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Natural Resource Stewardship and Science

Plant Community Trends at Tallgrass Prairie National Preserve

1998–2018

Natural Resource Report NPS/HTLN/NRR—2022/2463

ON THE COVER
Lead plant (*Amorpha canescens*) at the Tallgrass Prairie National Preserve, 2018
Photography by

Plant Community Trends at Tallgrass Prairie National Preserve

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Executive Summary

The Heartland Inventory and Monitoring Network monitors plant communities at Tallgrass Prairie National Preserve and evaluates a variety of environmental variables that affect vegetation patterns, including climate and ecological disturbances such as fire and grazing. Here we report on 2002–2018 trends in management actions (fire and grazing) and key plant community indicators. Temperature has increased over the past 50 years in the region. Precipitation and a standardized precipitation-evapotranspiration index included a high degree of interannual variability and did not demonstrate directional change.

We documented a decline in disturbance intensity (i.e., less frequent prescribed fire and lower stocking rates) since 2006. A preserve goal is to maintain 30 to 60% of the area as bare ground (soil and rock) for ideal greater prairie-chicken habitat. Bare areas have been in decline and minimally meet the goal preserve wide. Bare areas vary by pasture and year, with bare areas exceeding the threshold in earlier years and Big Pasture and Red House Pasture falling short in some recent years. Although the preserve-scale mean minimally met the objective, there was a great deal of heterogeneity across monitoring sites. Litter cover and depth were greater than ecological recommendations for the greater prairie-chicken, especially in 2018. Litter depth demonstrated a great deal of variability and included deep litter. Woody plants were targeted to remain below 5% cover. Preserve- and pasture-scale cover means were well below this threshold but are increasing.

Species richness on a per site basis (alpha diversity) and preserve-wide richness (gamma diversity) showed no apparent directional change when corrected for differences in sample size. Comparison of native species composition between 2002 and 2018 revealed a 36.9% difference in the Sørensen Index, although observer error accounted for almost 2/3 of this apparent change. The preserve continues to have characteristic tallgrass prairie species, and nonnative species continue to be low. Similar to targeted invasive plant monitoring, we found the target species Kentucky bluegrass to be below park thresholds. Continued evaluation of fire frequency and grazing intensity will be critical to achieving ecological goals including conserving the greater prairie-chicken. Development of a grazing plan may assist with prescribing stocking rates that are consistent with the preserve’s ecological and cultural objectives and could include alternative herbivores, such as goats or expansion of bison.

Acknowledgments

We are grateful to the many botanists and technicians who have assisted with data collection and processing over the history of this project. We appreciate access and support from staff at Tallgrass Prairie National Preserve. Grazing data were collected and provided by The Nature Conservancy. A. Runyon provided climate analysis. We are also grateful to peer reviewers for help improving this manuscript.

Introduction

Tallgrass Prairie National Preserve, located in the heart of the Flint Hills geographic province (Kindscher et al. 2011), protects 10,894 acres (4409 ha) of remnant tallgrass prairie. The tallgrass prairie ecosystem is imperiled and the public-private partnership that protects this ecosystem and rich cultural history is unique (NPS 2000). Natural resource managers apply ecological disturbances such as fire and grazing to maintain habitat for the many species of plants and animals that live there. Because these organisms have disparate needs, the principle of heterogeneity guides the application of management techniques, providing a wide array of conditions, vegetation structures, and microhabitats to maximize biodiversity at the landscape scale (Hase 2016; Leis et al. 2013).

The greater prairie-chicken, found at the preserve, is an iconic species that requires heterogeneous habitat for its life cycle. Bare areas are used for lekking, warming, and finding insects to eat. More densely vegetated areas are often used for nesting and escape cover, while areas with a grass canopy and open ground layer are favored for chicks to navigate in safety while feeding (McKee 1998; Svedarsky et al. 2003). Ideally, these distinct structures must be in a matrix of grasses and forbs and within juxtaposition to one another. Because such heterogeneity also provides habitat for a variety of other organisms, managing for prairie-chickens provides an effective goal for the whole community (Fuhlendorf et al. 2006).

To achieve heterogeneity across the preserve, prescribed fire intervals are planned to range from 1–3 years in burn units (Hase 2016). Grazing is also deployed using a variety of grazing systems including moderate stocking rates. Fire frequency of the land that eventually became the Tallgrass Prairie National Preserve varied through historical periods, with the period from the late 1970s to the preserve's establishment in 1996 being very frequent at 1–3 years (Earls 2006). Fire frequency and grazing intensity have been reduced from nearly annual burns to more variable fire frequency since 2006 (Leis and Morrison 2018). Key indicators of desired vegetation conditions identified by preserve staff include bare areas, litter, and low abundance of woody and nonnative plants.

The Heartland Inventory and Monitoring Network began monitoring plant community trends in 1997 at the preserve. Herein, we report on trends in management actions (fire and grazing) and key plant community indicators for monitoring from 2002–2018.

Purple prairie clover (*Dalea purpurea*) among the rocks at Tallgrass Prairie National Preserve, 2018.

Methods

Study Site

The preserve is nearly 11,000 acres, although our monitoring and analyses have focused on the western preserve where long-term monitoring sites were installed (Figure 1). This approximately 10,000-acre (4,047 ha) portion of the preserve is remnant tallgrass prairie. The preserve is embedded in a matrix of remnant rangelands within the Flint Hills of Kansas. Monitoring sites were located primarily in the tallgrass prairie vegetation type with some sites in the rocky mixed prairie type (Figure 1; Kindscher et al. 2011).

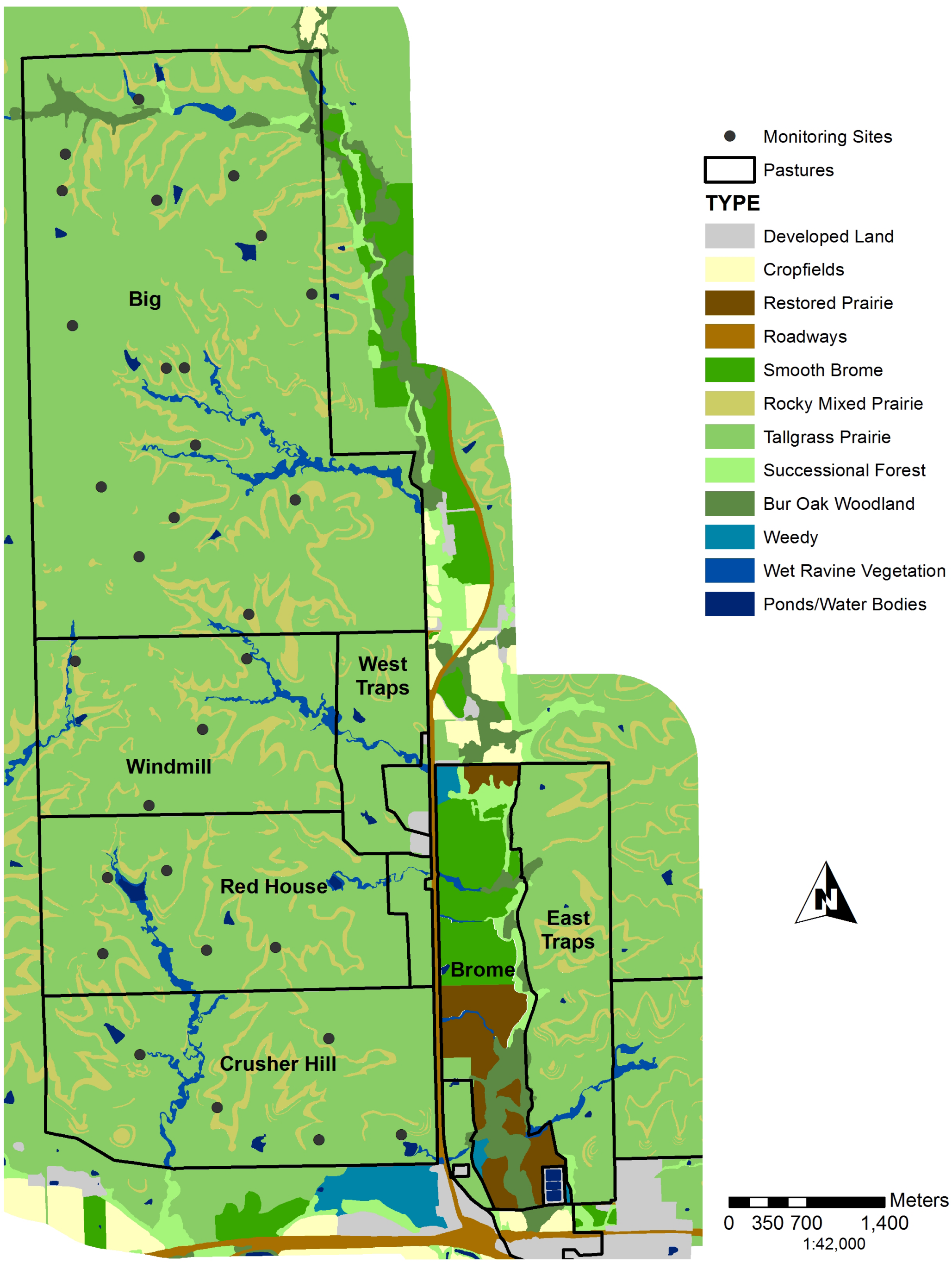

Figure 1. Vegetation types with respect to long-term monitoring sites at Tallgrass Prairie National Preserve.

Sampling Design

We established vegetation monitoring sites in the prairie beginning in 1997 and the design was finalized in 2002 (Figure 1; HTLN 2021). See James et al. (2009) for details on sampling design. Monitoring methods followed the prairie standard operating procedures outlined in the vegetation community monitoring protocol (James et al. 2009). Monitoring sites were 50 m x 20 m (0.1 ha) in size with two focal transects bounding the site on the 50-m sides (Figure 2). Ten subplots were established in each site along the 50-m transects. Each subplot consisted of a series of nested frames (0.01 m^2, 0.1 m^2, 1 m^2, and 10 m^2), but only observations at the 10-m^2 scale were summarized to the site scale (0.1 ha) for this study.

Data Summary

We included vegetation data from 2002–2018 in our analyses. Vegetation data were collected annually from 2002 to 2008, and then in 2010, 2014, and 2018 (n = 10 sample years). The revisit design changed through time (DeBacker et al. 2004; James et al. 2009) from a two season (mid-May, early October), annual visit type with a core of 18 sites to a one season (mid-June), one-visit-every-four-years rotating panel design with 30 sites. Conversion of the two-season sampling to a single dataset was done by using the maximum cover of the two seasons for each species observed.

Sample inclusion was guided by analyses conducted by Leis and Morrison (2018) who determined that the original core 18 and final core 30 sites came from the same population. The original 18 core sites were included in the final 30 core sites (Figure 2) and some of the 30-core sites were sometimes included as panel sites in prior years. The 30 core sites were included in any year that they were sampled. This resulted in the preserve-scale sample sizes given in Table 1.

Table 1. Sample size for monitored years at Tallgrass Prairie National Preserve, Kansas.

Year	Sample Size (N)
2002	19
2003	19
2004	19
2005	20
2006	25
2007	24
2008	23
2010	30
2014	30
2018	30

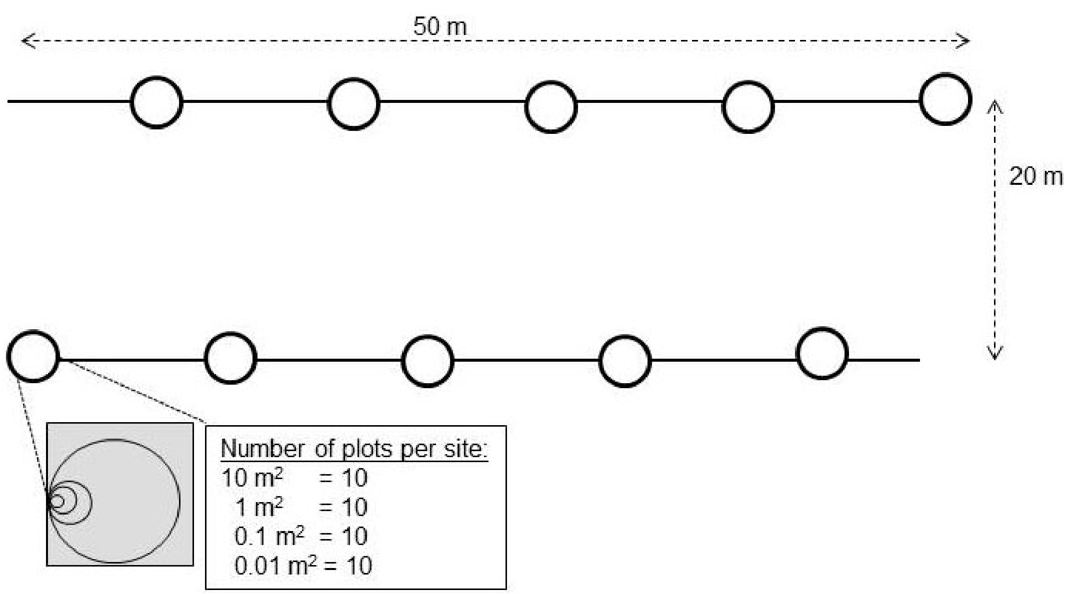

Figure 2. Heartland Inventory and Monitoring Network basic long-term vegetation monitoring sampling site design. Each site consists of 10 nested plots.

Site values were used to calculate pasture- and preserve-scale statistics. Vegetation monitoring at Tallgrass Prairie National Preserve consists of ground cover, ground flora species, and tree regeneration observations.

Vegetation and ground cover data were collected using a modified Daubemire cover class system in the 10-m^2 subplots (Table 2; James et al. 2009).

Table 2. Modified Daubenmire cover value scale used to determine ground cover for the Heartland Network Parks.

Cover Class Codes	Range of Cover (%)	Class Midpoints (%)
7	95-100	97.5
6	75-95	85.0
5	50-75	62.5
4	25-50	37.5
3	5-25	15.0
2	1-5	2.5
1	0-0.99	0.5

Climate

We evaluated historical (1895–2020) trends using the NOAA monthly U.S. Climate Gridded dataset (NClimGrid; Vose et al. 2014), which represents climate conditions for the continental U.S. as a 5- km gridded surface. The reference period (1895–1970) characterizes historical climate patterns. The trend for the current period (1971–2020) can then be compared to the reference period. Climate data was derived from the 5-km grid cell that includes the Tallgrass Prairie National Preserve centroid (Latitude = 38.45, Longitude = -96.57) and included precipitation and temperature, from which the Standardized Precipitation-Evapotranspiration Index (SPEI) was derived (see Runyon et al. 2021 for detailed SPEI methods). The SPEI was used to characterize drought periods, with values <0 indicating drought and values >0 indicating wet periods. SPEI represents climatic water deficit (precipitation minus potential evapotranspiration [PET]) and provides an assessment of water deficit or surplus that can influence vegetation (Li et al. 2019; Vicente-Serrano et al. 2010). The R package SPEI was used to calculate the metrics (Beguería and Vicente-Serrano 2017).

