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Natural Resource Stewardship and Science

Plant Community Composition and Structure Monitoring for Jewel Cave National Monument

2012 Annual Report

Natural Resource Technical Report NPS/NGPN/NRTR—2013/676

ON THE COVER
Long-term plant community monitoring plot PCM_018 in Jewel Cave National Monument, 2012.
Photograph by: NGPN

Plant Community Composition and Structure Monitoring for Jewel Cave National Monument

2012 Annual Report

Natural Resource Technical Report NPS/NGPN/NRTR—2013/676

Isabel W. Ashton
Michael Prowatzke
Stephen K. Wilson

National Park Service
Northern Great Plains Inventory & Monitoring Network
231 East Saint Joseph St.
Rapid City, SD 57701

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The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Technical Report Series is used to disseminate results of scientific studies in the physical, biological, and social sciences for both the advancement of science and the achievement of the National Park Service mission. The series provides contributors with a forum for displaying comprehensive data that are often deleted from journals because of page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data. Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

This report is available from the Northern Great Plains Inventory & Monitoring Network website http://science.nature.nps.gov/im/units/ngpn/monitor/plants.cfm and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/).

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Contents

Figures

Page

Tables

Page

Executive Summary

The Northern Great Plains Inventory & Monitoring Network surveyed 6 long-term monitoring plots in Jewel Cave National Monument (JECA) in 2012 as part of an effort to better understand the condition of plant communities in the park. We measured plant diversity and cover, tree density, and forest fuels, looked for the presence of exotic species that are of concern to park management, and evaluated the amount of human and natural disturbance at all plots. This effort was the second year in a multiple-year venture to document the current status and long-term trends in plant communities in JECA. At the end of five years, there will be an in-depth report describing the status of the plant community. In this report, we provide a simple summary of our results from sampling in 2012.

Jewel Cave National Monument has a high diversity of native plants. Dry conditions in 2012 tended to reduce plant diversity, but species richness was still within the range of natural variability. Forest densities are similar to historic conditions and characterized by a mosaic of open and closed canopy sites. To date, Jewel Cave National Monument has had effective exotic plant management. Average cover of exotic species was low, and only one site was above 10% cover. Kentucky bluegrass was the most widespread and abundant exotic species. The Jasper Fire in 2000 left a large amount of coarse woody debris throughout the park resulting in high total fuel loads. Because the forest structure is open and lacking ladder and fine fuels the high total fuel loads are only of moderate concern. To retain ecological integrity in JECA and the high diversity of native plants, it is important to continue efforts to reduce the cover of invasive plants. Continued monitoring efforts will be critical to track changes in the condition of the vegetation communities in JECA.

Acknowledgments

We thank all the authors of the NGPN Plant Community Monitoring Protocol, particularly Amy Symstad, for outstanding guidance on data collection and reporting. We greatly appreciate the staff at JECA for providing logistical support and safety checks. In particular, we thank Lori Filipi, Aaron Stover, and Dan Townsend for help in the field. The 2012 NGPN vegetation field crew of Kara Paintner-Green, Michael Prowatzke, Timothy Pine, Lauren Baur, Daina Jackson, Ryan Manuel, Anine Smith, Gretchen Addington, Kristina Fox, collected the NGPN data included in this report. We thank Stephen Wilson for invaluable support and instruction on managing data in the FFI database and for assistance with the GIS data.

Introduction

The Black Hills is a 1.5 million ha refuge of ponderosa pine (*Pinus ponderosa*) forest surrounded by the prairies of western South Dakota and eastern Wyoming. The ponderosa pine forest of the Black Hills is a unique ecosystem composed of species from the western Rocky Mountains, eastern deciduous forests, northern boreal forests, and the surrounding Great Plains (Larson and Johnson 2007). The National Park Service (NPS) plays an important role in preserving and restoring ponderosa woodlands 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 grim reality that there have been fundamental changes in the disturbance regimes, such as climate and fire, that have historically maintained ponderosa woodlands, and there is the continual pressure of exotic invasive species. In recent years, mountain pine beetle (*Dendroctonus ponderosae*) outbreaks have been of particular concern because they are increasing throughout the Black Hills and have caused 100% mortality of ponderosa pines in some areas (Hocking et al. 2010). Long-term monitoring in national parks is essential to sound management of ponderosa woodlands because it can provide information on environmental quality and condition, benchmarks of ecological integrity, and early warning of declines in ecosystem health.

Jewel Cave National Monument (JECA) is located in the southwestern Black Hills and has a mission to preserve Jewel Cave, through management of the surface and subsurface ecosystem, while providing opportunities for the pursuit of scientific interests and public enjoyment. While this is a relatively small area (516 ha, 1274 ac), JECA contains diverse native ponderosa forest and grassland communities (Marriot and Hartment 1986, Ashton et al. 2012b). The Northern Great Plains Inventory & Monitoring Program (NGPN) began two vegetation monitoring efforts in JECA in 2011: a program to monitor understory vegetation annually (Ashton et al. 2012b) and a large survey of forest condition that will be repeated every five years (Ashton et al. 2012a). 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). The long-term objectives of the NGPN plant community monitoring effort (Symstad et al. 2012b) in JECA are to:

1. Determine park-wide status and long-term trends in vegetation species composition (e.g., exotic vs. native) and structure (e.g., cover, height) of herbaceous and shrub species.

2. Determine park-wide status (at 5-year intervals) and long-term trends of tree density by species, height class, diameter class, and fuel loads

3. Improve our understanding of the effects of external drivers and management actions on plant community species composition and structure by correlating changes in vegetation composition and structure with changes in climate, landscape patterns, atmospheric chemical composition, fire, and invasive plant control.

This report is intended to provide a timely release of basic data sets and data summaries from our sampling efforts at JECA in 2012, our second year of sampling understory vegetation. NGPN visited 6 plots (Figure 1). Since not all plots are visited every year, it will take 3 more years to visit every plot in the park. We expect to produce reports with more in-depth data analysis and

interpretation when we complete 5 years of sampling. In the interim, reports, spatial data, and data summaries can be provided for park management and interpretation upon request.

