



Plant Community Composition and Structure Monitoring for Badlands National Park

2011-2015 Summary Report

Natural Resource Report NPS/NGPN/NRR—2016/1244



ON THE COVER

Long-term monitoring plot PCM-0041 Badlands National Park, 2015
Photograph by L. Mickelson, National Park Service

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Executive Summary

The Northern Great Plains Inventory & Monitoring Program and Fire Effects Program have been monitoring vegetation in Badlands National Park (BADL) for over 18 years. While methods have changed slightly, this report summarizes data from over 127 locations in BADL's north unit from 1998-2015. We use these data to explore the status and trends in plant communities, the role of climate and disturbance in maintaining species richness, and the occurrence of rare plants. A summary of the current condition (2011-2015) and trends (based on 1988-2015) in plant communities at BADL is found in the table below.

1. What is the current status of plant community composition and structure of BADL grasslands (species richness, cover, and diversity) and how has this changed from 1998-2015?

BADL plays a vital role in protecting and managing some of the largest remnants of native mixed-grass prairie in the region. Most sites within the park have a number of native grass and forb species that is well within the natural range of variability for northern mixed-grass prairie. We found no significant changes in native species richness or evenness from 1998-2015, but both metrics are threatened by the increasing cover of exotic species. Annual bromes, Kentucky bluegrass, and yellow sweet clover are the most abundant exotic plant species in BADL. Continued management efforts will be necessary to maintain native prairie within BADL.

2. How do trends in grassland condition relate to climate, fire history, and the presence of bison?

The large variability in the climate of BADL has made it difficult to discern strong patterns linking temperature, precipitation, to plant community structure (e.g. exotic cover, diversity). However, we did find that the relative cover of exotic species declined in response to increasing average annual maximum temperatures. Continued monitoring and a longer time series of vegetation data and climate will allow us to determine if hotter conditions continue to favor native species.

BADL has been using prescribed burning as a management tool since the 1980s. There was no difference in native diversity or exotic cover among plots that had burned recently and those that had not burned for over 10 or 25 years. However, plots that had not burned in many years had a higher cover of annual bromes than sites that burned more recently. Ongoing adaptive management programs and research will provide better guidance to park managers on whether prescribed burns should be used to reduce the cover of annual bromes.

We found that native species richness was higher in plots within areas of the park utilized by bison. This pattern is consistent with a past studies on the role of disturbance in maintaining grassland diversity.

3. What, if any, rare plants were found in BADL long-term monitoring plots?

We found only one rare plant in BADL. Barr's milkvetch (*Astragalus barrii*) was observed in a single vegetation monitoring plot. Since the rare plants within BADL are found in such low abundance, we recommend a more targeted effort to monitor their populations.

Table ES-1. Natural resource condition summary table for plant communities in Badlands National Park (BADL). Current values are based on data from 2011-2015 and trends are based on data from 1998-2015.

Indicator of Condition	Specific Measures	Current Value (mean $\pm$ SE)	Reference Condition and Data Source	Condition Status/Trend	Rationale for Resource Condition
Upland Plant Community Structure and Composition	Native species richness (1m ² quadrats)	6.1 $\pm$ 0.3 species	3-15 species		BADL plays a vital role in protecting and managing one of the largest remnants of native mixed-grass prairie in the region. The park is characterized by moderate native species richness that falls within a natural range of variability (Symstad and Jonas 2014). There has been no trend in native richness over time. In general, the sites in BADL had a high cover of exotic species. Only one of the sites visited in 2014 had less than 10% relative cover of exotic species. Yellow sweet-clover and annual bromes present a large challenge to managers of BADL, and more research on effective management strategies in mixed-grass prairie is greatly needed.
	Evenness (point-intercept transects)	0.68 $\pm$ 0.01	To be determined		
Exotic Plant Early Detection and Management	Relative cover of exotic species	28.8 $\pm$ 1.5 %	< 10 % cover		Many areas of BADL have a high cover of exotic species. Annual bromes, Kentucky bluegrass, and yellow sweet clover present the largest challenge to BADL. Exotic cover has remained high over the entire monitoring period. More research on effective management strategies of annual bromes and other exotic species in the mixed-grass prairie is greatly needed.
	Annual brome cover	11.1 $\pm$ 1.0 %	< 10 % cover		

Acknowledgments

We thank all the authors of the NGPN Plant Community Monitoring Protocol, particularly A. Symstad, for outstanding guidance on data collection and reporting. Thank you to the staff at BADL, particularly M. Haar, for providing logistical support, safety checks, and help in the field. With their assistance, the NGPN and Fire Ecology Program collected all the data included in this report. We thank M. Haar and J. Handley for providing comments that improved this report.

Introduction

During the last century, much of the prairie within the Northern Great Plains has been plowed for cropland, planted with non-natives to maximize livestock production, or otherwise developed, making it one of the most threatened ecosystems in the United States. The National Park Service (NPS) plays an important role in preserving and restoring some of the last pieces of intact prairies within its boundaries. The stewardship goal of the NPS is to “preserve ecological integrity and cultural and historical authenticity” (NPS 2012); however, resource managers struggle with the reality that there have been fundamental changes in the disturbance regimes, such as climate, fire, and large ungulate grazing, that have historically maintained prairies, and there is the continual pressure of exotic invasive species. Long-term monitoring in national parks is essential to sound management of prairie landscapes because it can provide information on environmental quality and condition, benchmarks of ecological integrity, and early warning of declines in ecosystem health.

Badlands National Park (BADL) was established in 1939 as a National Monument and in 1978 became a National Park with a mission to protect and preserve 242,756 acres of rugged badlands, mixed-grass prairie, and rich fossil deposits. The vegetation is a mosaic of sparsely vegetated badlands, native mixed-grass prairie, woody draws, and exotic grasslands. Vegetation monitoring began at BADL in 1998 by the Northern Great Plains Fire Ecology Program (NGPFire; Wienk et al. 2011). The Northern Great Plains Inventory & Monitoring Program (NGPN) began vegetation monitoring at BADL in 2011 (Ashton et al. 2012). Vegetation monitoring protocols and plot locations were chosen to represent the entire park and to coordinate efforts with the Northern Great Plains Fire Ecology Program (FireEP). A total of 127 plots were established by NGPFire and NGPN in BADL and the combined sampling efforts began in 2011 (Ashton et al. 2012). In this report, we use the data from 2011-2015 to assess the current condition of park vegetation and the data from 1998-2015 are used to look at longer-term trends.

Using 18 years of plant community monitoring data in BADL, we explore the following questions:

1. What is the current status of plant community composition and structure of BADL grasslands (species richness, cover, and diversity) and how has this changed from 1998-2015?
2. How do trends in grassland condition relate to climate, fire history, and the presence of bison?
3. What, if any, rare plants were found in BADL long-term monitoring plots?

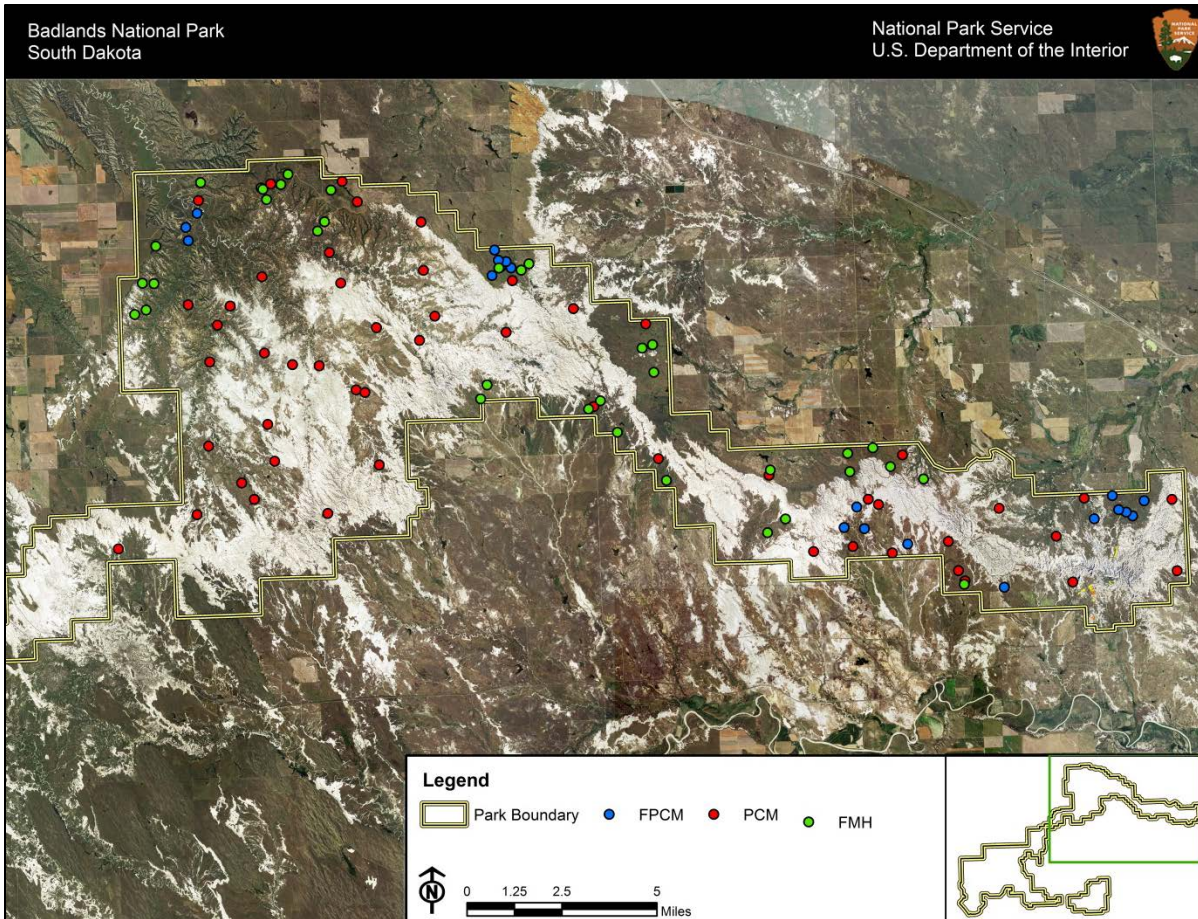


Figure 1. Map of Badlands National Park plant community monitoring plots, 1998-2015. Data has been collected from 127 monitoring plots in the park. PCM plots (red) were established by the Northern Great Plains Inventory & Monitoring Program (NGPN) and FPCM plots (blue) were established by the Fire Effects Program (NGPFire) between 2011 and 2015. Additional FMH plots (green) were monitored from 1997-2011 by NGPFire.

Methods

Two different methods and protocols have been used to monitor long-term vegetation plots at BADL since 1997: the NGPN monitoring protocol (Symstad et al. 2012b, a) and the Fire Monitoring Handbook (NPS 2003). All monitoring plots discussed in this paper are located in the north unit of BADL. Below, we briefly describe both methods, but focus on the NGPN monitoring protocol which is the current standard and was used to collect most of the data in this report. For more detail on any of the methods, please see the protocol publications (cited above).

NGPN and NGPFire Monitoring Plots 2011-2015

The NGPN and NGPFire implemented a survey to monitor plant community structure and composition in BADL using a spatially balanced probability design (Generalized Random Tessellation Stratified [GRTS]; Stevens and Olsen 2003, 2004). Using a GRTS design, NGPN selected 100 randomly located sites within BADL to become Plant Community Monitoring plots (PCM plots; Figure 1). The NGPN visits 20 PCM plots every year using a rotating sampling scheme where 10 sites were visited in the previous year and 10 sites are new visits. After 5 years (2011-2015), 50 PCM plots were visited at least twice during mid-June. With the current sampling scheme, it will take the NGPN 20 years to monitor all 100 plots. When a PCM plot fell within an active burn unit, NGPFire added additional visits based on a 1, 2, 5, and 10 year sampling schedule. NGPFire also established and monitored a number of new sites using the same GRTS sampling schema focused in active burn units (Fire FPCM plots). From 2011-2015, 32 FPCM plots were established. A total of 84 plots were established by NGPFire and NGPN from 2011-2015.

At each of the grassland sites we visited, we recorded plant species cover and frequency in a rectangular, 50 m x 20 m (0.1 ha), permanent plot (Figure 2). Data on ground cover, herb-layer height ≤ 2 m, and plant cover were collected on two 50 m transects (the long sides of the plot) using a point-intercept method (Figure 3). At 100 locations along the transects (every 0.5 m) a pole was dropped to the ground and all species that touched the pole were recorded, along with ground cover, and the height of the canopy (Figure 3). Using this method, absolute canopy cover can be greater than 100% (particularly in wet years and productive sites) because we record multiple layers of plants. Species richness data from the point-intercept method were supplemented in the 20 NGPN plots with species presence data collected in five sets of nested square quadrats (0.01 m², 0.1 m², 1 m², and 10 m²) located systematically along each transect (Figure 2).

When woody species were also present, tree regeneration and tall shrub density data were collected within a 10 m radius subplot centered in the larger 50 m x 20 m plot (Figure 2). Six PCM plots had trees close enough to the plot to warrant searching for seedlings, but we found seedlings in only one plot. BADL_PCM_0106 had 11 narrowleaf willow (*Salix exigua*) seedlings in 2015.

At all PCM plots, but not the FPCM plots, we also surveyed the area for common disturbances and target species of interest to the park. Common disturbances included such things as prairie dog towns, rodent mounds, animal trails, and fire. For all plots, the type and severity of the disturbances were recorded. We also surveyed the area for exotic species that have the potential to spread into the park and cause significant ecological impacts (Table 1). For each target species that was present at a

site, an abundance class was given on a scale from 1-5 where 1 = one individual, 2 = few individuals, 3 = cover of 1-5%, 4 = cover of 5-25%, and 5 = cover > 25% of the plot. The information gathered from this procedure is critical for early detection and rapid response to such threats.