SPEI is calculated as the monthly difference (D) of precipitation (P) and PET (Thornthwaite 1948; Buytaert and De Bièvre 2012):

$$Di = Pi - PETi$$

Recent Fire History

Fire history records (primarily prescribed fire) for 1998 to 2020 are included. Recent fire history for Tallgrass Prairie National Preserve was determined using a fire history geodatabase (Leis 2022). Although preserve management included fire for much of the last century, earlier years (pre-1998) must be evaluated qualitatively. A 30-m buffer was constructed from the center point of each monitoring site. If the buffered area was greater than 30% burned (i.e., ≥848 m^2), the whole site was considered burned. On-the-ground observations since 2009 validated the spatial data. Time since last fire (TSF) was then calculated from this dataset for each monitoring site-year combination. We did not account for seasonality in the time since fire calculations; rather we assigned burned status on an annual basis. We used a histogram approach to visualize and understand trends at the preserve and pasture scales.

Stocking Rates

Annual grazing data were collected from the preserve leasee, stored in a Microsoft Access database and used for stocking rate calculations. Rates were based on a 750-lb (340.2 kg) animal, as stocker cattle are typically used for grazing. Grazing systems through time at Tallgrass Prairie National Preserve have included pasture-based intensive early stocking (Smith and Owensby 1978), modified intensive early stocking (less than double stocking rates or extended season, based on preserve records), season long stocking (six months; Holechek et al. 2001) and patch burn grazing (implemented in Big Pasture in 2006; Fuhlendorf and Engle 2001; Leis et al. 2013). Bison replaced cattle in Windmill Pasture beginning in 2009. Data for Crusher Hill Pasture in 2006 were not used because stocking rates could not be adequately determined. Weight-based calculations were not available for bison, so we did not include stocking data beginning in 2010 for Windmill pasture.

Ground Cover

Ground cover was assessed using cover classes (Table 2). A site mean was calculated by averaging the cover class midpoints for ten subplots in each site. We observed foliar cover of grass litter, leaf litter (deciduous plant leaves), exposed rock, bare soil, and the cover of woody debris (e.g., branches and sticks). Total unvegetated area reflects space unoccupied by stem basal area in the subplots (James et al. 2009). Exposed rock and bare soil were combined into a "bare" class during analysis. We also measured litter depth in each plot in 2018. Three litter measurements in each plot were averaged and the plot means were used to create a site level mean for litter depth.

Community Diversity

Native plant community richness metrics evaluate how species richness differs across monitoring sites and the park. We limited these calculations to native ground flora species (not including tree regeneration).

Alpha diversity is synonymous with species richness at the site scale (i.e., mean number of species per monitoring site; Shannon and Weaver 1949). *Gamm*a diversity is the community-level richness (i.e., total number of species in the community) observed across all monitoring sites. PC-ORD (version 7.02) was used to calculate these diversity indices (McCune and Mefford 2016). A grand mean was then calculated for all sites in a community (IBM 2016).

Guild and Species Summary

Species guilds were assigned as designated in USDA Plants database (USDA 2017). Woody plants included non-tree shrub and subshrub species. Species level observations were averaged at the site and summed by guild. Native species richness was calculated by averaging the mean site richness of the sites sampled that year (see Table 1). The Sørensen Index was calculated to compare changes in species composition between the initial year of sampling, 2002, and the most recent year, 2018. Only the initial core 18 sites, which were sampled in both years, were used for this analysis. The Sørensen Index was calculated for each site, and a park-wide mean was determined. The Sørensen Index was calculated as

$$SI = \frac{2a}{(2a + b + c)} \times 100$$

where *a* is number of species present in both years, *b* is the number of species present in the first year only, and *c* is the number of species present in the second year only. The Sørensen Index is expressed as a percentage, where 100% represents complete similarity and 0% complete dissimilarity.

Tree Regeneration

Tree regeneration stems were tallied by species in the 10-m^2 subplots and reported in three size classes: (1) seedlings = stems <0.5 m tall; (2) small saplings = stems ≥0.5 m tall, and <2.5 cm DBH; and (3) large saplings = stems ≥0.5 m tall and DBH ≥2.5 cm and <5.0 cm. The small number of resulting observations were simply tallied for reporting.

Observer Error

We assessed our error in observing the ground flora with a double sampling method. At 14 of the 30 monitoring sites, after the transects were read, one plot from each of the two transects was randomly chosen for resampling. Sampling teams switched transects and sampled the ground flora in the randomly chosen plot. Pseudoturnover was calculated by comparing the two species lists from each plot and identifying species that were overlooked (a species was recorded by one observer but not the other), misidentified (the same specimen was apparently recorded as different species by the two observers), or at different specificity levels (cautious errors, in which one observer identified a plant to species and the other identified it only to genus).

Pseudoturnover was calculated as in Nilsson and Nilsson (1985):

$$\frac{A + B}{S_A + S_B} \times 100$$

where *A* was the number of species recorded exclusively by observer 1, *B* was the number of species recorded exclusively by observer 2, S_A was the total number of species recorded by observer 1, and S_B was the total number of species recorded by observer 2. Pseudoturnover is expressed as a percentage.

Statistical Analysis

Descriptive (graphical) analyses of ground cover and nonnative plants included all sampled sites (209 total observations) to obtain more precise parameter estimates. We evaluated trends by calculating statistics at both the preserve and pasture scales. We tested whether woody cover in 2018 differed from the 2014 level. Because the data were not normally distributed, the nonparametric Wilcoxon matched pairs test was used. Vegetation statistics were calculated in SPSS (IBM 2016). Statistical significance was assessed at the alpha = 0.05 level.

Results and Discussion

Climate

The long-term trend analysis (Figure 3) illustrates a characteristic mid-latitude continental climate with a high degree of interannual variability, particularly for precipitation. Temperatures in the recent period (1971–2020) increased over time ($P = 0.009$, $r^2 = 0.13$), whereas temperatures in the historical period (1895–1970) did not ($P = 0.18$, $r^2 = 0.03$) (Figure 3; Monahan and Fisichelli 2014). Temperatures across the whole record did increase significantly but there was much variability ($P = 0.001$, $r^2 = 0.09$). Minimum winter temperatures were greater for the recent period (data not shown). Precipitation is also an important factor influencing prairie vegetation (Bragg 1995) as it drives productivity and composition at short and long-term scales. Because of high interannual variability, there was no significant change in precipitation with time either in the historical ($P = 0.64$, $r^2 = 0.003$) or recent ($P = 0.23$, $r^2 = 0.03$) periods, but there was a weak relationship across the whole record ($P = 0.009$, $r^2 = 0.05$) (Figure 3; Monahan and Fisichelli 2014).

An analysis of SPEI, a composite index that describes drought conditions, demonstrated a weak increase toward wetter conditions across the whole time series ($P = 0.019$, $r^2 = 0.04$), but the shorter, recent period did not demonstrate any change ($P = 0.38$, $r^2 = 0.02$). The overall trend for SPEI was influenced by the dust bowl and 1950s drought periods. It is unclear to what extent the climatic conditions that caused those drought events have also influenced trends for the recent period (Figure 4; NOAA National Centers for Environmental information 2021). Increasing temperatures, especially in the winter, have also manifested slightly earlier first leaf index and extremely earlier first bloom index dates at the preserve (Monahan et al. 2016).

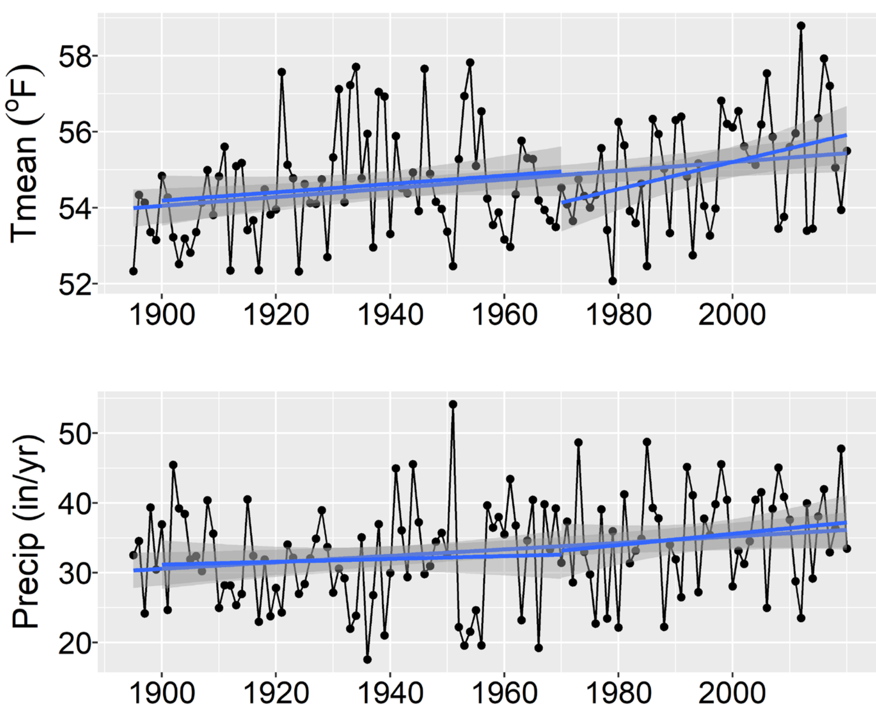

Figure 3. Temperature and precipitation trends for recent (1971–2020) and historical (1895–1970) periods as well as the whole record (1895–2020) at Tallgrass Prairie National Preserve. Shaded area around regression lines = standard error of predicted temperature and precipitation. Historical Period: 1900–1970, recent period: 1971–2020.

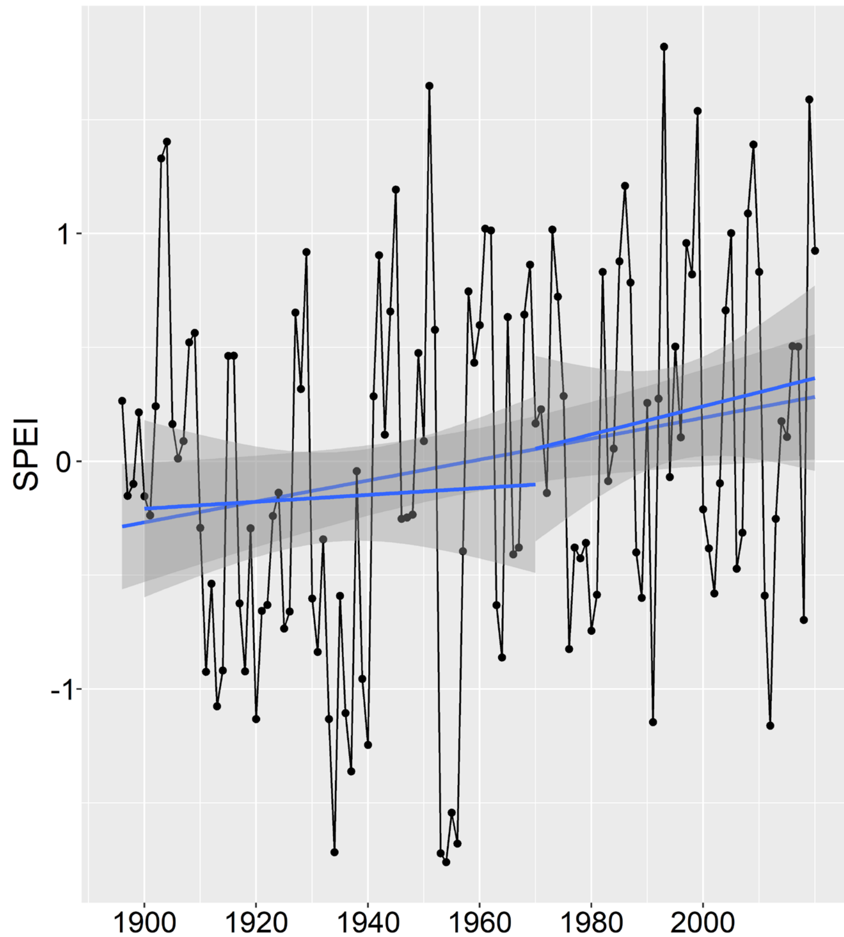

Figure 4. Standardized Precipitation-Evapotranspiration Index (SPEI) trends for recent (1971–2020) and historical (1895–1970) periods at Tallgrass Prairie National Preserve. Shaded area around regression lines = standard error of predicted SPEI values. Reference period: 1900–1970, recent period: 1971–2020.

Disturbance History

Recent Fire History

The preserve uses pyric herbivory, an ecological process by which herbivores preferentially graze burned areas, to manage the tallgrass prairie and greater prairie-chicken habitat (Fuhlendorf et al. 2009). The presence of fire on the landscape and the frequency at which it occurs are critical to the conservation and maintenance of tallgrass prairie species. As fire declines in this landscape, shrubs and trees are expected to increase, changing the ecosystem (Briggs et al. 2002; Heisler et al. 2003).

Leis and Morrison (2018) found that disturbance intensity, of which fire is a component, decreased after 2005. The decrease coincided with a shift in management philosophy that incorporated an ecological approach to disturbance (i.e., pyric herbivory). In fact, time since fire frequencies indicated that mean time since fire declined at both the preserve (Figure 5) and pasture scales (Figure 6) after 2005. Intervals especially lengthened during the most recent decade.

Preserve managers made adjustments to disturbance strategies beginning in 2006. Patch burn grazing using a three-year (three-patch) fire return interval was initiated in Big Pasture. Other pastures also decreased in fire frequency at that time, although hybrid grazing systems were deployed. Prescribed fire presents many challenges from funding and personnel to matching objectives with seasonality and weather. Recent dry periods also hindered fire operations, in addition to fire personnel being diverted for lengthening wildfire tours. Personnel have not been available in the preferred early fall window in some years because of wildfire deployments and post-deployment rehabilitation.

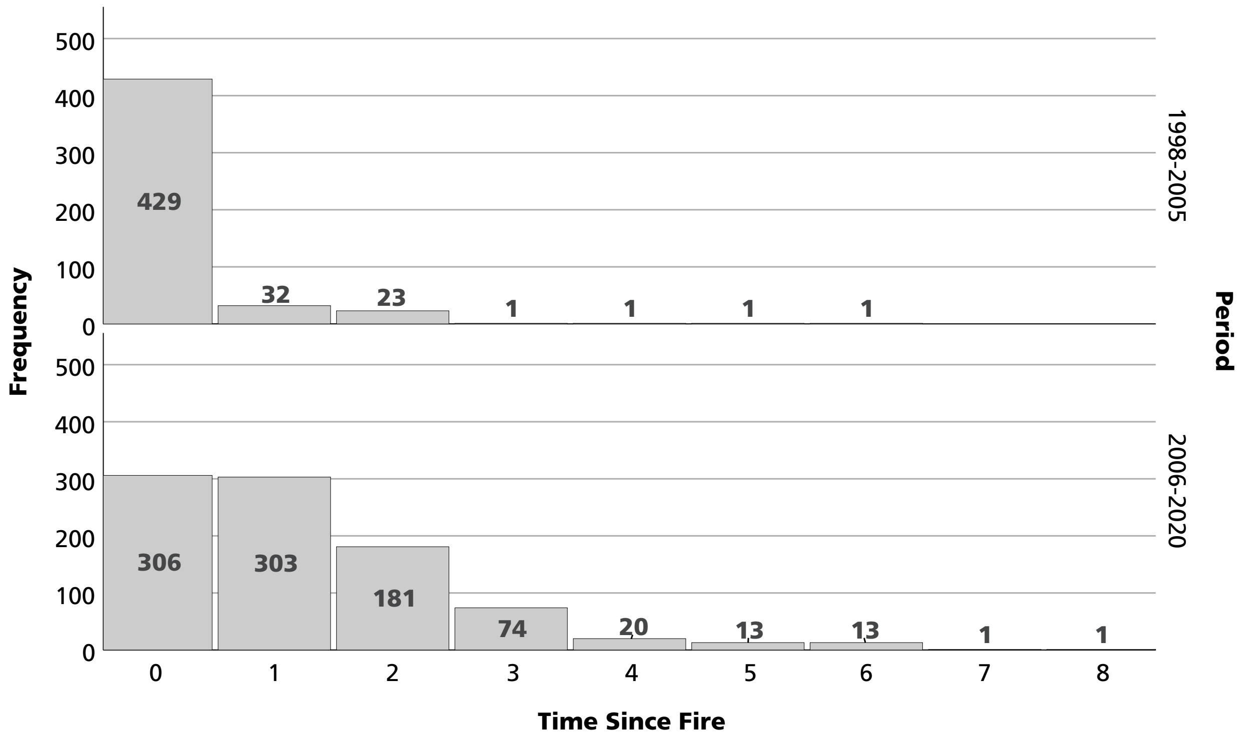

Figure 5. Cumulative frequency of time since fire (years) assignments to each monitoring site for periods from 1998–2005 and 2006–2020 at Tallgrass Prairie National Preserve, Kansas.

