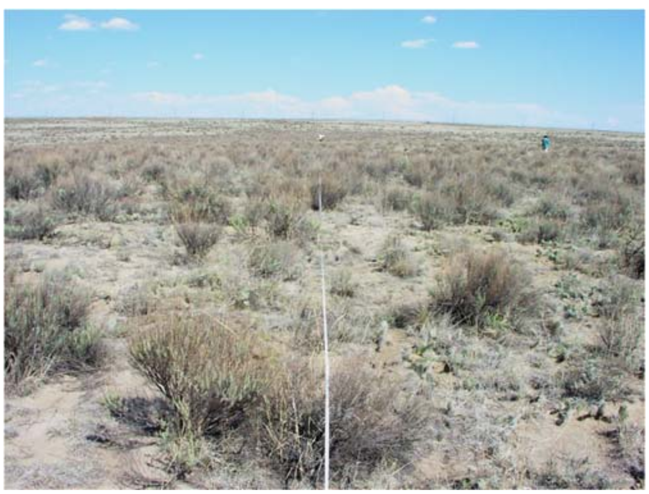
Other grasses that decreased in frequency between during the study include three-awn (62% decrease) and needle-and-thread (50% decrease).

Sandsage is the most drought sensitive of any of the PCD shrubs and declined markedly in cover and density since 1999 (Fig. 58). Over this period canopy cover decreased by 65% and density decreased by 49%. Similar drought-related declines have been documented by other researchers, for example, Gillen and Sims (2006) reported a 40% decrease in sandsage canopy cover in response to 5 years of below average precipitation.

On the other hand, greasewood, rabbitbrush, cholla, prickly pear, sand dropseed, alkali sacaton, and galleta grass appeared relatively unaffected by extended drought. Greasewood and cholla increased in density during the monitoring period. Rabbitbrush decreased in density but increased in cover during the monitoring period.

Drought 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 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 rabbitbrush and cholla; rabbitbrush had nearly 90% mortality and cholla individuals showed about 50% mortality. Four years later these mortality rates remained high (80% for rabbitbrush and 45% for cholla). These shrubs will most likely repopulate this area but how much time is needed is not yet evident.





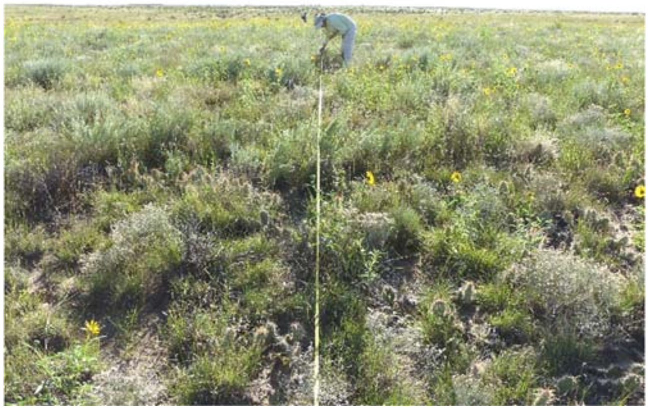


Figure 58. Sandsage shrubland plot ss32ug in 1998 (upper photo), 2002 (middle photo), and 2015 (lower photo). Photographs taken at end of west transect looking east.

Sand dropseed, alkali sacaton, and galleta grass are likely to do well in future conditions. In a long-term study in northwest Oklahoma in the Southern Plains, sand dropseed was the only perennial grass that didn't decline during drought (Gillen and Sims 2006). Sand dropseed reached its highest overall cover and frequency at PCD in 2015, likely in response to the extremely wet spring of 2015. Sand dropseed reproduces from seed as opposed to blue grama which reproduces primarily by tillering. Sand dropseed is important in stabilizing soil, especially when long-lived perennial grasses, such as blue grama, are depleted (Paulsen and Ares 1962). Sand dropseed roots are not extensive and can be crowded out by the more extensive roots of blue grama when conditions improve for blue grama (Paulsen and Ares 1962).

Russian thistle also responded to the extremely wet spring of 2015. The years with the highest Russian thistle abundance were 2004 and 2015, the years with extremely high April or May rainfall.

None of the grasses expected to do well in future conditions are as nutritious to cattle as blue grama. The slow recovery of blue grama 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.

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).

Effects of drought are not limited to vegetation. During the extreme drought of 2002, 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 desert than shortgrass prairie (P. Young, pers. comm.). Even the chollas were wilted and girdled by prairie dogs. This 100-year drought 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 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.

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. Six shortgrass prairie plots were placed within prairie dog colonies and, by 2010, prairie dogs had moved into two additional shortgrass plots. Analysis of the presence of prairie dogs vs. no prairie dogs helps explain vegetation changes that aren't easily attributed to cattle grazing or drought. Effects of prairie dogs on the dominant species at PCD are summarized in Table 10.

Table 10. Species response to prairie dogs.

Decreaser	Increaser	Neither increaser or decreaser
Blue grama	Three-awn grass	Sand dropseed
Prickly pear	Kochia	Galleta grass
	Russian thistle	

Studies have suggested that prairie dog grazing can increase blue grama (Koford 1958) or at least not exert a selective pressure against blue grama (Bonham and Lerwick 1976). However, our data show a loss in blue grama cover and frequency on plots associated with prairie dogs. This decline may be due to the effect of extreme drought coupled with prairie dogs.

Prickly pear was much less abundant on plots with prairie dogs (average frequency of 14%) than on plots without prairie dogs (average frequency of 50%) (Figs. 50 and 52). Prairie dogs include prickly pear in their diets (Koford 1958), especially in the winter (Summers and Linder 1978); this likely explains the lack of prickly pear on prairie dog towns.

Three-awn grass is known as an indicator of heavy cattle grazing. At PCD, this grass is 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. 50). 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.

Prior to year 2010, plots sg68ug and sg74ug were considered ungrazed plots without prairie dogs. However, prairie dogs were present at both of these plots in years 2010 and 2015. This helps explain why plot sg74ug had nearly 100% frequency of three-awn grass. 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. Interestingly, plot sg68ug has very little three-awn grass; the cover and frequency of three-awn grass at sg68ug are more similar to a non-prairie dog plot than a prairie dog plot.

Prairie dog towns noticeably stand out from areas without prairie dogs. This 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 34% cover on prairie dog towns and 38% cover off of prairie dog towns (difference not statistically significant), which goes against the casual observation (Fig. D-22).

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.

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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.*
Cypari	*Cyperus aristatus*

Forbs code	***Latin name***
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*
Medsat	*Medicago sativa*

Forbs code	***Latin name***
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*
UNKSS78	*Unknown forb in ss78*

Forbs code	***Latin name***
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 (Pleuraphis) 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*
Sticom	*Stipa (Hesperostipa)comata*

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

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

Appendix B. Vegetation monitoring plot locations (UTM coordinates NAD83 Zone 13).

Plot ID	Latitude	Longitude	UTM Northing	UTM Easting
GW01	38.35733344	-104.29463061	4245698	561629
GW02	38.35879692	-104.29371212	4245861	561708
GW04	38.35149368	-104.37898449	4244997	554263
GW05	38.32689950	-104.30892108	4242311	560406
GW06	38.32308649	-104.31465757	4241885	559907
GW09	38.30794265	-104.31069888	4240207	560266
GW10	38.30643727	-104.31552577	4240037	559845
GW11	38.30548977	-104.31498673	4239932	559893
GW13	38.29876145	-104.30746917	4239190	560556
GW14	38.29862525	-104.31327732	4239171	560048
GW16	38.29620330	-104.31295998	4238903	560078
GW19	38.29107349	-104.30949767	4238336	560385
GW20	38.28855716	-104.30558634	4238059	560729
SG61	38.35536378	-104.35641940	4245440	556232
SG63	38.34294624	-104.38524040	4244045	553723
SG64	38.34556533	-104.28498094	4244399	562482
SG65	38.34237568	-104.27875042	4244049	563029
SG67	38.33332373	-104.28402817	4243041	562576
SG68	38.34807169	-104.36447189	4244626	555534
SG69	38.35690957	-104.36403545	4245607	555565
SG70	38.32064929	-104.30322164	4241622	560909
SG74	38.30654204	-104.34806231	4240028	557000
SG77	38.29274777	-104.28062302	4238541	562909
SG78	38.28941035	-104.29435509	4238161	561711
SG79	38.28700474	-104.29767667	4237892	561422
SG80	38.34167562	-104.33408934	4243935	558194
SG81	38.28274875	-104.34625232	4237389	557177
SS08	38.35996695	-104.34564371	4245957	557170
SS21	38.28901296	-104.36595926	4238072	555449
SS27	38.34429371	-104.29328087	4244252	561758
SS30	38.31288370	-104.36706685	4240720	555334
SS31	38.29848904	-104.36006712	4239127	555957
SS32	38.31070424	-104.36882520	4240477	555182
SS36	38.28434609	-104.35961961	4237558	556007
SS37	38.28123942	-104.35530460	4237216	556387
SS38	38.27987786	-104.35995623	4237062	555981
SS39	38.27648051	-104.35151649	4236690	556722
SS40	38.26891132	-104.34071012	4235857	557673
RP46	38.33027490	-104.38694931	4242638	553583

Plot ID	Latitude	Longitude	UTM Northing	UTM Easting
RP49	38.32371145	-104.37962562	4241914	554228
RP50	38.32250135	-104.37915539	4241780	554270
RP56	38.30530294	-104.37862733	4239872	554329
RP58	38.29182493	-104.37606641	4238378	554563
RP59	38.28681674	-104.37389793	4237823	554756
RP60	38.28110036	-104.37073720	4237191	555037

Appendix C. Example field forms.

Shrubs – Line Intercept Field Form (Excel file)

Transect Number															
Date															
Photo Time															
Disturbance description															
Prairie Dog Town (None, Active, Inactive															
Comments															
Observers															
		Gaps less than 10 cm are counted as canopy cover; plant does not have to be rooted in belt transect in order to count. Plants must be live.													
														Total (cm)	**Total (m)**
NORTH		Tape measurements (cm)													
Chynau	Rabbitbrush													0	0
Cylimb	Cholla													0	0
Gutsar	Snakeweed													0	0
Ipolep	Bush morning glory													0	0
Olifil	Sandsage													0	0
Sarver	Greasewood													0	0
Yucgla	Yucca													0	0
SOUTH		Tape measurements (cm)												0	0
Chynau	Rabbitbrush													0	0
Cylimb	Cholla													0	0
Gutsar	Snakeweed													0	0
Ipolep	Bush morning glory													0	0
Olifil	Sandsage													0	0
Sarver	Greasewood													0	0
Yucgla	Yucca													0	0
EAST		Tape measurements (cm)												0	0
Chynau	Rabbitbrush													0	0
Cylimb	Cholla													0	0
Gutsar	Snakeweed													0	0
Ipolep	Bush morning glory													0	0
Olifil	Sandsage													0	0
Sarver	Greasewood													0	0
Yucgla	Yucca													0	0
WEST		Tape measurements (cm)												0	0
Chynau	Rabbitbrush													0	0
Cylimb	Cholla													0	0
Gutsar	Snakeweed													0	0
Ipolep	Bush morning glory													0	0
Olifil	Sandsage													0	0
Sarver	Greasewood													0	0
Yucgla	Yucca													0	0

Shrubs – Belt Transect Field Form (Excel file)

Transect N																
Date																
Photo Time																
Disturbance description																
Prairie Dog Town (None, Active, Inactive																
Comments																
Observers																
			Begin at 1 m mark on the E and W lines for belt transect (to avoid double counting)													
			Yucca: count number of heads/clump													
NORTH			**Belt Transect**													Total
Chynau	Rabbitbrush															0
Cylimb	Cholla															0
Gutsar	Snakeweed															0
Ipolep	Bush morning glory															0
Olifil	Sandsage															0
Sarver	Greasewood															0
Yucgla	Yucca															0
			Belt Transect													0
SOUTH																0
Chynau	Rabbitbrush															0
Cylimb	Cholla															0
Gutsar	Snakeweed															0
Ipolep	Bush morning glory															0
Olifil	Sandsage															0
Sarver	Greasewood															0
Yucgla	Yucca															0
			Belt Transect													0
EAST																0
Chynau	Rabbitbrush															0
Cylimb	Cholla															0
Gutsar	Snakeweed															0
Ipolep	Bush morning glory															0
Olifil	Sandsage															0
Sarver	Greasewood															0
Yucgla	Yucca															0
			Belt Transect													0
WEST																0
Chynau	Rabbitbrush															0
Cylimb	Cholla															0
Gutsar	Snakeweed															0
Ipolep	Bush morning glory															0
Olifil	Sandsage															0
Sarver	Greasewood															0
Yucgla	Yucca															0