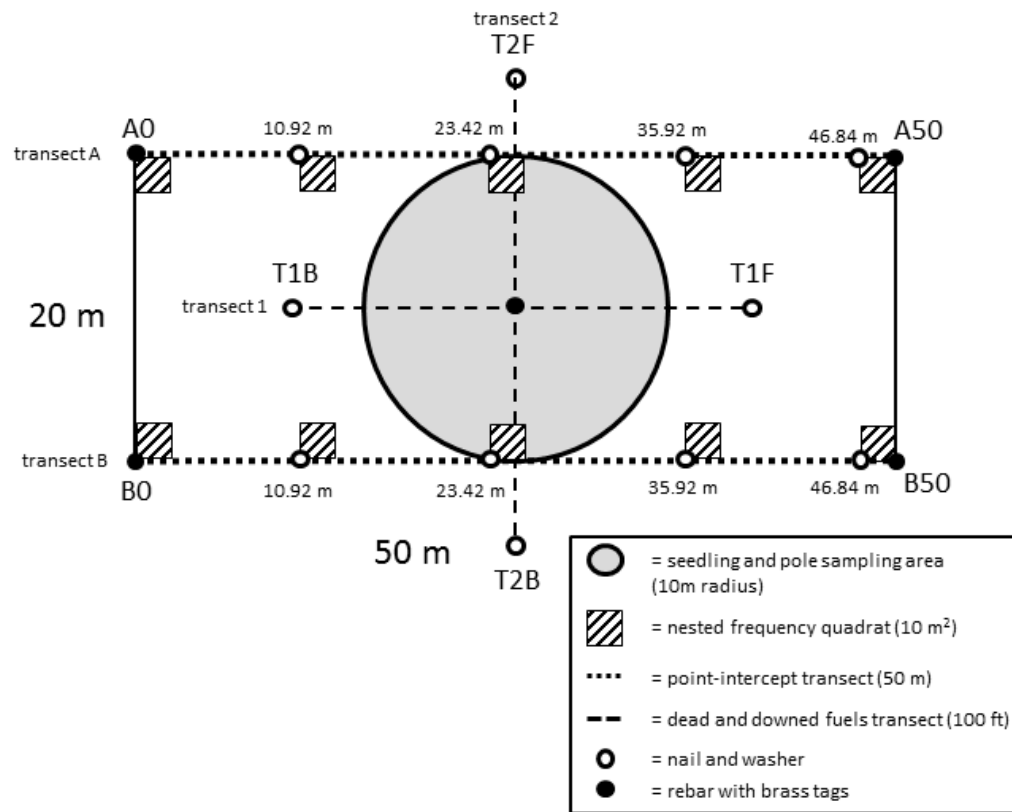


Figure 2. Long-term monitoring plot layout used for sampling vegetation in Badlands National Park.



Figure 3. The Northern Great Plains Inventory & Monitoring vegetation crew used point-intercept (left panel) and quadrats (right panel) to document plant diversity and abundance.

Table 1. Exotic species surveyed for at Badlands National Park as part of the early detection and rapid response program within the Northern Great Plains Network. Asterisks indicate species of management concern to Badlands National Park.

Scientific Name	Common Name
<i>Alliaria petiolata</i>	garlic mustard
<i>Polygonum cuspidatum</i> ; <i>P. sachalinense</i> ; <i>P. x bohemicum</i>	knotweeds
<i>Pueraria montana</i> var. <i>lobata</i>	kudzu
<i>Iris pseudacorus</i>	yellow iris
<i>Ailanthus altissima</i>	tree of heaven
<i>Lepidium latifolium</i>	perennial pepperweed
<i>Arundo donax</i>	giant reed
<i>Rhamnus cathartica</i>	common buckthorn
<i>Heracleum mantegazzianum</i>	giant hogweed
<i>Centaurea solstitialis</i>	yellow star thistle
<i>Hieracium aurantiacum</i> ; <i>H. caespitosum</i>	orange and meadow hawkweed
<i>Isatis tinctoria</i>	Dyer's woad
<i>Taeniatherum caput-medusae</i>	medusahead
<i>Chondrilla juncea</i>	rush skeletonweed
<i>Gypsophila paniculata</i>	baby's breath
<i>Centaurea virgata</i> ; <i>C. diffusa</i>	knapweeds
<i>Linaria dalmatica</i> ; <i>L. vulgaris</i>	toadflax
<i>Euphorbia myrsinites</i> & <i>E. cyparissias</i>	myrtle spurge
<i>Dipsacus fullonum</i> & <i>D. laciniatus</i>	common teasel
<i>Salvia aethiopsis</i>	Mediterranean sage
<i>Ventenata dubia</i>	African wiregrass
<i>Elaeagnus angustifolia</i> *	Russian olive
<i>Euphorbia esula</i> *	leafy spurge
<i>Falcaria vulgaris</i> *	sickleweed
<i>Poa bulbosa</i> *	bulbous bluegrass
<i>Potentilla recta</i> *	sulphur cinquefoil
<i>Rhaponticum repens</i> *	Russian knapweed
<i>Sideritis montana</i> *	mountain ironwort
<i>Tamarix</i> spp. *	tamarisk
<i>Tanacetum vulgare</i> *	common tansy
<i>Thymelaea passerina</i> *	spurge flax

Other Monitoring Plots (1997-2015)

In 1997, NGPFire began monitoring plots within BADL to evaluate the effectiveness of prescribed burns. Starting in 1998, data collection followed the NPS National Fire Ecology Program protocols (NPS 2003): in grassland plots vegetation cover and height data were collected using a point-intercept method, with 100 points evenly distributed along a single 30 m transect. In forested sites, plots are 0.1 ha (20 x 50 m) in size and point-intercept data was collected along the two 50 m sides. For each live tree with a DBH > 15 cm located within the 0.1 ha plot, the species and DBH were recorded. The densities of smaller trees (2.54 cm ≤ DBH ≤ 15 cm) were measured within a subset of

the plot area. NGPFire plot locations were located randomly within major vegetation types within areas planned for prescribed burning (burn units) in the near future. The plots were then sampled 1, 2, 5, and 10 years after a prescribed burn. A total of 43 plots were monitored using these methods. Hereafter, we refer to these plots as Fire Monitoring Handbook (FMH) plots. These FMH plots are being retired after 10 years of monitoring is completed (e.g. the rebar will be removed).

Data Management and Analysis

We used FFI (FEAT/FIREMON Integrated; <http://frames.gov/ffi/>) as the primary software environment for managing our sampling data. FFI is used by a variety of agencies (e.g., NPS, USDA Forest Service, U.S. Fish and Wildlife Service), has a national-level support system, and generally conforms to the Natural Resource Database Template standards established by the Inventory and Monitoring Program.

Species scientific names, codes, and common names are from the USDA Plants Database (USDA-NRCS 2015). However, nomenclature follows the Integrated Taxonomic Information System (ITIS) (<http://www.itis.gov>). In the few cases where ITIS recognizes a new name that was not in the USDA PLANTS database, the new name was used, and a unique plant code was assigned. This report uses common names after the first occurrence in the text, but scientific names can be found in Appendix A.

After data for the sites were entered, 100% of records were verified to the original data sheet to minimize transcription errors. A further 10% of records were reviewed a second time. After all data were entered and verified, automated queries were used to check for errors in the data. When errors were caught by the crew or the automated queries, changes were made to the original datasheets and/or the FFI database as needed. Summaries were produced using the FFI reporting and query tools and statistical summaries, and graphics were generated using R software (version 3.2.2). Most often, linear mixed models were used to test for significant responses where plot was considered a random factor.

Plant life forms (e.g., shrub, forb) were based on definitions from the USDA Plants Database (USDA-NRCS 2015). When only a plant genus was confirmed, the plant life form was assigned only when all species in that genus were the same life form. If any species present in the park within that genus is exotic, the genus was classified as exotic for analyses. The conservation status ranks of plant species in Nebraska is determined by the South Dakota Natural Heritage Program (SDNHP). For the purpose of this report, a species was considered rare if its conservation status rank was S1, S2, or S3. See Table 2. Definitions of state and global species conservation status ranks. for a detailed definition of each conservation status rank.

We measured diversity at the plots in two ways: species richness and Pielou's Index of Evenness. Species richness is simply a count of the species recorded in an area. Pielou's Index of Evenness, J' , measures how even abundances are across taxa, and J' ranges between 0 and 1. Values near 0 indicate dominance by a single species and values near 1 indicate nearly equal abundance of all species present. Plant richness was calculated for each plot using the total number of species

intersected along the transects. Average height was calculated as the average height per plot using all species intersected on the transects.

Table 2. Definitions of state and global species conservation status ranks.

Status Rank*	Category	Definition
S1/G1	Critically imperiled	Due to extreme rarity (5 or fewer occurrences) or other factor(s) making it especially vulnerable to extirpation.
S2/G2	Imperiled	Due to rarity resulting from a very restricted range, very few populations (often 20 or fewer), steep declines, or other factors making it very vulnerable to extirpation.
S3/G3	Vulnerable	Due to a restricted range, relatively few populations (often 80 or fewer), recent widespread declines, or other factors making it vulnerable to extirpation.
S4/G4	Apparently secure	Uncommon but not rare; some cause for concern due to declines or other factors.
S5/G5	Secure	Common, widespread and abundant.
S#S#/ G#G#	Range rank (e.g. S2S3)	Used to indicate uncertainty about the status of the species or community. Ranges cannot skip more than one rank.

* Adapted from NatureServe status assessment table (<http://www.natureserve.org/conservation-tools/conservation-status-assessment>)

Climate data from the Interior 2 NE, SD, US weather station were downloaded from NOAA's online database (NOAA 2015). A fire history map was compiled for BADL and cross-referenced with plot locations. For each plot visit, we determined the number of years since it burned and the number of recorded fires.

Reporting on Natural Resource Condition

Results were summarized in a Natural Resource Condition Table based on the templates from the State of the Park report series (<http://www1.nrintra.nps.gov/im/stateoftheparks/index.cfm>). The goal of the study is to improve park priority setting and to synthesize and communicate complex park condition information to the public in a clear and simple way. By focusing on specific indicators, such as exotic species cover, it will also be possible and straightforward to revisit the metric in subsequent years. The status and trend of each indicator is scored and assigned a corresponding symbol based on the key found in Table 3.

We chose a set of indicators and specific measures that can describe the condition of vegetation in the Northern Great Plains and the status of exotic plant invasions. The measures include: absolute herb-layer canopy cover, native species richness, evenness, relative cover of exotic species, and annual brome cover. Reference values were based on descriptions of historic condition and variation, past studies, and/or management targets. Current park condition was compared to a reference value, and status was scored as good condition, warrants moderate concern, or warrants significant concern based on this comparison (Table 3). Good condition was applied to values that fell within the range of the reference value, and significant concern was applied to conditions that fell outside the bounds of the reference value. In some cases, reference conditions can be determined only after we have accumulated more data. When this is the case, we refer to these as "To be determined", or TBD, and estimate condition based on our professional judgment.

Table 3. Key to the symbols used in the Natural Resource Condition Table. The background color represents the current status, the arrow summarizes the trend, and the thickness of the outside line represents the degree of confidence in the assessment. A symbol that does not contain an arrow indicates that there is insufficient information to assess a trend. Based on the State of the Park reports (<http://www.nps.gov/stateoftheparks/>).

Condition Status		Trend in Condition		Confidence in Assessment	
	Warrants Significant Concern		Condition is Improving		High
	Warrants Moderate Concern		Condition is Unchanging		Medium
	Resource is in Good Condition		Condition is Deteriorating		Low

Results and Discussion

Status & Trends in Community Composition and Structure of BADL Prairies

There are 634 plant species on the BADL species list and we found 357 plant species in monitoring plots from 1998-2015 at BADL (Appendix A). Graminoids, which includes grasses, sedges, and rushes, accounted for most of the vegetative cover at BADL, but forbs, shrubs, and subshrubs (defined as a low-growing shrub usually under 0.5m) were also present (Figure 4). We found 76 exotic plant species at BADL, all of which were forbs or graminoids. Exotic graminoids were particularly abundant (Figure 4). The shrubs and subshrubs were all native species. We did not find any targeted exotic plants (Table 1).

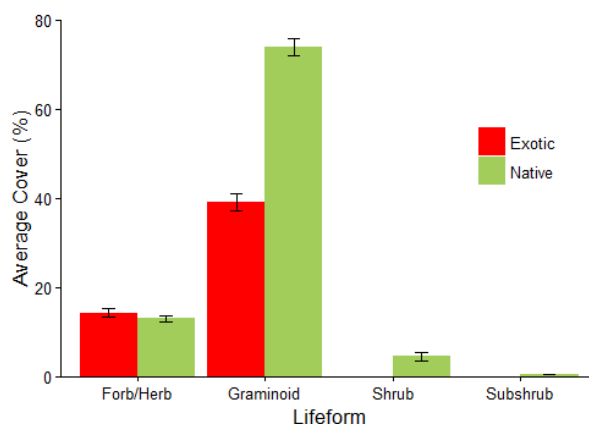


Figure 4. Average cover by lifeform of native (green) and exotic (red) plants recorded in monitoring plots in Badlands National Park (1998-2015). Absolute cover can be greater than 100% because the point-intercept methods records layers of overlapping vegetation.

Western wheatgrass (*Pascopyrum smithii*) was the most abundant native grass and averaged over 40% absolute cover (Figure 5). Japanese brome (*Bromus japonicus*), Kentucky bluegrass (*Poa pratensis*), and yellow sweetclover (*Melilotus officinalis*) were the most pervasive exotics at BADL. The relative cover of these and other exotic plant species has remained high since 1998, averaging 32.5 ± 1.1 % (mean $\pm$ one standard error; Figure 6). In more recent years, 2011-2015, cover was 28.8 ± 1.5 % but this decline is not statistically significant. Exotic species are widespread across the entire park (Figure 7). Maps of Kentucky bluegrass, Japanese brome, and yellow sweet clover are provided in Appendix B.

Japanese brome, the most abundant exotic plant in BADL, is an Eurasian annual grass that has been a part of the Northern Great Plains landscape for more than a century, but its invasion in the region has accelerated since 1950 (Schachner et al. 2008). The presence of annual bromes in mixed grass prairie is associated with decreased productivity and altered nutrient cycling (Ogle et al. 2003). While the cover of Japanese brome has varied over time in BADL (Figure 6) there is no evidence that it has been increasing. From 1998-2015, the average relative cover of annual bromes was 14.3 ± 0.8 % and the average for the last 5 years was 11.1 ± 1.0 %. Data from parks across the Northern Great Plains show that increasing annual brome relative cover is associated with reduced native species richness

(Figure 8). Reducing the cover of annual bromes presents a major challenge for the park, as it has for the past 15 years.