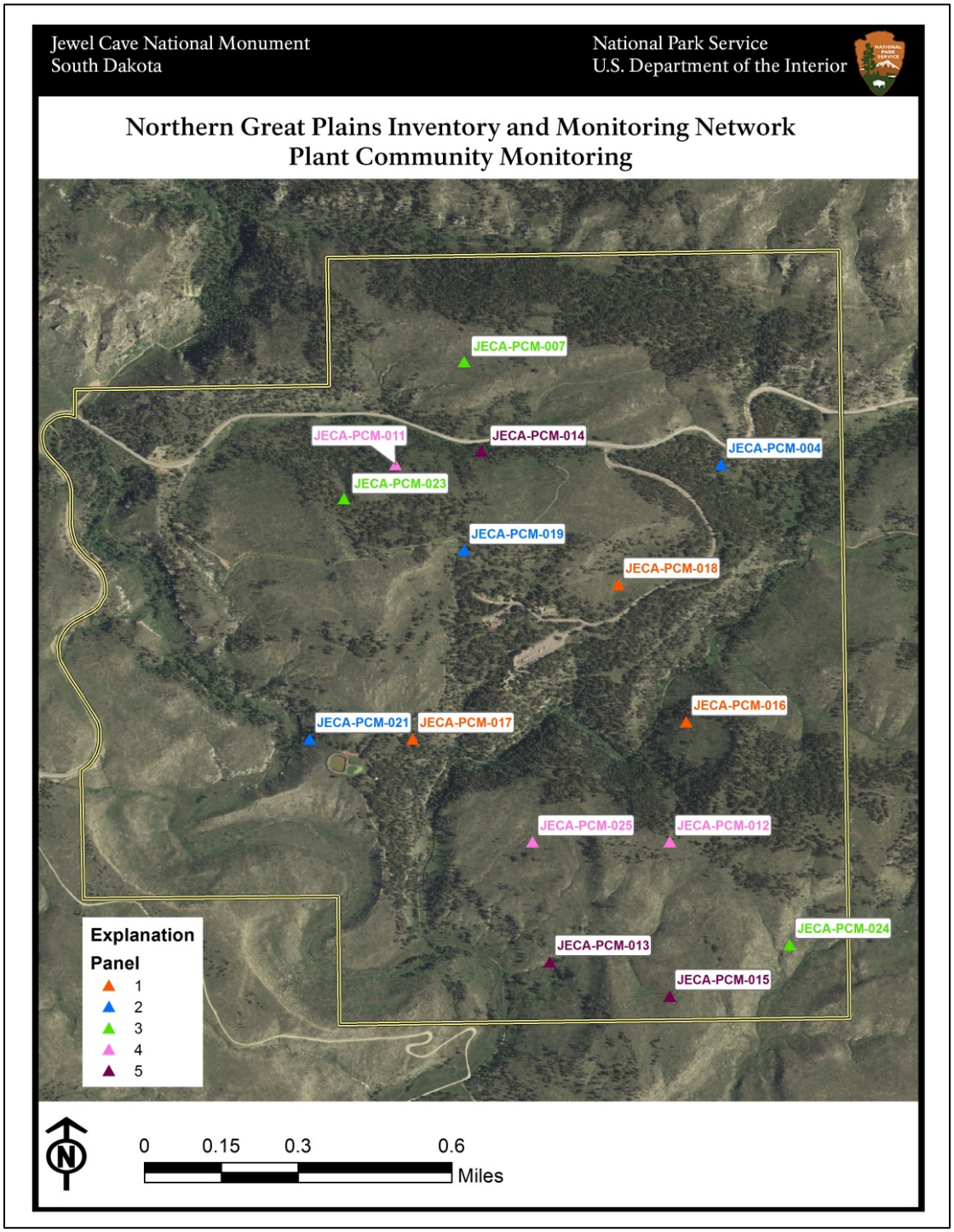

Figure 1. Map of Jewel Cave National Monument (JECA) and plant community monitoring plots surveyed in 2012. Plots in panel 1 (orange) and panel 2 (blue) were surveyed in 2012.

Methods

The NGPN Plant Community Composition and Structure Monitoring Protocol (Symstad et al. 2012b, a) describes in detail the methods used for sampling long-term plots. Below, we briefly describe the general approach. For those interested in more detail please see Symstad et al. 2012, available at http://science.nature.nps.gov/im/units/ngpn/monitor/plants.cfm

Sample design

NGPN implemented a survey to monitor plant community structure and composition in JECA using a spatially balanced probability design (Generalized Random Tessellation Stratified [GRTS]; Stevens and Olsen 2003, 2004). Using a GRTS design, we selected 15 randomly located sites within JECA. We split these 15 sites into 5 panels with 3 sites each. We visit 2 panels (6 sites) every year, and after 5 years we will have visited all 15 sites twice. In 2012, we visited sites in panel 1 and panel 2 (Figure 1) the first week of July.

When implemented successfully, probability-based survey designs allow for unbiased inference from sampled sites to un-sampled elements of the resource of interest (Hansen et al. 1983), and with repeat visits it allows for discerning trends in that resource (Larsen et al. 1995). In other words, after 5 years, we can use data from our randomly selected sites to estimate the ecological integrity of vegetation communities for the whole park.

Plot layout and sampling

At each of the sites we visited, NGPN 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. Species richness data from the point-intercept method were supplemented with species presence data collected in 5 sets of nested square quadrats (0.01 m^2, 0.1 m^2, 1 m^2, and 10 m^2) located systematically along each transect (Figure 2). In 2012, sampling at JECA took two 4-person crews approximately 312 crew hours with travel time (see Appendix A for a detail of activities each day).

Plant species were identified in the field to species level and not to lower taxonomic groupings (e.g., subspecies or variety). This was a change from the data collected in 2011 by NGPN where plants were identified to the lowest taxonomic level possible. The change was made in coordination with the FireEP because it better reflects the botanical skills of the crew and simplifies data management and analysis. When we were unable to identify a plant, the plant was assigned a unique identifier and collected or photographed. Most of these unknowns were subsequently identified in the office; however, in some cases identification was impossible. In these cases, the species was classified by growth form and, where possible, lifecycle (e.g., annual graminoid).

When woody species were 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). Trees with diameter at breast height (DBH) > 15 cm were mapped and tagged. For each tree, the species, DBH, status, and condition (e.g., leaf-discoloration, insect-damaged, etc.) were recorded. In ponderosa pine woodlands, dead and downed woody fuel load data were collected on two perpendicular 100 ft (30.48 m) transects centered at the center of the plot (Figure 2). Using these

methods, a more thorough assessment of forest structure and health and fuel loads (60 plots) was conducted in 2011 (Ashton et al. 2012a). The smaller subset of annual data presented in this report will be used to supplement the 5 year surveys and to help detect trends in forest density, insect damage, and fuel loads.