Example Microplot Field Form (Excel file) for Shortgrass Habitat

Plot number		GRZD	DOGS	DATA TYPE & LOCATION	Shrubs	Grasses	Grasses	Grasses	Grasses	Grasses	Forbs	Forbs	Forbs	soil	litter
sg81ug		0/1	0/1		Opuspp	Arispp	Chogra	Hiljam	Spoair	Spocry	Bassie	Pecang	Salaus	soil	litter
sg81ug	5	0	1	MN1											
sg81ug	10	0	1	MN2											
sg81ug	15	0	1	MN3											
sg81ug	20	0	1	MN4											
sg81ug	25	0	1	MN5											
sg81ug	30	0	1	MN6											
sg81ug	35	0	1	MN7											
sg81ug	40	0	1	MN8											
				MN MEAN											
				STD.DEV.											
				CV											
sg81ug	4	0	1	MS1											
sg81ug	9	0	1	MS2											
sg81ug	14	0	1	MS3											
sg81ug	19	0	1	MS4											
sg81ug	24	0	1	MS5											
sg81ug	29	0	1	MS6											
sg81ug	34	0	1	MS7											
sg81ug	39	0	1	MS8											
				MS MEAN											
				STD.DEV.											
				CV											
sg81ug	2	0	1	ME1											
sg81ug	7	0	1	ME2											
sg81ug	12	0	1	ME3											
sg81ug	17	0	1	ME4											
sg81ug	22	0	1	ME5											
sg81ug	27	0	1	ME6											
sg81ug	32	0	1	ME7											
sg81ug	37	0	1	ME8											
				ME MEAN											
				STD.DEV.											
				CV											
sg81ug	9	0	1	MW1											
sg81ug	14	0	1	MW2											
sg81ug	19	0	1	MW3											
sg81ug	24	0	1	MW4											
sg81ug	29	0	1	MW5											
sg81ug	34	0	1	MW6											
sg81ug	39	0	1	MW7											
sg81ug	44	0	1	MW8											
				MW MEAN											
				STD.DEV.											
				CV											
				MICROPLOT MEANS											
				STD.DEV.											
				CV											

Example Frequency Field Form (Excel file) for Greasewood Habitat

PLOT NUMBER			Shrubs	Grasses	Grasses	Grasses	Grasses	Grasses	Forbs	Forbs
gw01g			Opuspp 15	Arispp 15	Chogra 15	Hiljam 15	Spoair 15	Spocry 15	Bassie 15	Salaus 15
gw01g	Freq if 1		0	0	0	0	0	0	0	0
gw01g	Freq of 1,2		0	0	0	0	0	0	0	0
gw01g	Freq if 1,2,3		0	0	0	0	0	0	0	0
gw01g	Freq of 1,2,3,4		0	0	0	0	0	0	0	0
gw01g	Meter									
gw01g	2	FN1								
gw01g	4	FN2								
gw01g	6	FN3								
gw01g	8	FN4								
gw01g	10	FN5								
gw01g	12	FN6								
gw01g	14	FN7								
gw01g	16	FN8								
gw01g	18	FN9								
gw01g	20	FN10								
gw01g	22	FN11								
gw01g	24	FN12								
gw01g	26	FN13								
gw01g	28	FN14								
gw01g	30	FN15								
gw01g	32	FN16								
gw01g	34	FN17								
gw01g	36	FN18								
gw01g	38	FN19								
gw01g	40	FN20								
gw01g	42	FN21								
gw01g	44	FN22								
gw01g	46	FN23								
gw01g	48	FN24								
gw01g	50	FN25								
gw01g	Freq of 1		0	0	0	0	0	0	0	0
gw01g	Freq of 1,2		0	0	0	0	0	0	0	0
gw01g	Freq if 1,2,3		0	0	0	0	0	0	0	0
gw01g	Freq of 1,2,3,4		0	0	0	0	0	0	0	0
gw01g	Meter									
gw01g	2	FS1								
gw01g	4	FS2								
gw01g	6	FS3								
gw01g	8	FS4								
gw01g	10	FS5								
gw01g	12	FS6								
gw01g	14	FS7								
gw01g	16	FS8								
gw01g	18	FS9								
gw01g	20	FS10								
gw01g	22	FS11								
gw01g	24	FS12								
gw01g	26	FS13								
gw01g	28	FS14								
gw01g	30	FS15								
gw01g	32	FS16								
gw01g	34	FS17								
gw01g	36	FS18								
gw01g	38	FS19								
gw01g	40	FS20								
gw01g	42	FS21								
gw01g	44	FS22								
gw01g	46	FS23								
gw01g	48	FS24								
gw01g	50	FS25								
gw01g	Freq of 1		0	0	0	0	0	0	0	0
gw01g	Freq of 1,2		0	0	0	0	0	0	0	0
gw01g	Freq if 1,2,3		0	0	0	0	0	0	0	0
gw01g	Freq of 1,2,3,4		0	0	0	0	0	0	0	0

Appendix D. Graphs for species and bare ground for each habitat type.

Total Shrubs, greasewood habitat

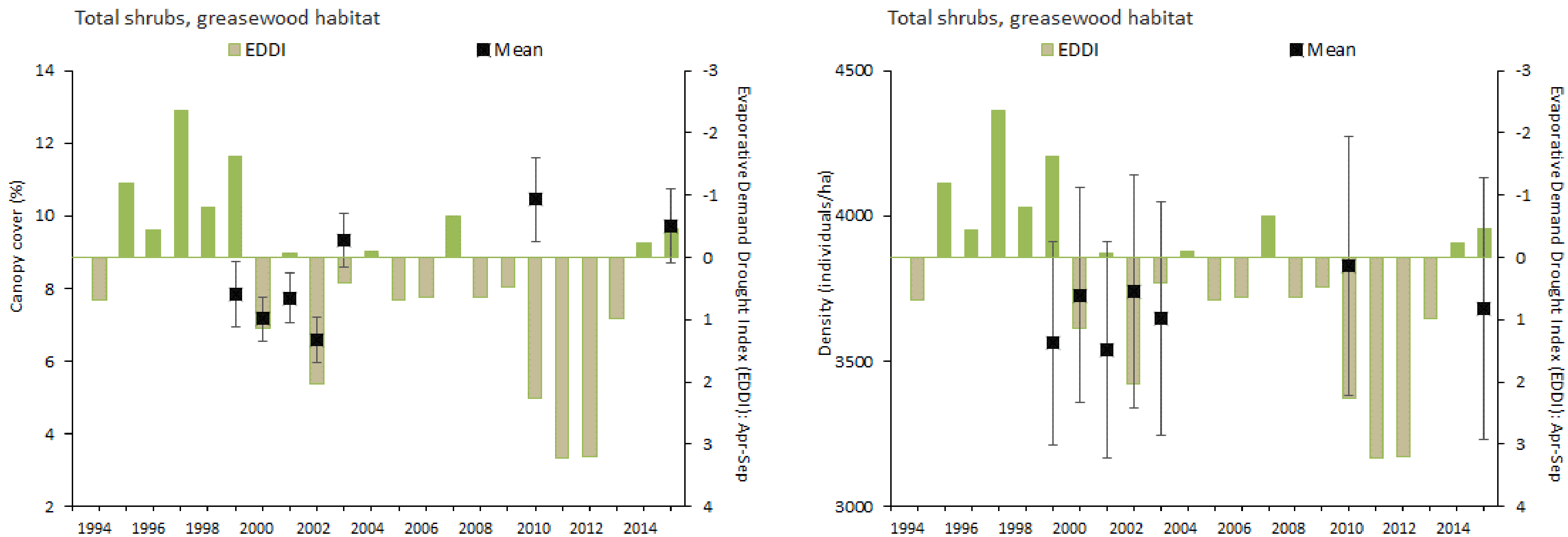

Figure D-1. Shrub summary for mean **cover and density** (± 1 SE) for greasewood habitat (n=11).

Greasewood (*Sarcobatus vermiculatus*) and Sandsage (*Oligosporus filifolius)*

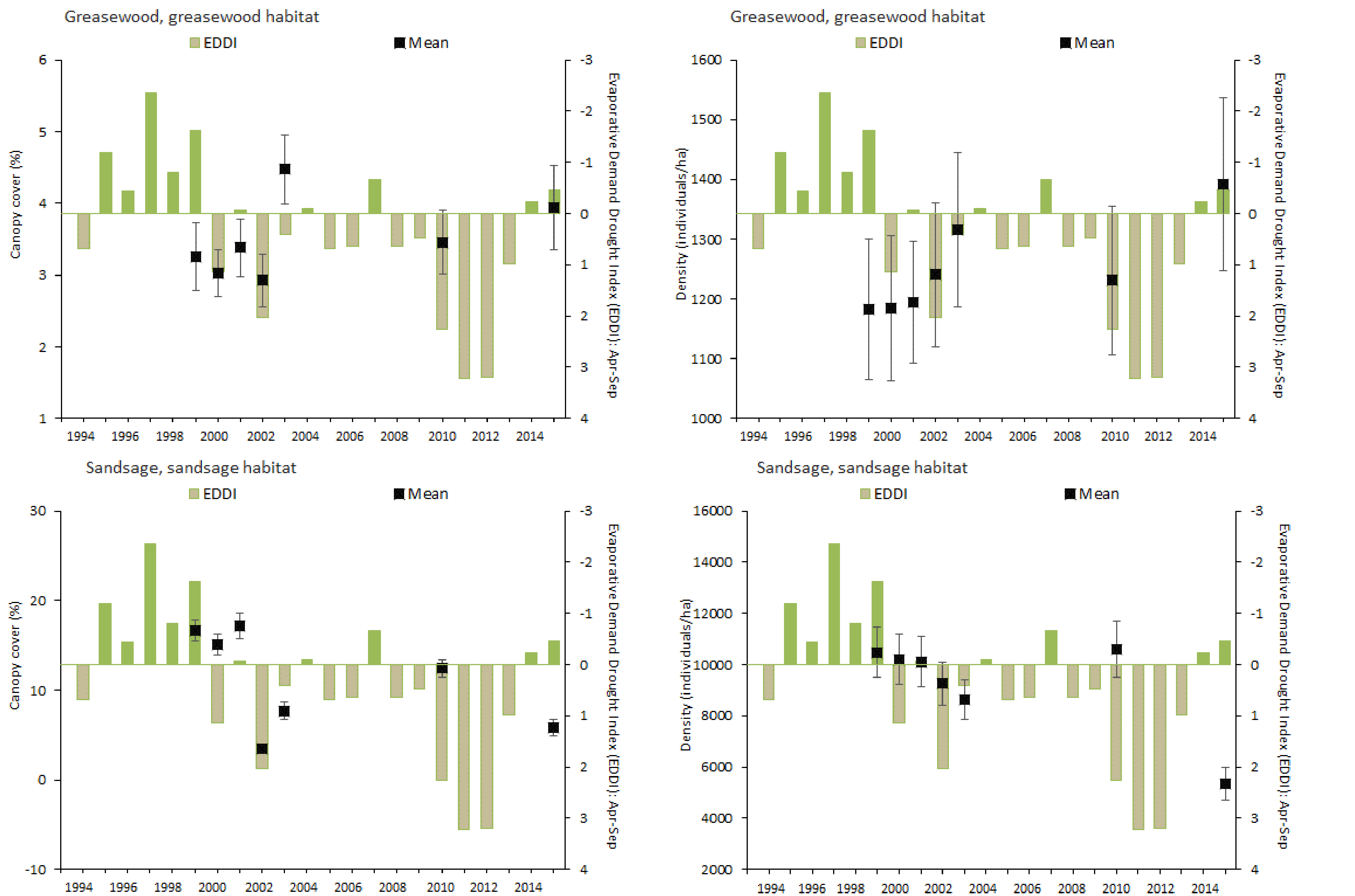

Figure D-2. Greasewood and sandsage mean **cover and density** (± 1 SE) for greasewood (n=13) and sandsage (n=11) habitats.