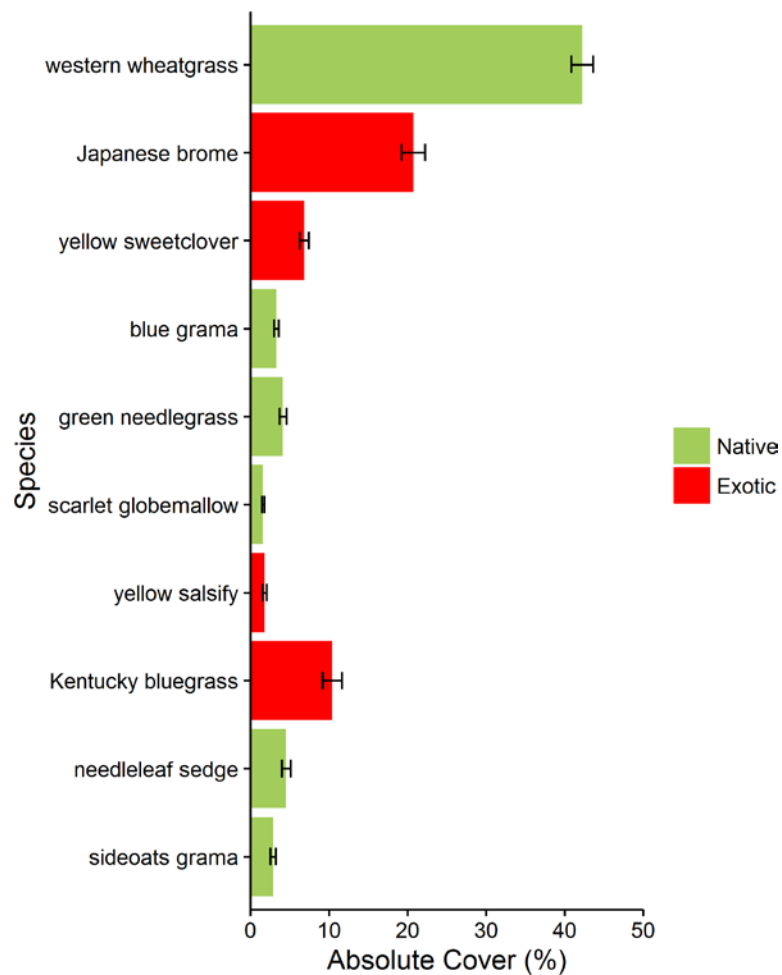


Figure 5. The average absolute cover of the 10 most common native (green) and exotic (red) plants recorded at Badlands National Park in 1998-2015. Bars represent means $\pm$ one standard error.

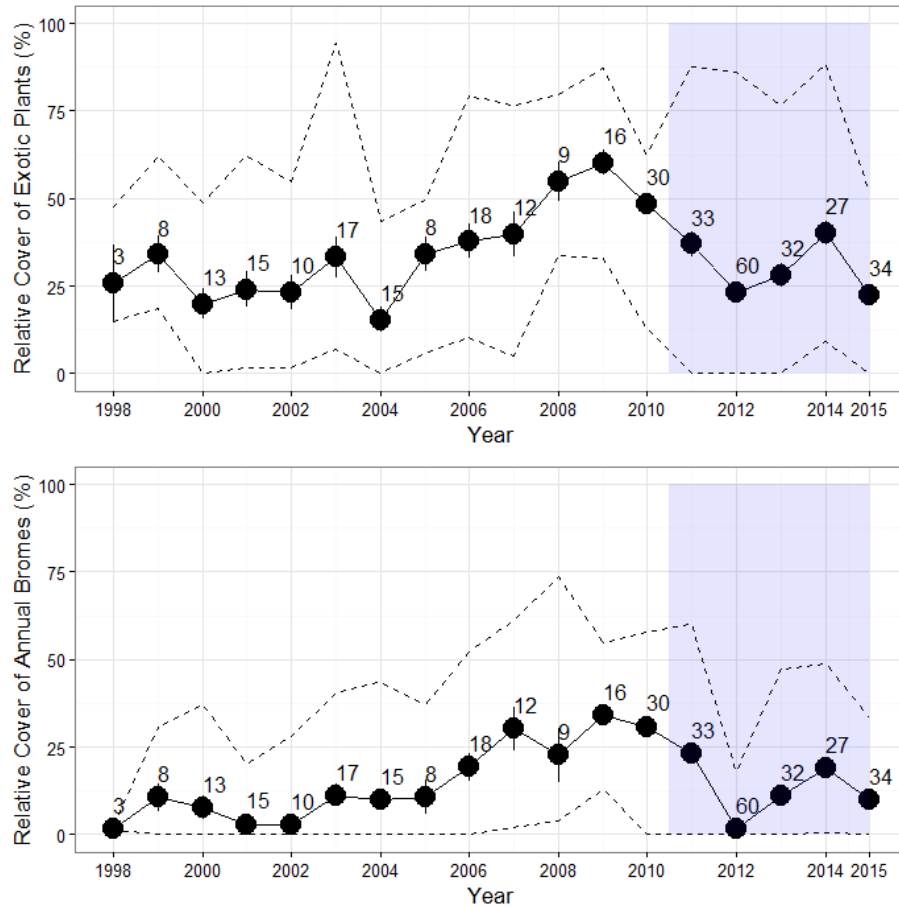


Figure 6. Trends in the relative cover of exotic plants (top) and annual bromes (bottom) in Badlands National Park from 1998 to 2015. Points represent mean $\pm$ one standard error and sample size is to the right of the point. Years with fewer than 3 monitoring plots were excluded from the graph. The shaded area highlights the period from 2011-2015 when sampling methods were consistent and distribution of plots was more even and consistent across years. The dashed line represents the maximum and minimum cover values for each year.

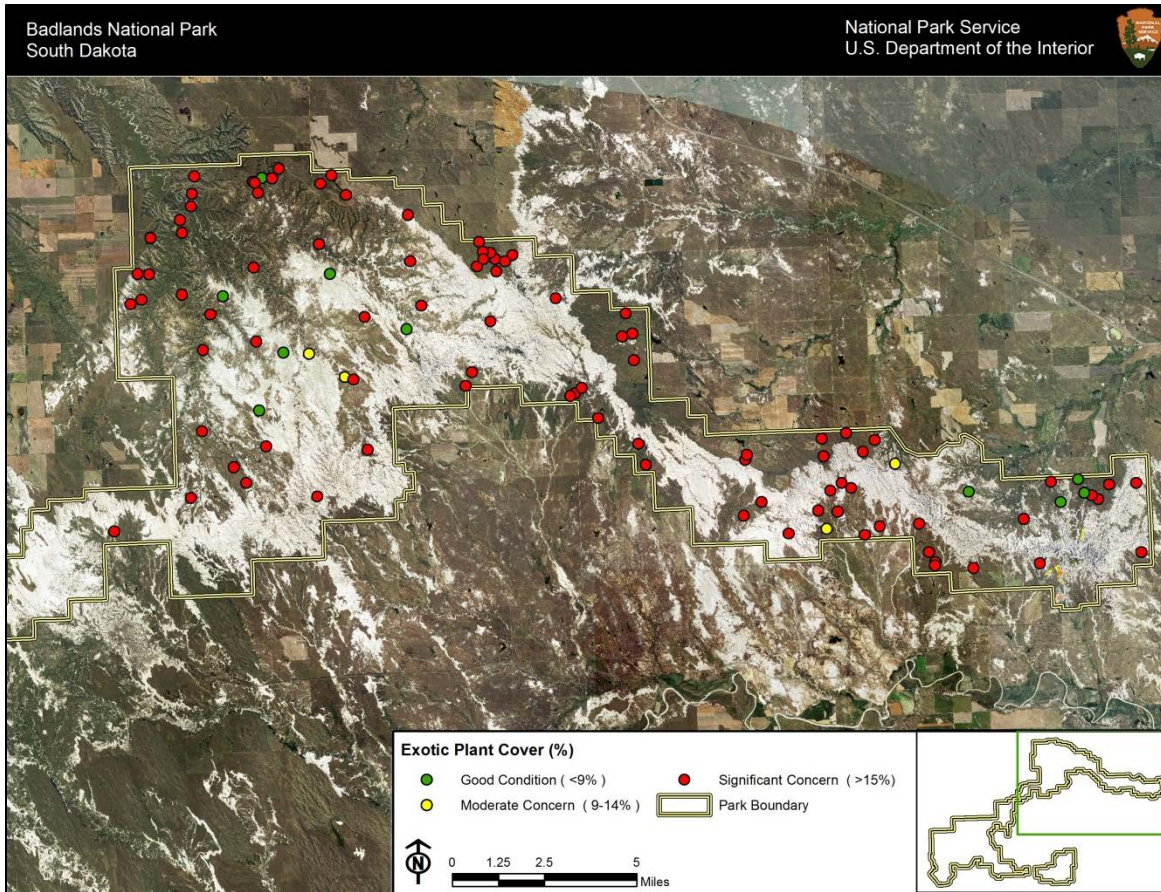


Figure 7. Map of exotic plant cover in Badlands National Park. Colors indicate the percent cover of exotic plants at a site averaged across all site visits.

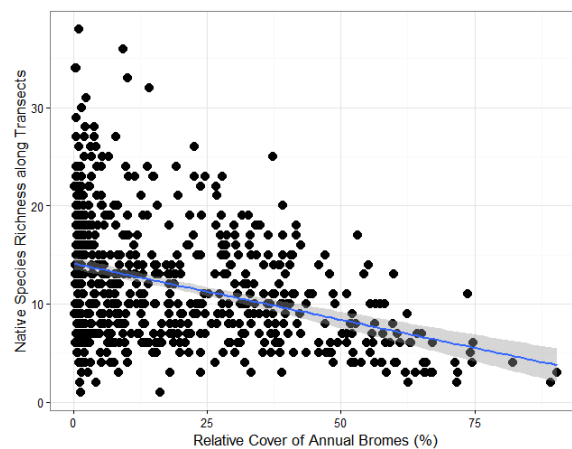


Figure 8. The relationship between native species richness and the relative cover of annual bromes in long-term monitoring plots in national park units of the Northern Great Plains, 1998-2015.

Species Richness, Diversity, and Evenness

One of the ways for the NPS to measure how effectively the mission of ‘preserving ecological integrity’ is being accomplished is to examine trends in native plant diversity and evenness within

their boundaries. Average species richness has been measured by point-intercept since 1998 and in 1 m² and 10 m² quadrats since 2011 (Table 4).

Table 4. Average plant species richness in monitoring plots at Badlands National Park from 1998 to 2015. Values represent means $\pm$ one standard error.

Richness Type	Point-intercept (1998-2011; n=127)	1 m ² quadrats (2011-2015, n=93)	10 m ² quadrats (2011-2015, n=93)
Species richness	14.7 $\pm$ 0.4	8.5 $\pm$ 0.4	14.2 $\pm$ 0.5
Native species richness	10.6 $\pm$ 0.4	6.1 $\pm$ 0.3	10.4 $\pm$ 0.4
Exotic species richness	4.3 $\pm$ 0.2	2.5 $\pm$ 0.2	3.8 $\pm$ 0.2
Graminoid species richness	7.0 $\pm$ 0.3	3.1 $\pm$ 0.2	4.5 $\pm$ 0.2
Forb species richness	7.2 $\pm$ 0.2	5.2 $\pm$ 0.3	9.0 $\pm$ 0.4

While there was some variation across sites, the plots we visited in BADL tended to have a moderate diversity of native plants compared to other mixed-grass prairies. Species richness in the mixed-grass prairie is determined by numerous factors including fire regime, grazing, prairie dog disturbance, and weather fluctuations (Symstad and Jonas 2011). In BADL, there is also a mixed history of past land-use practices that have affected current species richness. While it is difficult to define a reference condition for species richness that can vary so much spatially and temporally, the natural range of variation over long-time periods may be a good starting point (Symstad and Jonas 2014). Long-term records of species diversity in mixed-grass prairie from a relatively undisturbed site in Kansas vary between 3 and 15 species per square meter over the course of 30 years (Symstad and Jonas 2014). Compared to this, the BADL average of 6 native species per square meter (Table 4) is within the natural range. However, native species richness is spatially variable. Some sites, such as PCM_0027, are on sparsely vegetated badlands and average only 1.6 native species per square meter (Figure 9). One of the most diverse plots, PCM_0018, is on a ridge north of the Sage Creek Rim Road. It has a mix of native shrub and grassland habitat and averages 14 species per square meter (Figure 9).



Figure 9. Photographs of long-term monitoring plots PCM_0027 and PCM_0018. PCM_0027 (left) has low plant diversity because it is in unvegetated badlands. Plot PCM_0018 (right) is a prairie site and has a large diversity of native plant species.

We did not find any trends over time in species richness or evenness (Figure 10). Native diversity in 1m² quadrats was fairly similar from 2011-2015; it ranged from a low in 2012 of 4.7 ± 0.54 (a drought year) to a high of 6.8 ± 0.56 in 2014 (a wet year). We have a longer record of native richness from point-intercept data (Figure 10; top). From 1998-2015, we recorded an average between 5 and 12 native species. There was no trend in Peilou's Index of Evenness, J', which measures how even abundances are across taxa (Figure 10). A large variation in richness and evenness across sites within the park and from year-to-year contribute to a large range of values (dashed lines in Figure 10) and makes detecting long-term trends difficult.