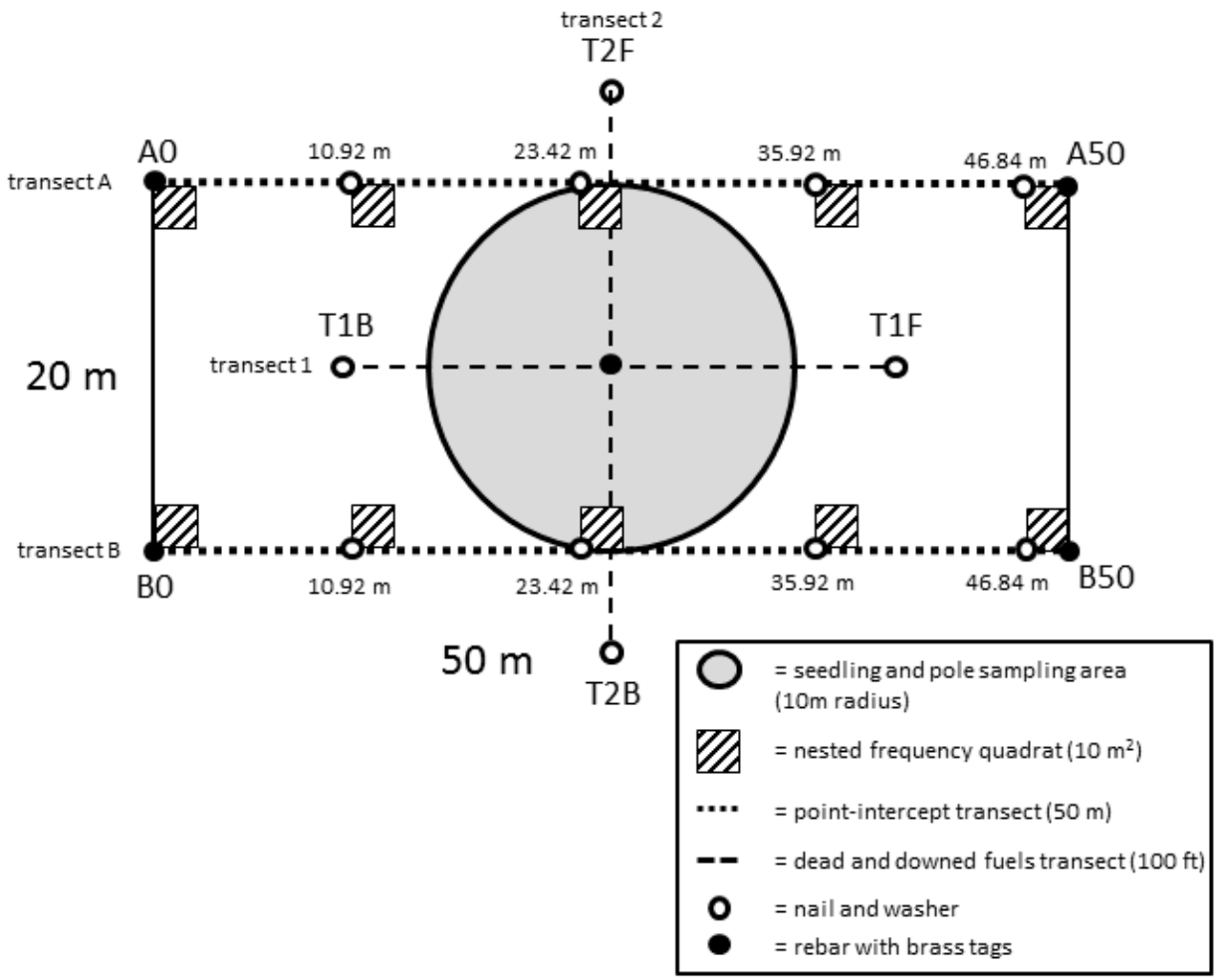

Figure 2. Long-term monitoring plot used for sampling vegetation in Jewel Cave National Monument.

At all plots, we also surveyed the area for common disturbances and target species of interest to the park. Common disturbances included such things as roads, rodent mounds, animal trails, and fire. For all plots, the type and severity of the disturbances were recorded. The target species lists were developed in cooperation with the park and NGPN staff during the winter and spring prior to the field season. Usually, these are invasive and/or exotic species that are not currently widespread in the park but pose a significant threat if allowed to establish. 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. In addition, this method tracks the presence of plant species that are considered rare or vulnerable to loss in South Dakota, and may occur in JECA. The JECA target species list for 2012 can be found in Table 1.

Table 1. Exotic species of management concern at Jewel Cave National Monument and rare species that were surveyed for during the 2012 field season.

Exotic Species			**Rare species**	
Scientific Name	Common Name		**Scientific Name**	**Common Name**
Carduus nutans	musk thistle		*Achnatherum robustum*	sleepy grass
Centaurea stoebe	spotted knapweed		*Boechera divaricarpa/ Boechera holboelli*	limestone rockcress
Centaurea diffusa	diffuse knapweed		*Botrychium campestre*	prairie moonwort
Centaurea jacea	brownray knapweed		*Botrychium lineare*	narrowleaf grapefern
Centaurea solstitialis	yellow star thistle		*Botrychium lunaria*	common moonwort
Cirsium vulgare	bull thistle		*Erigeron ochroleucus*	buff fleabane
Convolvulus arvensis	field bindweed		*Fritillaria atropurpurea*	spotted mission bells
Elaeagnus angustifolia	Russian olive		*Lobelia spicata*	palespike lobelia
Euphorbia esula	leafy spurge		*Oenothera flava*	yellow evening primrose
Linaria dalmatica	Dalmatian toadflax		*Oenothera laciniata*	cutleaf evening primrose
Linaria vulgaris	yellow toadflax		*Physaria montana*	mountain bladderpod
Rhaponticum repens	Russian knapweed		*Platanthera stricta*	slender bog orchid
Tamarix spp.	tamarisk		*Thelesperma megapotamicum*	Hopi tea
Tanacetum vulgare	common tansy		*Townsendia exscapa*	Easter daisy
			Townsendia hookeri	Hooker's Townsend daisy

Data Management and Analysis

NGPN 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 2012). 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.