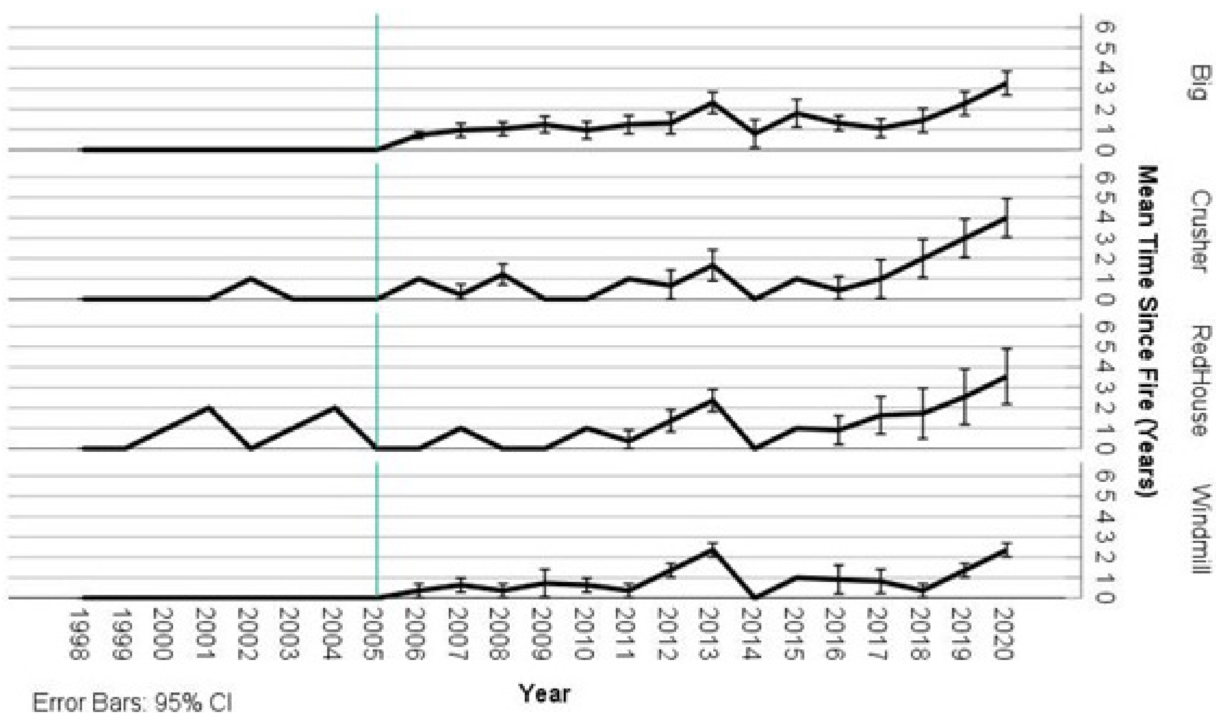

Figure 6. Mean time since fire across monitoring sites for years 1998–2020 by pasture at Tallgrass Prairie National Preserve, Kansas. The vertical line (in blue) indicates a reduction in disturbance intensity that occurred after 2005. Error bars are 95% confidence intervals.

Stocking

Grazing is an important aspect of the ranching legacy conserved by Tallgrass Prairie National Preserve as well as an ecological conservation management process (Bahr Vermeer & Haecke and John Milner Associates 2004; Fuhlendorf and Engle 2001). As part of the reduction of disturbance intensity after 2005, cattle stocking rates also declined (Figure 7). Mean stocking rates declined across the preserve after 2005 (Figure 8) as part of a planned reduction in disturbance intensity (Figure 7). Windmill Pasture (1,047 acres) was subsequently converted to bison in 2009 and was lightly stocked with 13 to 22 animals from 2009–2014. Then in 2016, Windmill Pasture was fully stocked (88 bison).

Stocking rates declined the most in Red House Pasture, except for 2020. Although there are no vegetation monitoring sites in Two Section Pasture, we included it here to provide a complete description of the grazing regime. In 2018, cattle numbers were further reduced in some pastures while they increased in Two Section Pasture that year. Cemetery Pasture and East Traps Pasture, not shown here, were last stocked in 2000 and 2005, respectively. The lightest stocking in Big Pasture occurred in 2020 when staff prescribed the stocking rate based on the burn patch (1/3 of the pasture) rather than the whole pasture.

Lighter stocking rates have been prescribed in some years as part of drought mitigation strategies as well as conservation goals. Grazing animals can affect vegetation structure differently depending on the grazing intensity as well as interactions with burned areas (Fuhlendorf et al. 2006; Hovik et al. 2012). The greater prairie-chicken is an umbrella species that requires heterogenous habitat (Svedarsky et al. 2003). Both grazing intensity and distribution in concert with prescribed fire were used to manage habitat for this species. A variety of vegetation structures are needed for the community of tallgrass prairie species, including wildlife, to survive, so continued evaluation of vegetation and disturbance intensity provides flexibility, especially in light of the changing climate.

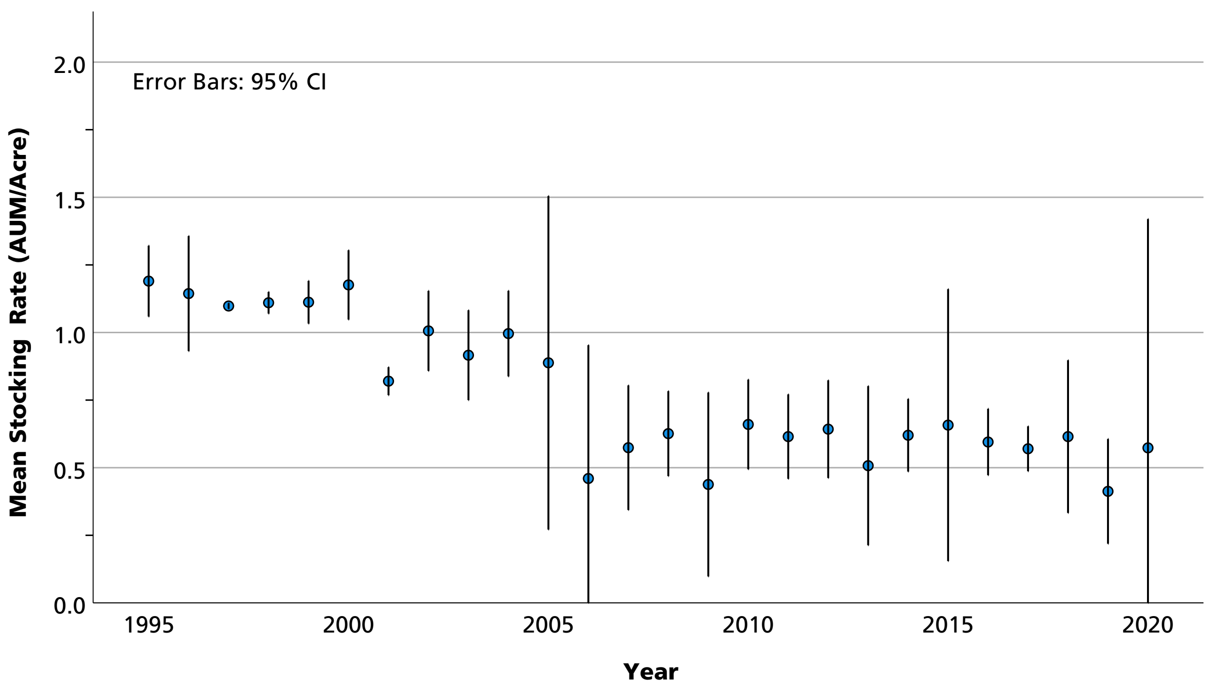

Figure 7. Mean stocking rate (animal unit months (AUM)/acre) through the monitoring record at Tallgrass Prairie National Preserve, Kansas. Error bars are 95% confidence intervals.

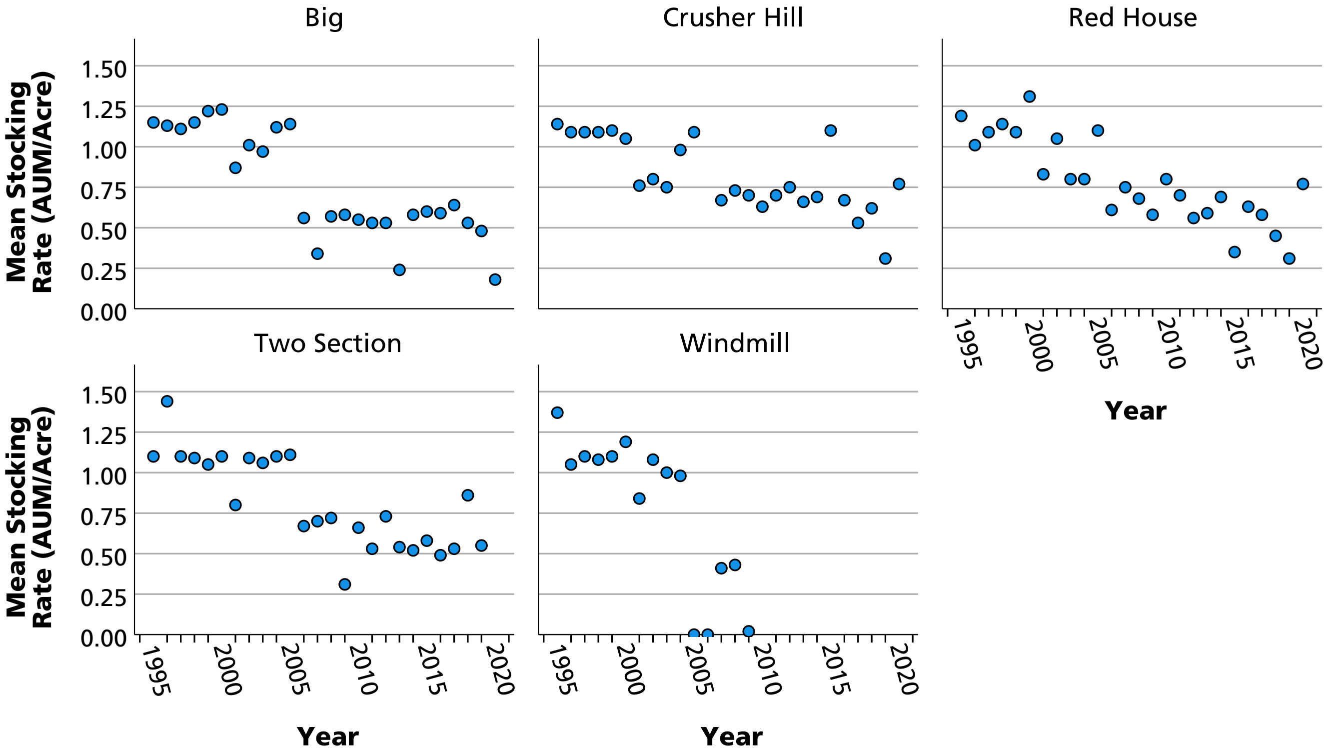

Figure 8. Stocking rate (animal unit months (AUM)/acre) through the monitoring record by pasture at Tallgrass Prairie National Preserve, Kansas. We were unable to calculate stocking rates in Windmill pasture after bison were stocked in 2009.

Ground Cover

Bare Areas

Estimates of ground cover types describe needed habitat components for tallgrass prairie species including the greater prairie-chicken. Across the preserve, we found that bare areas continued to decline across the preserve (Leis and Morrison 2018; Figure 9). This reduction in bare areas was consistent with the reduction of disturbance intensity from both grazing and fire. We noted a great deal of heterogeneity within each pasture (Figure 10). The preserve set an ecological goal of maintaining 30 to 60% of ground cover as bare areas to meet life history needs for greater prairie-chickens (Hase 2016). Mean bare area cover exceeded this range from 2002–2007 at the preserve scale and at the pasture scale. Bare area cover exceeded the goal in 2002–2007 for all pastures. In Big Pasture and Red House Pasture, bare area cover fell short of the desired range in one or more of the last three monitoring events.

Litter

We measured litter in two ways, percent cover (all years) and litter depth (2018 only). Together they provide a picture of this layer of vegetation structure. Greater prairie-chicken use areas with litter to build nests and evade predators, and they use bare areas for warming in the sun, foraging, movement, or lekking (Svedarsky et al. 2003). Recommendations for nest success describe optimal litter cover of < 25% (McKee et al. 1998). Mean litter cover estimates at the preserve were variable through time, likely relating to timing and frequency of fires or precipitation levels. In 2018, grass litter was more than double the recommended amount (Figure 9). Grassland bird habitat monitoring also observed the spike in grass litter cover in 2018 (Peitz and Kull 2020).

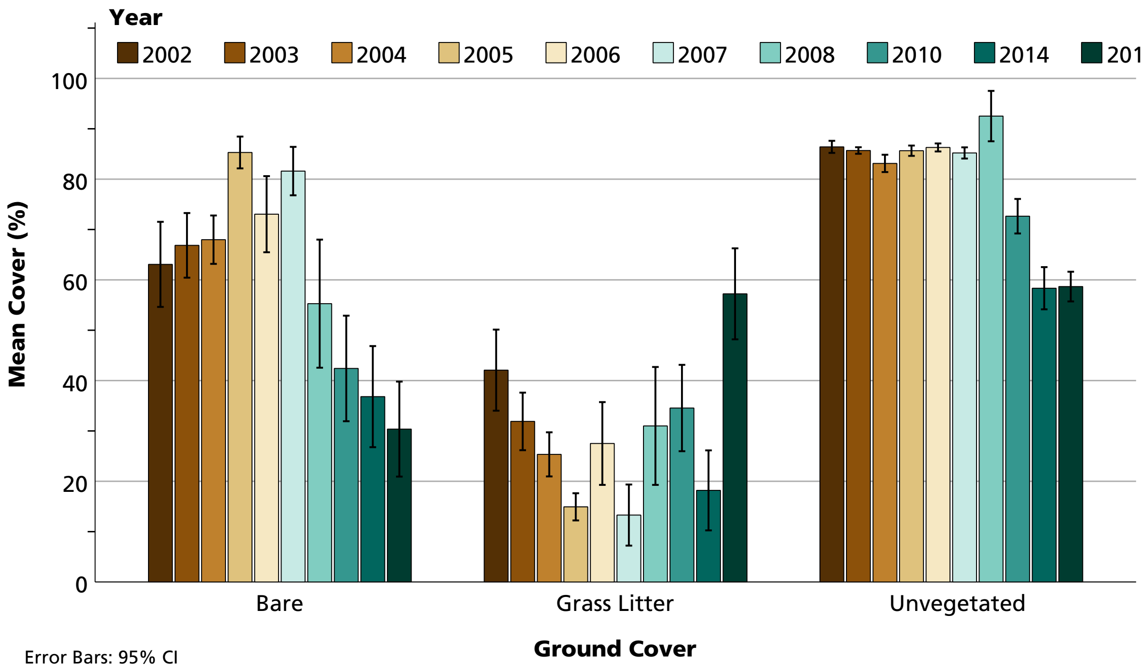

Figure 9. Mean cover by ground cover type in monitoring sites at Tallgrass Prairie National Preserve, Kansas, for 2002–2018. Bare is a combination of bare soil and bare rock types. Error bars are 95% confidence intervals.