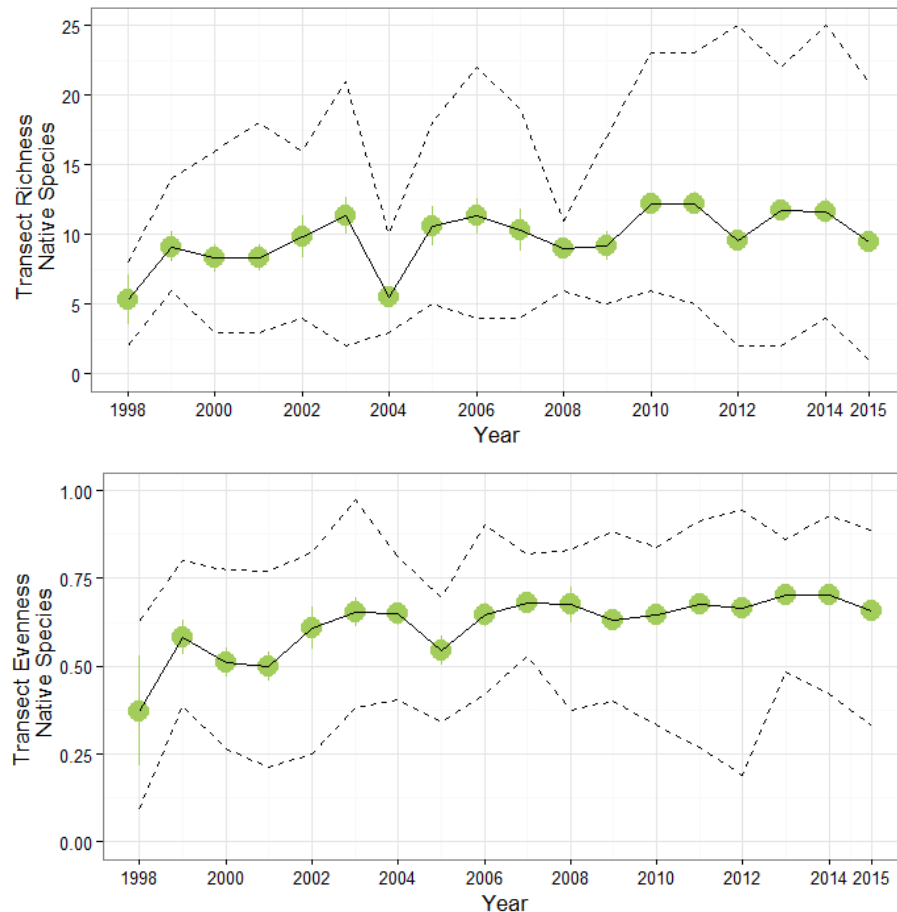


Figure 10. Trends in native species richness and evenness in Badlands National Park, 1998-2015. Data are means $\pm$ one standard error. The dashed line indicates the maximum and minimum values for each year.

Disturbance from grazing, prairie dogs, fire, and humans affects plant community structure and composition in mixed-grass prairie. We measured the approximate area affected by natural and human disturbances at each site we visited from 2011 to 2015 by surveying the area for ~ 5 minutes at the end of the plot visit. The most common disturbances were the trails, wallows, and the grazing impacts of bison. Soil disturbance from small mammals (e.g. gophers, these excluded prairie dogs) and disturbance from erosion and flooding were also common. We found no correlation with total disturbance, small or large animal disturbance and native richness or exotic cover. Disturbances are

patchy in BADL making it difficult to detect trends because they are not found in all plots. As more monitoring data are collected in future years, we may be able to better explore the statistical relationship between these metrics and disturbance.

The Influence of Climate, Fire, and Bison on Plant Community Structure and Diversity

Climate

The 30-year normal temperatures at a nearby weather station, Interior3 NE, South Dakota and ranged from average minimum monthly temperatures in January of 15.6° F to maximum monthly July temperatures of 91.2° F (based on 1980-2010). The 30-year normal annual precipitation totals 18.5 inches. Annual precipitation at BADL in 1998-2015 was variable and ranged between 11.0 and 27.1 inches, in 2002 and 1998, respectively. There were dry years in the early to mid-2000s and in 2012 (Figure 11). Last year, 2013, and 1998 were much wetter than average. The native vegetation is adapted to this variation, and productivity responds strongly to decreases in spring and summer precipitation (Yang et al. 1998, Smart et al. 2007). Species richness and diversity in regional grasslands are also sensitive to temperature and precipitation fluctuation, but the response is complex and less predictable (Jonas et al. 2015).

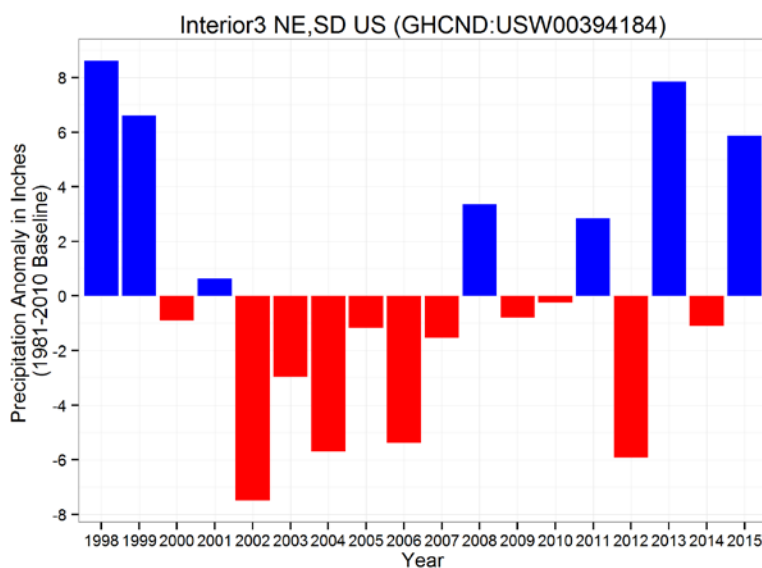


Figure 11. The total annual precipitation anomaly from 1998-2015 for Badlands National Park. Positive values (blue) represent years wetter than and negative values (red) are drier than the 1981-2010 normal. The anomaly is measured in inches and based on data from a nearby weather station.

We found that the relative cover of exotic species declines in response to increasing average annual maximum temperatures ($F_{1,232}=35.0$, $P<0.001$) but it does not respond to changes in precipitation or minimum temperatures. Native richness and plant height decreased in 2012, an extremely hot and dry year. However, when 2012 was excluded, there was not a statistically significant relationship between climate and native richness or height. Continued monitoring and a longer time series of vegetation data and climate will allow us to determine whether the response to the 2012 drought is typical.

Fire History

Historically, fire was a common disturbance in Northern Great Plains grasslands, with natural fire return intervals of 8-25 years (Wienk et al. 2007). Natural fires have been suppressed for most of the last century, but the use of prescribed burning to mitigate the effects of the absence of natural fires has increased over time since its start at Wind Cave National Park in 1973 (Wienk et al. 2011). As of 2015, there is a mosaic of recently burned and unburned areas in BADL (Figure 12).

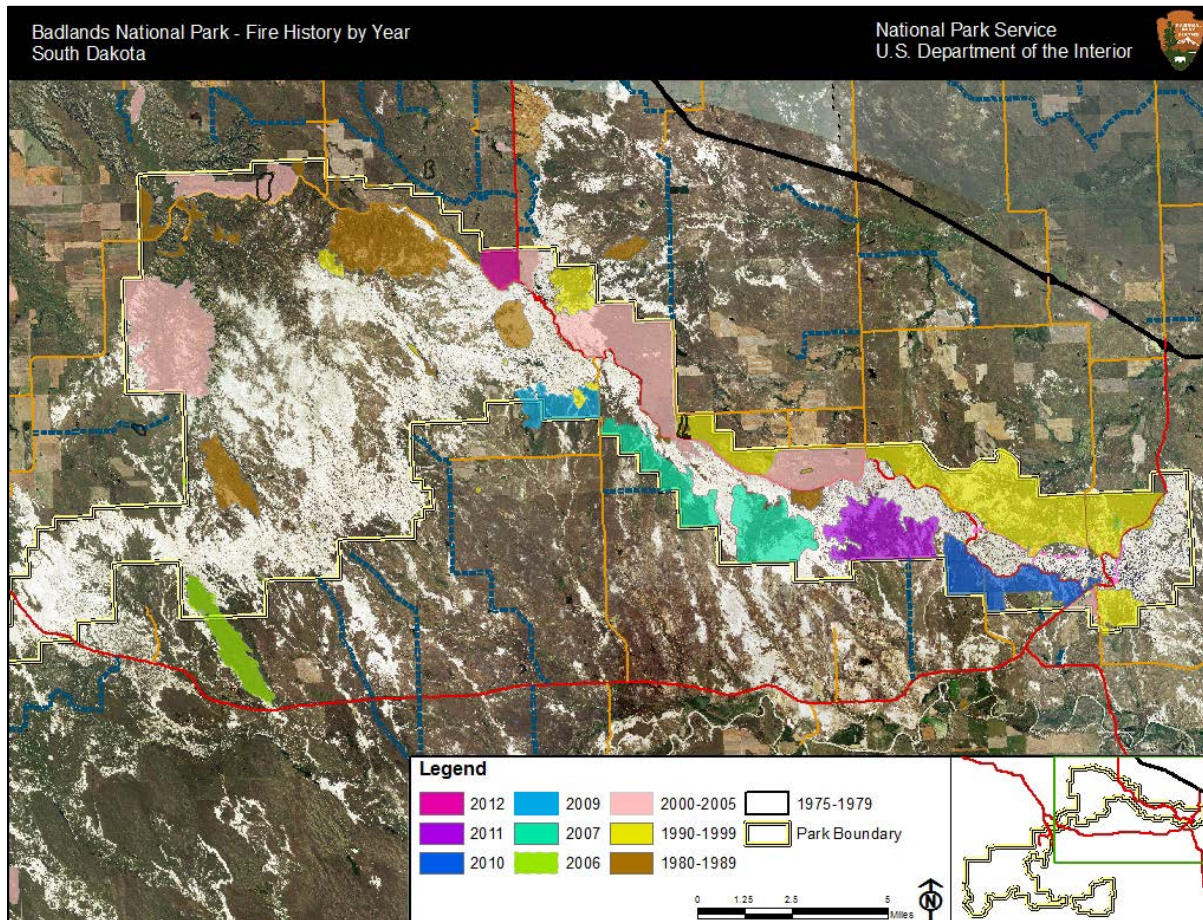


Figure 12. Map of recent fire history at Badlands National Park.

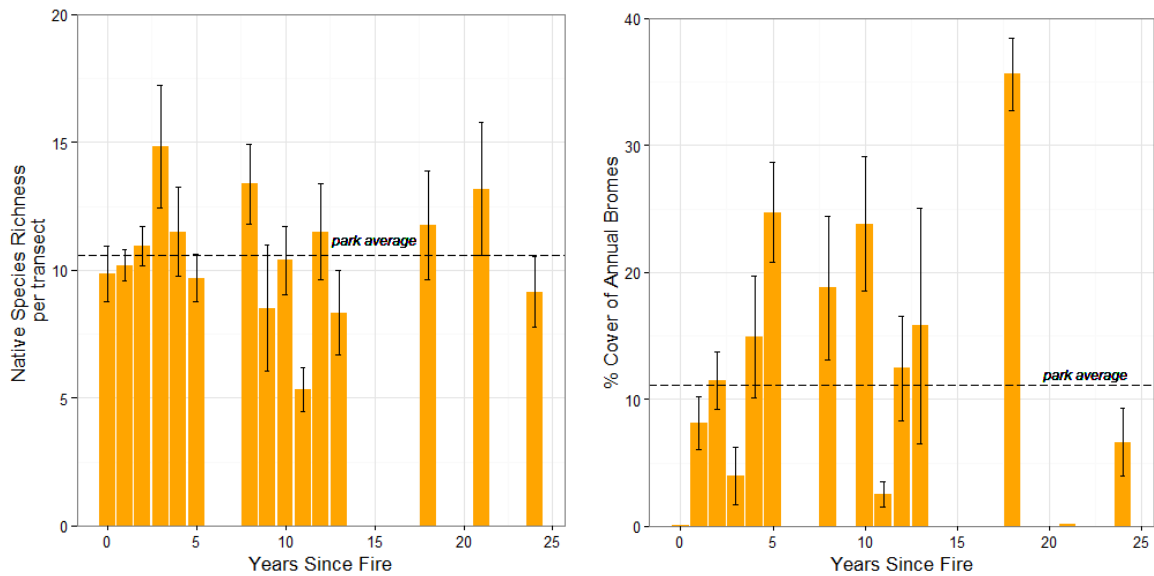


Figure 13. Native species richness (left panel) and relative percent cover of annual bromes (right panel) across plots with different fire histories. Observations vary between plots that have recently burned (0 years since fire) and plots that had burned 24 years previously (24 years since fire). Bars represent means $\pm$ one standard error and sample sizes range from 4 to 45 plots. The dashed line indicates the average native species richness and relative percent cover of exotic species of all plots in the park.

The effects of specific prescribed burns on vegetation and fuel loads and more details about fires at BADL can be found in past NGPFire annual reports (see <http://www.nps.gov/ngpfire/docs.htm>). Here, we were interested in determining the relationship between fire history and vegetation. We compared three vegetation metrics, native species richness and relative cover of all exotic plants and annual brome, with the length of time between the data collection at a plot and the most recent fire at that plot (years since fire). For example, a site that burned in the spring and then was visited in the summer would be 0 years since fire. We excluded plots that had not burned from this analysis, because we do not have confidence in the historical fire record (pre-1975).

We found no relationship between native richness and years since fire (Figure 13; $F_{1,192}=2.9$, $P=0.089$) or the relative cover of exotic species and years since fire ($F_{1,192}=2.4$, $P=0.12$). Annual bromes, however, did respond to fire. Plots that had not burned in many years had a higher cover of annual bromes than sites that burned more recently ($F_{1,192}=7.6$, $P=0.006$). This suggests that prescribed fire can benefit the mixed-grass prairie in BADL, but the reduction in annual brome cover may be short-lived.

The best approach to reducing exotic species abundance in BADL will likely include burning; however there may also be a need for targeted herbicides and seeding of native species. Ongoing research on this topic and an upcoming adaptive management initiative for annual brome control in NGPN parks should provide more data and guidance to help with these management decisions.

Bison

Bison were reintroduced to BADL in 1963 and the park now manages for a population of approximately 700 animals (Licht *in press*). Bison can influence the productivity and diversity of mixed-grass prairie through grazing and the creation of bison wallows, both of which limit the cover of dominant grass species (Collins and Barber 1986). In BADL, there is some evidence that bison have only a small effect on mixed-grass prairie communities, especially when compared to prairie dog, because they are in relatively low density (Fahnestock and Detling 2002). It is estimated that bison probably consume about 12% of plant productivity in a normal precipitation year (Licht *in press*). We used the monitoring data from 1998 to 2015 to compare species richness and exotic species cover between areas in BADL of similar ecological site types with and without bison (Figure 14). We focused on 3 of the most ecological site types found in and out of the bison pasture; these included clay pan and two loamy soils (Figure 14).

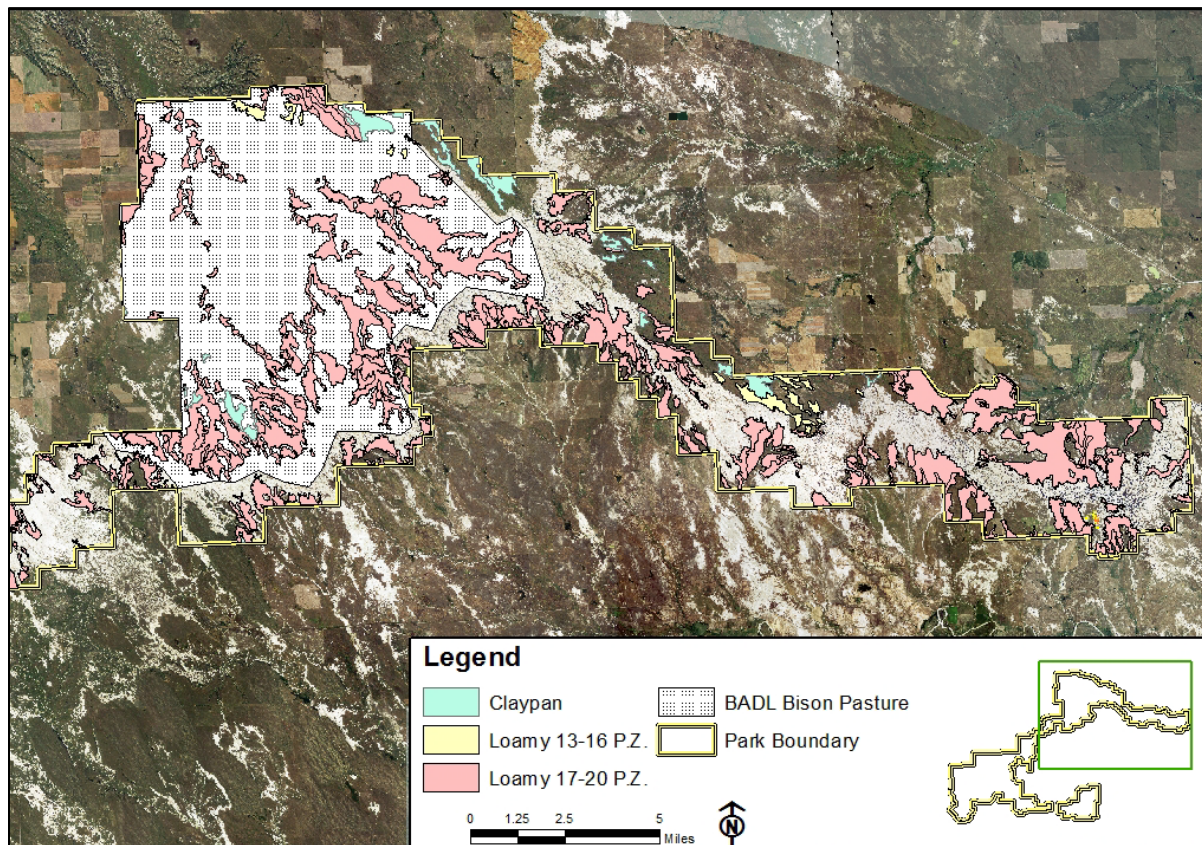


Figure 14. A map of the common ecological site types in and outside of bison pasture in Badlands National Park. The ecological site types are from the Web Soil Survey (NRCS 2015) and the bison pasture was estimated by D. Licht (personal communication).

We found that native plant diversity was higher in plots within the bison pasture areas ($F_{1,107}=14.2$, $P<0.001$) and this pattern was consistent across ecological site types (Table 5). Total exotic cover and annual brome cover varied across ecological site types, but not with the presence of bison ($F_{1,107}=1.1$, $P=0.29$, $F_{1,107}=0.4$, $P=0.55$). This pattern of increased plant diversity in mixed-grass

prairie grazed by bison is consistent with a past studies on the role of disturbance in maintaining grasslands (e.g. Collins and Barber 1986). Other factors could also influence this pattern including differences in past land-use history, wilderness management (the wilderness and bison boundary are similar), or slight differences in climate. With future monitoring we will increase our sample of plots within the park and our confidence in the assessment of grassland condition in and outside of the bison pasture.

Table 5. Average native species richness of plots within and outside the bison pasture at Badlands National Park.

Soil Ecological Site Name	No Bison Present			Bison Pasture		
	# of plots	# of plot visits	Native Richness (mean $\pm$ se)	# of plots	# of plot visits	Native Richness (mean $\pm$ se)
Claypan	3	6	11.3 $\pm$ 1.1	4	7	16.3 $\pm$ 1.5
Loamy 13-16 P.Z.	2	6	8.1 $\pm$ 1.2	2	6	13.2 $\pm$ 2.5
Loamy 17-20 P.Z.	37	88	9.9 $\pm$ 0.4	10	16	11.9 $\pm$ 1.0
All soil types	85	218	9.6 $\pm$ 0.3	42	87	12.2 $\pm$ 0.5

Rare Plants

While repeating rare plant surveys and locating rare species is not the focus of NGPN plant community monitoring, we identified one rare plant species in BADL from 1998 to 2015. Barr's milkvetch (*Astragalus barrii*, S3), was observed in a single vegetation monitoring plot at BADL (Table 6). Barr's milkvetch was observed at a single point in 2014 and at two points in 2015, and all occurrences were within the same plot. This species is a regional endemic, with a range limited to South Dakota, Wyoming, Nebraska, and Montana (Figure 15). Due to this limited range, it is also classified as a globally vulnerable species (G3).

Table 6. Rare species occurrence in Badlands National Park from 1998-2015. Status ranks are based on the South Dakota Natural Heritage Program's designations. Plot count is the number of unique plots a species was recorded in across all years. Mean cover is the average cover of that species across all years in plots where cover measurements were recorded.

Species	Common Name	Status Rank	Plot Count	Mean Cover (%)
<i>Astragalus barrii</i>	Barr's milkvetch	S3	1	<0.01

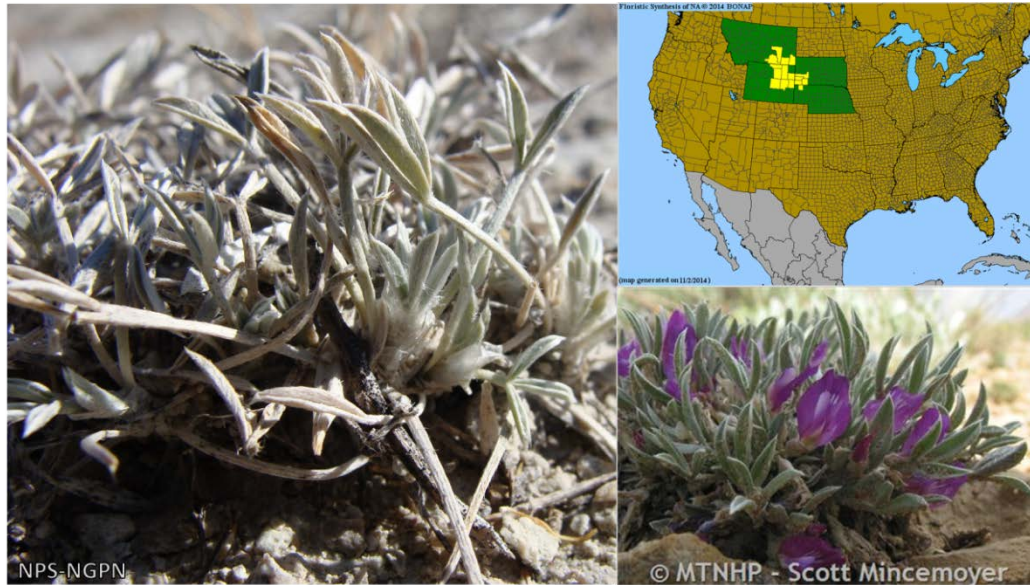


Figure 15. Barr's milkvetch (*Astragalus barrii*, S3), a rare species observed at Badlands National Park. Left: Barr's milkvetch as observed by NGPN staff; Upper right: global distribution map; Lower right: in full bloom.

While several vegetation community mapping projects have been completed for BADL, there are limited floristic diversity and rare species surveys available for the park, and we recommend a park-wide survey be done when funds are available. A full rare plant survey will be more likely to accurately quantify the status of rare plants found in BADL and better document locations of rare species in areas of BADL with no NGPN monitoring plots. Any future construction efforts that could disturb native vegetation (e.g. trail building), should avoid damaging species considered rare in South Dakota.

Conclusion

The Northern Great Plains Inventory & Monitoring Program and Fire Effects Program have been monitoring vegetation in Badlands National Park for over 18 years. While methods have changed slightly, this report summarizes data from over 127 locations from 1998-2015. Below, we list the questions we asked and provide a summarized answer, for more details see the Results and Discussion section. We conclude with a Natural Resource Condition Table (Table 7) that summarizes the current status and trends in a few key vegetation metrics.

1. What is the current status of plant community composition and structure of BADL grasslands (species richness, cover, and diversity) and how has this changed from 1998-2015?

BADL plays a vital role in protecting and managing some of the largest remnants of native mixed-grass prairie in the region. Most sites within the park have a number of native grass and forb species that is well within the natural range of variability for northern mixed-grass prairie. We found no significant trends in native species richness or evenness from 1998-2015, but both are threatened by the increasing cover of exotic species (Table 7). Annual bromes, Kentucky bluegrass, and yellow sweet clover are the most abundant exotic plant species in BADL. Continued control efforts will be necessary to maintain native prairie within BADL.

2. How do trends in grassland condition relate to climate, fire history, and the presence of bison?

The large variability in the climate of BADL has made it difficult to discern strong patterns linking temperature, precipitation, and plant community structure (e.g. exotic cover, diversity). However, we did find that the relative cover of exotic species declined in response to increasing average annual maximum temperatures. Continued monitoring and a longer time series of vegetation data and climate will allow us to determine if hotter conditions continue to favor native species.

BADL has been using prescribed burning as a management tool since the 1980s. There was no difference in native diversity or exotic cover among plots that had burned recently and those that had not burned for over 10 or 25 years. However, those that had not burned in many years had a higher cover of annual bromes than sites that burned more recently. Ongoing adaptive management programs and research will provide better guidance to the park on whether prescribed burns should be used to reduce the cover of annual bromes.

We found that native species richness was higher in plots within areas of the park utilized by bison. This pattern is consistent with a past studies on the role of disturbance in maintaining grassland diversity.

3. What, if any, rare plants were found in BADL long-term monitoring plots?

We found only one rare plant in BADL. Barr's milkvetch (*Astragalus barrii*) was observed in a single vegetation monitoring plot. Since the rare plants within BADL are found in such low abundance, we recommend a more targeted effort to monitor their populations.

Table 7. Natural resource condition summary table for plant communities in Badlands National Park (BADL). Current values are based on data from 2011-2015 and trends are based on data from 1998-2015.

Indicator of Condition	Specific Measures	Current Value (mean $\pm$ SE)	Reference Condition and Data Source	Condition Status/Trend	Rationale for Resource Condition
Upland Plant Community Structure and Composition	Native species richness (1m ² quadrats)	6.1 $\pm$ 0.3 species	3-15 species		BADL plays a vital role in protecting and managing one of the largest remnants of native mixed-grass prairie in the region. The park is characterized by moderate native species richness that falls within a natural range of variability (Symstad and Jonas 2014). There has been no trend in native richness over time. In general, the sites in BADL had a high cover of exotic species. Only one of the sites visited in 2014 had less than 10% relative cover of exotic species. Yellow sweet-clover and annual bromes present a large challenge to managers of BADL, and more research on effective management strategies in mixed-grass prairie is greatly needed.
	Evenness (point-intercept transects)	0.68 $\pm$ 0.01	To be determined		
Exotic Plant Early Detection and Management	Relative cover of exotic species	28.8 $\pm$ 1.5 %	< 10 % cover		Many areas of BADL have a high cover of exotic species. Annual bromes, Kentucky bluegrass, and yellow sweet clover present the largest challenge to BADL. Exotic cover has remained high over the entire monitoring period. More research on effective management strategies of annual bromes and other exotic species in the mixed-grass prairie is greatly needed.
	Annual brome cover	11.1 $\pm$ 1.0 %	< 10 % cover		

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Appendix A: List of plant species found at BADL, 1998-2015