After data for the sites were entered, 100% of records were verified to the original datasheet to minimize transcription errors. A further 10% of records were reviewed a second time. After all data were entered and verified, automated queries were developed 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 the FFI database as needed.

Plant life forms (e.g., shrub, forb) were based on definitions from the USDA Plants Database (USDA-NRCS 2012). Summaries were produced using the FFI reporting and query tools, and statistical summaries and graphics were generated using R software (version 2.15.1).

We measured diversity at the plots in 3 ways: species richness, the Shannon Index, and Pielou's Index of Evenness. Species richness is simply a count of the species recorded in an area. The Shannon Index, H', is a measure of the number of species in an area and how even abundances are across the community. It typically ranges between 0 (low richness and evenness) to 3.5 (high species richness and evenness). Peilou's Index of Evenness, J', measures how even abundances are across taxa. It ranges between 0 and 1, where lower numbers indicate that a community is not even or that just a few species make up the majority of the total cover.

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 Natural Resource Condition Table is to improve park priority settings 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 or total fuel loads, it will be possible and straightforward to compare conditions in subsequent years. The status, trend, and confidence of assessments for each indicator is scored and assigned a corresponding symbol based on the key found in Table 2.

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, and relative cover of exotic species. 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, caution, or significant concern based on this comparison (Table 2). 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. Trend was scored in a similar fashion and categorized as improving, unchanging, deteriorating, or insufficient information.

Confidence in status and trend assessments within the Natural Resource Condition Table was scored as high, medium, or low. Confidence primarily reflects the quality of the data collected, rather than the quality of the reference condition. Confidence in the data summarizes three aspects of data quality: how well data represent the resource, quality of methods, and the length of the record.

Table 2. 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://www1.nrintra.nps.gov/im/stateoftheparks/index.cfm).

Status		**Trend**		**Confidence**	
	Significant Concern		Condition is Improving		High
	Caution		Condition is Unchanging		Medium
	Good Condition		Condition is Deteriorating		Low

Results and Discussion

Understory plant community composition and structure

The vegetation at JECA suffered from a very dry winter and spring, and when the field crews visited the park in early July, there was less green vegetation than in previous years (Figure 3). Average canopy cover was 66 % (Table 3) in 2012. The productive summer in 2011 and a dry winter and spring in 2012 contributed to a large amount of standing litter on the ground (ground cover at sites averaged 64% plant litter). Despite the dry conditions, NGPN found 152 plant species in 2012 at JECA (Appendix B). Graminoids, which includes grasses, sedges, and rushes, accounted for most of the vegetative cover at JECA, but forbs and shrubs were also abundant (Figure 4).

Figure 3. A vegetation transect at plot PCM_018 in Jewel Cave National Monument in 2011 (top panel) and 2012 (bottom panel). Both photographs were taken in early summer and show the dramatic reduction in moisture available in 2012.

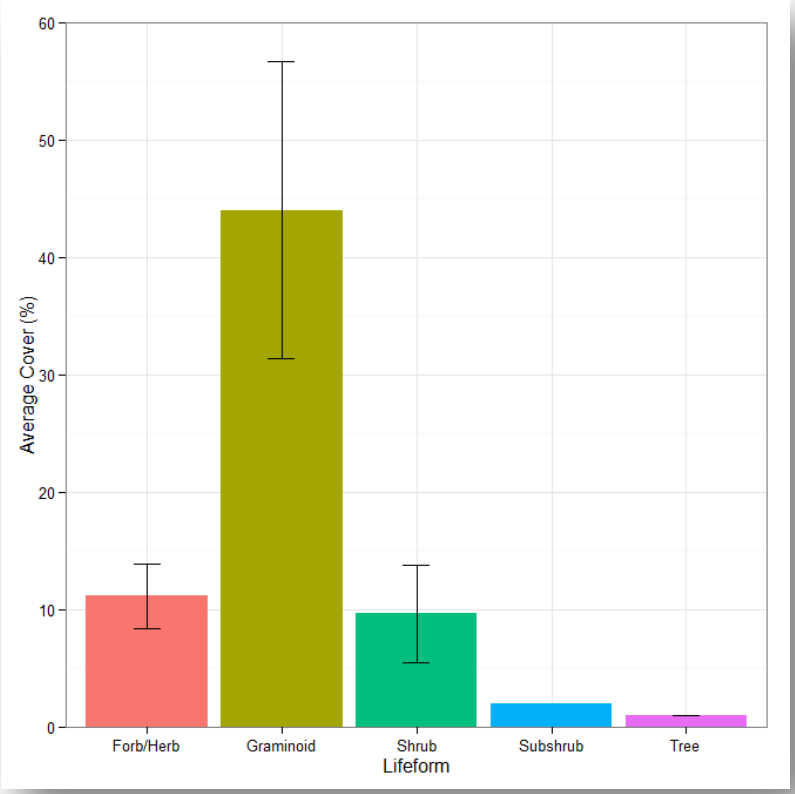

Figure 4. Average cover by life forms in 6 plant community monitoring plots in Jewel Cave National Monument in 2012. Bars represent means ± standard errors. Graminoids were the most abundant life-form across all the plots at Jewel Cave National Monument.

There was a great deal of variation in species composition across the 6 sites. The most common species found from the point-intercept method were graminoids (Figure 5), with the only exceptions being wild bergamot (*Monarda fistulosa*) and western snowberry (*Symphoricarpos occidentalis*). We did not find any of the rare plants or target species of management concern.

Species richness varies by the scale that it is examined. Table 4 presents average species richness, taken from the point-intercept method, 1 m^2 quadrats, and 10 m^2 quadrats for the monitoring plots in 2012. On average, there are about 2 exotic species found in each 10 m^2 quadrat along the point-intercept (Table 4). Average forb and graminoid richness were similar along the transects, but we found many more forbs when surveying the 10 m^2 plot (Table 4). From the point-intercept data, we found average plot diversity, H', to be 2.4 ± 0.19. Evenness, J', averaged 0.84 ± 0.03 across the plots (Table 3). When including only native species, average diversity and evenness were 2.4 ± 0.16 and 0.84 ± 0.03, respectively.

Table 3. Natural resource condition summary table for upland plant communities in Jewel Cave National Monument.