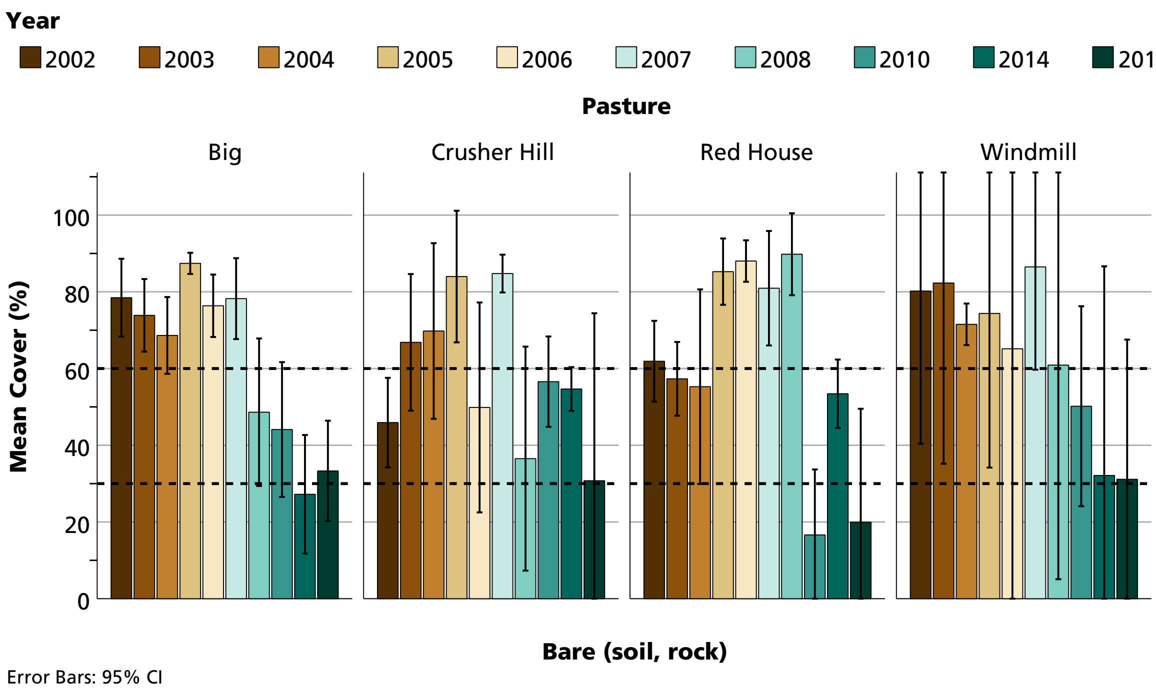

Figure 10. Mean cover of bare soil and rocks in monitoring sites at Tallgrass Prairie National Preserve, Kansas, for 2002–2018. Dashed lines indicated desired levels for bare ground cover. Error bars are 95% confidence intervals.

Ideal greater prairie-chicken habitat is recommended to have litter depth up to about 5 cm (Svedarsky et al. 2003). Although our mean depth for 2018 (5.2 cm) was similar to the goal, we found a great deal of heterogeneity including litter up to 16 cm deep (Figure 11). Deep litter can hinder movements of greater prairie-chicken and reduce suitability especially at depths >10 cm (Svedarsky et al. 2003). Mean deciduous leaf litter and woody debris (not shown) were minimal (0.1%) in all years, leaving grass litter as the dominant component of litter.

The minimal available bare areas and heterogenous litter observed in 2018 may be the result of the continued decrease in grazing and fire intensity at the preserve. If these disturbances continue to decrease, greater prairie-chicken populations could be affected by the resulting declines in suitable habitat in the future.

Ground Flora

Guild

We analyzed the ground flora by summarizing species by guild (functional group) and highlighting particular species or species groups of interest to the park.

Grass

Grass is characteristically the most abundant (% cover) taxonomic family in tallgrass prairie. It also indicates available forage for grazers such as cattle and bison and provides seeds for wildlife like small mammals and birds. Grasses experienced a decline in the middle of the monitoring record, 2005–2006 (Figure 12). This decline may be related to the drought described by the SPEI in 2006 (Figure 4). Conversely, we observed the greatest grass cover in 2010 following a light stocking year in 2009 and a few years of adequate moisture described by the SPEI. We included additional summaries of a mesic matrix grass, big bluestem (*Andropogon gerardii*), and the more xeric gramma grasses (*Bouteloua* spp.) for reference in Appendix B. These species may serve as indicators of plant community change in the future.

Forbs

Forb cover, although expected to be less than grass cover, provides important habitat for pollinators and to a lesser extent large ungulates like cattle and deer. Forbs are an important part of greater prairie-chicken habitat; forbs are required for insect habitat, seed production, and escape cover. Moreover, greater prairie-chicken nest success was found to decline when forb cover was ≤ 5% (McKee et al. 1998). The forb guild at the preserve was more

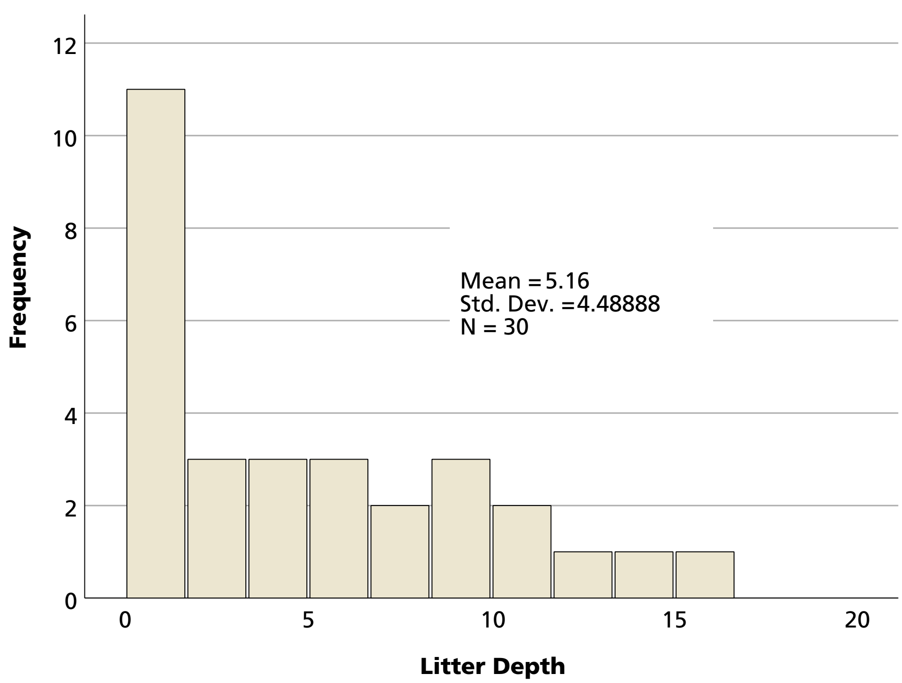

Figure 11. Frequency distribution of litter depth (cm) for monitoring sites at Tallgrass Prairie National Preserve, Kansas, in 2018.

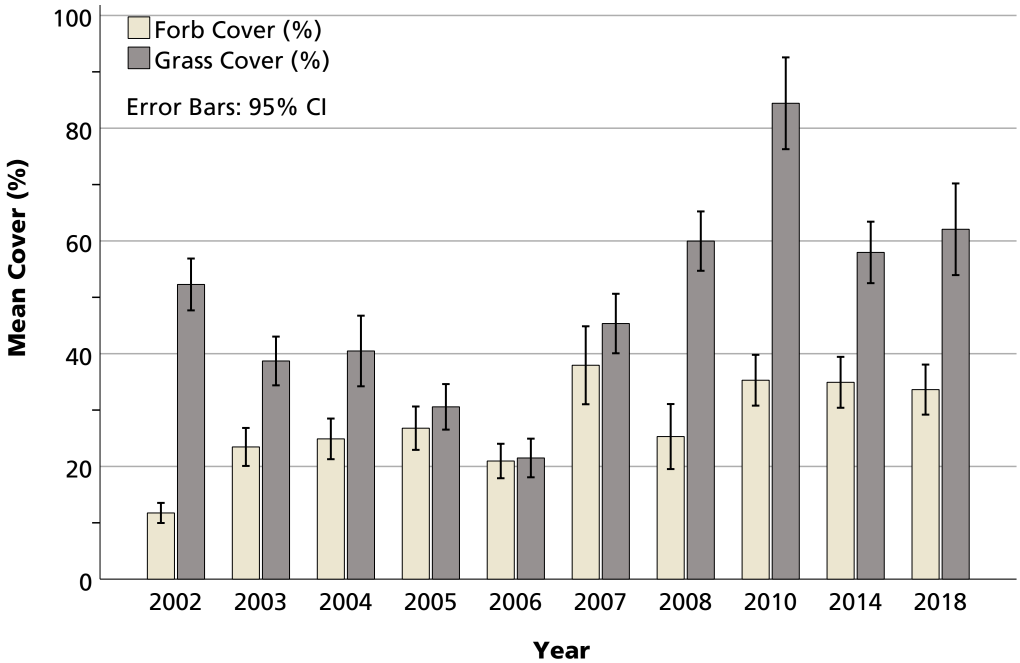

Figure 12. Mean percent cover for native forb and grass guilds at Tallgrass Prairie National Preserve for 2002–2018. Error bars are 95% confidence intervals.

consistent than the grass guild ranging from a low of 12% in 2002 to a peak of 38% cover in 2007, meeting minimum greater prairie-chicken requirements (Figure 12). Although forbs typically have less areal cover than grasses, the two guilds were similar during a dry period, 2005–2006 (Figure 12). Milkweeds, an important pollinator genus, were present at low levels across the monitoring periods, but may be in decline in Big Pasture (Appendix B). Because of the small number of observations, future monitoring events are needed to understand this trend.

Grass-like Plants

Grass-like plants included the sedges and rushes. The pattern exhibited by grass-like plants was unclear although the year of greatest abundance, 2008, was the wettest monitored year (45.04 in). Sedges are an important dormant season forage for bison (Coppedge et al. 1998; Jung 2015).

Woody Plants

Native woody plants (non-tree species) are important sources of habitat in the prairie when they remain below a 5% abundance threshold (McKee et al. 1998). As a result, the preserve's fire management goal of <5% woody plant cover was designed with grassland bird habitat as a priority (Horncastle et al. 2005; Hovick et al. 2014; Hase 2016). Fire and grazing act in concert to prevent proliferation of these species, but there may be a range of appropriate disturbance intensities (Collins and Gibson 1990; Hoch et al. 2002). Mean woody plant cover was <2% for all monitoring events, but woody plants have been increasing in monitoring sites (Figure 13; Leis and Morrison 2018). Although 2018 observations were significantly greater than 2014 ($Z = -2.07$, $P = 0.04$), the difference was not likely to be biologically meaningful because that represents an increase of only 0.24%. This difference is within the error we expect from field observations (Morrison et al. 2020). Big Pasture had the greatest abundance of woody plants. The guild increased in all pastures except Red House Pasture (Figure 14).

Of the woody species observed at TAPR, *Ceanothus* spp. (New Jersey Tea [*C. americanus*] and Jersey tea [*C. herbaceous*]) seemed to increase the most. Potentially invasive native species observed in monitoring sites included smooth sumac *(Rhus glabra*) and buckbrush (*Symphoricarpos orbiculat*us). Lastly, we observed prairie rose (*Rosa arkansana*), also categorized as a woody plant and not typically considered invasive. Importantly, we did not observe dogwood species (*Cornus* spp.), a group of native invasive shrubs, within our monitoring sites. Dogwood has been observed elsewhere at the preserve, however.

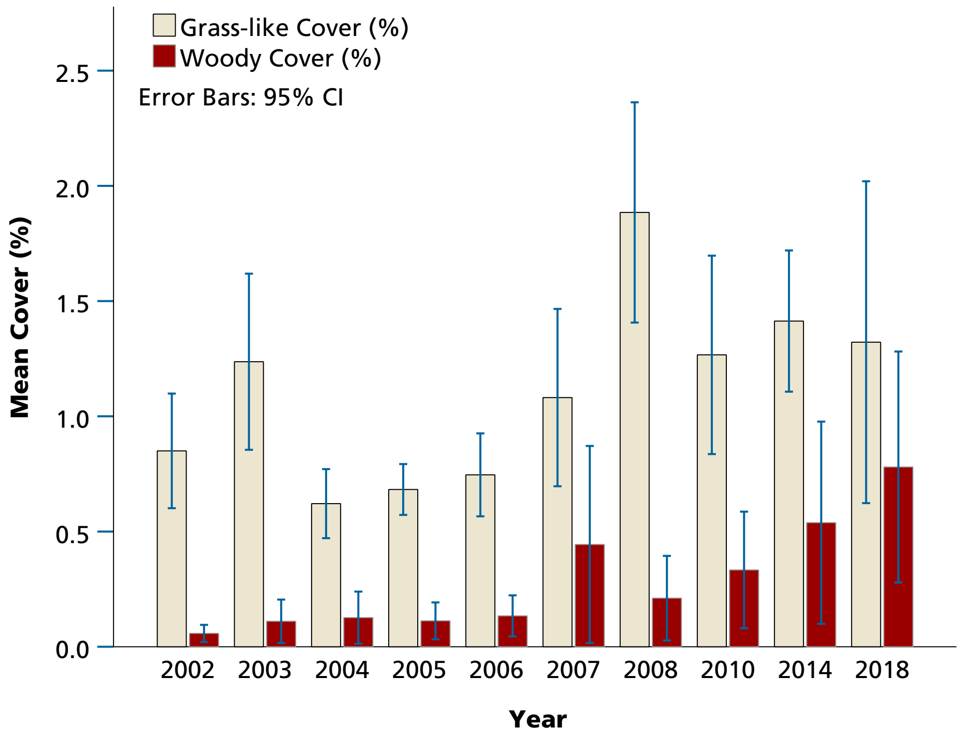

Figure 13. Mean percent cover of native woody plants (non-tree species) and grass-like plants at Tallgrass Prairie National Preserve for 2002–2018. Error bars are 95% confidence intervals.