Family	Code	Scientific Name	Common Name	Exotic	Rare
Agavaceae	YUGL	<i>Yucca glauca</i>	soapweed yucca	No	No
Alismataceae	SALA2	<i>Sagittaria latifolia</i>	broadleaf arrowhead	No	No
Amaranthaceae	AMAL	<i>Amaranthus albus</i>	prostrate pigweed	Yes	No
	AMBL	<i>Amaranthus blitoides</i>	mat amaranth	Yes	No
	AMRE	<i>Amaranthus retroflexus</i>	redroot pigweed	No	No
Anacardiaceae	RHAR4	<i>Rhus aromatic</i>	fragrant sumac	No	No
	RHTR	<i>Rhus trilobata</i>	skunkbush sumac	No	No
	TORA2	<i>Toxicodendron radicans</i>	eastern poison ivy	No	No
	TORY	<i>Toxicodendron rydbergii</i>	western poison ivy	No	No
Apiaceae	LOFO	<i>Lomatium foeniculaceum</i>	desert biscuitroot	No	No
	LOMA3	<i>Lomatium macrocarpum</i>	bigseed biscuitroot	No	No
	LOMAT	<i>Lomatium</i> spp.	biscuitroot	No	No
	MUSIN	<i>Musineon</i> spp.	wildparsley	No	No
	MUDI	<i>Musineon divaricatum</i>	leafy wildparsley	No	No
	OSLO	<i>Osmorhiza longistylis</i>	longstyle sweetroot	No	No
Asclepiadaceae	ASPU	<i>Asclepias pumila</i>	plains milkweed	No	No
	ASSP	<i>Asclepias speciosa</i>	showy milkweed	No	No
	ASVE	<i>Asclepias verticillata</i>	whorled milkweed	No	No
	ASVI	<i>Asclepias viridiflora</i>	green comet milkweed	No	No
Asteraceae	ACMI2	<i>Achillea millefolium</i>	common yarrow	No	No
	AGGL	<i>Agoseris glauca</i>	pale agoseris	No	No
	AMAR2	<i>Ambrosia artemisiifolia</i>	common ragweed	No	No
	AMBRO	<i>Ambrosia</i> spp.	ragweed	Yes	No
	AMPS	<i>Ambrosia psilostachya</i>	cuman ragweed	No	No
	AMTR	<i>Ambrosia trifida</i>	great ragweed	No	No
	ANMI3	<i>Antennaria microphylla</i>	littleleaf pussytoes	No	No
	ANPA4	<i>Antennaria parvifolia</i>	small-leaf pussytoes	No	No
	ARCA12	<i>Artemisia campestris</i>	field sagewort	No	No
	ARCA13	<i>Artemisia cana</i>	silver sagebrush	No	No
	ARDR4	<i>Artemisia dracunculus</i>	tarragon	No	No
	ARFR4	<i>Artemisia frigida</i>	fringed sagewort	No	No
	ARLO7	<i>Artemisia longifolia</i>	longleaf sagebrush	No	No
	ARLU	<i>Artemisia ludoviciana</i>	white sagebrush	No	No
	ASTER	<i>Aster</i> spp.	aster	No	No
	BREU	<i>Brickellia eupatorioides</i>	false boneset	No	No
	CANU4	<i>Carduus nutans</i>	Nodding thistle	Yes	No
	CIAR4	<i>Cirsium arvense</i>	Canada thistle	Yes	No
	CICA11	<i>Cirsium canescens</i>	prairie thistle	Yes	No
	CIFL	<i>Cirsium flodmanii</i>	Flodman's thistle		No
	CIRSI	<i>Cirsium</i> spp.	thistle	Yes	No
	CIUN	<i>Cirsium undulatum</i>	wavyleaf thistle	No	No
	COCA5	<i>Conyza canadensis</i>	horseweed	No	No
	CORA4	<i>Conyza ramosissima</i>	dwarf horseweed	No	No
	CROC	<i>Crepis occidentalis</i>	largeflower hawksbeard	No	No
	DIPR2	<i>Diaperia prolifera</i>	bighead pygmycudweed	No	No

Family	Code	Scientific Name	Common Name	Exotic	Rare
	DYPA	<i>Dyssodia papposa</i>	fetid marigold	No	No
	ECAN2	<i>Echinacea angustifolia</i>	blacksamson echinacea	No	No
	ERCA4	<i>Erigeron canus</i>	hoary fleabane	No	No
	ERIGE2	<i>Erigeron</i> spp.	fleabane	No	No
	ERNA10	<i>Ericameria nauseosa</i>	rubber rabbitbrush	No	No
	ERPU2	<i>Erigeron pumilus</i>	shaggy fleabane	No	No
	ERST3	<i>Erigeron strigosus</i>	prairie fleabane	No	No
	ERSU2	<i>Erigeron subtrinervis</i>	threenerve fleabane	No	No
	GRSQ	<i>Grindelia squarrosa</i>	curlycup gumweed	No	No
	GUSA2	<i>Gutierrezia sarothrae</i>	broom snakeweed	No	No
	HEAN3	<i>Helianthus annuus</i>	common sunflower	No	No
	HELIA3	<i>Helianthus</i> spp.	sunflower	Yes	No
	HEMA2	<i>Helianthus maximiliani</i>	Maximilian sunflower	No	No
	HEPA19	<i>Helianthus pauciflorus</i>	stiff sunflower	No	No
	HEPE	<i>Helianthus petiolaris</i>	prairie sunflower	No	No
	HEVI4	<i>Heterotheca villosa</i>	hairy false goldenaster	No	No
	IVAX	<i>Iva axillaris</i>	povertyweed	No	No
	LASE	<i>Lactuca serriola</i>	prickly lettuce	Yes	No
	LIPU	<i>Liatris punctata</i>	dotted blazing star	No	No
	LOAR5	<i>Logfia arvensis</i>	field cottonrose	No	No
	LYJU	<i>Lygodesmia juncea</i>	rush skeletonplant	No	No
	MUOB99	<i>Mulgedium oblongifolium</i>	blue lettuce	No	No
	NOCU	<i>Nothocalais cuspidata</i>	prairie false dandelion	No	No
	OLRI	<i>Oligoneuron rigidum</i>	stiff goldenrod	No	No
	PACA15	<i>Packera cana</i>	woolly groundsel	No	No
	PAPL12	<i>Packera plattensis</i>	prairie groundsel	No	No
	RACO3	<i>Ratibida columnifera</i>	upright prairie coneflower	No	No
	SEIN2	<i>Senecio integerrimus</i>	lambstongue ragwort	No	No
	SOLID	<i>Solidago</i> spp.	Goldenrod	No	No
	SOMI2	<i>Solidago missouriensis</i>	Missouri goldenrod	No	No
	SOMO	<i>Solidago mollis</i>	velvety goldenrod	No	No
	SONE	<i>Solidago nemoralis</i>	gray goldenrod	No	No
	SYER	<i>Symphyotrichum ericoides</i>	white heath aster	No	No
	SYFA	<i>Symphyotrichum falcatum</i>	white prairie aster	No	No
	SYLA3	<i>Symphyotrichum laeve</i>	smooth blue aster	No	No
	SYMPH4	<i>Symphyotrichum</i>	Aster	No	No
	SYOB	<i>Symphyotrichum oblongifolium</i>	aromatic aster	No	No
	TAOF	<i>Taraxacum officinale</i>	common dandelion	Yes	No
	TEAC	<i>Tetaneuris acaulis</i>	stemless four-nerve daisy	No	No
	TRDU	<i>Tragopogon dubius</i>	yellow salsify	Yes	No
	XASP99	<i>Xanthisma spinulosum</i>	lacy tansyaster	No	No
	XAST	<i>Xanthium strumarium</i>	cocklebur	No	No
	SORI2	<i>Solidago rigida</i>	stiff goldenrod	No	No
Boraginaceae	CRCE	<i>Cryptantha celosioides</i>	buttecandle	No	No
	CRMI5	<i>Cryptantha minima</i>	little cryptantha	No	No

Family	Code	Scientific Name	Common Name	Exotic	Rare
	CRTH	<i>Cryptantha thrysiflora</i>	calcareous cryptantha	No	No
	LACE	<i>Lappula cenchrusoides</i>	Great Plains stickseed	No	No
	LAOC3	<i>Lappula occidentalis</i>	flatspine stickseed	No	No
	LAPPU	<i>Lappula</i> spp.	stickseed	Yes	No
	LASQ	<i>Lappula squarrosa</i>	European stickseed	Yes	No
	LIIN2	<i>Lithospermum incisum</i>	narrowleaf stoneseed	No	No
	MELA3	<i>Mertensia lanceolata</i>	prairie bluebells	No	No
Brassicaceae	ALDE	<i>Alyssum desertorum</i>	desert madwort	Yes	No
	ALSI8	<i>Alyssum simplex</i>	alyssum	Yes	No
	ARABI	<i>Arabidopsis</i> spp.	rockcress	Yes	No
	ARABI2	<i>Arabis</i> spp.	rockcress	No	No
	ARGL	<i>Arabis glabra</i>	tower rockcress	No	No
	ARHI	<i>Arabis hirsuta</i>	hairy rockcress	No	No
	ALPA7	<i>Alyssum parviflorum</i>	alyssum	Yes	No
	BOHO99	<i>Boechera holboellii</i>	Holboell's rockcress	No	No
	CABU2	<i>Capsella bursa-pastoris</i>	shepherd's purse	Yes	No
	CAMI2	<i>Camelina microcarpa</i>	littlepod false flax	Yes	No
	CHTE2	<i>Chorispora tenella</i>	blue mustard	Yes	No
	COOR	<i>Conringia orientalis</i>	hare's ear mustard	Yes	No
	DEPI	<i>Descurainia pinnata</i>	western tansymustard	No	No
	DESO2	<i>Descurainia sophia</i>	herb sophia	Yes	No
	DRNE	<i>Draba nemorosa</i>	woodland draba	No	No
	DRRE2	<i>Draba reptans</i>	Carolina draba	No	No
	ERCA14	<i>Erysimum capitatum</i>	sanddune wallflower	No	No
	ERCH9	<i>Erysimum cheiranthoides</i>	wormseed wallflower	No	No
	ERIN7	<i>Erysimum inconspicuum</i>	shy wallflower	No	No
	ERRE4	<i>Erysimum repandum</i>	spreading wallflower	Yes	No
	ERAS2	<i>Erysimum asperum</i>	western wallflower	No	No
	LEDE	<i>Lepidium densiflorum</i>	common pepperweed	No	No
	LEPID	<i>Lepidium</i> spp.	pepperweed	Yes	No
	PHLU99	<i>Physaria ludoviciana</i>	foothill bladderpod	No	No
	SIAL2	<i>Sisymbrium altissimum</i>	tall tumbled mustard	Yes	No
	STAF99	<i>Strigosella africana</i>	African mustard	Yes	No
	TUGL	<i>Turritis glabra</i>	tower rockcress	Yes	No
	THAR5	<i>Thlaspi arvense</i>	field pennycress	Yes	No
Cactaceae	ESMI3	<i>Escobaria missouriensis</i>	Missouri foxtail cactus	No	No
	ESMI3	<i>Escobaria missouriensis</i>	Missouri foxtail cactus	No	No
	OPFR	<i>Opuntia fragilis</i>	brittle pricklypear	No	No
	OPHU	<i>Opuntia humifusa</i>	devil's-tongue	No	No
	OPMA2	<i>Opuntia macrorhiza</i>	twistspine pricklypear	No	No
	OPPO	<i>Opuntia polyacantha</i>	plains pricklypear	No	No
	OPUNT	<i>Opuntia</i> spp.	pricklypear	No	No
Campanulaceae	TRLE3	<i>Triodanis leptocarpa</i>	slimpod Venus' looking-glass	No	No
	TRPE4	<i>Triodanis perfoliata</i>	clasping Venus' looking-glass	No	No
Caprifoliaceae	SYOC	<i>Symphoricarpos occidentalis</i>	western snowberry	No	No

Family	Code	Scientific Name	Common Name	Exotic	Rare
Caryophyllaceae	CEAR4	<i>Cerastium arvense</i>	field chickweed	No	No
	CEFO2	<i>Cerastium fontanum</i>	common mouse-ear chickweed	Yes	No
	PASE	<i>Paronychia sessiliflora</i>	creeping nailwort	No	No
	SIAN2	<i>Silene antirrhina</i>	sleepy silene	No	No
	SILEN	<i>Silene</i> spp.	catchfly	Yes	No
Chenopodiaceae	ATAR2	<i>Atriplex argentea</i>	silverscale saltbush	No	No
	ATCA2	<i>Atriplex canescens</i>	fourwing saltbush	No	No
	ATSU	<i>Atriplex suckleyi</i>	Suckley's endolepis	No	No
	CHAL7	<i>Chenopodium album</i>	lambquarters	Yes	No
	CHDE	<i>Chenopodium desiccatum</i>	aridland goosefoot	No	No
	CHENO	<i>Chenopodium</i> spp.	goosefoot	Yes	No
	CHFR3	<i>Chenopodium fremontii</i>	Fremont's goosefoot	No	No
	CHPR5	<i>Chenopodium pratericola</i>	desert goosefoot	No	No
	CHSI2	<i>Chenopodium simplex</i>	mapleleaf goosefoot	No	No
	HAGL	<i>Halogeton glomeratus</i>	saltlover	Yes	No
	KOSC	<i>Kochia scoparia</i>	burningbush, kochia	Yes	No
	KRLA2	<i>Krascheninnikovia lanata</i>	winterfat	No	No
	MONU	<i>Monolepis nuttalliana</i>	Nuttall's povertyweed	No	No
	SACO8	<i>Salsola collina</i>	slender Russian thistle	Yes	No
	SAKA	<i>Salsola kali</i>	Russian thistle	Yes	No
	SALSO	<i>Salsola</i> spp.	Russian thistle	Yes	No
	SATR12	<i>Salsola tragus</i>	prickly Russian thistle	Yes	No
Commelinaceae	TRADE	<i>Tradescantia</i> spp.	spiderwort	No	No
	TRBR	<i>Tradescantia bracteata</i>	longbract spiderwort	No	No
	TROC	<i>Tradescantia occidentalis</i>	prairie spiderwort	No	No
Convolvulaceae	COAR4	<i>Convolvulus arvensis</i>	field bindweed	Yes	No
Cupressaceae	JUSC2	<i>Juniperus scopulorum</i>	Rocky Mountain juniper	No	No
Cyperaceae	CABR10	<i>Carex brevior</i>	shortbeak sedge	No	No
	CADU6	<i>Carex duriuscula</i>	needleleaf sedge	No	No
	CAFI	<i>Carex filifolia</i>	threadleaf sedge	No	No
	CAIN9	<i>Carex inops</i>	sun sedge	No	No
	CAPR5	<i>Carex praegracilis</i>	clustered field sedge	No	No
	CAREX	<i>Carex</i> spp.	sedge	No	No
	CASA9	<i>Carex saximontana</i>	Rocky Mountain sedge	No	No
	CYAC2	<i>Cyperus acuminatus</i>	tapertip flatsedge	No	No
	ELAC	<i>Eleocharis acicularis</i>	needle spikerush	No	No
	ELCO2	<i>Eleocharis compressa</i>	flatstem spikerush	No	No
	ELEOC	<i>Eleocharis</i> spp.	spikerush	No	No
	ELPA3	<i>Eleocharis palustris</i>	common spikerush	No	No
Euphorbiaceae	CHAMA15	<i>Chamaesyce</i> spp.	sandmat	Yes	No
	EUBR	<i>Euphorbia brachycera</i>	horned spurge	No	No
	EUGL3	<i>Euphorbia glyptosperma</i>	ribseed sandmat	No	No
	EUMA7	<i>Euphorbia maculata</i>	spotted sandmat	No	No
	EUMA8	<i>Euphorbia marginata</i>	snow on the mountain	No	No
	EUMI5	<i>Euphorbia missurica</i>	prairie sandmat	No	No
	EUPHO	<i>Euphorbia</i> spp.	spurge, sandmat	Yes	No