Indicator of Condition	Specific Measures	2012 Value (mean ± SE)	Reference Condition and Data Source	Condition Status/Trend	Rationale for Resource Condition
Upland Plant Community Structure and Composition	Absolute herb-layer canopy cover	66 ± 10.2 %	TBD		Jewel Cave National Monument has a large diversity of native plants. The condition assessment for canopy cover and evenness is based on professional judgment, but as we collect more data and understand the natural range of variability our confidence in these assessments will increase. Forest densities are similar to historic conditions and are characterized by a mosaic of open and closed canopy sites.
	Native species richness (based on average of 10 $1m^2$ quadrats per plot)	9 ± 0.6 species	8 -18 species [(1)]		
	Evenness (based on point-intercept of 2-50m transects per plot)	0.84 ± 0.03	TBD		
	Mature tree density	113 ± 43 stems/ha	131 + 24.7 [(2)]		
Fire and Fuel Dynamics	Total fuel loads	24 ± 6.0 tons/acre	Between 2 and 10		The current fire ecology program aims to maintain fuel loads of less than 10 tons/acre. The Jasper Fire in 2000 left a large amount of coarse woody debris throughout the park resulting in high total fuel loads. Because the forest structure is open and lacking ladder and fine fuels the high total fuel loads are only of moderate concern.
Exotic Plant Early Detection and Management	Relative cover of exotic species	7 ± 3.3 %	≤ 10 % cover		To date, Jewel Cave National Monument has had effective exotic plant management. Average cover of exotic species was low, and only one site was above 10% cover. Kentucky bluegrass was the most widespread and abundant exotic species. Annual bromes, which are problematic invaders for many of the parks in the region, are found only in low abundance.
	Annual brome cover	< 1 %	≤ 10 % cover		

References and Data Sources: 1. Symstad, A. J. and J. L. Jonas. *in press*. Using natural range of variation to set decision thresholds: a case study for Great Plains grasslands.in G. R. Gutenspergen, editor. Application of threshold concepts in natural resource decision making. Springer Verlag; 2. Brown, P. M. and B. Cook. 2006. Early settlement forest structure in Black Hills ponderosa pine forests. Forest Ecology and Management 223:284-290.

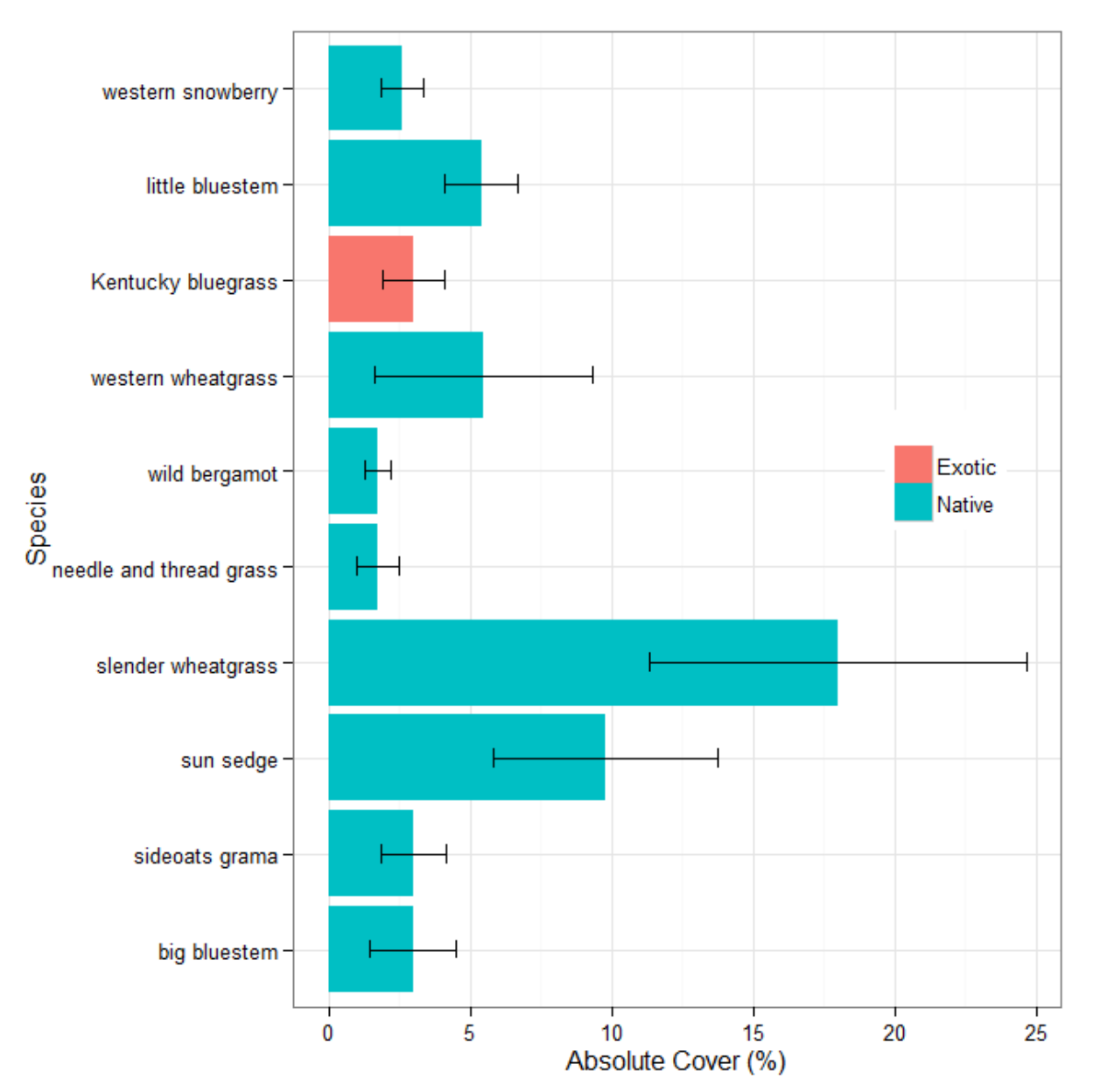

Figure 5. The average absolute cover of the 10 most common native (blue) and exotic (red) plants recorded at 6 sites at Jewel Cave National Monument in 2012. Bars represent means ± standard errors. The common native species, like slender wheatgrass, accounted for greater cover than exotic species.