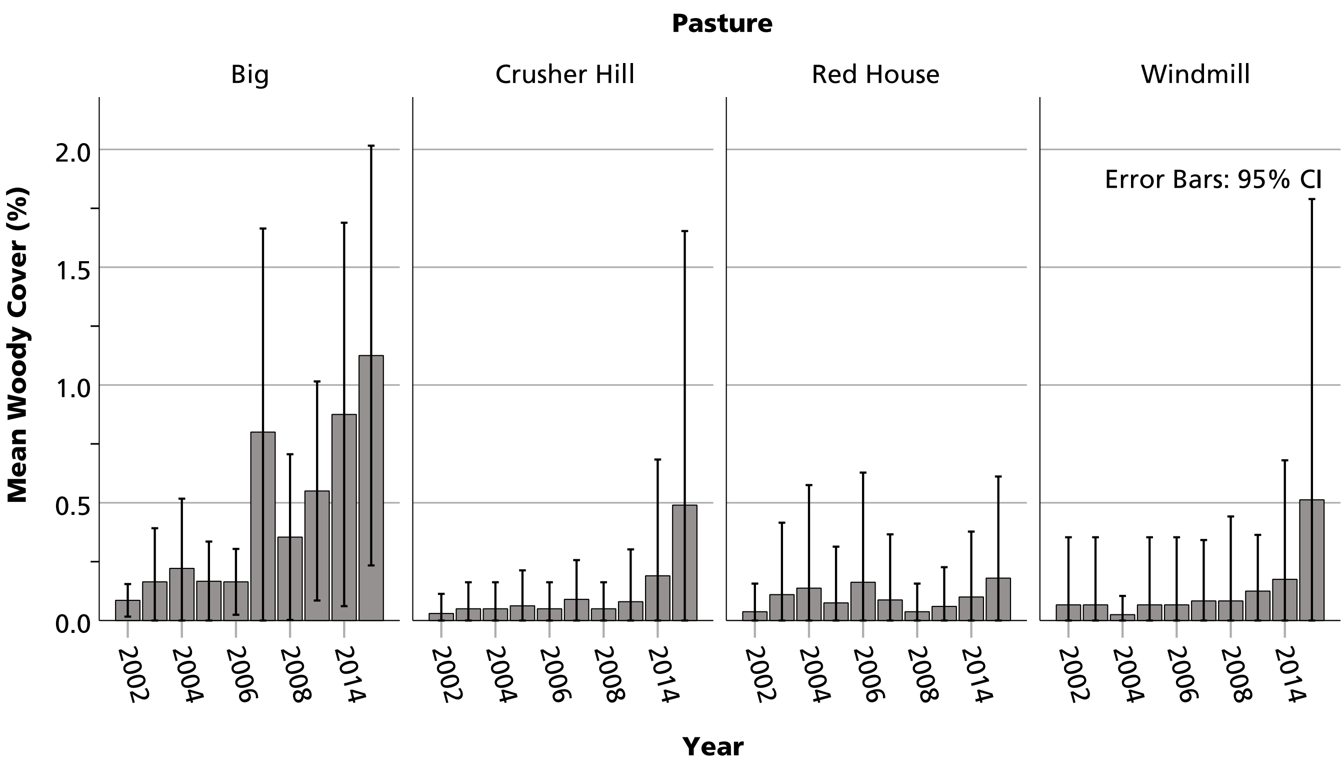

Figure 14. Mean percent cover of native woody plants (non-tree species) by pasture at Tallgrass Prairie National Preserve for 2002–2018. Error bars are 95% confidence intervals.

Studies have suggested that increased atmospheric CO_2 and related changes to climate may encourage the growth of C3 plants, which include woody plants and many nonnative invaders (Archer 1995; Van Auken 2009; Buitenwerf et al. 2012). Other analyses suggest that historical regional land use changes that resulted in landscape fragmentation and reduction in prescribed fire may have had a greater influence on the proliferation of woody plants than climate change (Van Auken 2009; Hanberry 2021). The continued maintenance of grassland surrounding the preserve serves as a buffer to such change.

Trees

No midstory or overstory trees (>5 cm DBH) were observed in the monitored years. Only two tree seedlings (<0.5 cm tall) were observed through the entire period. Both observations were of elm (*Ulmus* sp.) and were found in the same site in north Big Pasture. This lack of trees is a testament to the success of preserve management. The strategic use of fire, grazing, and invasive plant treatments help to maintain the prairie landscape (Figures 5 and 7). Studies at nearby Konza prairie indicate that fire return intervals are a critical consideration for managing tallgrass prairie (Hoch et al. 2002; Ratajczak et al. 2011). The preserve also benefits from the conservation of tallgrass prairie within the neighboring rangelands.

Nonnative plants

Expansion of nonnative plants concerns natural area and rangeland managers globally. The preserve has maintained a limited abundance of nonnative species and abundance through our monitoring record (Figure 15). These species were the least abundant during 2005–2007. Since 2008, total cover of nonnative plants across the monitoring sites was <6% (Figure 15). Twenty-eight species of nonnative plants have been recorded through the record, but only seven were observed in 2018. These seven species were found in about half of the 30 monitoring sites. Kentucky bluegrass (*Poa pratensis*) was the most abundant of these, but mean cover was <1% in 2018, well below the preserve goal of <5% cover (Hase 2016). Kentucky bluegrass abundance represented about 6% of the total nonnative plant cover. Targeted invasive monitoring observed <1.0 acre of Kentucky bluegrass and generally low levels of invasive plants in the prairie (Young 2020). Annual brome (i.e., *Bromus arvensis*) was observed through time in low abundance in monitoring sites but was found in about 30% of sites in 2018. Targeted invasive plant monitoring indicates a substantial reduction in this species from 2010 levels (Young 2020). At the pasture scale, we observed the greatest number of nonnative species in Big Pasture, but Red House Pasture had greater abundance of nonnative plants.

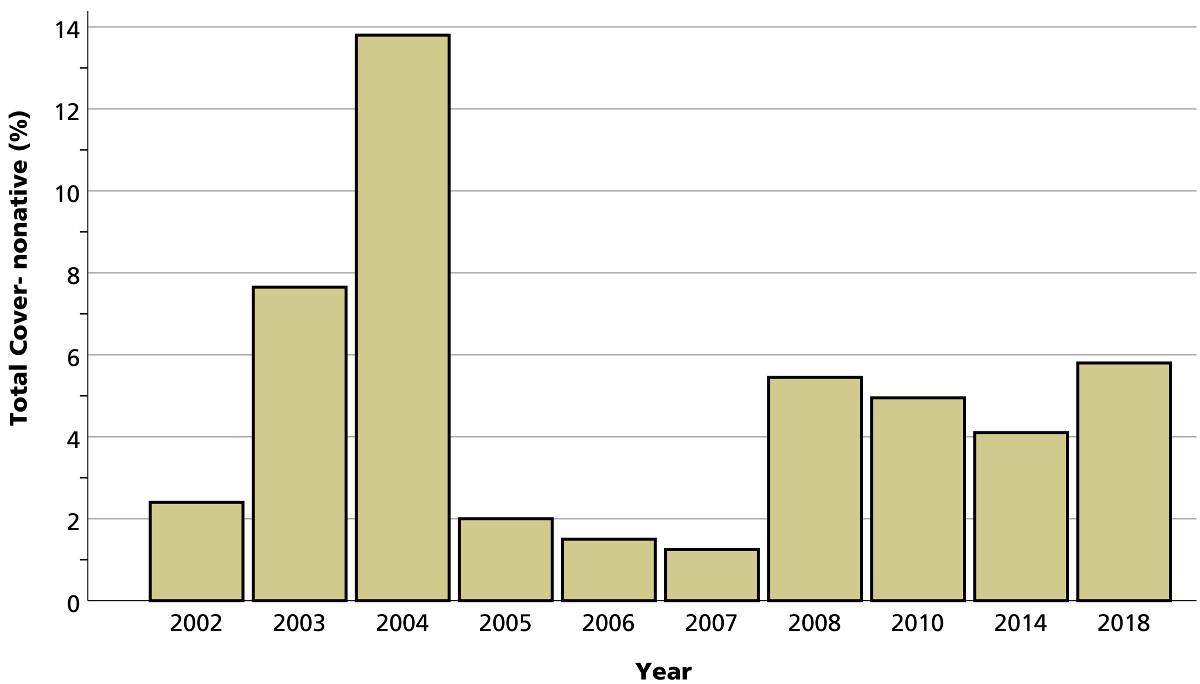

Figure 15. Total cover of nonnative species in monitoring sites across Tallgrass Prairie National Preserve, Kansas, 2002–2018.

Maintaining cool season invasive grasses below target thresholds may become more challenging as climate change progresses. However, as nonnative plants like Kentucky bluegrass increase, management may be more difficult (Toledo et al. 2014). Changes in phenology and precipitation patterns may support cool season plants like nonnative grasses and woody plants more so than the climate of the recent past (Knapp et al. 2020). The earlier onset of spring, which is characteristically wet in the Great Plains, may provide an extended period of productivity for C3 plants during which native C4 plants remain dormant. This potential shift could affect the abundance of C3 and C4 functional groups. Vigilant monitoring and prioritization of problematic plant treatment strategies, along with supporting dominance of native species through ecological processes like grazing and fire, may contribute to resilience as climate change progresses (Hobbs and Huenneke 1992; Vujnovic et al. 2002). Future research exploring the relationship of native to nonnative species at the preserve may help predict tipping points or inform treatments (Suding and Gross 2006).

Species Richness and Composition

We calculated native species richness (alpha diversity) and preserve-wide richness (gamma diversity) for all sites (Figure 16). Although we noticed an increasing pattern of gamma diversity, the pattern was likely the result of an increasing number of sites sampled over time (Table 1). If gamma diversity is calculated based only on the 18 core sites sampled consistently, there is no apparent increase in species richness over time. Comparison of native species composition in the core 18 sites between 2002 and 2018 revealed a 63.1 ±5.3% similarity based on the Sørensen Index.

Observer Error

Observer error for the ground flora community was measured for the first time in 2018 (Table 3). Observer error has multiple components. In this study, we quantified overlooking error (i.e., when a species was present but not noticed by an observer), misidentification error (i.e., when a species was noticed but incorrectly identified), and cautious error (i.e., when one observer lumped an observation

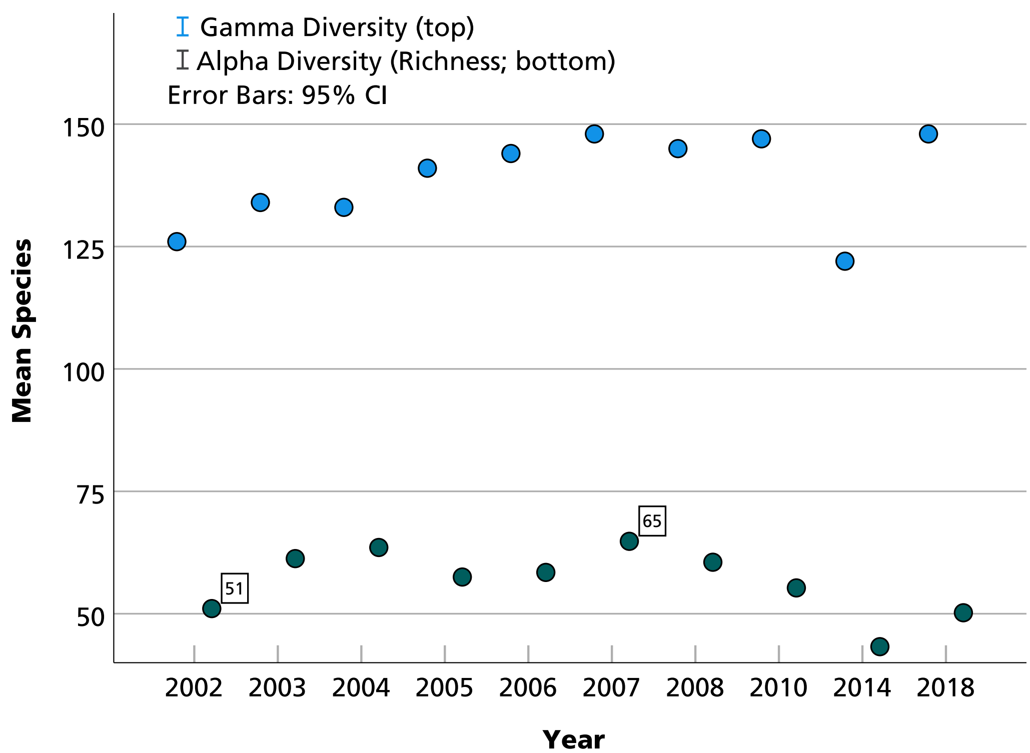

Figure 16. Native plant community diversity metrics, gamma diversity (preserve-wide richness), and alpha diversity (site-level richness) for Tallgrass Prairie National Preserve, Kansas, 2002–2018.

to genus level and the other observer was more specific). The greatest source of error came from overlooking of species by one of the observers (18.6%). Misidentification error and cautious error were low (1.4% and 0.6%, respectively). Total pseudoturnover is a function of all three types of error and averaged 20.5% for the sampling event resulting in 79.5% agreement (Table 3). We aimed to keep our species agreement around 80% based on a survey of the literature (Morrison 2016; Morrison et al. 2020). We suspect that sample frame relocation between observers may have been an important source of error that we could not control. We do not have a quantitative assessment of the contribution of this source of error, but we plan to implement methods to attempt to reduce it in future monitoring events.

Table 3. Observer error rates for 2018 sampling event at Tallgrass Prairie National Preserve, Kansas (N = 28).

Error Component	Mean Error Rate (%)
Overlooking	18.6
Misidentification	1.4
Cautious	0.6
Total pseudoturnover	20.5

We also assessed the amount of agreement on the cover classes for species both observers recorded. Overall, on average there was 73.7% agreement on cover classes, 22.5 percent of observations were within one cover class and 3.8% of observations differed by >1 cover class. This level of agreement falls on the lower end of what we have measured across five network parks (range: 73–85%; Morrison et al. 2020; Leis 2021; Leis and Short 2021).

If pseudoturnover is taken into account, the change in species composition based on the Sørensen Index is considerably less compared to the uncorrected value (36.9% dissimilarity – 20.5% pseudoturnover = 16.4% actual change). This correction for pseudoturnover can only be considered as an approximate estimate, however, since observer error was measured at the plot scale rather than at the site scale, and no pseudoturnover estimates are available for 2002, when different observers were involved.

Protocol changes

We expected a small decline in species observed when the revisit design changed in 2014 (James et al. 2009; Appendix B). In prior years, sites were visited twice in a sample year, but beginning in 2014, sites were only visited once. It is also possible that some detected species were not phenologically at the same level of cover as when previously recorded. For example, warm season grasses tend to peak in late July to early August, so the June cover observations could have been less. It is unclear whether the change in sample design contributed to the patterns we observed for species cover a diversity metrics in 2014–2018 as compared to prior years.

Management Implications

The preserve manages tallgrass prairie for a variety of species and ecological objectives, including maintaining populations of greater prairie-chicken, an icon umbrella species. The preserve continues to have characteristic tallgrass prairie species with a small shift in native species composition. Vegetation structure has changed over time but is currently meeting objectives, including heterogeneity amongst key indicators for endemic species like the greater prairie-chicken. Continued evaluation of fire frequency and grazing intensity will be critical to achieving ecological goals, including conserving the greater prairie-chicken.

Refocusing on achieving the desired fire return intervals should contribute to maintenance of the desired plant community structure over time. Continued development of grazing plans may similarly assist with prescribing stocking rates that are consistent with the preserve's ecological and cultural objectives. Plans could also identify alternative herbivores or expansion of bison to be deployed in target areas for specific objectives. For example, multispecies grazing could reduce problematic woody plant growth in draws or riparian areas.