Family	Code	Scientific Name	Common Name	Exotic	Rare
	EUSE4	<i>Euphorbia serpens</i>	matted sandmat	No	No
	EUSE5	<i>Euphorbia serpyllifolia</i>	thymeleaf sandmat	No	No
	EUSP	<i>Euphorbia spathulata</i>	warty spurge	No	No
	EUST4	<i>Euphorbia stictospora</i>	slimseed sandmat	No	No
Fabaceae	ACAM99	<i>Acemispom americanus</i>	American bird's-foot trefoil	No	No
	AMCA6	<i>Amorpha canescens</i>	leadplant	No	No
	AMNA	<i>Amorpha nana</i>	dwarf false indigo	No	No
	ASAG2	<i>Astragalus agrestis</i>	purple milkvetch	No	No
	ASBA	<i>Astragalus barrii</i>	Barr's milkvetch	No	S3/G3
	ASBI2	<i>Astragalus bisulcatus</i>	twogrooved milkvetch	No	No
	ASCR2	<i>Astragalus crassicaupus</i>	groundplum milkvetch	No	No
	ASFL2	<i>Astragalus flexuosus</i>	flexile milkvetch	No	No
	ASGI5	<i>Astragalus gilviflorus</i>	plains milkvetch	No	No
	ASGR3	<i>Astragalus gracilis</i>	slender milkvetch	No	No
	ASLA27	<i>Astragalus laxmannii</i>	Laxmann's milkvetch	No	No
	ASLO4	<i>Astragalus lotiflorus</i>	lotus milkvetch	No	No
	ASMI10	<i>Astragalus missouriensis</i>	Missouri milkvetch	No	No
	ASMO7	<i>Astragalus mollissimus</i>	woolly locoweed	No	No
	ASMU99	<i>Astragalus multiflorus</i>	looseflower milkvetch	No	No
	ASPL2	<i>Astragalus plattensis</i>	Platte River milkvetch	No	No
	ASRA2	<i>Astragalus racemosus</i>	cream milkvetch	No	No
	ASTRA	<i>Astragalus</i> spp.	milkvetch	No	No
	DAAU	<i>Dalea aurea</i>	golden prairie clover	No	No
	DACA7	<i>Dalea candida</i>	white prairie clover	No	No
	DAPU5	<i>Dalea purpurea</i>	purple prairie clover	No	No
	GLLE3	<i>Glycyrrhiza lepidota</i>	American licorice	No	No
	HEAL	<i>Hedysarum alpinum</i>	alpine sweetvetch	Yes	No
	LAPO2	<i>Lathyrus polymorphus</i>	manystem pea	No	No
	LUPU	<i>Lupinus pusillus</i>	rusty lupine	No	No
	MELU	<i>Medicago lupulina</i>	black medick	Yes	No
	MEOF	<i>Melilotus officinalis</i>	yellow sweetclover	Yes	No
	MESA	<i>Medicago sativa</i>	alfalfa	Yes	No
	OXLA3	<i>Oxytropis lambertii</i>	purple locoweed	No	No
	OXSE	<i>Oxytropis sericea</i>	white locoweed	No	No
	PEAR6	<i>Pedimelum argophyllum</i>	silverleaf Indian breadroot	No	No
	PECU3	<i>Pedimelum cuspidatum</i>	largebract Indian breadroot	No	No
	PEDI9	<i>Pedimelum digitatum</i>	palmleaf Indian breadroot	No	No
	PEES	<i>Pedimelum esculentum</i>	large Indian breadroot	No	No
	PSLA3	<i>Psoralidium lanceolatum</i>	lemon scurfpea	Yes	No
	PSTE5	<i>Psoralidium tenuiflorum</i>	slimflower scurfpea	No	No
	THRH	<i>Thermopsis rhombifolia</i>	golden pea	No	No
	VIAM	<i>Vicia americana</i>	American vetch	No	No
Fumariaceae	COMI2	<i>Corydalis micrantha</i>	smallflower fumewort	No	No
Geraniaceae	GECA5	<i>Geranium carolinianum</i>	Carolina geranium	No	No

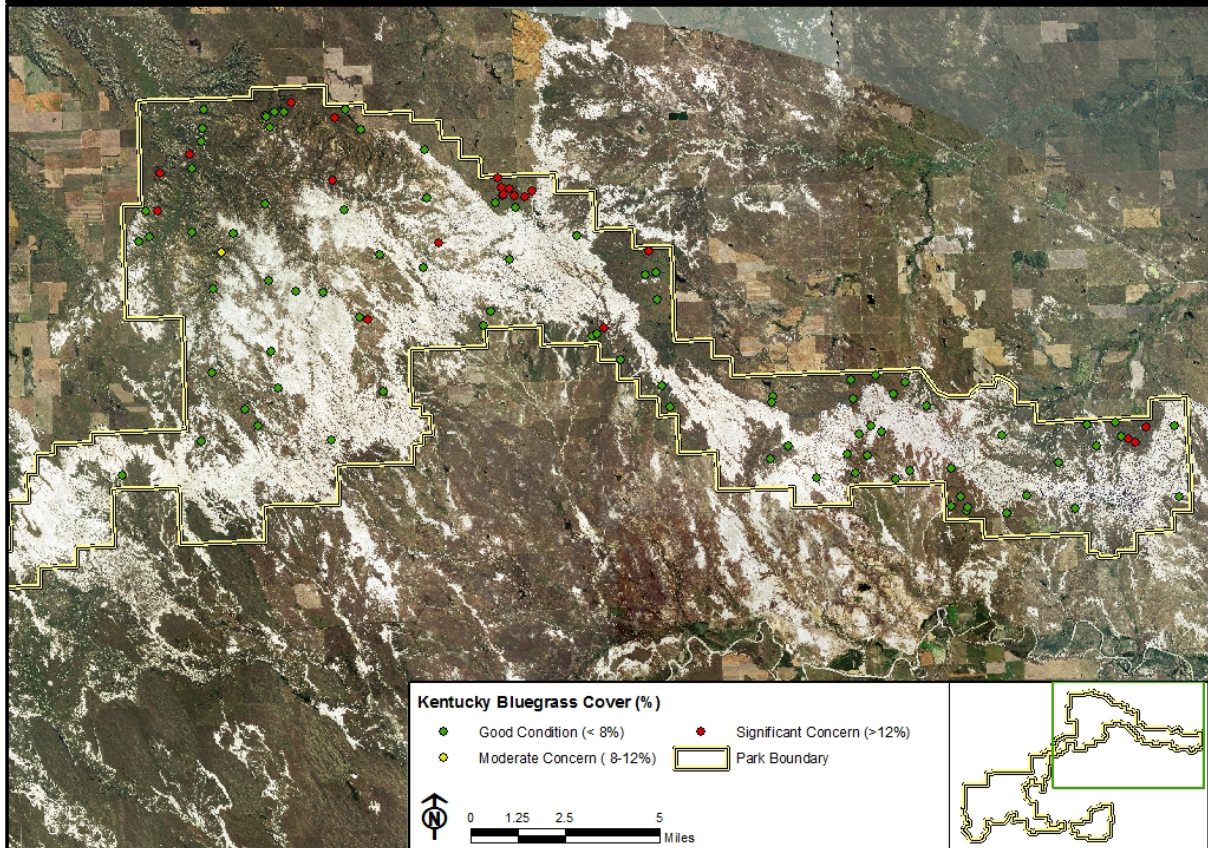
Family	Code	Scientific Name	Common Name	Exotic	Rare
Geraniaceae	GERAN	<i>Geranium</i> spp.	geranium	No	No
Grossulariaceae	RIAM2	<i>Ribes americanum</i>	American black currant	No	No
	RIAU	<i>Ribes aureum</i>	golden currant	No	No
	RIBES	<i>Ribes</i> spp.	currant	No	No
	RICE	<i>Ribes cereum</i>	wax currant	No	No
	RIMI	<i>Ribes missouriense</i>	Missouri gooseberry	No	No
Hydrophyllaceae	ELNY	<i>Ellisia nyctelea</i>	Aunt Lucy	No	No
Iridaceae	SIAN3	<i>Sisyrinchium angustifolium</i>	narrowleaf blue-eyed grass	No	No
Iridaceae	SIMO2	<i>Sisyrinchium montanum</i>	strict blue-eyed grass	No	No
Juncaceae	JUBA	<i>Juncus balticus</i>	Baltic rush	No	No
	JUIN2	<i>Juncus interior</i>	inland rush	No	No
Lamiaceae	HEDR	<i>Hedeoma drummondii</i>	Drummond's false pennyroyal	No	No
	HEHI	<i>Hedeoma hispida</i>	rough false pennyroyal	No	No
	NECA2	<i>Nepeta cataria</i>	catnip	Yes	No
	SARE3	<i>Salvia reflexa</i>	lanceleaf sage	No	No
Liliaceae	ALTE	<i>Allium textile</i>	textile onion	No	No
	CAGU	<i>Calochortus gunnisonii</i>	Gunnison's mariposa lily	No	No
	CANU3	<i>Calochortus nuttallii</i>	sego lily	No	No
	LEMO4	<i>Leucocrinum montanum</i>	common starlily	No	No
	MARA7	<i>Maianthemum racemosum</i>	feathery false lily of the valley	No	No
	MAST4	<i>Maianthemum stellatum</i>	starry false lily of the valley	No	No
	LIRI	<i>Linum rigidum</i>	stiffstem flax	No	No
Malvaceae	SPCO	<i>Sphaeralcea coccinea</i>	scarlet globemallow	No	No
Melanthiaceae	TOVE2	<i>Toxicoscordion venenosum</i>	meadow deathcamas	No	No
Nyctaginaceae	MIHI	<i>Mirabilis hirsuta</i>	hairy four o'clock	No	No
	MILI3	<i>Mirabilis linearis</i>	narrowleaf four o'clock	No	No
Oleaceae	FRPE	<i>Fraxinus pennsylvanica</i>	green ash	No	No
Onagraceae	OEBI	<i>Oenothera biennis</i>	common evening primrose	No	No
	OECE2	<i>Oenothera cespitosa</i>	tufted evening primrose	No	No
	OECU99	<i>Oenothera curtiflora</i>	velvetweed	No	No
	OENOT	<i>Oenothera</i> spp.	evening-primrose	No	No
	OESU99	<i>Oenothera suffrutescens</i>	scarlet beeblossom	No	No
Oxalidaceae	OXDI2	<i>Oxalis dillenii</i>	slender yellow woodsorrel	No	No
	OXST	<i>Oxalis stricta</i>	common yellow woodsorrel	No	No
Plantaginaceae	PLEL	<i>Plantago elongata</i>	prairie plantain	No	No
	PLMA2	<i>Plantago major</i>	common plantain	Yes	No
	PLPA2	<i>Plantago patagonica</i>	woolly plantain	No	No
Poaceae	ACHY	<i>Achnatherum hymenoides</i>	Indian ricegrass	No	No
	AGCR	<i>Agropyron cristatum</i>	crested wheatgrass	Yes	No
	AGST2	<i>Agrostis stolonifera</i>	creeping bentgrass	No	No
	ALPR3	<i>Alopecurus pratensis</i>	meadow foxtail	Yes	No
	ANGE	<i>Andropogon gerardii</i>	big bluestem	No	No