Species richness in the mixed-grass prairie is determined by numerous factors including fire regime, large ungulate grazing, prairie dog disturbance, and weather fluctuations (Symstad and Jonas 2011). Along with species composition, species richness also varied across sites (Table 5). The plot with the lowest native diversity, PCM_018, was very close to the road and visitor center parking lot (Figure 1). 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 *in press*). Long-term records of species diversity in mixed-grass prairie in a moderately grazed site in Montana ranged between 8 and 18 species per square meter (10-90th percentile range) between 1933-1945 and the range for a relatively undisturbed site in Kansas from 1932-1972 was between 3 and 15 species per square meter (Symstad and Jonas, *in press*). Native species richness in the 1m^2 quadrats at JECA dropped by 2 species in 2012 compared to 2011 (Ashton et al. 2012a) but was still within the range of natural variability despite dry conditions.

Table 4. Average plant species richness plant community monitoring plots at Jewel Cave National Monument in 2012. Values represent means ± standard errors, n=6.

	Point-intercept	**1 m^2 quadrats**	**10 m^2 quadrats**
Total species richness	19 ± 2.2	10 ± 0.7	21 ± 1.5
Native species richness	17 ± 1.7	9 ± 0.6	19 ± 1.5
Exotic species richness	2 ± 0.7	2 ± 0.1	2 ± 0.3
Graminoid species richness	8 ± 1.1	3 ± 0.2	5 ± 0.2
Forb species richness	7 ± 1.6	5 ± 0.5	13 ± 1.0

The average relative cover of exotic species at sites in JECA was fairly low (7%; Table 3). Much of the exotic cover at sites in JECA was due to the presence of Kentucky bluegrass (Table 5). A major management challenge for parks in the region is to control the spread of cheatgrass and Japanese brome (annual bromes). The presence of annual bromes in mixed-grass prairie is associated with decreased productivity and altered nutrient cycling (Ogle et al. 2003), and there is strong evidence from regions further west that cheatgrass alters fire regimes and the persistence of native species (D'Antonio and Vitousek 2003). Overall, cover of annual bromes in JECA was fairly low <1%, and there were many sites with no bromes present (Table 5). PCM_019 (Figure 6), which included a patch of smooth brome, Japanese brome, common mullein, and Kentucky bluegrass, had the highest cover of exotics (22%; Table 5).

Table 5. Characteristics of the plant community in 6 plots at Jewel Cave National Monument in 2012 including average native species richness, exotic plant cover, cover of annual bromes, and area of disturbance.

Plot	Average native species richness 1 m^2 plots	Exotic cover (%)	Annual brome cover (%)	Kentucky bluegrass cover (%)	Disturbance within site (m^2)
JECA_PCM_004	10	5	0	5	1250
JECA_PCM_016	11	6	0	0	2292
JECA_PCM_017	10	8	0	6	1000
JECA_PCM_018	7	1	0	1	2296
JECA_PCM_019	8	22	4	7	2290
JECA_PCM_021	9	0	0	0	2315
Site Average	*9 ± 0.6 species*	*7 ± 3.3 %*	*0.6 ± 0.6 %*	*3.1 ± 1.3%*	

Figure 6. The long-term monitoring plot, PCM_019, which had the highest exotic species cover and a high density of tree and shrub seedlings in Jewel Cave National Monument in 2012.

Disturbance from grazing, rodents, fire, and humans affects plant community structure and composition in mixed-grass prairie and ponderosa woodlands. For this reason, we measured the

approximate area affected by natural and human disturbances at each site we visited. In 2012, the type of disturbance varied and included fire, animal trails, small mammal excavations, grazing, and old forest roads. There was natural disturbance evident in all plots (Table 5). In most cases, the entire plot area had been burned. The two exceptions were PCM_004 and PCM_017, which were only partially burned. In the future, when we have collected more data from the park we may be able to estimate how disturbances affect species diversity.

Tree density and fuel loads

Trees or seedlings were found in all 6 plots visited in 2012, and ponderosa pine was the only mature tree or pole found. Seedlings of chokecherry (*Prunus virginiana*) and western serviceberry (*Amelanchier alnifolia*) were common and sometimes quite dense at plots. The highest density of seedlings, 11,967 seedlings ha^{-1}, was found in PCM_019 (Figure 6). Mature tree density averaged 113 stems ha^{-1} (Table 6) which was lower than the average for the whole park measured in 2011. The difference between the two estimates is likely due to the larger number of sites visited in 2011 than in 2012. Historic reconstructions of forest density from 1900 found a very similar density to the 2012 value (Brown and Cook 2006).

Table 6. Tree and seedling density in 2011 and 2012 at Jewel Cave National Monument.

Indicator	2011 Average across the park	2012 Average from 6 plots
Mature tree density (stems/ha)	201 ± 39	113 ± 43
Snag density (stems/ha)	82 ± 13	20 ± 7.3
Seedling density (stems/ha)	7060 ± 1196	4723 ± 2277

The average total fuel load was 24 tons $acre^{-1}$. There was a large range of fuel loads from 5 ton $acre^{-1}$ (PCM_004) to 43 ton $acre^{-1}$ (PCM_016). Litter and duff depth averaged 1.9 in and 3.68 in, respectively. The average fuel load in 2012 was equivalent to the 2011 values. Both are much higher than the FireEP target of less than 10 tons $acre^{-1}$ due to the Jasper Fire in 2000 leaving a large amount of coarse woody debris throughout the park. Because the forest structure is open and lacking ladder and fine fuels the high total fuel loads is only of moderate concern.

Conclusions

In conclusion, we found that Jewel Cave National Monument has a high diversity of native plants. Dry conditions in 2012 tended to reduce plant diversity compared to 2011, but species richness was still within the range of natural variability for mixed-grass prairie. Forest densities are similar to historic conditions and characterized by a mosaic of open and closed canopy sites. To date, Jewel Cave National Monument has had effective exotic plant management. Average cover of exotic species was low, and only one site was above 10% cover. Kentucky bluegrass was the most widespread and abundant exotic species. To retain ecological integrity in JECA and the high diversity of native plants, it is important to continue efforts to reduce the cover of invasive plants. The Jasper Fire in 2000 left a large amount of coarse woody debris throughout the park resulting in high total fuel loads. Continued monitoring efforts will be critical to track changes in the condition of the vegetation communities in JECA.

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Appendix A: Field journal for plant community monitoring in JECA for the 2012 season

Plant community composition monitoring in JECA was completed using a crew of 8 people working 3 10-hour days and a crew of 2 people working a 6 hour day. We spent 312 total crew hours at JECA. We also had 42 hours of assistance from JECA staff.