Rabbitbrush (*Chrysothamnus nauseosus*)

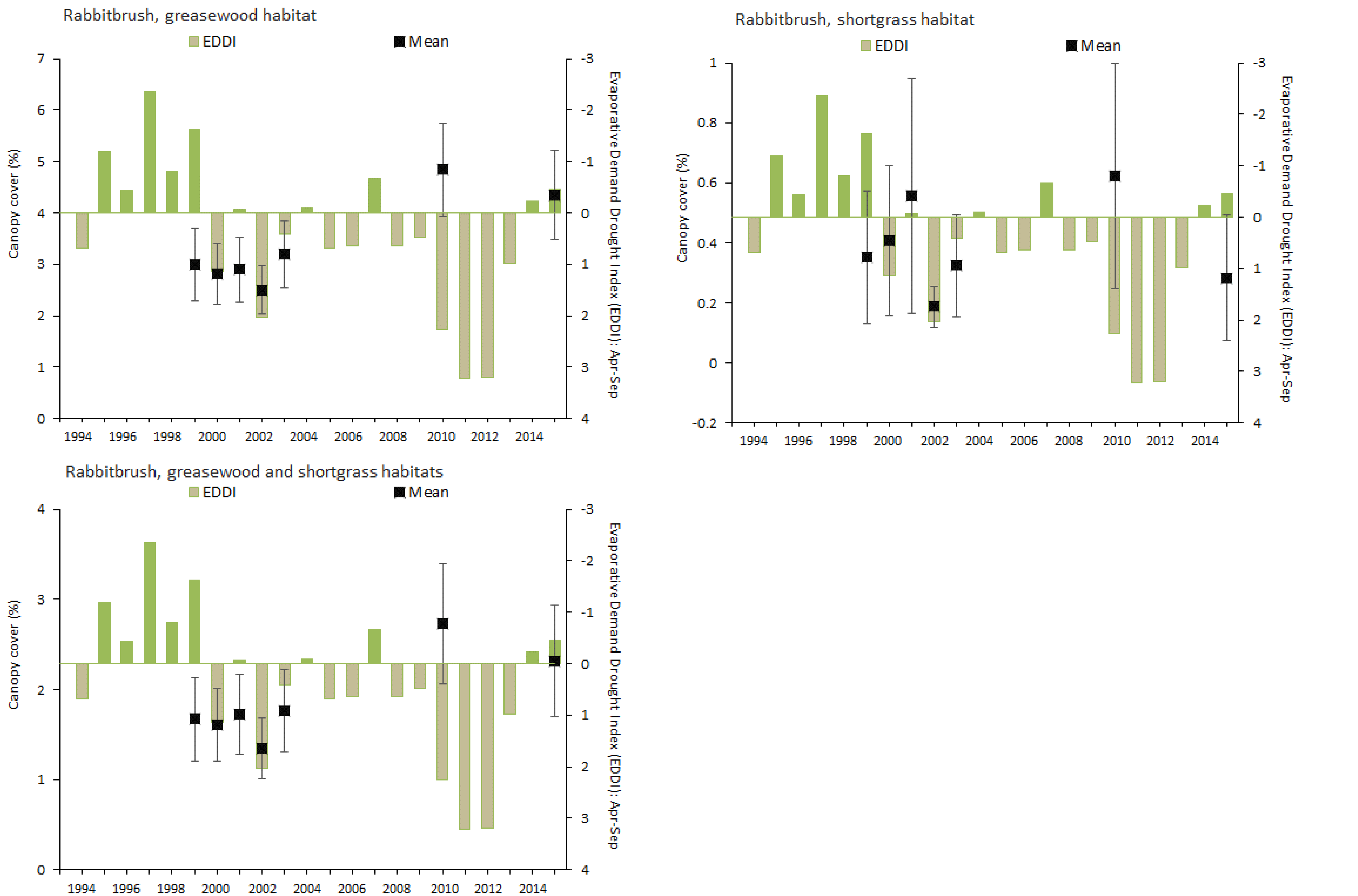

Figure D-3. Rabbitbrush mean **cover** (± 1 SE) for greasewood (n=11), shortgrass (n=11), and both habitats combined (n=22).

Rabbitbrush (*Chrysothamnus nauseosus*)

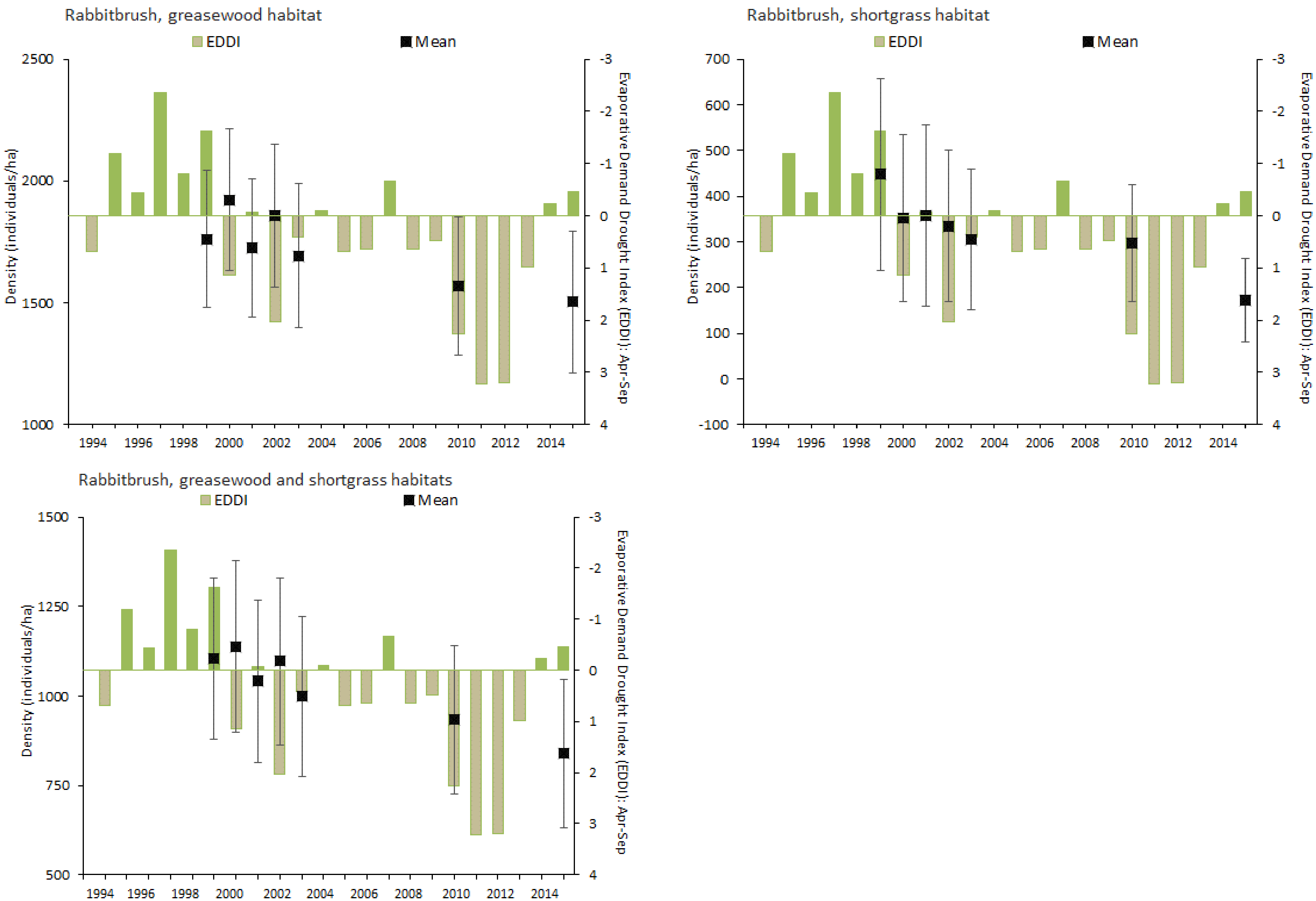

Figure D-4. Rabbitbrush mean **density** (± 1 SE) for greasewood (n=11), shortgrass (n=11), and both habitats combined (n=22).

Cholla (*Cylindropuntia imbricata*)

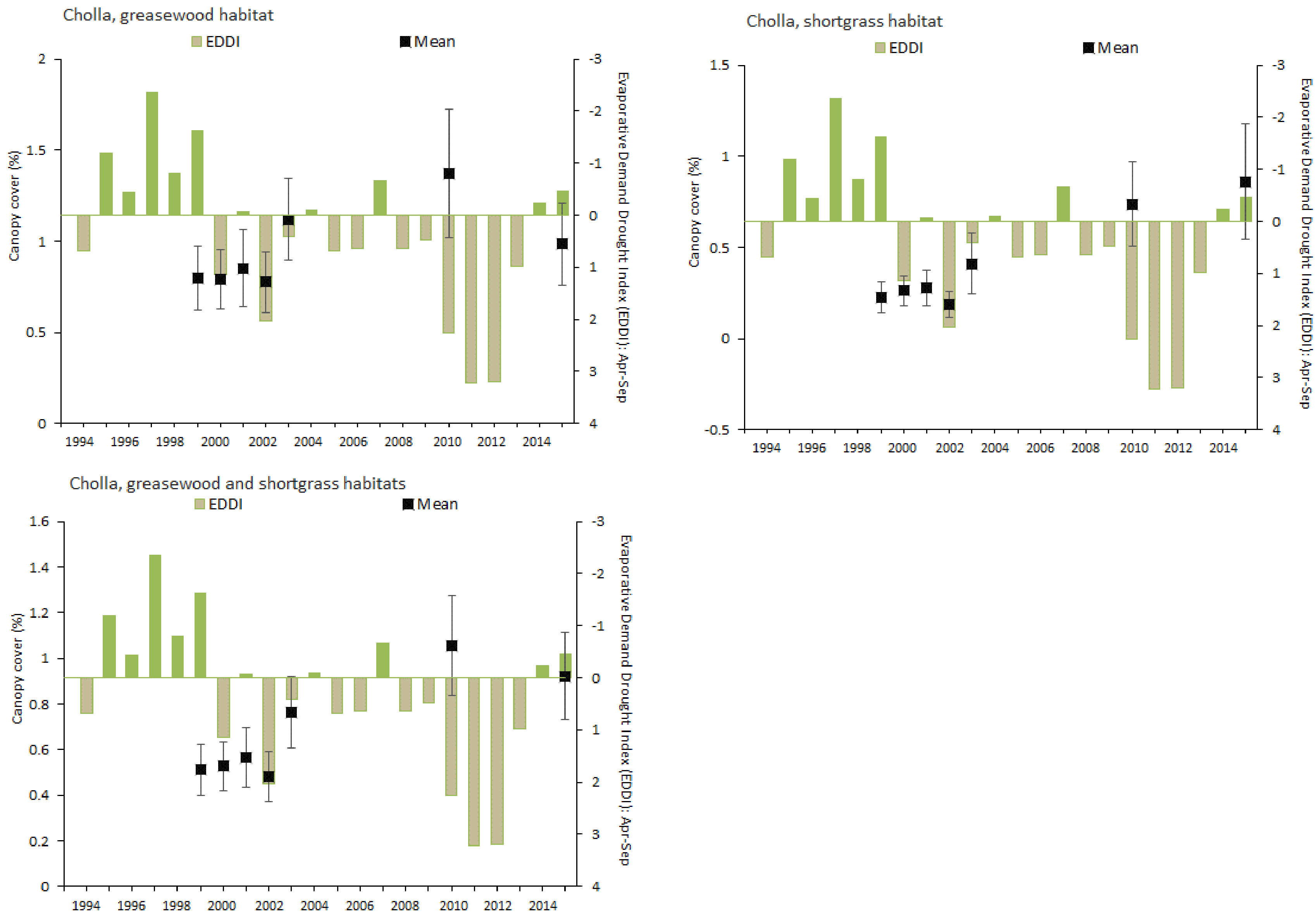

Figure D-5. Cholla mean **cover** (± 1 SE) for greasewood (n=11), shortgrass (n=11) and both habitats combined (n=22).

Cholla (*Cylindropuntia imbricata*)

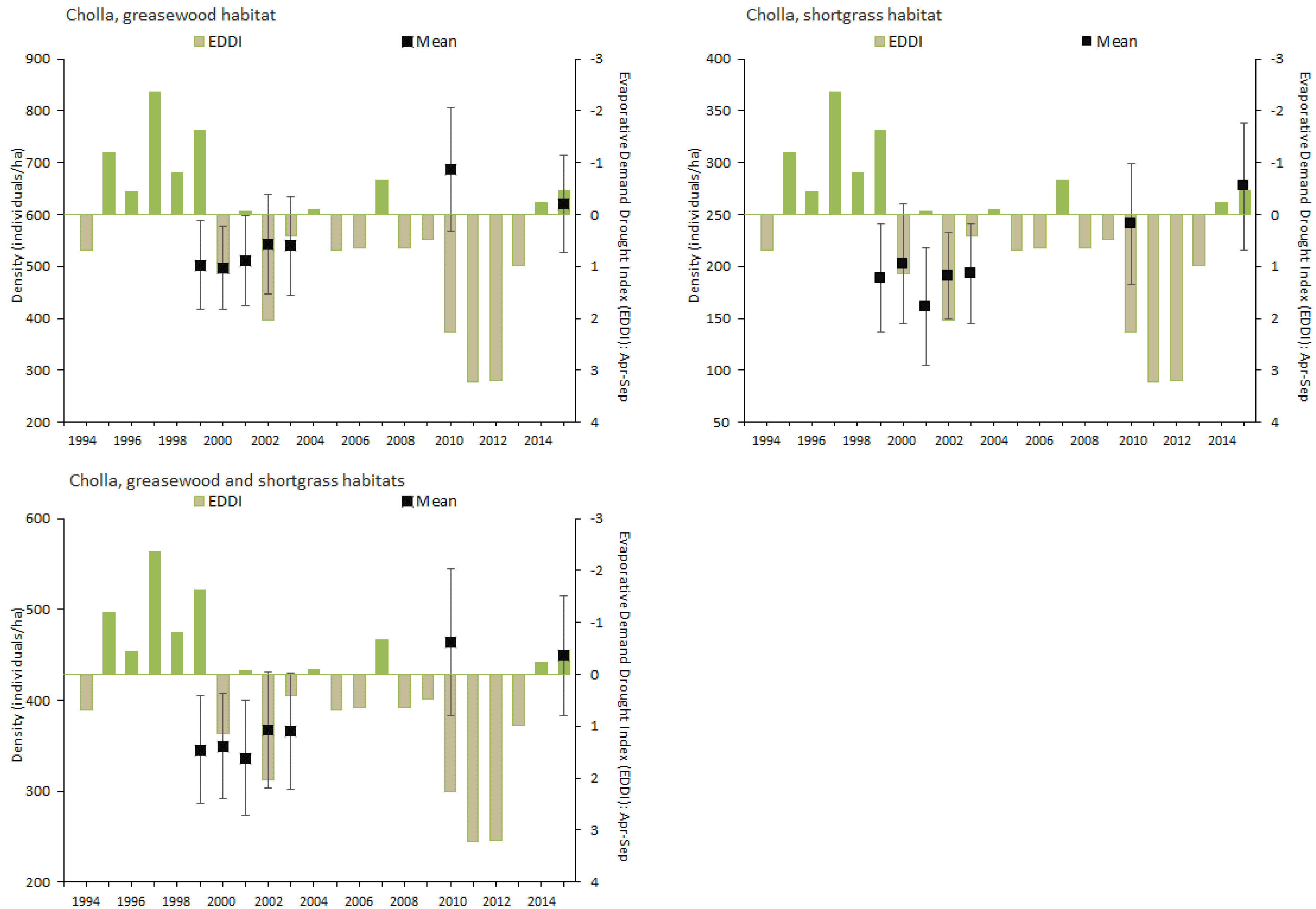

Figure D-6. Cholla mean **density** (± 1 SE) for for greasewood (n=11), shortgrass (n=11), and both habitats combined (n=22).

Prickly pear (*Opuntia* spp.)

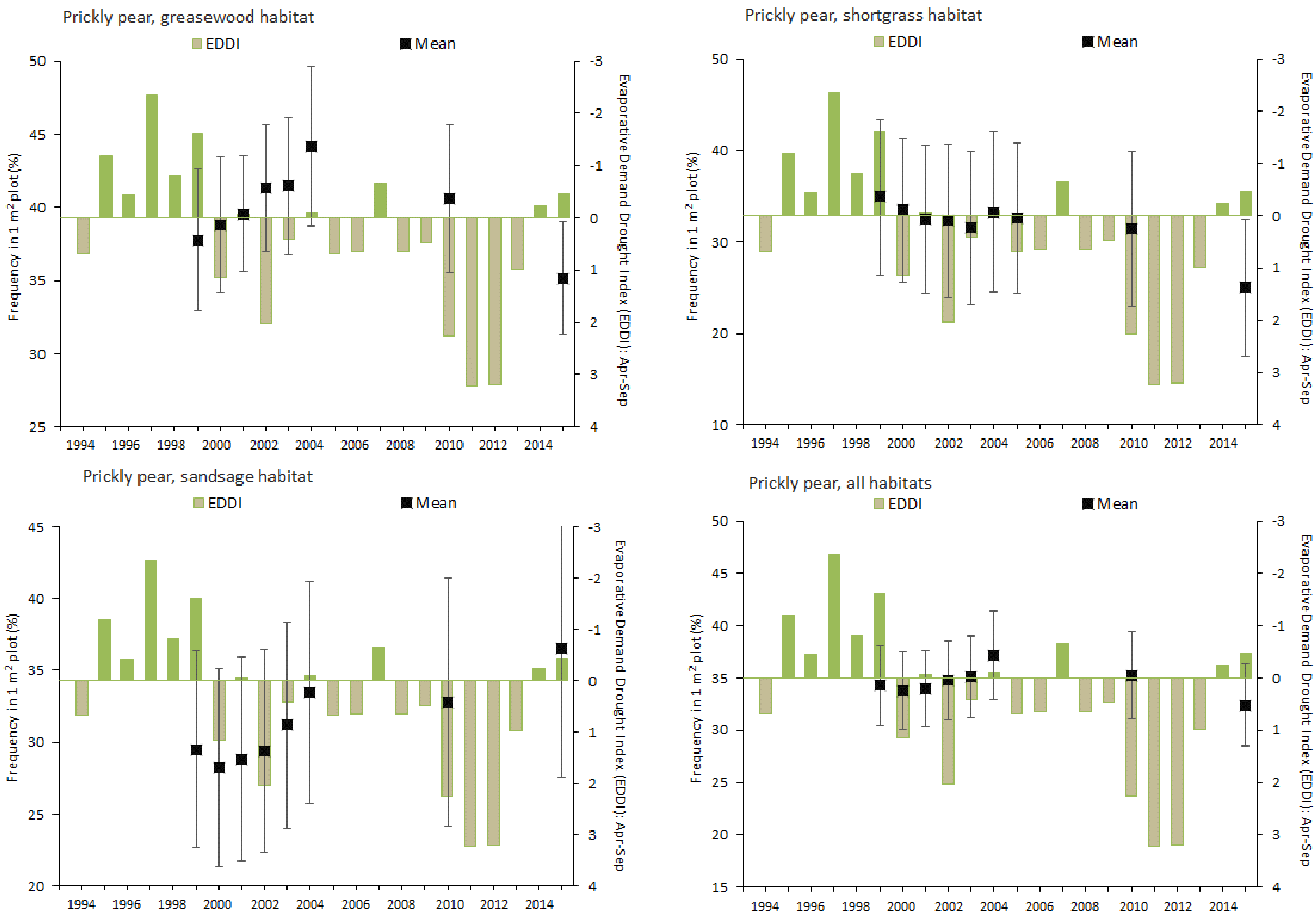

Figure D-7. Prickly pear mean **frequency** (± 1 SE) for greasewood (n=13), shortgrass (n=11), sandsage (n=11), and all habitats combined (n=35).

Blue grama (*Chondrosum gracile*)

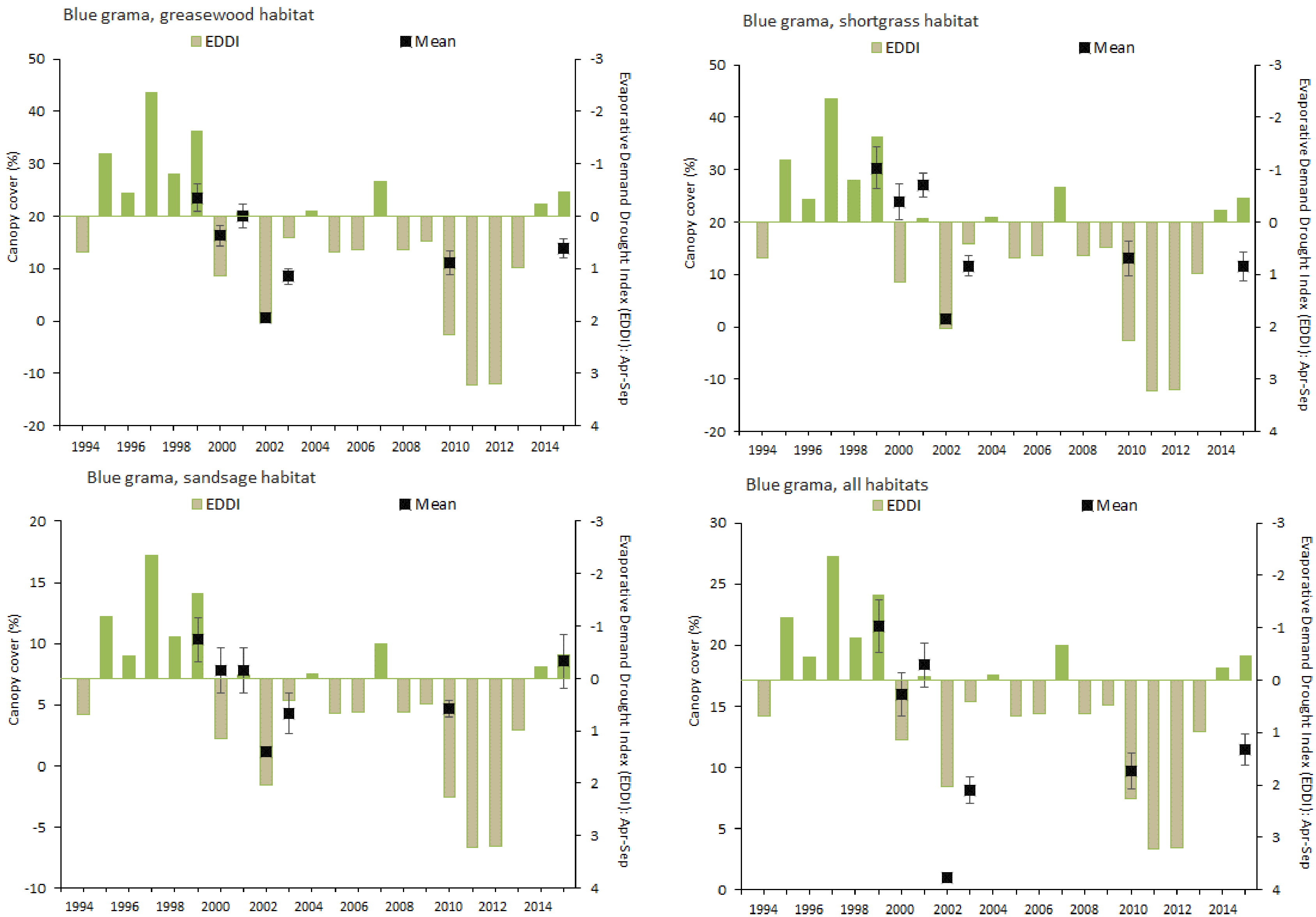

Figure D-8. Blue grama mean **cover** (± 1 SE) for greasewood (n=13), shortgrass (n=11), sandsage (n=11), and all habitats combined (n=35).

Blue grama (*Chondrosum gracile*)

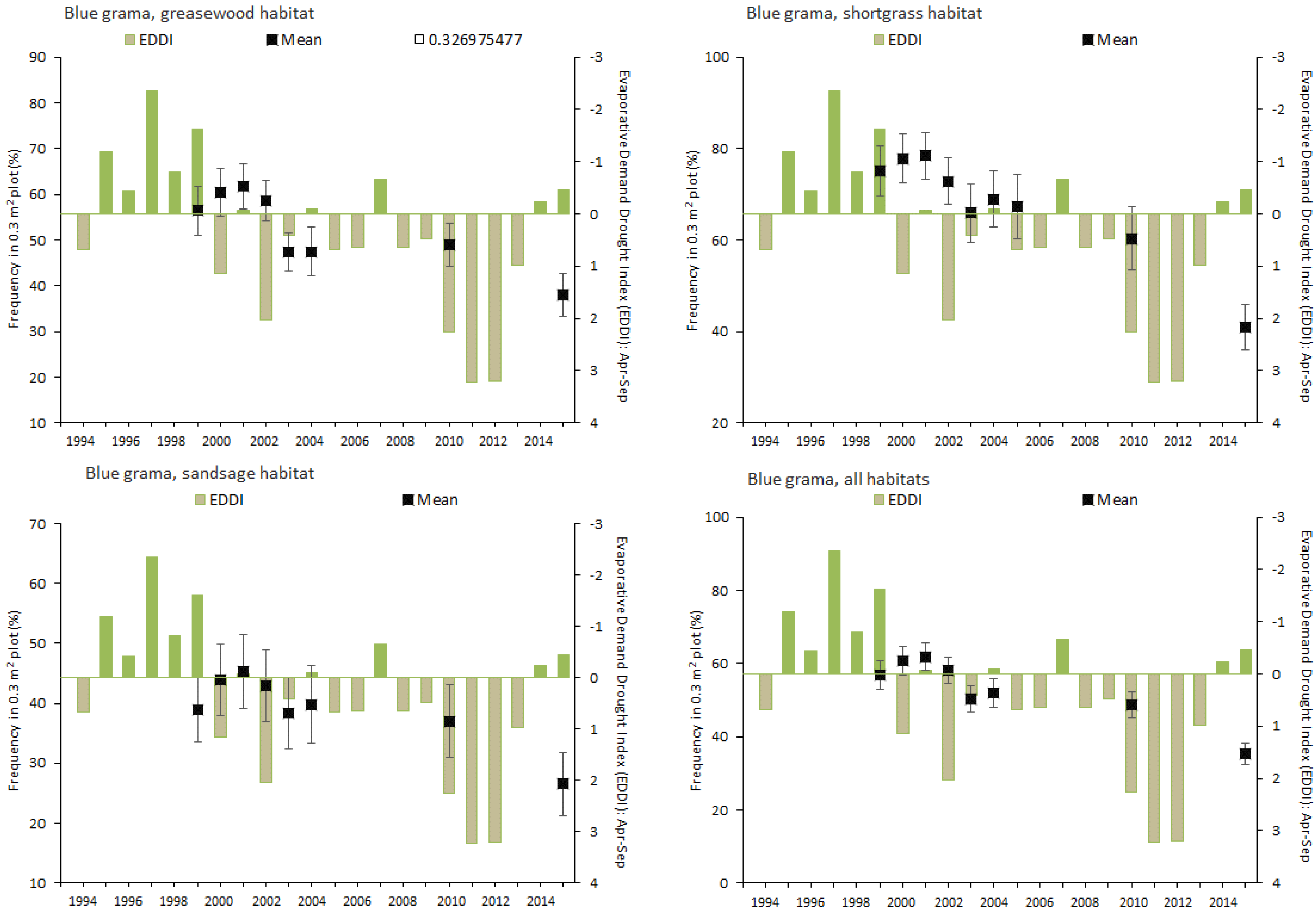

Figure D-9. Blue grama mean **frequency** (± 1 SE) for greasewood (n=13), shortgrass (n=11), sandsage (n=11), and all habitats combined (n=35).

Alkali sacaton grass (*Sporobolus airoides*)

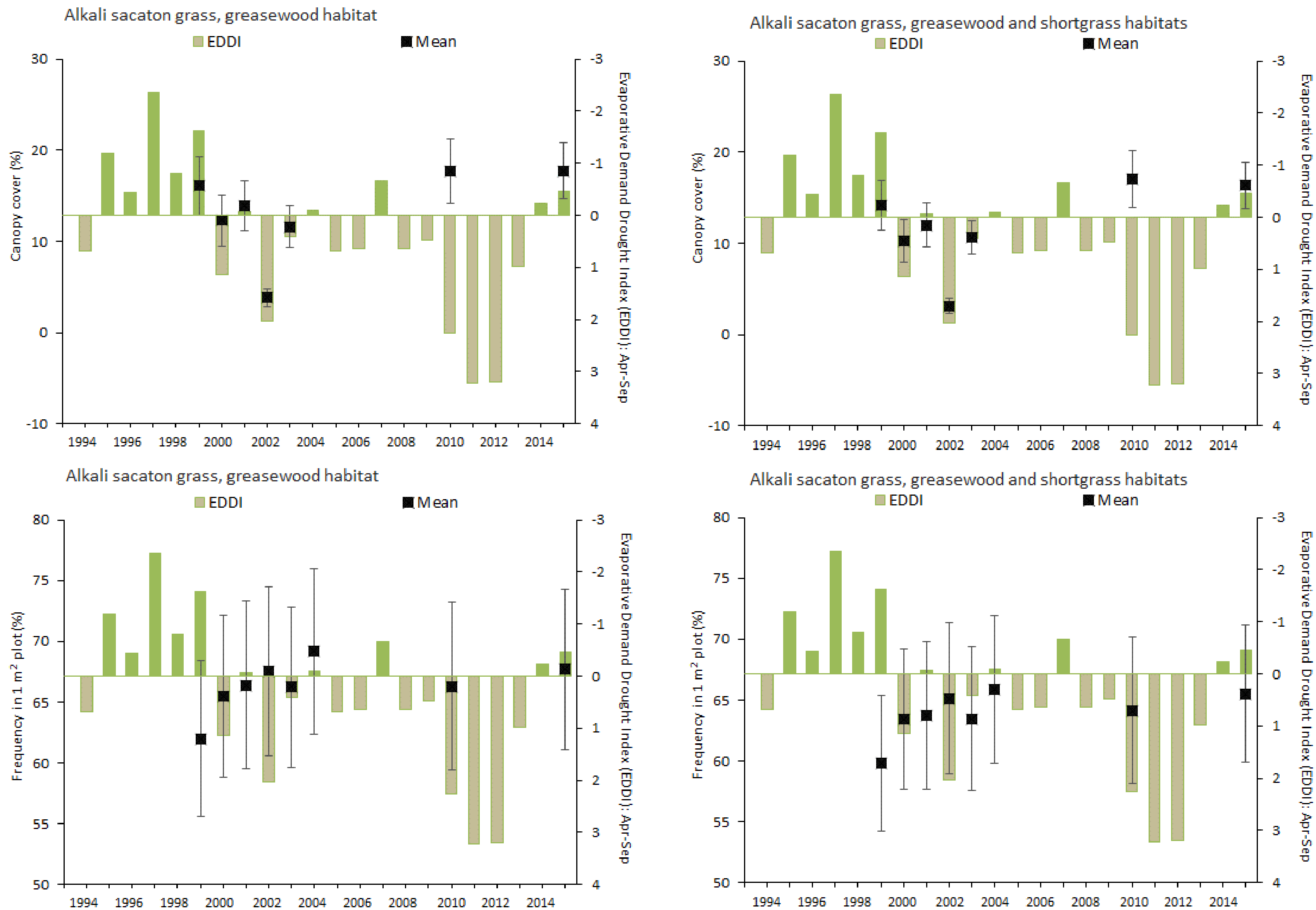

Figure D-10. Alkali sacaton grass mean **cover and frequency** (± 1 SE) in greasewood (n=13) and greasewood and shortgrass combined (n=17). Shortgrass plots that did not have >10% frequency were eliminated.

Galleta grass (*Hilaria jamesii*)

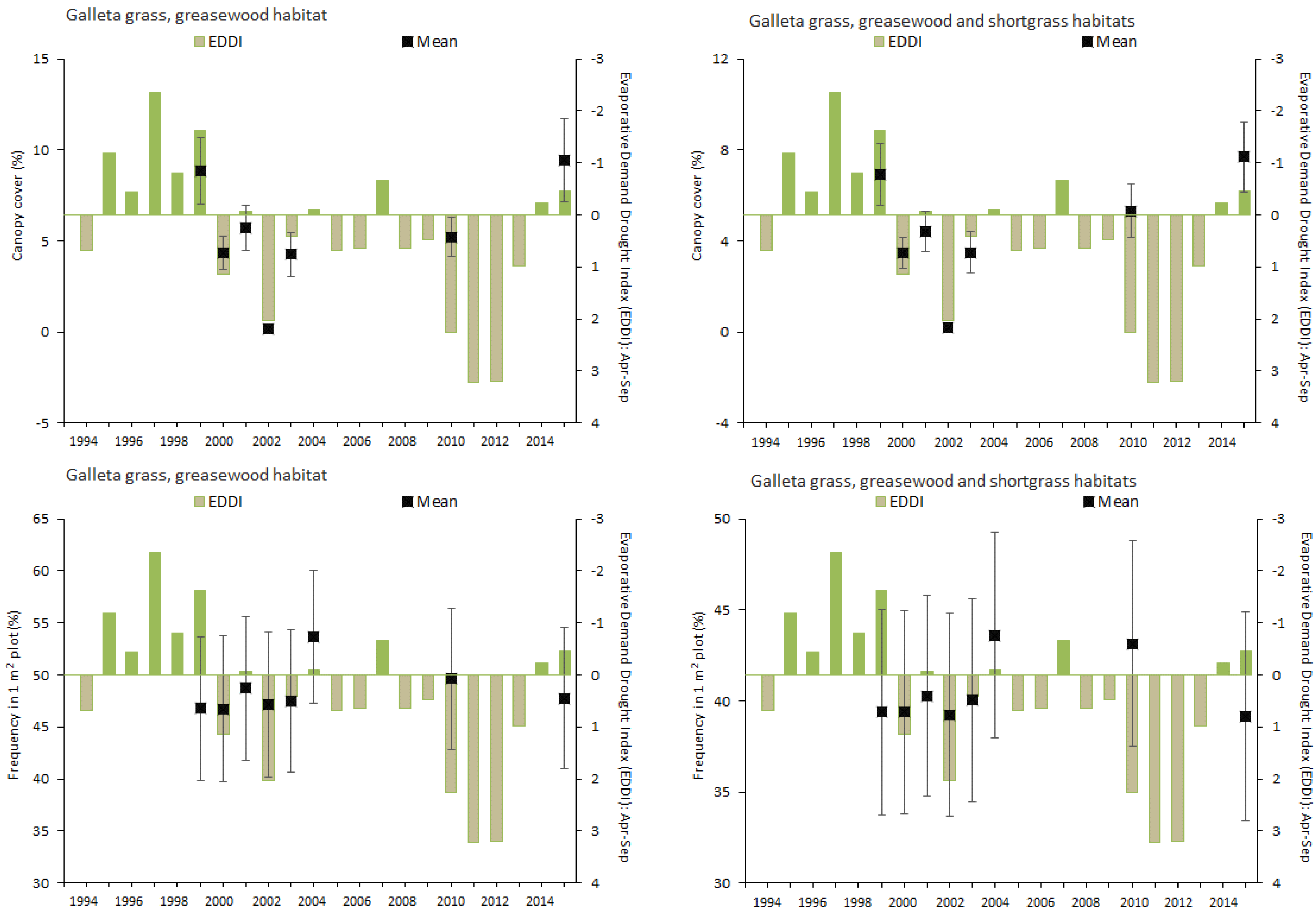

Figure D-11. Galleta grass mean **cover and frequency** (± 1 SE) in greasewood (n=13) and greasewood and shortgrass combined (n=21). Shortgrass plots that did not have >10% frequency were eliminated.

Three-awn grass (*Aristida* spp.)

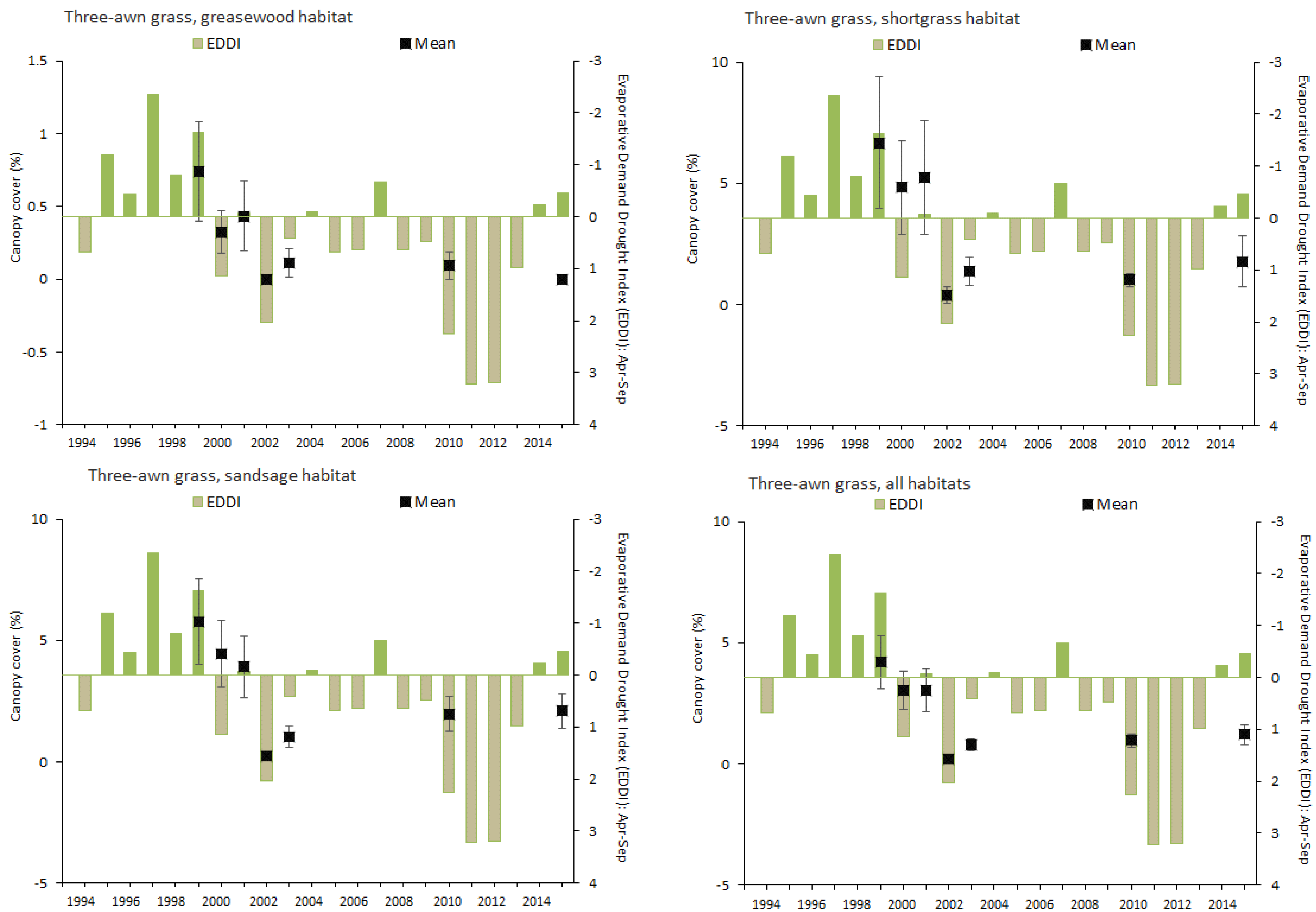

Figure D-12. Three-awn grass mean **cover** (± 1 SE) for greasewood (n=13), shortgrass (n=11), sandsage (n=11), and all habitats combined (n=35).

Three-awn grass (*Aristida* spp.)

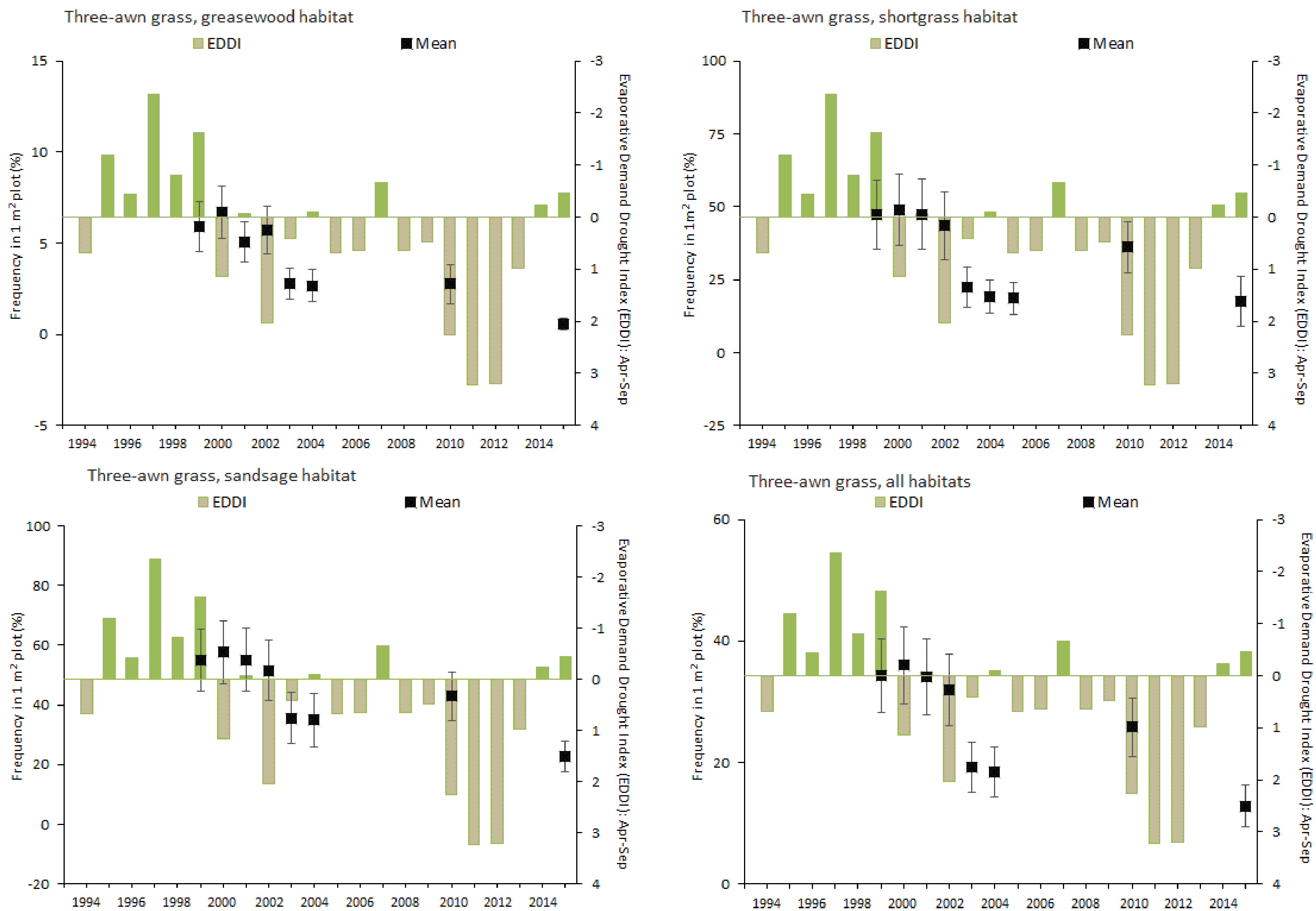

Figure D-13. Three-awn grass mean **frequency** (± 1 SE) for greasewood (n=13), shortgrass (n=11), sandsage (n=11), and all habitats combined (n=35).

Sand dropseed (*Sporobolus cryptandrus*)

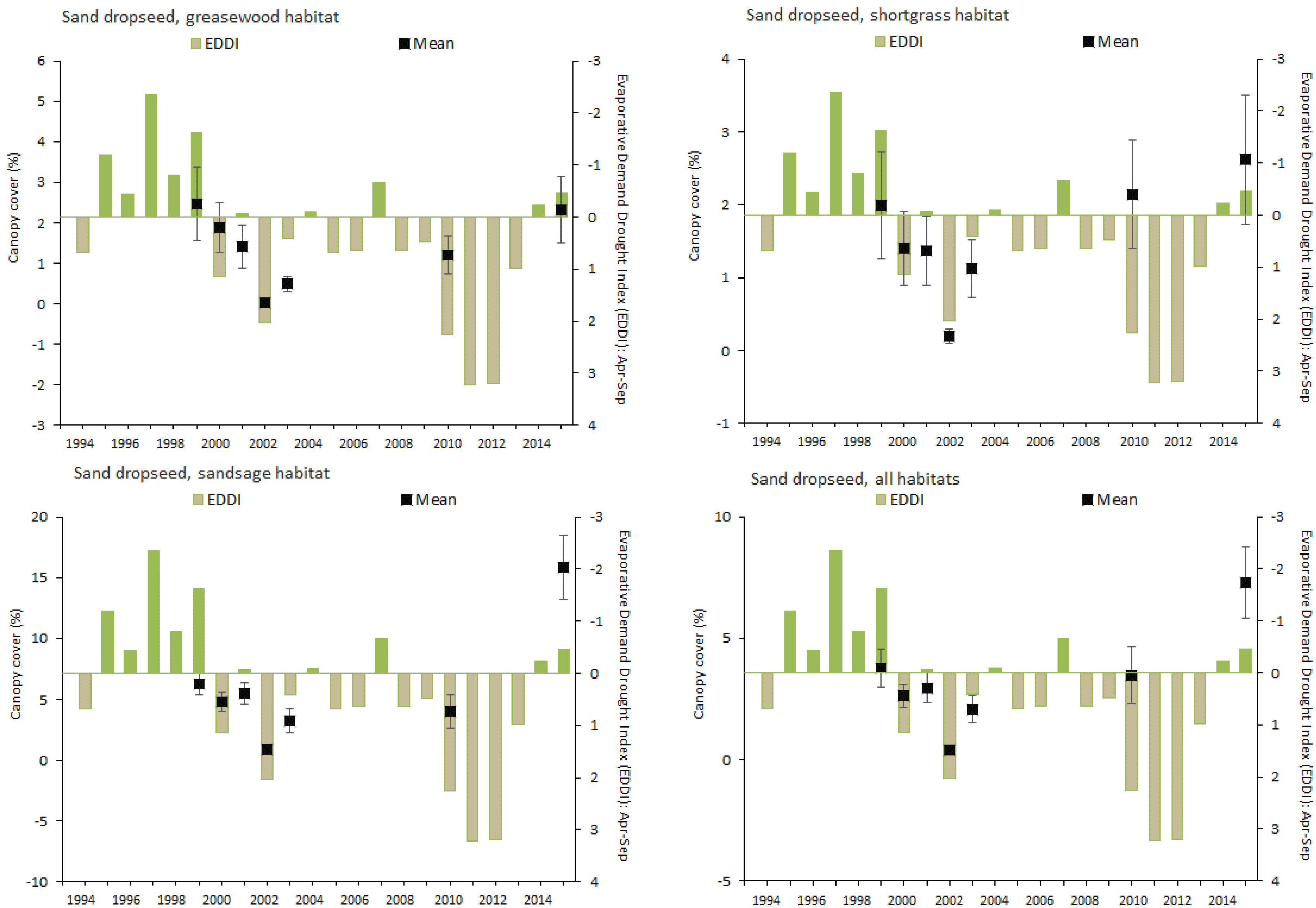

Figure D-14. Sand dropseed mean **cover** (± 1 SE) for greasewood (n=13), shortgrass (n=11), sandsage (n=11), and all habitats combined (n=35).

Sand dropseed (*Sporobolus cryptandrus*)

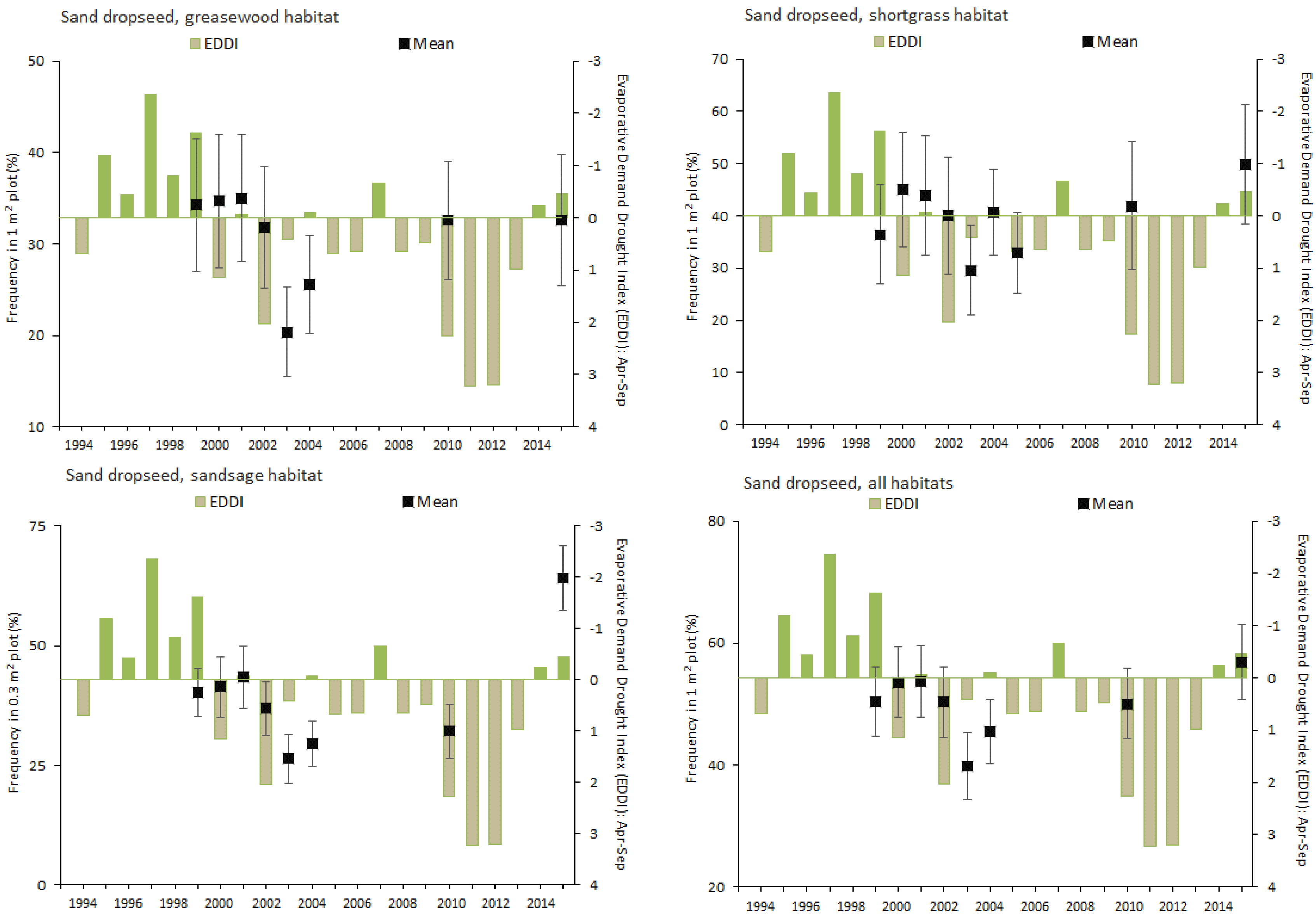

Figure D-15. Sand dropseed mean **frequency** (±1 SE) for greasewood (n=13), shortgrass (n=11), sandsage (n=11), and all habitats combined (n=35).

Kochia (*Bassia* spp.)

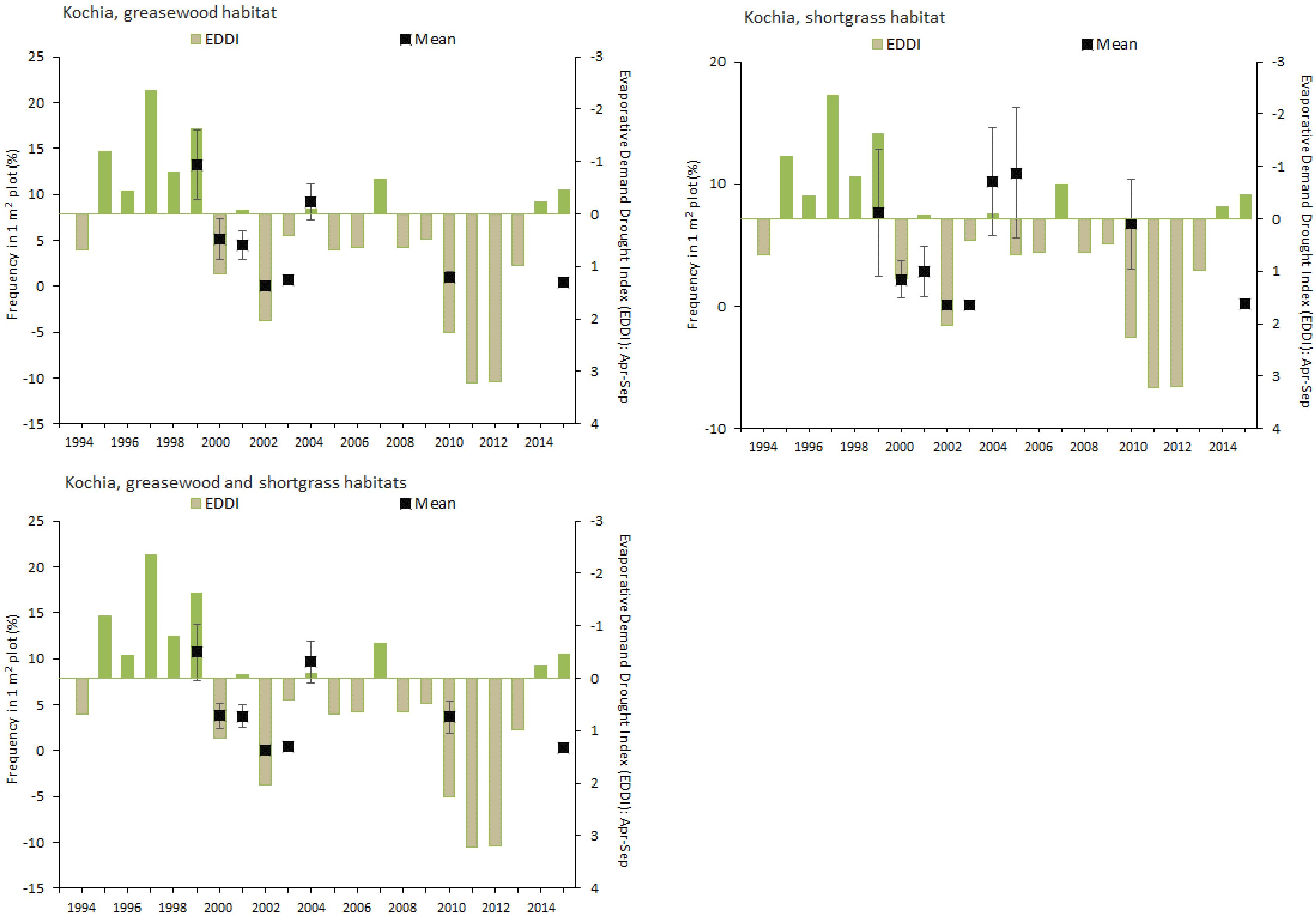

Figure D-16. Kochia mean **frequency** (± 1 SE) for greasewood (n=13), shortgrass (n=11), and both habitats combined (n=24).

Russian thistle (*Salsola* spp.)

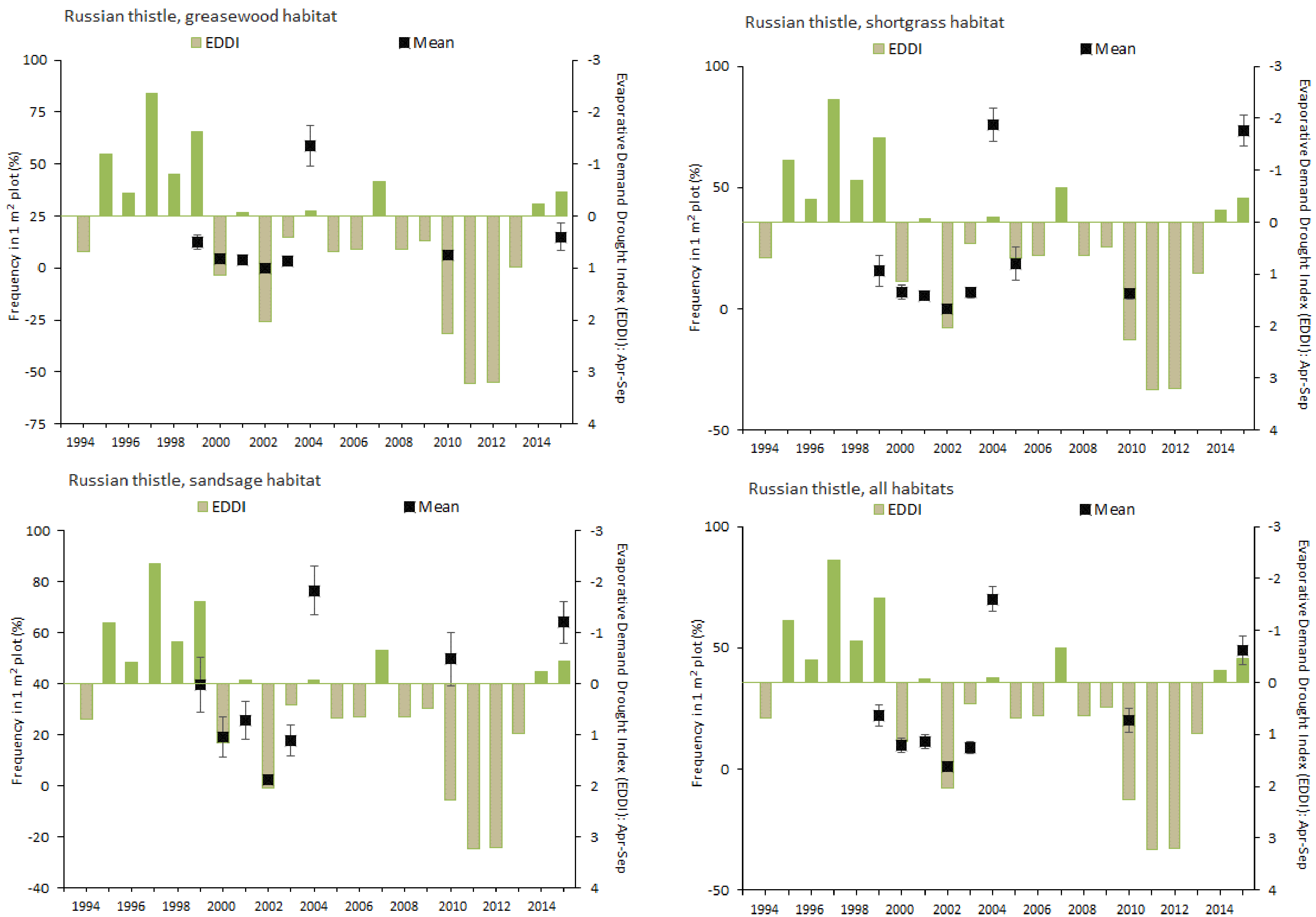

Figure D-17. Russian thistle mean **frequency** (± 1 SE) for greasewood (n=13), shortgrass (n=11), sandsage (n=11), and all habitats combined (n=35).

Bare ground

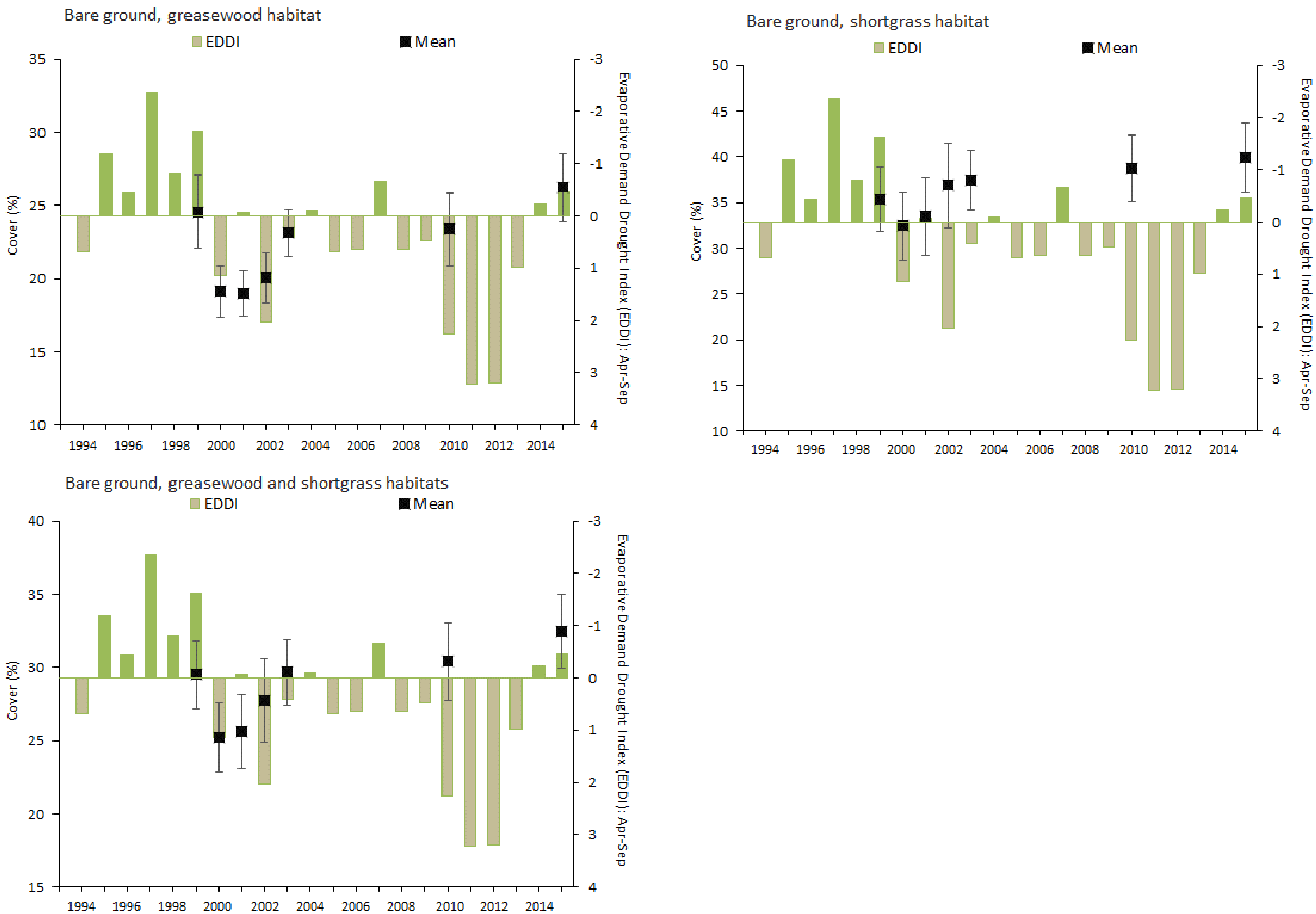

Figure D-18. Bare ground mean **cover** (± 1 SE) for greasewood (n=13), shortgrass (n=11), and both habitats combined (n=24). Bare ground and litter are much more ephemeral and not as easily measured in the sandsage habitat.

Litter

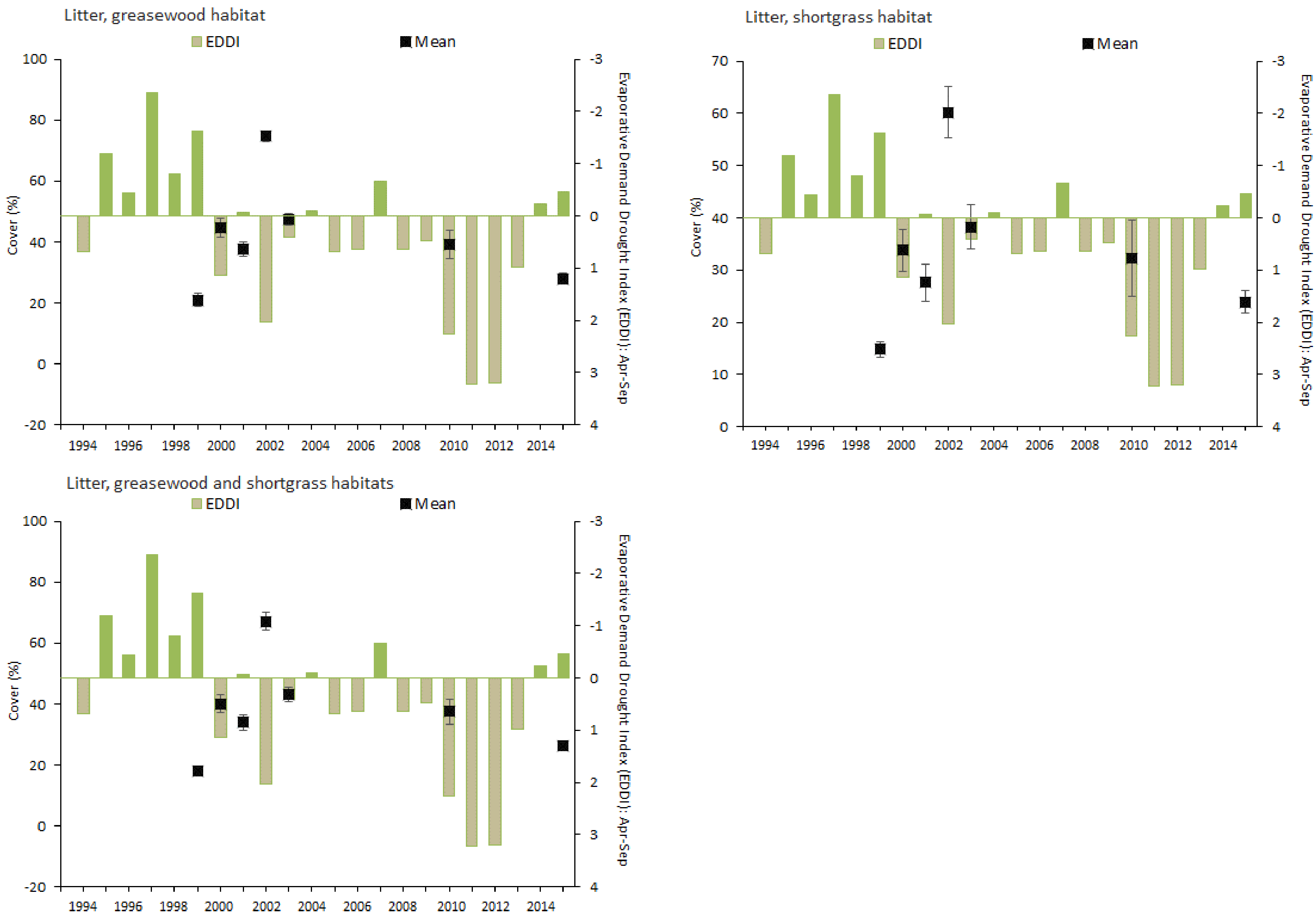

Figure D-19. Litter mean **cover** (± 1 SE) for greasewood (n=13), shortgrass (n=11), and both habitats combined (n=24). Bare ground and litter are much more ephemeral and not as easily measured in the sandsage habitat.

Shortgrass Prairie Dog Plots

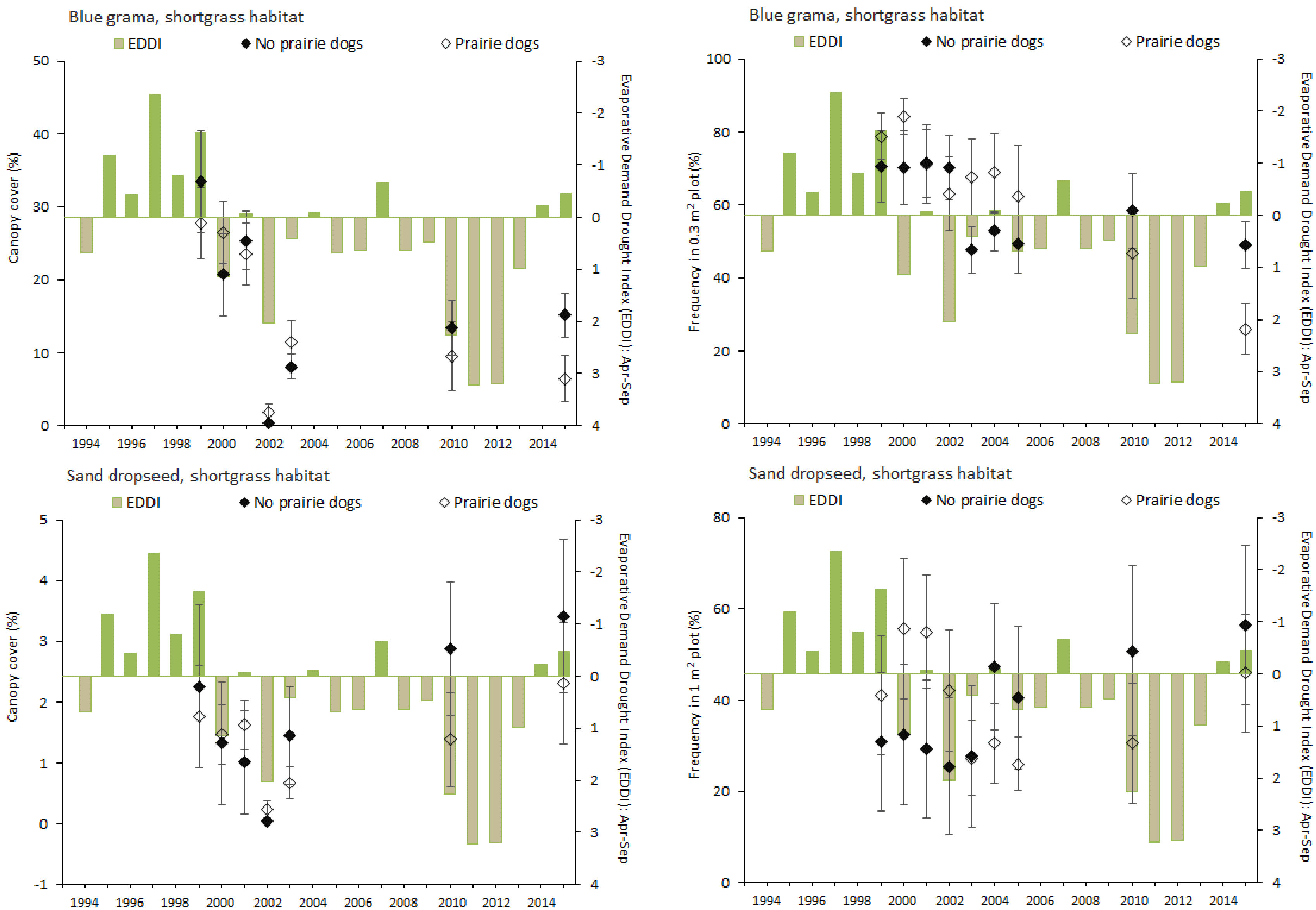

Figure D-20. Blue grama and sand dropseed mean **cover and frequency** (± 1 SE) in shortgrass plots with and without prairie dogs (n=5 no prairie dogs; n=6 (1999-2000), 8 (2001-2010) prairie dogs).

Shortgrass Prairie Dog Plots

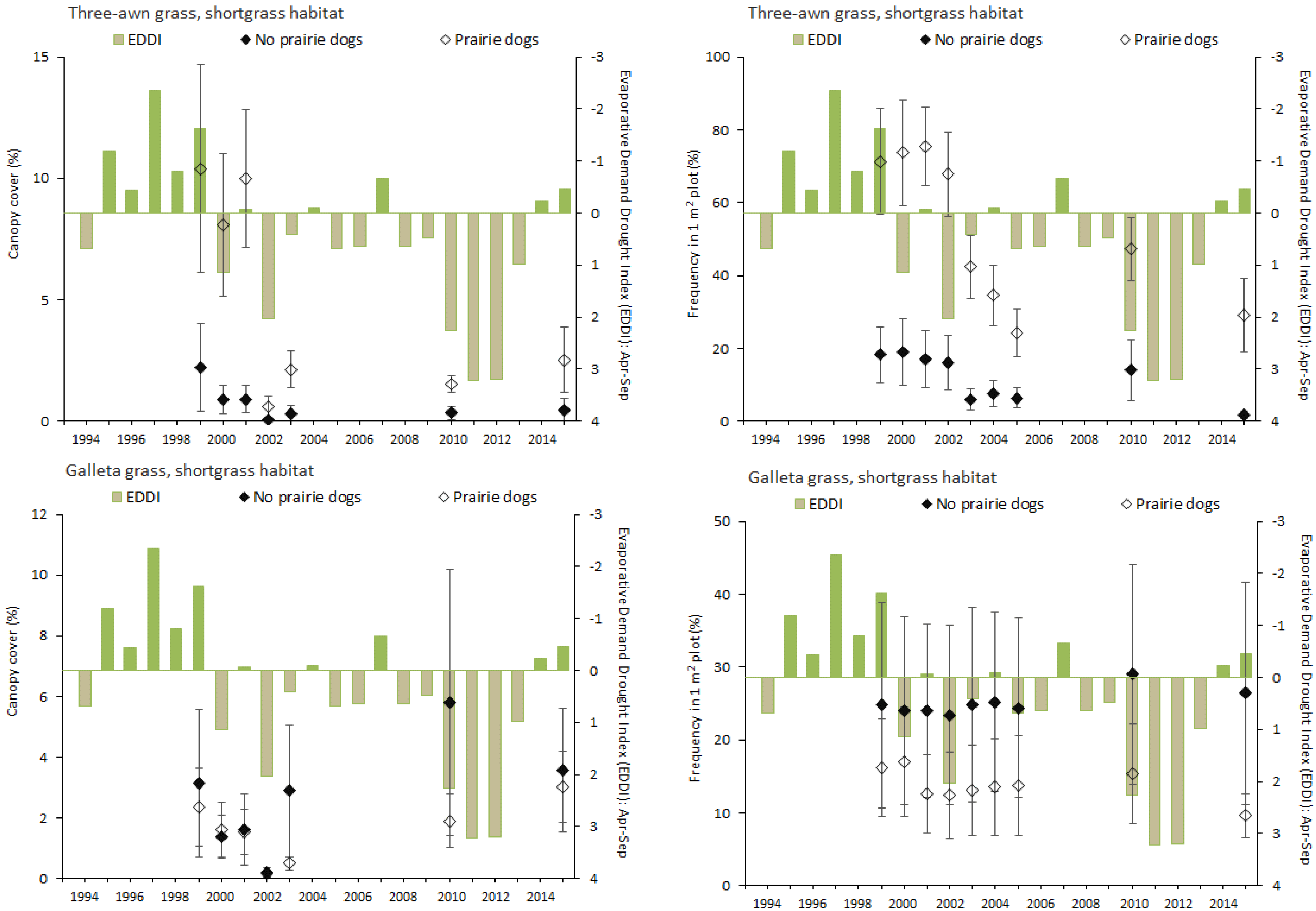

Figure D-21. Three-awn grass and galleta grass mean **cover and frequency** (± 1 SE) in shortgrass plots with and without prairie dogs (n=5 no prairie dogs; n=6 (1999-2000), 8 (2001-2010) prairie dogs).

Shortgrass Prairie Dog Plots

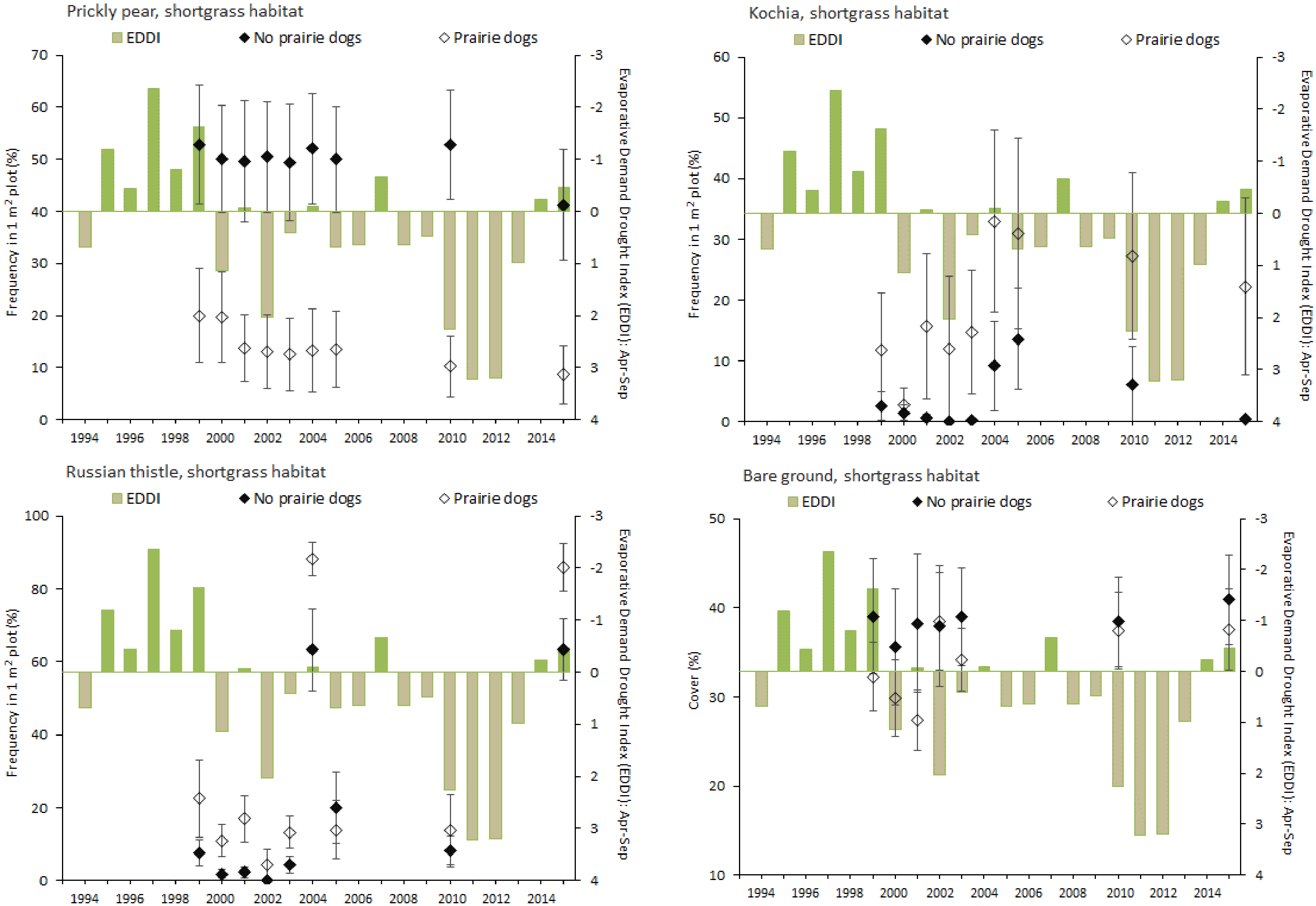

Figure D-22. Prickly pear, kochia, and Russian thistle mean **frequency** (± 1 SE) and bare ground mean **cover** (± 1SE) in shortgrass plots with and without prairie dogs (n=5 no prairie dogs; n=6 (1999-2000), 8 (2001-2010) prairie dogs).