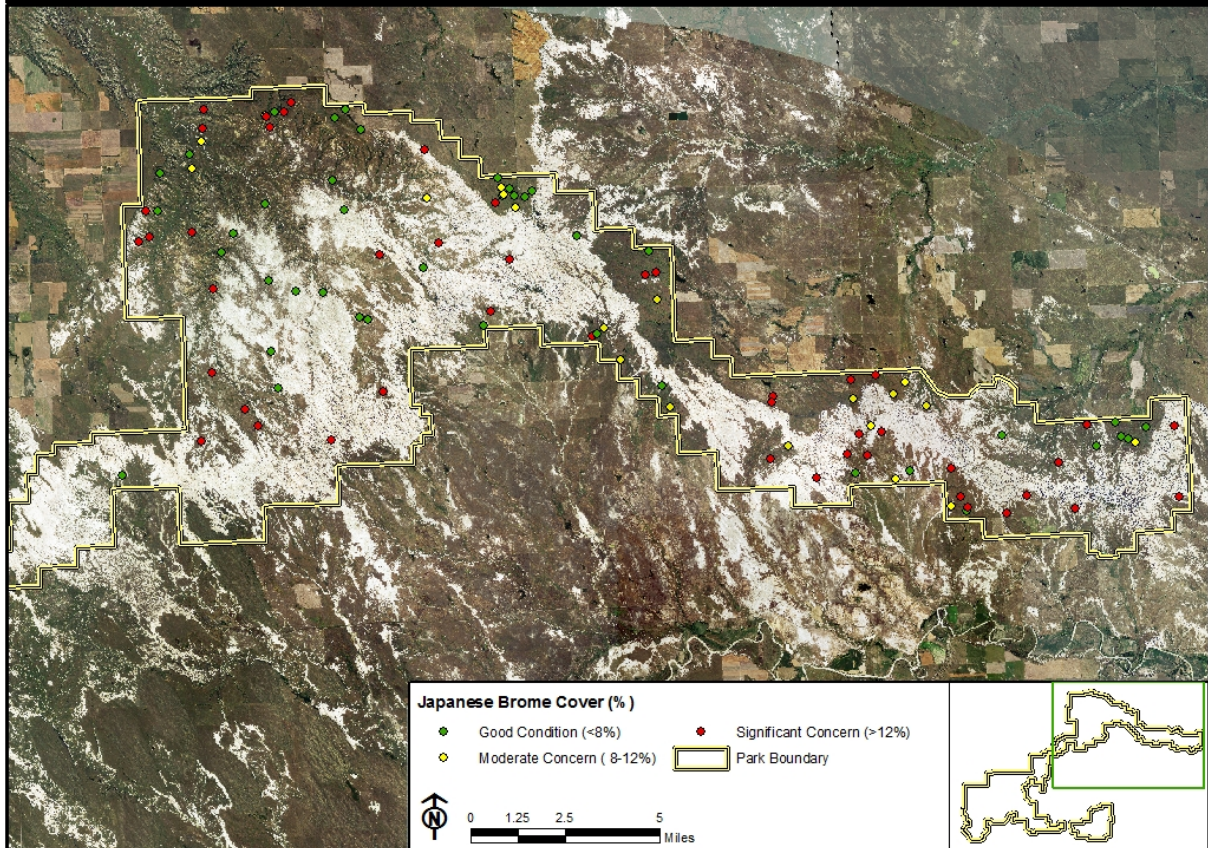
Family	Code	Scientific Name	Common Name	Exotic	Rare
	ARIST	<i>Aristida</i> spp.	threeawn	No	No
	ARPU9	<i>Aristida purpurea</i>	purple threeawn	No	No
	BOCU	<i>Bouteloua curtipendula</i>	sideoats grama	No	No
	BODA2	<i>Bouteloua dactyloides</i>	buffalograss	No	No
	BOGR2	<i>Bouteloua gracilis</i>	blue grama	No	No
	BOHI2	<i>Bouteloua hirsuta</i>	hairy grama	No	No
	BRCI2	<i>Bromus ciliatus</i>	fringed brome	No	No
	BRIN2	<i>Bromus inermis</i>	smooth brome	Yes	No
	BRJA	<i>Bromus japonicus</i>	Japanese brome	Yes	No
	BROMU	<i>Bromus</i> spp.	brome	Yes	No
	BRSQ2	<i>Bromus squarrosus</i>	corn brome	Yes	No
	BRTE	<i>Bromus tectorum</i>	cheatgrass	Yes	No
	BUDA	<i>Buchloe dactyloides</i>	buffalograss	No	No
	CALO	<i>Calamovilfa longifolia</i>	prairie sandreed	No	No
	DASP2	<i>Danthonia spicata</i>	poverty oatgrass	No	No
	DIOL	<i>Dichanthelium oligosanthes</i>	Heller's rosette grass	No	No
	DISP	<i>Distichlis spicata</i>	saltgrass	No	No
	ELCA11	<i>Elymus caninus</i>	bearded wheatgrass	No	No
	ELCA4	<i>Elymus canadensis</i>	Canada wildrye	No	No
	ELEL5	<i>Elymus elymoides</i>	squirreltail	No	No
	ELLA3	<i>Elymus lanceolatus</i>	thickspike wheatgrass	No	No
	ELRE4	<i>Elymus repens</i>	quackgrass	Yes	No
	ELTR7	<i>Elymus trachycaulus</i>	slender wheatgrass	No	No
	ELVI3	<i>Elymus virginicus</i>	Virginia wildrye	No	No
	ELYMU	<i>Elymus</i> spp.	wildrye	Yes	No
	FEOC	<i>Festuca occidentalis</i>	western fescue	No	No
	FEOV	<i>Festuca ovina</i>	sheep fescue	No	No
	HECO26	<i>Hesperostipa comata</i>	needle and thread	No	No
	HOJU	<i>Hordeum jubatum</i>	foxtail barley	No	No
	HOPU	<i>Hordeum pusillum</i>	little barley	No	No
	KOMA	<i>Koeleria macrantha</i>	prairie Junegrass	No	No
	MUCU3	<i>Muhlenbergia cuspidata</i>	plains muhly	No	No
	MUPA99	<i>Muhlenbergia paniculata</i>	tumblegrass	No	No
	MURA	<i>Muhlenbergia racemosa</i>	marsh muhly	No	No
	NAVI4	<i>Nassella viridula</i>	green needlegrass	No	No
	PACA6	<i>Panicum capillare</i>	witchgrass	No	No
	PANIC	<i>Panicum</i> spp.	panicgrass	No	No
	PASM	<i>Pascopyrum smithii</i>	western wheatgrass	No	No
	PAVI2	<i>Panicum virgatum</i>	switchgrass	No	No
	PHPR3	<i>Phleum pratense</i>	timothy	Yes	No
	POA	<i>Poa</i> spp.	bluegrass	Yes	No
	POAL2	<i>Poa alpina</i>	alpine bluegrass	No	No
	POCO	<i>Poa compressa</i>	Canada bluegrass	Yes	No
	POPA2	<i>Poa palustris</i>	fowl bluegrass	No	No
	POPR	<i>Poa pratensis</i>	Kentucky bluegrass	Yes	No
	POSE	<i>Poa secunda</i>	Sandberg bluegrass	No	No
	PSJU3	<i>Psathyrostachys juncea</i>	Russian wildrye	Yes	No

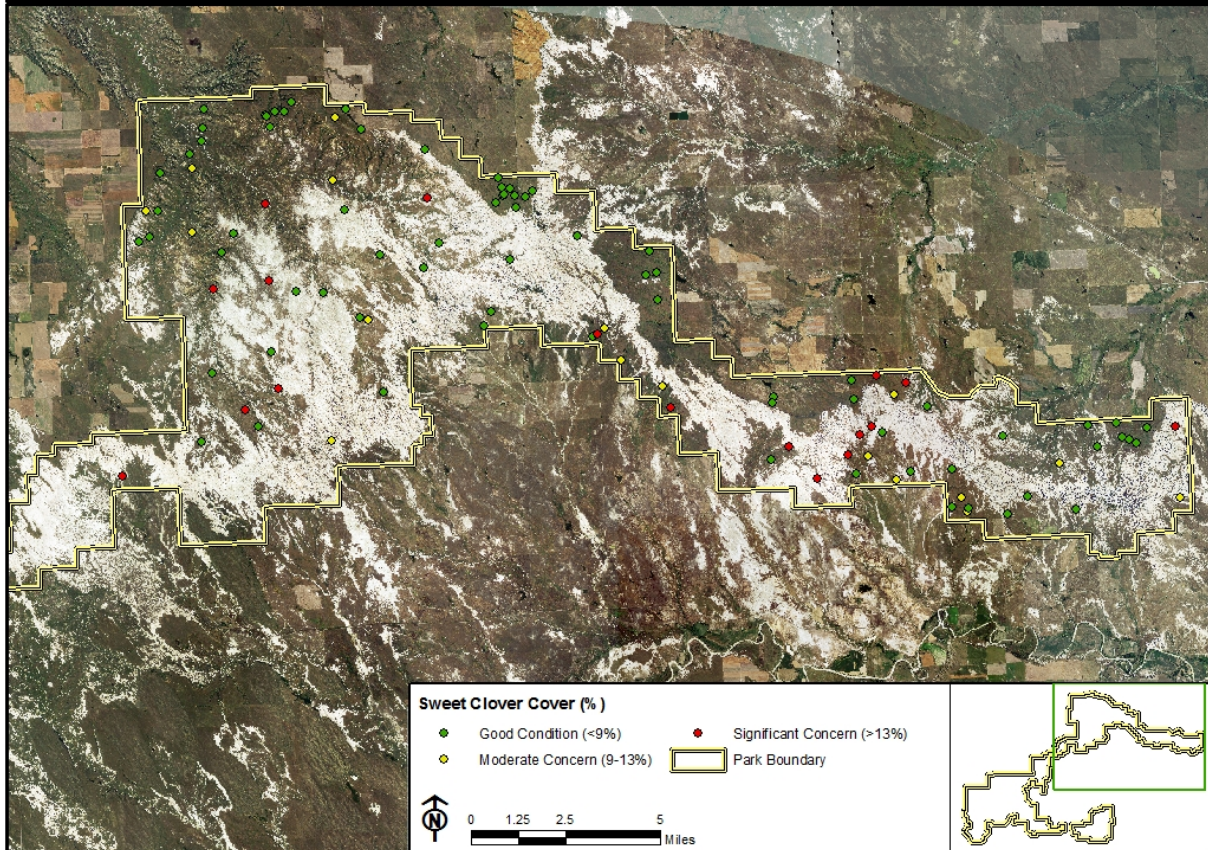
Family	Code	Scientific Name	Common Name	Exotic	Rare
	PSSP6	<i>Pseudoroegneria spicata</i>	bluebunch wheatgrass	No	No
	SCSC	<i>Schizachyrium scoparium</i>	little bluestem	No	No
	SPAS	<i>Sporobolus asper</i>	composite dropseed	Yes	No
	SEVI4	<i>Setaria viridis</i>	green foxtail	Yes	No
	SPAI	<i>Sporobolus airoides</i>	alkali sacaton	No	No
	SPCO16	<i>Sporobolus compositus</i>	composite dropseed	No	No
	SPCR	<i>Sporobolus cryptandrus</i>	sand dropseed	No	No
	SPHE	<i>Sporobolus heterolepis</i>	prairie dropseed	No	No
	SPORO	<i>Sporobolus</i> spp.	dropseed	No	No
	SPPE	<i>Spartina pectinata</i>	prairie cordgrass	No	No
	VUOC	<i>Vulpia octoflora</i>	sixweeks fescue	No	No
Polemoniaceae	COLI2	<i>Collomia linearis</i>	tiny trumpet	No	No
	IPCO5	<i>Ipomopsis congesta</i>	ballhead ipomopsis	No	No
	MIGR	<i>Microsteris gracilis</i>	slender phlox	No	No
	PHGR16	<i>Phlox gracilis</i>	slender phlox	No	No
	PHAN4	<i>Phlox andicola</i>	prairie phlox	No	No
	PHHO	<i>Phlox hoodii</i>	spiny phlox	No	No
	PHLOX	<i>Phlox</i> spp.	phlox	No	No
Polygalaceae	POAL4	<i>Polygala alba</i>	white milkwort	No	No
	POVE	<i>Polygala verticillata</i>	whorled milkwort	No	No
Polygonaceae	ERFL4	<i>Eriogonum flavum</i>	alpine golden buckwheat	No	No
	ERPA9	<i>Eriogonum pauciflorum</i>	fewflower buckwheat	No	No
	FACO	<i>Fallopia convolvulus</i>	black bindweed	Yes	No
	POAV	<i>Polygonum aviculare</i>	prostrate knotweed	Yes	No
	PORA3	<i>Polygonum ramosissimum</i>	bushy knotweed	Yes	No
	RUAL4	<i>Rumex altissimus</i>	pale dock	No	No
	RUCR	<i>Rumex crispus</i>	curly dock	Yes	No
	RUMEX	<i>Rumex</i> spp.	dock	Yes	No
Primulaceae	RUST4	<i>Rumex stenophyllus</i>	narrowleaf dock	Yes	No
	ANOC2	<i>Androsace occidentalis</i>	western rockjasmine	No	No
Ranunculaceae	ANCA9	<i>Anemone caroliniana</i>	Carolina anemone	No	No
	ANCY	<i>Anemone cylindrica</i>	candle anemone	No	No
	ANEMO	<i>Anemone</i> spp.	anemone	Yes	No
	ANPA	<i>Anemone parviflora</i>	smallflowered anemone	No	No
	DECA3	<i>Delphinium carolinianum</i>	Carolina larkspur	No	No
	MYMI2	<i>Myosurus minimus</i>	tiny mousetail	No	No
	RAMA2	<i>Ranunculus macounii</i>	Macoun's buttercup	No	No
	RANUN	<i>Ranunculus</i> spp.	buttercup	Yes	No
Rosaceae	POPE8	<i>Potentilla pensylvanica</i>	Pennsylvania cinquefoil	No	No
	POTEN	<i>Potentilla</i> spp.	cinquefoil	No	No
	PRAM	<i>Prunus americana</i>	American plum	No	No
	PRPU3	<i>Prunus pumila</i>	sandcherry	No	No
	PRVI	<i>Prunus virginiana</i>	chokecherry	No	No
	ROAR3	<i>Rosa arkansana</i>	prairie rose	No	No
	ROBL	<i>Rosa blanda</i>	smooth rose	No	No
	ROWO	<i>Rosa woodsii</i>	Woods' rose	No	No

Family	Code	Scientific Name	Common Name	Exotic	Rare
Rubiaceae	GAAP2	<i>Galium aparine</i>	stickywilly	No	No
	GABO2	<i>Galium boreale</i>	northern bedstraw	No	No
	GALIU	<i>Galium</i> spp.	bedstraw	No	No
Salicaceae	SAEX	<i>Salix exigua</i>	narrowleaf willow	No	No
Santalaceae	COUM	<i>Comandra umbellata</i>	bastard toadflax	No	No
Scrophulariaceae	COPA3	<i>Collinsia parviflora</i>	maiden blue eyed Mary	No	No
	ORLU2	<i>Orthocarpus luteus</i>	yellow owl's-clover	No	No
	PEAL2	<i>Penstemon albidus</i>	white penstemon	No	No
	PEER	<i>Penstemon eriantherus</i>	fuzzytongue penstemon	No	No
	PEGL3	<i>Penstemon glaber</i>	sawsepal penstemon	No	No
	PEGR5	<i>Penstemon gracilis</i>	lilac penstemon	No	No
	PENST	<i>Penstemon</i> spp.	beardtongue	No	No
	SYWY99	<i>Synthyris wyomingensis</i>	Wyoming kittentails	No	No
	VEAR	<i>Veronica arvensis</i>	corn speedwell	Yes	No
	VEPE2	<i>Veronica peregrina</i>	neckweed	No	No
	VETH	<i>Verbascum thapsus</i>	common mullein	Yes	No
Smilacaceae	SMILA2	<i>Smilax</i> spp.	greenbrier	No	No
Solanaceae	PHHE5	<i>Physalis heterophylla</i>	clammy groundcherry	No	No
	PHLO4	<i>Physalis longifolia</i>	longleaf groundcherry	No	No
	PHVI5	<i>Physalis virginiana</i>	Virginia groundcherry	No	No
	SORO	<i>Solanum rostratum</i>	buffalobur nightshade	No	No
	SOTR	<i>Solanum triflorum</i>	cutleaf nightshade	No	No
Ulmaceae	CEOC	<i>Celtis occidentalis</i>	common hackberry	No	No
	ULAM	<i>Ulmus americana</i>	American elm	No	No
Urticaceae	PAPE5	<i>Parietaria pensylvanica</i>	Pennsylvania pellitory	No	No
Verbenaceae	VEBR	<i>Verbena bracteata</i>	bigbract verbena	No	No
	VEST	<i>Verbena stricta</i>	hoary verbena	No	No
Violaceae	VINU2	<i>Viola nuttallii</i>	Nuttall's violet,	No	No
	VIOLA	<i>Viola</i> spp.	violet	Yes	No
Vitaceae	PAVI5	<i>Parthenocissus vitacea</i>	woodbine	No	No
	VIRI	<i>Vitis riparia</i>	riverbank grape	No	No

Appendix B: Maps of Relative Exotic Species Cover at Badlands National Park







The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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