Date	Day of week	Approximate Travel Time (hrs)	Housing	Sites Completed	Notes
Jul 02, 2012	Monday	2.5	N/A	PCM-004 PCM-017	2 plot surveys 1 plot establishment
Jun 03, 2012	Tuesday	2.5	N/A	PCM-016 (¾) PCM-019	1.75 plot surveys
Jun 05, 2012	Thursday	2.5	N/A	PCM-018 PCM-021	2 plot surveys 1 plot establishment
Jun 17, 2012	Tuesday	2.5	N/A	PCM-016 (¼)	0.25 plot surveys

Appendix B: List of plant species found in 2012 at JECA

Species found in monitoring plots at Jewel Cave National Monument in 2012. Species in bold are not on the park's certified species list.

Family	Species Code	*Scientific Name*	Common Name	Exotic
Anacardiaceae	RHTR	*Rhus trilobata*	skunkbush sumac	
	TORY	*Toxicodendron rydbergii*	poison ivy	
Apiaceae	MUTE3	*Musineon tenuifolium*	slender wildparsley	
Apocynaceae	APFL	*Apocynum ×floribundum*	intermediate dogbane	
	APAN2	*Apocynum androsaemifolium*	spreading dogbane	
Asclepiadaceae	ASOV	*Asclepias ovalifolia*	milkweed	
	ASPU	*Asclepias pumila*	plains milkweed	
	ASSP	*Asclepias speciosa*	showy milkweed	
	ASVI	*Asclepias viridiflora*	green comet milkweed	
Asteraceae	ACMI2	*Achillea millefolium*	common yarrow	
	ANMI3	*Antennaria microphylla*	littleleaf pussytoes	
	ANPA4	*Antennaria parvifolia*	small leaf pussytoes	
	ARLU	*Artemisia ludoviciana*	white sagebrush	
	CIAR4	*Cirsium arvense*	Canada thistle	*
	CIFL	***Cirsium flodmanii***	**Flodman's thistle**	
	CIUN	*Cirsium undulatum*	wavyleaf thistle	
	COCA5	*Conyza canadensis*	horseweed	
	ECAN2	*Echinacea angustifolia*	blacksamson echinacea	
	ERIGE2	*Erigeron*	fleabane spp.	
	ERFL	*Erigeron flagellaris*	trailing daisy	
	ERFO3	*Erigeron formosissimus*	beautiful fleabane	
	ERST3	*Erigeron strigosus*	prairie fleabane	
	ERSU2	*Erigeron subtrinervis*	three-nerve fleabane	
	GRSQ	*Grindelia squarrosa*	curlycup gumweed	
	HEPA19	*Helianthus pauciflorus*	stiff sunflower	
	LIPU	*Liatris punctata*	dotted blazing star	
	LYJU	*Lygodesmia juncea*	rush skeletonplant	
	PACA15	*Packera cana*	woolly groundsel	
	PAPL12	*Packera plattensis*	prairie groundsel	
	RUHI2	*Rudbeckia hirta*	blackeyed Susan	
	SOCA6	*Solidago canadensis*	common goldenrod	
	SOMI2	*Solidago missouriensis*	Missouri goldenrod	
	SOMO	*Solidago mollis*	velvety goldenrod	
	SONE	*Solidago nemoralis*	gray goldenrod	
	SORI2	***Solidago rigida***	**stiff goldenrod**	
	SOSP2	***Solidago speciosa***	**showy goldenrod**	
	SYER	*Symphyotrichum ericoides*	white heath aster	
	SYLA3	*Symphyotrichum laeve*	smooth blue aster	
	SYOB	*Symphyotrichum oblongifolium*	aromatic aster	
	TAOF	*Taraxacum officinale*	common dandelion	*
	TEAC	*Tetraneuris acaulis*	stemless four-nerve daisy	

Family	Species Code	*Scientific Name*	Common Name	Exotic
	TRDU	*Tragopogon dubius*	common salsify, goat's beard	*
Boraginaceae	CYOF	*Cynoglossum officinale*	common houndstongue	*
	LIIN2	*Lithospermum incisum*	fringed gromwell, puccoon	
Brassicaceae	**ARPY4**	***Arabis pycnocarpa***	**creamflower rockcress**	
	BOPI99	*Boechera pinetorum*	Holboell's rockcress	
	ERAS2	*Erysimum asperum*	western wallflower	
	ERRE4	***Erysimum repandum***	**spreading wallflower**	*
	PHLU99	*Physaria ludoviciana*	foothill bladderpod	
	SIAL2	*Sisymbrium altissimum*	tall tumblemustard	*
	THAR5	*Thlaspi arvense*	fanweed, field pennycress	*
Campanulaceae	CARO2	*Campanula rotundifolia*	bluebell	
Caprifoliaceae	SYAL	*Symphoricarpos albus*	common snowberry	
	SYOC	*Symphoricarpos occidentalis*	western snowberry, wolfberry	
Chenopodiaceae	CHPR5	*Chenopodium pratericola*	desert goosefoot	
Cyperaceae	CAREX	*Carex*	carex spp.	
	CADU6	***Carex duriuscula***	**needleleaf sedge**	
	CAIN9	*Carex inops*	long-stolon sedge	
	CARI	*Carex richardsonii*	Richardson's sedge	
	CARO5	*Carex rossii*	Ross's sedge	
Elaeagnaceae	SHCA	*Shepherdia canadensis*	russet buffaloberry	
Ericaceae	ARUV	*Arctostaphylos uva-ursi*	bearberry, kinnikinnick	
Euphorbiaceae	EUBR	*Euphorbia brachycera*	horned spurge	
Fabaceae	ASAG2	*Astragalus agrestis*	purple milkvetch	
	ASDR3	*Astragalus drummondii*	Drummond's milkvetch	
	ASFL2	*Astragalus flexuosus*	pliant milkvetch	
	ASLA27	*Astragalus laxmannii*	Laxmann’s milkvetch	
	ASMI9	***Astragalus miser***	**timber milkvetch**	
	ASMI10	*Astragalus missouriensis*	Missouri milkvetch	
	DACA7	***Dalea candida***	**white prairieclover**	
	DAPU5	*Dalea purpurea*	purple prairieclover	
	GLLE3	*Glycyrrhiza lepidota*	wild licorice	
	LAPO2	***Lathyrus polymorphus***	**manystem pea**	
	LUAR3	*Lupinus argenteus*	silvery lupine	
	MELU	*Medicago lupulina*	black medic	*
	MEOF	*Melilotus officinalis*	yellow sweetclover	*
	OXLA3	*Oxytropis lambertii*	purple locoweed	
	OXSE	*Oxytropis sericea*	locoweed, white crazyweed	
	PEAR6	*Pediomelum argophyllum*	silverleaf Indian breadroot	
	PEES	*Pediomelum esculentum*	breadroot scurfpea	
	THRH	*Thermopsis rhombifolia*	goldenpea, prairie thermopsis	
	VIAM	*Vicia americana*	American vetch	
Gentianaceae	FRSP	*Frasera speciosa*	green gentian, monument plant	
Grossulariaceae	RIAM2	*Ribes americanum*	American black currant	
	RIHI	*Ribes hirtellum*	hairy-stem gooseberry	
	RIOX	*Ribes oxyacanthoides*	Canadian gooseberry	
Iridaceae	IRMI	*Iris missouriensis*	Rocky Mountain iris, wild iris	
	SIMO2	*Sisyrinchium montanum*	mountain blue-eyed grass	