Because of the natural variability in climate metrics and complexity of the disturbance history and vegetation, further investigation of climate related trends may be helpful, especially in planning for the future. Climate change planning for the near future should focus on the effects of increasing temperatures and phenological shifts.

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Appendix A. Species Observed

Table A1. All species observed at prairie sites (N = 30) at Tallgrass Prairie National Preserve, Kansas. Values for mean cover, standard error (SE), and occurrence are for 2018 (most recent monitoring event) only. Species with 0 values were observed during monitoring events from 2002–2014, but not in 2018. N = native, I = nonnative.

Species	Common Name	Guild	Origin	2018 Mean Cover (%)	SE	Occurrence (% Sites Observed) 2018
Acalypha ostryifolia	pineland threeseed mercury	forb	N	0.00	0.00	0.00
Acalypha virginica	Virginia threeseed mercury	forb	N	0.00	0.00	0.00
Achillea millefolium	common yarrow	forb	N	0.24	0.05	83.33
Agalinis tenuifolia	slenderleaf false foxglove	forb	N	0.00	0.00	0.00
Agrostis hyemalis	winter bentgrass	grass	N	0.05	0.02	36.67
Allium spp.	onion	forb	N	0.00	0.00	3.33
Allium canadense	meadow garlic	forb	N	0.00	0.00	0.00
Alopecurus carolinianus	Carolina foxtail	grass	N	0.00	0.00	0.00
Ambrosia artemisiifolia	annual ragweed	forb	N	0.01	0.00	10.00
Ambrosia psilostachya	Cuman ragweed	forb	N	0.88	0.20	96.67
Amorpha canescens	leadplant	forb	N	10.72	0.84	100.00
Amphiachyris dracunculoides	prairie broomweed	forb	N	0.04	0.02	20.00
Andropogon gerardii	big bluestem	grass	N	23.23	2.42	100.00
Androsace occidentalis	western rockjasmine	forb	N	0.00	0.00	0.00
Anemone caroliniana	Carolina anemone	forb	N	0.00	0.00	0.00
Antennaria neglecta	field pussytoes	forb	N	0.04	0.01	33.33
Apocynum cannabinum	Indianhemp	forb	N	0.00	0.00	3.33
Arctium minus	lesser burdock	forb	I	0.00	0.00	0.00
Arenaria serpyllifolia	thymeleaf sandwort	forb	I	0.00	0.00	0.00
Aristida oligantha	prairie threeawn	grass	N	0.00	0.00	0.00
Arnoglossum plantagineum	Tuberous Indian plantain	forb	N	0.01	0.00	13.33
Artemisia campestris	field sagewort	forb	N	0.01	0.01	3.33
Artemisia ludoviciana	white sagebrush	forb	N	1.59	0.50	96.67
Asclepias spp.	milkweed	forb	N	0.00	0.00	6.67
Asclepias stenophylla	slimleaf milkweed	forb	N	0.01	0.00	20.00
Asclepias tuberosa	butterfly milkweed	forb	N	0.00	0.00	3.33
Asclepias verticillata	whorled milkweed	forb	N	0.02	0.01	33.33
Asclepias viridiflora	green comet milkweed	forb	N	0.05	0.03	30.00
Asclepias viridis	green antelopehorn	forb	N	0.20	0.04	73.33
Astragalus canadensis	Canadian milkvetch	forb	N	0.00	0.00	0.00
Astragalus crassicarpus	groundplum milkvetch	forb	N	0.01	0.00	16.67
Baptisia spp.	wild indigo	forb	N	0.00	0.00	0.00
Baptisia australis	blue wild indigo	forb	N	0.15	0.04	70.00
Baptisia bracteata var. leucophaea	longbract wild indigo	forb	N	0.14	0.04	50.00
Bothriochloa laguroides	silver beardgrass	grass	N	0.00	0.00	0.00
Bouteloua curtipendula	sideoats grama	grass	N	1.40	0.50	83.33

Table A1 (continued). All species observed at prairie sites (N = 30) at Tallgrass Prairie National Preserve, Kansas. Values for mean cover, standard error (SE), and occurrence are for 2018 (most recent monitoring event) only. Species with 0 values were observed during monitoring events from 2002–2014, but not in 2018. N = native, I = nonnative.

Species	Common Name	Guild	Origin	2018 Mean Cover (%)	SE	Occurrence (% Sites Observed) 2018
Bouteloua dactyloides	buffalograss	grass	N	1.05	0.37	56.67
Bouteloua gracilis	blue grama	grass	N	0.08	0.04	20.00
Bouteloua hirsuta	hairy grama	grass	N	0.25	0.13	46.67
Brickellia eupatorioides	false boneset	forb	N	0.31	0.06	90.00
Bromus spp.	brome	grass	I	0.00	0.00	0.00
Bromus arvensis	Japanese chess	forb	I	0.03	0.01	30.00
Bromus inermis	smooth brome	grass	I	0.00	0.00	0.00
Callirhoe alcaeoides	light poppymallow	forb	N	0.30	0.06	80.00
Calylophus serrulatus	yellow sundrops	forb	N	0.00	0.00	0.00
Calystegia sepium	hedge false bindweed	forb	N	0.00	0.00	6.67
Camelina microcarpa	littlepod false flax	forb	I	0.00	0.00	3.33
Capsella bursa-pastoris	shepherd's purse	forb	I	0.00	0.00	0.00
Carex spp.	sedge	grass-like	N	0.87	0.18	100.00
Ceanothus spp.	ceanothus	woody	N	0.06	0.03	23.33
Ceanothus herbaceus	Jersey tea	woody	N	0.45	0.22	36.67
Cerastium brachypodum	shortstalk chickweed	forb	N	0.01	0.01	6.67
Chamaecrista fasciculata	partridge pea	forb	N	0.00	0.00	0.00
Chamaesyce spp.	sandmat	forb	N	0.00	0.00	3.33
Chamaesyce maculata	spotted sandmat	forb	N	0.00	0.00	3.33
Chamaesyce prostrata	prostrate sandmat	forb	N	0.01	0.01	16.67
Chloris verticillata	tumble windmill grass	grass	N	0.00	0.00	3.33
Cirsium altissimum	tall thistle	forb	N	0.01	0.00	13.33
Cirsium undulatum	wavyleaf thistle	forb	N	0.39	0.17	63.33
Comandra umbellata	bastard toadflax	forb	N	0.00	0.00	0.00
Convolvulus arvensis	field bindweed	forb	I	0.00	0.00	0.00
Conyza canadensis	Canadian horseweed	forb	N	0.01	0.01	13.33
Corydalis micrantha	smallflower fumewort	forb	N	0.00	0.00	0.00
Croton capitatus	hogwort	forb	N	0.00	0.00	0.00
Croton monanthogynus	prairie tea	forb	N	0.02	0.01	23.33
Cyperus spp.	flatsedge	grass-like	N	0.05	0.01	43.33
Cyperus esculentus	yellow nutsedge	grass-like	N	0.00	0.00	0.00
Cyperus lupulinus	Great Plains flatsedge	grass-like	N	0.00	0.00	0.00
Dalea aurea	golden prairie clover	forb	N	0.00	0.00	0.00
Dalea candida	white prairie clover	forb	N	0.06	0.01	66.67
Dalea multiflora	roundhead prairie clover	forb	N	0.02	0.01	16.67
Dalea purpurea	purple prairie clover	forb	N	0.29	0.07	70.00
Delphinium carolinianum	Carolina larkspur	forb	N	0.02	0.01	33.33
Descurainia pinnata	western tansymustard	forb	N	0.00	0.00	0.00
Desmanthus illinoensis	Illinois bundleflower	forb	N	0.00	0.00	0.00

Table A1 (continued). All species observed at prairie sites (N = 30) at Tallgrass Prairie National Preserve, Kansas. Values for mean cover, standard error (SE), and occurrence are for 2018 (most recent monitoring event) only. Species with 0 values were observed during monitoring events from 2002–2014, but not in 2018. N = native, I = nonnative.

Species	Common Name	Guild	Origin	2018 Mean Cover (%)	SE	Occurrence (% Sites Observed) 2018
Desmodium spp.	ticktrefoil	forb	N	0.00	0.00	0.00
Desmodium illinoense	Illinois ticktrefoil	forb	N	0.01	0.01	6.67
Desmodium sessilifolium	sessileleaf ticktrefoil	forb	N	0.04	0.02	20.00
Dichanthelium spp.	rosette grass	grass	N	0.00	0.00	0.00
Dichanthelium oligosanthes var. scribnerianum	Scribner's rosette grass	grass	N	0.64	0.07	100.00
Dichanthelium villosissimum var. praecocius	whitehair rosette grass	grass	N	0.01	0.01	10.00
Digitaria cognata	fall witchgrass	grass	N	0.00	0.00	3.33
Digitaria ischaemum	smooth crabgrass	grass	I	0.00	0.00	0.00
Draba brachycarpa	shortpod draba	forb	N	0.00	0.00	0.00
Draba cuneifolia	wedgeleaf draba	forb	N	0.00	0.00	3.33
Draba reptans	Carolina draba	forb	N	0.00	0.00	0.00
Echinacea angustifolia	blacksamson echinacea	forb	N	0.05	0.03	13.33
Echinochloa muricata	rough barnyardgrass	grass	N	0.00	0.00	0.00
Eleocharis spp.	spikerush	grass-like	N	0.00	0.00	0.00
Eleocharis compressa	flatstem spikerush	grass-like	N	0.38	0.29	33.33
Elymus canadensis	Canada wildrye	grass	N	0.03	0.02	13.33
Elymus virginicus	Virginia wildrye	grass	N	0.02	0.01	26.67
Eragrostis cilianensis	stinkgrass	grass	I	0.00	0.00	0.00
Eragrostis spectabilis	purple lovegrass	grass	N	0.00	0.00	0.00
Erigeron annuus	eastern daisy fleabane	forb	N	0.00	0.00	0.00
Erigeron philadelphicus	Philadelphia fleabane	forb	N	0.01	0.01	6.67
Erigeron strigosus	prairie fleabane	forb	N	0.32	0.21	53.33
Erythronium mesochoreum	midland fawnlily	forb	N	0.00	0.00	0.00
Escobaria missouriensis	Missouri coryphanthe	forb	N	0.00	0.00	0.00
Eupatorium altissimum	tall thoroughwort	forb	N	0.00	0.00	0.00
Euphorbia corollata	flowering spurge	forb	N	0.01	0.01	6.67
Euphorbia marginata	snow on the mountain	forb	N	0.00	0.00	3.33
Euphorbia spathulata	warty spurge	forb	N	0.03	0.01	30.00
Euthamia gymnospermoides	Texas goldentop	forb	N	0.30	0.26	30.00
Evolvulus nuttallianus	shaggy dwarf morning-glory	forb	N	0.01	0.01	6.67
Gaura mollis	Gaura	forb	N	0.00	0.00	0.00
Geranium carolinianum	Carolina geranium	forb	N	0.01	0.01	3.33
Grindelia squarrosa	curlycup gumweed	forb	N	0.00	0.00	0.00
Hedeoma hispida	rough false pennyroyal	forb	N	0.02	0.01	26.67
Helianthus spp.	sunflower	forb	N	0.00	0.00	0.00
Heliopsis helianthoides	smooth oxeye	forb	N	0.00	0.00	3.33
Hieracium longipilum	hairy hawkweed	forb	N	0.02	0.02	6.67
Hordeum pusillum	little barley	grass	N	0.02	0.02	10.00
Hybanthus verticillatus	babyslippers	forb	N	0.08	0.03	30.00

Table A1 (continued). All species observed at prairie sites (N = 30) at Tallgrass Prairie National Preserve, Kansas. Values for mean cover, standard error (SE), and occurrence are for 2018 (most recent monitoring event) only. Species with 0 values were observed during monitoring events from 2002–2014, but not in 2018. N = native, I = nonnative.

Species	Common Name	Guild	Origin	2018 Mean Cover (%)	SE	Occurrence (% Sites Observed) 2018
Hymenopappus scabiosaeus	Carolina woollywhite	forb	N	0.07	0.02	40.00
Juncus spp.	rush	grass-like	N	0.02	0.01	13.33
Koeleria macrantha	prairie Junegrass	grass	N	0.32	0.07	76.67
Krigia biflora	twoflower dwarfdandelion	forb	N	0.00	0.00	0.00
Krigia caespitosa	Sunflower	forb	N	0.00	0.00	0.00
Kummerowia stipulacea	Korean clover	forb	I	0.00	0.00	0.00
Lactuca spp.	lettuce	forb	N	0.00	0.00	0.00
Lactuca serriola	prickly lettuce	forb	I	0.00	0.00	6.67
Lamium amplexicaule	henbit deadnettle	forb	I	0.00	0.00	0.00
Lepidium campestre	field pepperweed	forb	I	0.00	0.00	0.00
Lepidium densiflorum	common pepperweed	forb	N	0.12	0.03	53.33
Lespedeza capitata	roundhead lespedeza	forb	N	0.24	0.06	66.67
Lespedeza violacea	violet lespedeza	forb	N	3.36	1.25	63.33
Lespedeza virginica	slender lespedeza	forb	N	0.03	0.02	16.67
Leucospora multifida	narrowleaf paleseed	forb	N	0.00	0.00	0.00
Liatris spp.	blazing star	forb	N	0.01	0.01	3.33
Liatris aspera	tall blazing star	forb	N	0.00	0.00	3.33
Liatris punctata	dotted blazing star	forb	N	0.06	0.03	23.33
Linum sulcatum	grooved flax	forb	N	0.07	0.02	53.33
Lithospermum incisum	narrowleaf stoneseed	forb	N	0.02	0.01	20.00
Lomatium foeniculaceum	desert biscuitroot	forb	N	0.04	0.01	23.33
Lotus unifoliolatus var. *unifoliolatus*	American bird's-foot trefoil	forb	N	0.00	0.00	0.00
Malvastrum hispidum	hispid false mallow	forb	N	0.00	0.00	0.00
Mimosa nuttallii	Sensitive brier	forb	N	0.22	0.09	43.33
Mirabilis albida	white four o'clock	forb	N	0.01	0.01	10.00
Monarda fistulosa	wild bergamot	forb	N	0.10	0.05	23.33
Muhlenbergia cuspidata	plains muhly	grass	N	0.02	0.01	10.00
Myosotis verna	spring forget-me-not	forb	N	0.00	0.00	0.00
Myosurus minimus	tiny mousetail	forb	N	0.00	0.00	0.00
Nothocalais cuspidata	prairie false dandelion	forb	N	0.00	0.00	0.00
Nothoscordum bivalve	crowpoison	forb	N	0.02	0.01	16.67
Oenothera spp.	evening primrose	forb	N	0.00	0.00	0.00
Oenothera biennis	common evening primrose	forb	N	0.02	0.02	3.33
Oenothera laciniata	cutleaf evening primrose	forb	N	0.00	0.00	0.00
Oenothera macrocarpa	bigfruit evening primrose	forb	N	0.01	0.00	6.67
Oenothera speciosa	pinkladies	forb	N	0.02	0.01	16.67
Oligoneuron rigidum var. *rigidum*	Stiff goldenrod	forb	N	0.02	0.01	13.33
Onosmodium bejariense var. *bejariense*	Western false gromwell	forb	N	0.06	0.03	13.33
Opuntia macrorhiza	twistspine pricklypear	forb	N	0.02	0.01	10.00

Table A1 (continued). All species observed at prairie sites (N = 30) at Tallgrass Prairie National Preserve, Kansas. Values for mean cover, standard error (SE), and occurrence are for 2018 (most recent monitoring event) only. Species with 0 values were observed during monitoring events from 2002–2014, but not in 2018. N = native, I = nonnative.

Species	Common Name	Guild	Origin	2018 Mean Cover (%)	SE	Occurrence (% Sites Observed) 2018
Opuntia polyacantha	plains pricklypear	forb	N	0.00	0.00	0.00
Oxalis spp.	woodsorrel	forb	N	0.13	0.02	76.67
Oxalis violacea	violet woodsorrel	forb	N	0.02	0.01	26.67
Packera plattensis	Platte groundsel	forb	N	0.06	0.01	56.67
Panicum capillare	witchgrass	grass	N	0.00	0.00	3.33
Panicum virgatum	switchgrass	grass	N	1.94	0.41	100.00
Pascopyrum smithii	western wheatgrass	grass	N	0.01	0.01	6.67
Paspalum spp.	crowngrass	grass	N	0.00	0.00	0.00
Pediomelum argophyllum	Silvery scurf-pea	forb	N	0.07	0.05	13.33
Pediomelum esculentum	Breadroot scurf-pea	forb	N	0.09	0.02	46.67
Penstemon spp.	beardtongue	forb	N	0.00	0.00	0.00
Penstemon cobaea	cobaea beardtongue	forb	N	0.00	0.00	3.33
Physalis spp.	groundcherry	forb	N	0.00	0.00	0.00
Physalis heterophylla	clammy groundcherry	forb	N	0.00	0.00	0.00
Physalis pumila	dwarf groundcherry	forb	N	0.10	0.02	66.67
Physalis virginiana	Virginia groundcherry	forb	N	0.09	0.02	70.00
Plantago spp.	plantain	forb	N	0.04	0.01	36.67
Plantago patagonica	woolly plantain	forb	N	0.00	0.00	0.00
Plantago pusilla	dwarf plantain	forb	N	0.00	0.00	0.00
Plantago rhodosperma	redseed plantain	forb	N	0.00	0.00	0.00
Poa compressa	Canada bluegrass	grass	I	0.00	0.00	0.00
Poa pratensis	Kentucky bluegrass	grass	I	0.14	0.05	46.67
Polygala verticillata	whorled milkwort	forb	N	0.00	0.00	0.00
Polygonum pensylvanicum	Pennsylvania smartweed	forb	N	0.00	0.00	3.33
Polygonum ramosissimum	bushy knotweed	forb	N	0.00	0.00	0.00
Pseudognaphalium obtusifolium ssp. *obtusifolium*	Fragrant cudweed	forb	N	0.00	0.00	0.00
Psoralidium lanceolatum	lemon scurfpea	forb	N	0.00	0.00	0.00
Psoralidium tenuiflorum	slimflower scurfpea	forb	N	3.29	0.64	93.33
Ratibida columnifera	upright prairie coneflower	forb	N	0.11	0.02	70.00
Ratibida pinnata	pinnate prairie coneflower	forb	N	0.00	0.00	3.33
Rhus glabra	smooth sumac	woody	N	0.11	0.10	6.67
Rosa arkansana	prairie rose	woody	N	0.08	0.06	13.33
Ruellia humilis	fringeleaf wild petunia	forb	N	0.24	0.02	96.67
Rumex crispus	curly dock	forb	I	0.00	0.00	3.33
Salvia azurea	azure blue sage	forb	N	0.48	0.08	93.33
Schedonnardus paniculatus	tumblegrass	grass	N	0.00	0.00	0.00
Schizachyrium scoparium	little bluestem	grass	N	26.77	2.06	100.00
Scutellaria parvula	small skullcap	forb	N	0.01	0.00	16.67
Senecio riddellii	Riddell’s ragwort	forb	N	0.00	0.00	0.00

Table A1 (continued). All species observed at prairie sites (N = 30) at Tallgrass Prairie National Preserve, Kansas. Values for mean cover, standard error (SE), and occurrence are for 2018 (most recent monitoring event) only. Species with 0 values were observed during monitoring events from 2002–2014, but not in 2018. N = native, I = nonnative.

Species	Common Name	Guild	Origin	2018 Mean Cover (%)	SE	Occurrence (% Sites Observed) 2018
Setaria pumila	yellow foxtail	grass	I	0.00	0.00	0.00
Setaria viridis	green bristlegrass	grass	I	0.00	0.00	0.00
Silene antirrhina	sleepy silene	forb	N	0.05	0.02	43.33
Silphium laciniatum	compassplant	forb	N	0.01	0.01	3.33
Sisymbrium altissimum	tall tumblemustard	forb	I	0.00	0.00	0.00
Sisyrinchium campestre	prairie blue-eyed grass	forb	N	0.15	0.02	83.33
Solanum carolinense	Carolina horsenettle	forb	N	0.00	0.00	6.67
Solanum rostratum	buffalobur nightshade	forb	N	0.00	0.00	3.33
Solidago spp.	goldenrod	forb	N	0.00	0.00	0.00
Solidago canadensis	Canada goldenrod	forb	N	0.49	0.31	33.33
Solidago missouriensis	Missouri goldenrod	forb	N	0.48	0.14	90.00
Sorghastrum nutans	Indiangrass	grass	N	1.32	0.30	100.00
Spermolepis inermis	Red River scaleseed	forb	N	0.03	0.01	23.33
Sphenopholis obtusata	prairie wedgescale	grass	N	0.14	0.06	46.67
Spiranthes cernua	nodding lady's tresses	forb	N	0.00	0.00	0.00
Sporobolus spp.	dropseed	grass	N	0.00	0.00	3.33
Sporobolus compositus	composite dropseed	grass	N	4.58	0.82	100.00
Sporobolus compositus var. compositus	Tall dropseed	grass	N	0.00	0.00	0.00
Sporobolus neglectus	puffsheath dropseed	grass	N	0.00	0.00	0.00
Sporobolus vaginiflorus	poverty dropseed	grass	N	0.00	0.00	0.00
Stellaria media	common chickweed	forb	I	0.00	0.00	0.00
Stenaria nigricans var. nigricans	Madder	forb	N	0.00	0.00	3.33
Strophostyles leiosperma	slickseed fuzzybean	forb	N	0.00	0.00	0.00
Symphoricarpos orbiculatus	coralberry	woody	N	0.08	0.06	10.00
Symphyotrichum ericoides var. ericoides	Squarrose white wild aster	forb	N	2.60	0.73	100.00
Symphyotrichum laeve var. laeve	Smooth wild aster	forb	N	0.00	0.00	3.33
Symphyotrichum oblongifolium	Aromatic wild aster	forb	N	0.47	0.20	70.00
Symphyotrichum sericeum	Western silvery wild aster	forb	N	0.11	0.08	26.67
Taraxacum officinale	common dandelion	forb	I	0.00	0.00	0.00
Thlaspi arvense	field pennycress	forb	I	0.00	0.00	0.00
Torilis arvensis	spreading hedgeparsley	forb	I	0.00	0.00	3.33
Tradescantia bracteata	longbract spiderwort	forb	N	0.01	0.01	20.00
Tradescantia ohiensis	bluejacket	forb	N	0.00	0.00	0.00
Tragia spp.	noseburn	forb	N	0.01	0.01	3.33
Tragia betonicifolia	betonyleaf noseburn	forb	N	0.01	0.01	6.67
Tragia ramosa	branched noseburn	forb	N	0.05	0.02	20.00
Tragopogon dubius	yellow salsify	forb	I	0.00	0.00	0.00
Trichostema brachiatum	fluxweed	forb	N	0.00	0.00	6.67
Tridens flavus	purpletop tridens	grass	N	0.04	0.02	23.33

Table A1 (continued). All species observed at prairie sites (N = 30) at Tallgrass Prairie National Preserve, Kansas. Values for mean cover, standard error (SE), and occurrence are for 2018 (most recent monitoring event) only. Species with 0 values were observed during monitoring events from 2002–2014, but not in 2018. N = native, I = nonnative.

Species	Common Name	Guild	Origin	2018 Mean Cover (%)	SE	Occurrence (% Sites Observed) 2018
Trifolium spp.	clover	forb	I	0.00	0.00	0.00
Triodanis leptocarpa	slimpod Venus' looking-glass	forb	N	0.01	0.00	10.00
Triodanis perfoliata	clasping Venus' looking-glass	forb	N	0.02	0.01	30.00
Triosteum perfoliatum	feverwort	forb	N	0.00	0.00	3.33
Verbena simplex	narrowleaf vervain	forb	N	0.00	0.00	0.00
Verbena stricta	hoary verbena	forb	N	0.00	0.00	3.33
Vernonia baldwinii	Baldwin's ironweed	forb	N	3.30	0.70	100.00
Veronica arvensis	corn speedwell	forb	I	0.00	0.00	0.00
Veronica peregrina	neckweed	forb	N	0.00	0.00	0.00
Viola spp.	violet	forb	N	0.02	0.01	23.33
Viola bicolor	field pansy	forb	N	0.00	0.00	0.00
Viola nephrophylla	northern bog violet	forb	N	0.00	0.00	0.00
Viola pedatifida	prairie violet	forb	N	0.08	0.02	53.33
Viola sororia	common blue violet	forb	N	0.00	0.00	0.00
Viola tricolor	johnny jumpup	forb	I	0.02	0.01	20.00
Vulpia octoflora	sixweeks fescue	grass	N	0.14	0.04	53.33
Zigadenus nuttallii	Nuttall's deathcamas	forb	N	0.02	0.01	16.67

Appendix B. Supplemental Species Assessments

We analyzed a suite of individual species or species groups to learn more about trends relating to preserve goals and objectives. Included here are summaries for big bluestem (*Andropogon gerardii*), the grama grasses (*Bouteloua* spp.), and milkweeds (*Asclepias* spp.). Big bluestem is a critical forage species for large ungulates in the tallgrass prairie and may serve as an indicator of climate change or disturbance intensity. Conversely, the grama species tend to prefer dryer sites and are a critical forage species for bison during the winter months. Lastly, milkweeds represent an important genus for grassland pollinators in the region.

Big Bluestem

Big bluestem (*Anthropogon gerardii*) is an important matrix grass in tallgrass prairie (Bragg 1995). Climate change may shift the range of this matrix grass (Yurkonis and Harris 2019), so we documented it here as a baseline for future observations. Big bluestem peaked in 2014 but varied annually between 7 and 34% cover (Figure B1). Pasture-level observations exhibit a similar pattern to the preserve mean (Figure B2).

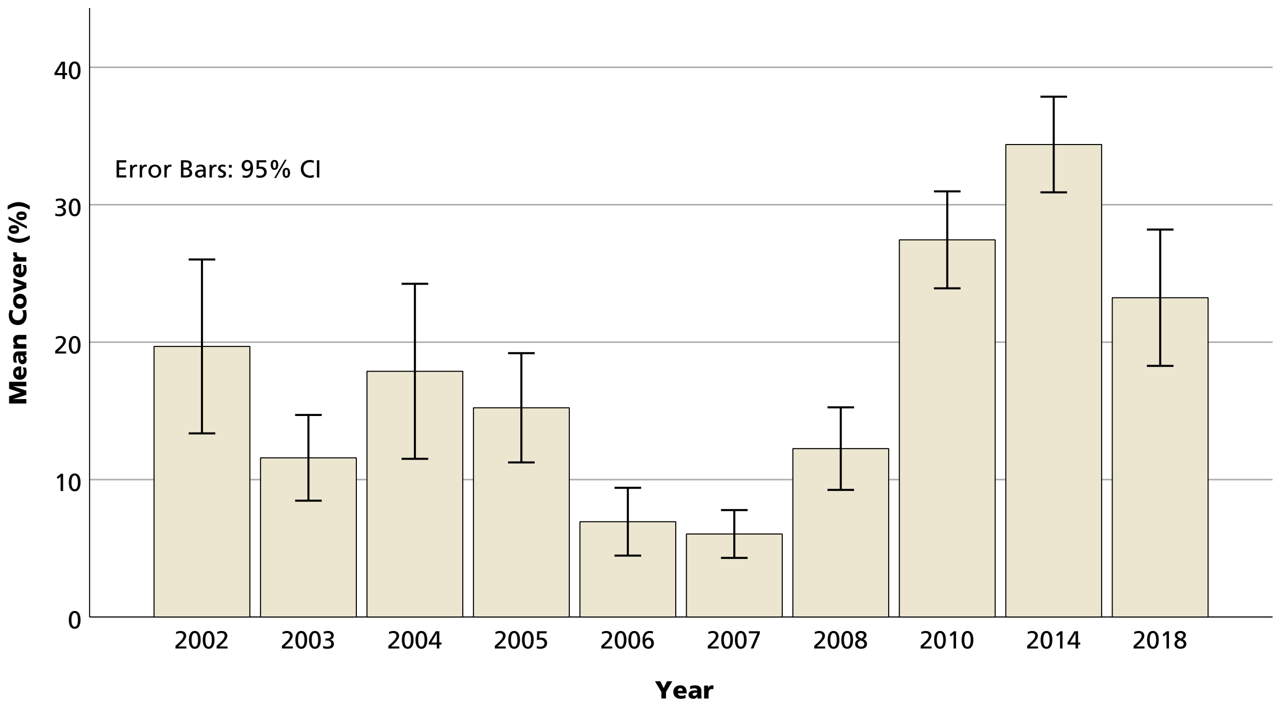

Figure B1. Mean percent cover for big bluestem (*Andropogon gerardii*) at Tallgrass Prairie National Preserve for 2002–2018. Error bars are 95% confidence intervals.

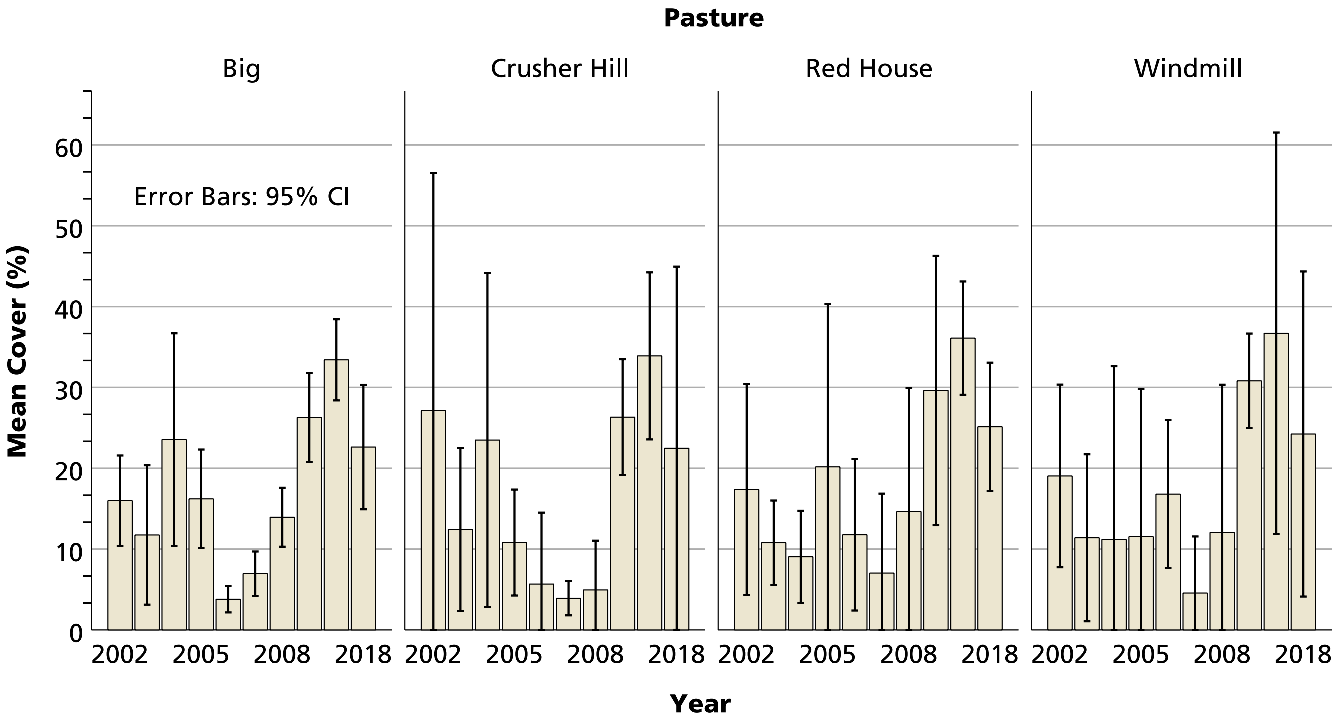

Figure B2. Mean percent cover for big bluestem (*Andropogon gerardii*) by pasture at Tallgrass Prairie National Preserve for 2002–2018. Error bars are 95% confidence intervals.

Grama grasses

We also analyzed a suite of semiarid grasses (*Bouteloua* spp.) that are often more abundant in mixed and shortgrass prairie types as a baseline indicator for the hotter and potentially dryer conditions expected in the future. These species are important to the tallgrass prairie because of their ability to retain nutritional value later in the season than many mesic grass species. They are critical for overwintering grazers, such as bison or deer, at the preserve.

We found that the *Bouteloua* grasses have declined by about two thirds from initial observations in 2002 and 2003 (Figure B3). The reductions in disturbance intensity could be favoring the more mesic species in the prairie, but the reason for the trend is not clear. At the pasture scale, the *Bouteloua* species have substantially reduced cover in Windmill Pasture, where the bison reside, and Red House Pasture (Figure B4).

Milkweeds

We summarized the milkweeds (*Asclepias* spp.) as an important plant group for grassland pollinators (Zaya et al. 2017). Milkweeds ranged from 0.1–0.4% cover through time (Figure B5). The most common species was *Aslcepias viridis*, although five species have been observed at monitoring sites. We found that milkweeds seem to be in decline in Big Pasture, while Windmill Pasture had consistent abundance over time (Figure B6).

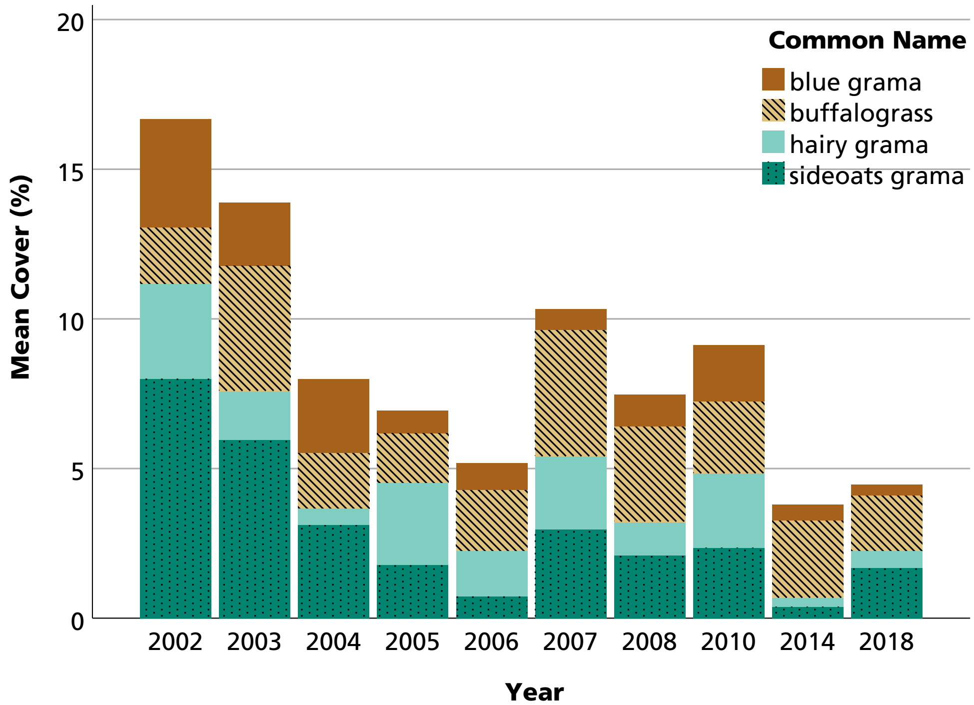

Figure B3. Cumulative mean percent cover for semiarid grass species (blue grama [*Bouteloua gracilis*], buffalograss [*Bouteloua dactyloides*], hairy grama [*Bouteloua hirsuta*], and sideoats grama [*Bouteloua curtipendula*)]) at Tallgrass Prairie National Preserve, 2002–2018. Error bars are 95% confidence intervals.

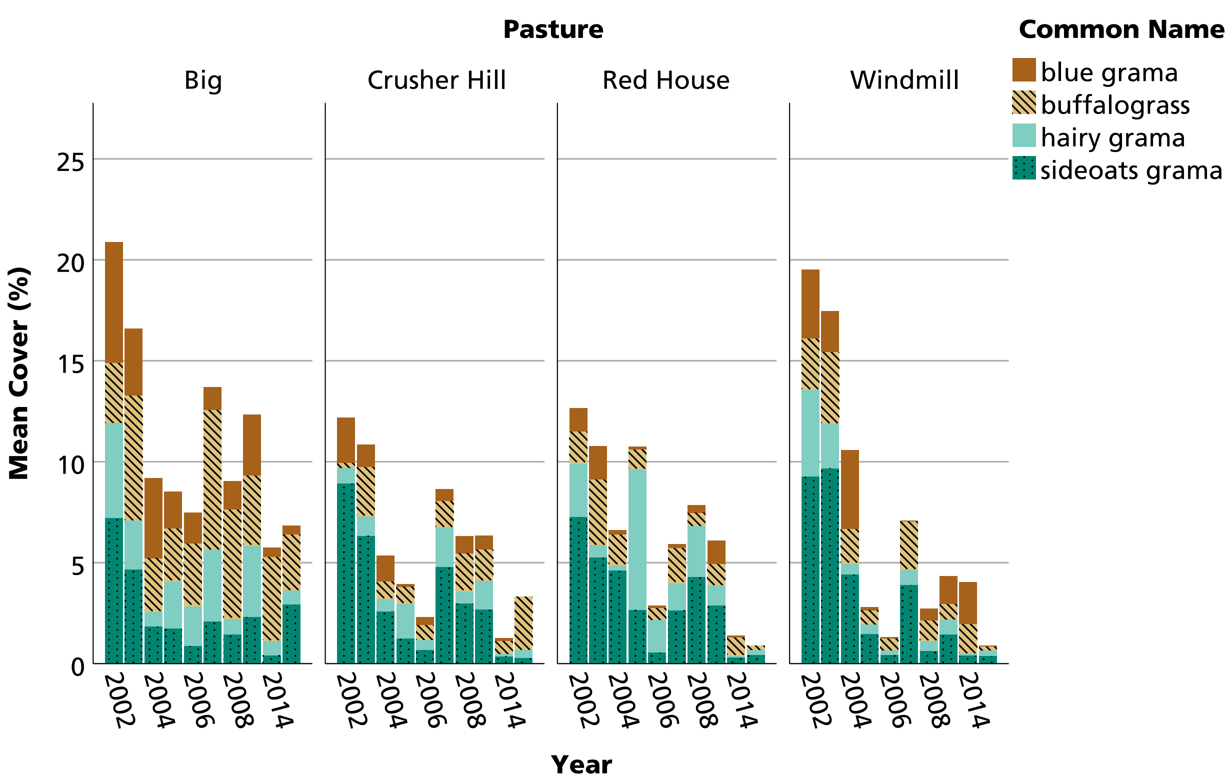

Figure B4. Cumulative mean percent cover for semiarid grass species (blue grama [*Bouteloua gracilis*], buffalograss [*Bouteloua dactyloides*], hairy grama [Bouteloua hirsuta], and sideoats grama [*Bouteloua curtipendula*]) by pasture at Tallgrass Prairie National Preserve, 2002–2018. Error bars are 95% confidence intervals.

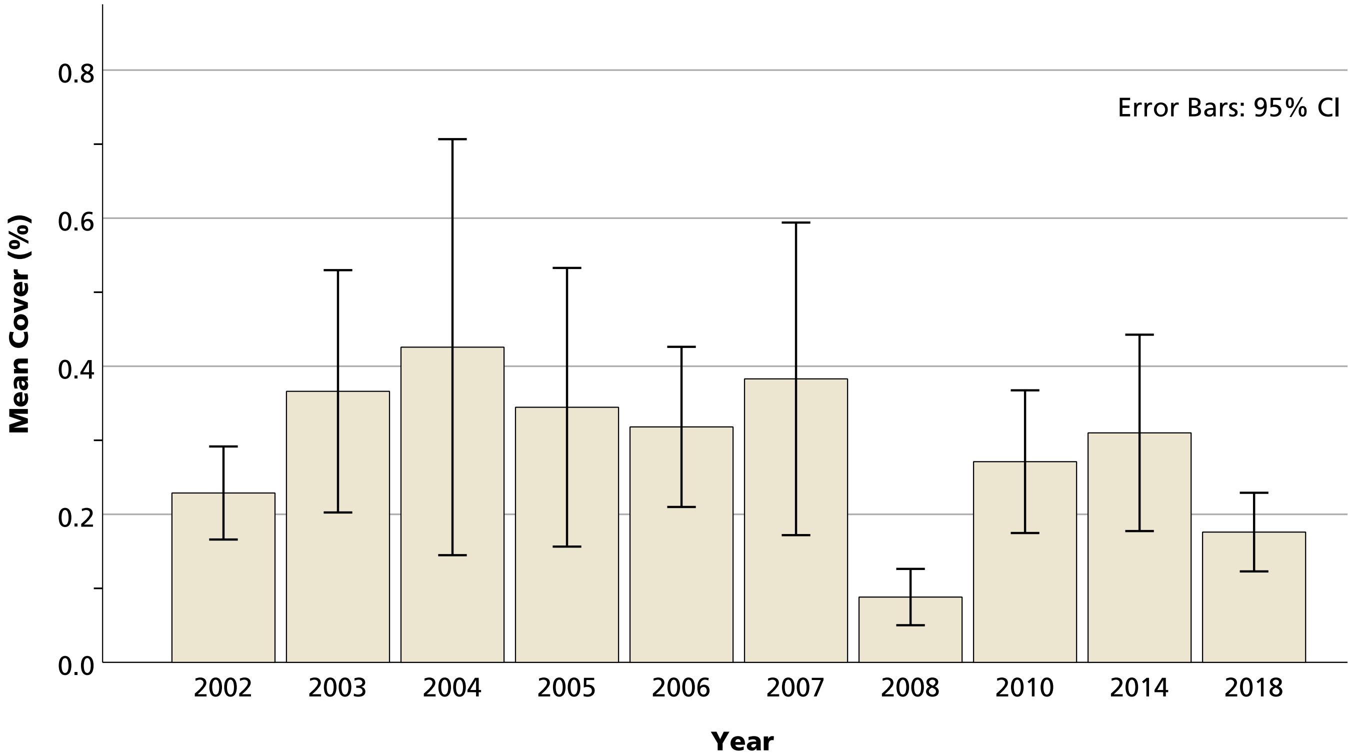

Figure B5. Mean percent cover for milkweeds (*Asclepias* spp.) at Tallgrass Prairie National Preserve, 2002–2018. Error bars are 95% confidence intervals.

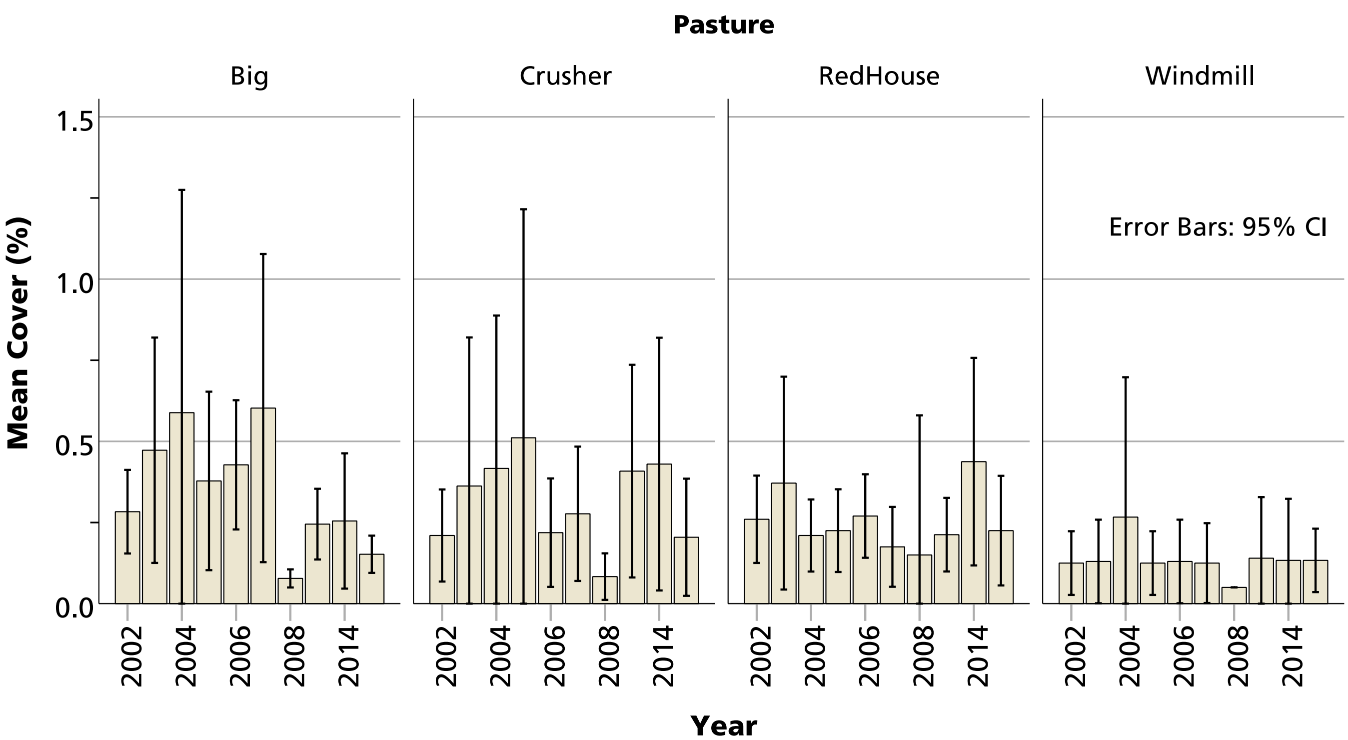

Figure B6. Mean percent cover for milkweeds (*Asclepias* spp.) by pasture at Tallgrass Prairie National Preserve, 2002–2018. Error bars are 95% confidence intervals.

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