Family	Species Code	*Scientific Name*	Common Name	Exotic
Lamiaceae	MOFI	*Monarda fistulosa*	wild bergamot	
Liliaceae	ALCE2	*Allium cernuum*	nodding onion	
	CAGU	*Calochortus gunnisonii*	Gunnison mariposa lily	
	LEMO4	*Leucocrinum montanum*	common starlily, star-lily	
	MAST4	*Maianthemum stellatum*	false Solomon's seal	
Linaceae	LILE3	*Linum lewisii*	blue flax, prairie flax	
Malvaceae	SPCO	*Sphaeralcea coccinea*	scarlet globemallow	
Onagraceae	OESU99	*Oenothera suffrutescens*	scarlet beeblossom	
Pinaceae	PIPO	*Pinus ponderosa*	ponderosa pine	
Plantaginaceae	PLPA2	*Plantago patagonica*	woolly plantain	
	SYWY99	*Synthyris wyomingensis*	Wyoming kittentails	
Poaceae	ACHY	*Achnatherum hymenoides*	Indian ricegrass	
	ACRI8	*Achnatherum richardsonii*	Richardson needlegrass	
	ALCA4	***Alopecurus carolinianus***	**Carolina foxtail**	
	ANGE	*Andropogon gerardii*	big bluestem	
	BOCU	*Bouteloua curtipendula*	sideoats grama	
	BOGR2	*Bouteloua gracilis*	blue grama	
	BOHI2	*Bouteloua hirsuta*	hairy grama	
	BRAN	*Bromus anomalus*	nodding brome	
	BRIN2	*Bromus inermis*	awnless brome, smooth brome	*
	BRJA	*Bromus japonicus*	Japanese brome	*
	DAIN	*Danthonia intermedia*	timber oatgrass	
	DASP2	*Danthonia spicata*	poverty oatgrass	
	ELEL5	*Elymus elymoides*	squirreltail	
	ELRE4	*Elymus repens*	quackgrass	*
	ELTR7	*Elymus trachycaulus*	slender wheatgrass	
	FESA	*Festuca saximontana*	mountain fescue	
	HECO26	*Hesperostipa comata*	needle and thread	
	HESP11	*Hesperostipa spartea*	porcupinegrass	
	KOMA	*Koeleria macrantha*	junegrass, prairie Junegrass	
	MUCU3	*Muhlenbergia cuspidata*	plains muhly	
	MUPA99	*Muhlenbergia paniculata*	tumblegrass	
	MURA	*Muhlenbergia racemosa*	green muhly, marsh muhly	
	NAVI4	*Nassella viridula*	green needlegrass	
	PASM	*Pascopyrum smithii*	western wheatgrass	
	PIMI7	*Piptatherum micranthum*	littleseed ricegrass	
	POCO	*Poa compressa*	Canada bluegrass	*
	POPR	*Poa pratensis*	Kentucky bluegrass	*
	PSSP6	*Pseudoroegneria spicata*	bluebunch wheatgrass	
	SCSC	*Schizachyrium scoparium*	little bluestem	
	SPHE	*Sporobolus heterolepis*	prairie dropseed	
	VUOC	***Vulpia octoflora***	**sixweeks fescue**	
Polemoniaceae	PHAL3	*Phlox alyssifolia*	alyssumleaf phlox, phlox	
	PHHO	*Phlox hoodii*	Hood's phlox, spiny phlox	
Polygalaceae	POAL4	*Polygala alba*	white milkwort	
Polygonaceae	POAC3	*Polygonum achoreum*	leathery knotweed	
Ranunculaceae	ANCY	*Anemone cylindrica*	candle anemone, cottonweed	
	ANMU	***Anemone multifida***	**Pacific anemone**	

Family	Species Code	*Scientific Name*	Common Name	Exotic
	ANPA19	*Anemone patens*	eastern pasqueflower	
Rosaceae	AMAL2	*Amelanchier alnifolia*	juneberry, western serviceberry	
	CEMO2	*Cercocarpus montanus*	alderleaf mountain mahogany	
	FRVI	*Fragaria virginiana*	thickleaved wild strawberry	
	GETR	*Geum triflorum*	old man's whiskers, prairie smoke	
	PHMO4	*Physocarpus monogynus*	mountain ninebark	
	POCO13	*Potentilla concinna*	elegant cinquefoil	
	PRVI	*Prunus virginiana*	chokecherry	
	ROAC	*Rosa acicularis*	prickly rose	
	ROAR3	*Rosa arkansana*	prairie rose	
	ROWO	*Rosa woodsii*	Woods' rose	
Rubiaceae	GABO2	*Galium boreale*	northern bedstraw	
Santalaceae	COUM	*Comandra umbellata*	bastard toadflax	
Scrophulariaceae	VETH	*Verbascum thapsus*	common mullein	*
Solanaceae	**PHVI5**	***Physalis virginiana***	**Virginia groundcherry**	
Unknown family	UNKGRAM	*Unknown graminoid*	unknown graminoid	*
	UNKFORB	*Unknown forb*	unknown forb	*
Violaceae	VIOLA	*Viola*	violet	*
	VIAD	*Viola adunca*	blue violet, hookedspur violet	
	VICA4	*Viola canadensis*	Canada violet	

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National Park Service
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Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov