National Park Service
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Natural Resource Stewardship and Science

Forest Structure and Fuel Loads at Jewel Cave National Monument

2011 Status Report

Natural Resource Technical Report NPS/NGPN/NRTR—2012/586

ON THE COVER
A view of a long-term forest monitoring plot at Jewel Cave National Monument, 2011
Photograph by: Daina Jackson, NGPN, NPS

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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 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. 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 Northern Great Plains Network website (http://science.nature.nps.gov/im/units/ngpn/reportpubs/reports.cfm) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/).

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Executive Summary

The Northern Great Plains Inventory & Monitoring Network (NGPN) and the Northern Great Plains Fire Ecology Program surveyed 60 forested plots in Jewel Cave National Monument (JECA) in 2011. This effort will be repeated in 2016 and every 5 years thereafter to better understand status and trends in forest vegetation. We measured tree stem density, tree diameter, live and dead tree condition, fire fuel loads, cover of exotic species, and disturbance in all plots. By using a randomized survey approach, we are able to use these data to estimate the status of the forest, not just of the plots, from the park as a whole. In this report, we provide a summary of our results from sampling in 2011. We found the following:

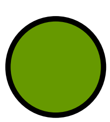
- Ponderosa pine was the only species to occur in all plots. Western serviceberry and chokecherry seedlings were common and occurred in many of the plots. Besides ponderosa pine, the most common mature tree species we encountered was Rocky Mountain juniper.

- In 2011, forest basal area averaged 7.5 m^2 per hectare, but was spatially variable. Areas that experienced high severity burning in the 2000 Jasper fire had much lower basal areas than unburned areas. Less than 5% of the park area had basal areas that are considered high enough to have an increased risk of mountain pine beetle infestation.

- In 2011, we found no plots in the park that had evidence of mountain pine beetles. However, there are mountain pine beetles in the park and JECA has been actively cutting damaged trees. All the plots visited had some evidence of historic fires, but severity differed. Fire severity was correlated with increased total fuel loads and lower basal areas, but there was no relationship between seedling density or exotic cover and severity.

- Exotic species were present in low abundance in JECA. The cover class of targeted exotics averaged less than 2 individuals in the plots we visited. The most common exotic species was Canada thistle.

The data and information in this report is summarized below in a natural resource condition table with a goal of communicating this complex park condition information in a clear and simple way. Green indicates good condition but there is insufficient information to determine a trend in condition at this time. Further details about the table and its content are presented in the discussion of this paper.

Resource	**Condition Status/Trend**	**Rationale**
Forest condition		The ponderosa pine forest that blankets JECA is an outstanding natural resource with a low abundance of exotic species and a high diversity of plants. As of 2011, overall condition of the forest community was good. The Jasper Fire in 2000 reduced forest density and basal area but patches of old growth forest remain. Of moderate concern is the large amount of coarse woody debris resulting from high tree mortality caused by the fire. Resource trends are difficult to discern because few quantitative studies of past conditions were completed but continued forest surveys will allow us to discern changes in the future.

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 thank the Northern Great Plains Fire Ecology Program for ongoing assistance with fieldwork and development of methods. We greatly appreciate the staff at JECA for providing logistical support. The 2011 NGPN vegetation and Fire Effects field crew collected all the data included in this report. We thank Timothy Shepherd for invaluable support and instruction on managing data in the FFI database and Stephen Wilson for assistance with the GIS data. Comments from Rene Ohms, Anine Smith, and Gretchen Addington improved this report.

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 (Figure 1). 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). Natural and anthropogenic disturbances, such as fire and logging, are an integral part of the history of this ecosystem (reviewed in Shepperd and Battaglia 2002). Evaluating the current status and long-term trend in forest condition is critical as climate change threatens to increase the prevalence of disturbances and drought stress (Allen et al. 2010). 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).

Jewel Cave National Monument (JECA) is located in the southwestern Black Hills (Figure 1) 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 forest and grassland communities (Marriot and Hartment 1986, Ashton et al. 2012) with ponderosa pine forests dominating the landscape (Salas and Pucherelli 1998).

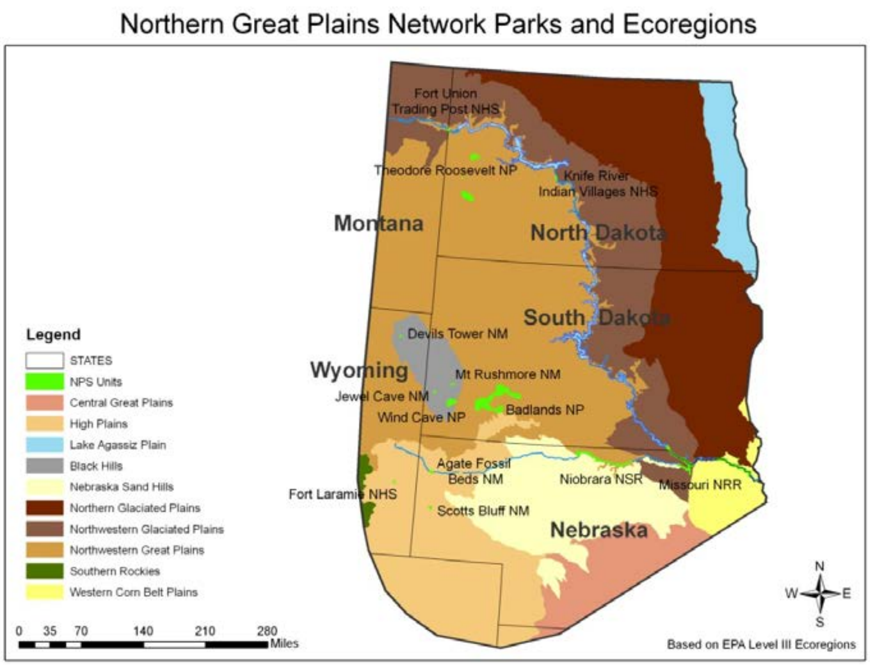


Figure 1. Parks and ecoregions of the Northern Great Plains Network. Based on the U.S. Environmental Protection Agency's Level III ecoregions classes (Omernik 2007).

Historically, smaller fires have maintained a relative state of equilibrium in this area of the southern Black Hills (Shinneman and Baker 1997). During the period of 1388-1900, the average number of years between wide-spread fires in the area was estimated at 20-32 years, while smaller, lower intensity fires were more frequent, estimated to return every 16 years (Brown and Sieg 1996). However, post-settlement times (i.e., after 1874) have been quite different. Generally, fires have been excluded from the surrounding forests, and there have been long time periods without fire in the monument (e.g., 1890-1994; Brown and Sieg 1996). The Jasper Fire of 2000, the largest fire recorded in the Black Hills, ended the more than 100 year reprieve. The fire eventually tracked across nearly 34,000 ha (≈ 83,500 acres) leaving behind a variety of effects. Seventy-five percent of the landscape was moderately to severely burned, with more than 50% of the trees lost to fire-injury (Lentile et al. 2005). Ninety-five percent of the monument was affected by this conflagration (NPS 2004), resulting in a patchwork of intact and entirely consumed ponderosa pine stands (Figure 2).

Figure 2. The landscape of Jewel Cave National Monument in 2011 is characterized by a patchwork of burned and intact ponderosa pine forest as a result of the Jasper Fire 11 years earlier.

Scientifically credible information on the current status and long-term trends of the composition, structure, and function of the forests in JECA is required for sound management. In 2011, the National Park Service Northern Great Plains Inventory & Monitoring Network (NGPN) and the Northern Great Plains Fire Ecology Program sampled 60 forested sites in JECA selected by a spatially balanced probability survey design (Stevens and Olsen 2004). The general goal of this monitoring effort was to better understand the condition of JECA's forest by sampling and characterizing upland vegetation, exotic plant prevalence, and fire and fuel dynamics (Gitzen et al. 2010). More specifically, the long-term monitoring objectives are to: (1) determine park-wide status (at 5-year intervals) and long-term trends of tree density by species, height class, diameter class, and fuel loads and (2) 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 (Symstad et al. 2011). In this report, we present the results from 2011, our first year of monitoring, which we hope will provide a baseline from which to compare our future efforts.

Methods

The NGPN Plant Community Composition and Structure Monitoring Protocol (Symstad et al. 2011) describes in detail the methods used for sampling long-term plots in JECA forests. Below, we briefly describe the general approach, sample frame, plot locations, and sampling methods. For those interested in more detail, please see Symstad et al. 2011, available at http://science.nature.nps.gov/im/units/ngpn/monitor/plants/plants.cfm.

Sample design

We implemented a survey to monitor forest structure and fuel loads in JECA using a spatially balanced probability survey design (Generalized Randon Tessellation Stratified (GRTS); Stevens and Olsen 2003, 2004). For JECA, we defined the target population as vegetation in the entire park. A 54 x 54 m grid was overlaid on the park to create the sample frame and sampling locations were at the center of a random subset of grid cells. We excluded the following areas from the sample frame: administrative areas, roads, utility lines and an appropriate buffer, areas within 10 m of a park boundary, paved trails, and areas with little to no potential for terrestrial vegetation (e.g. large areas of bare rock). The final design included 60 randomly located sites (Figure 3).

Probability-based surveys provide unbiased estimation of both status and, with repeated visits, trend across a resource (Larsen et al. 1995). 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). Thus, we can use data from our randomly selected sites to estimate the condition of the entire extent of JECA vegetation (minus excluded areas). When these sites are revisited in 2016 and every five years thereafter, we will be able report on the change in the condition of JECA forests over time.

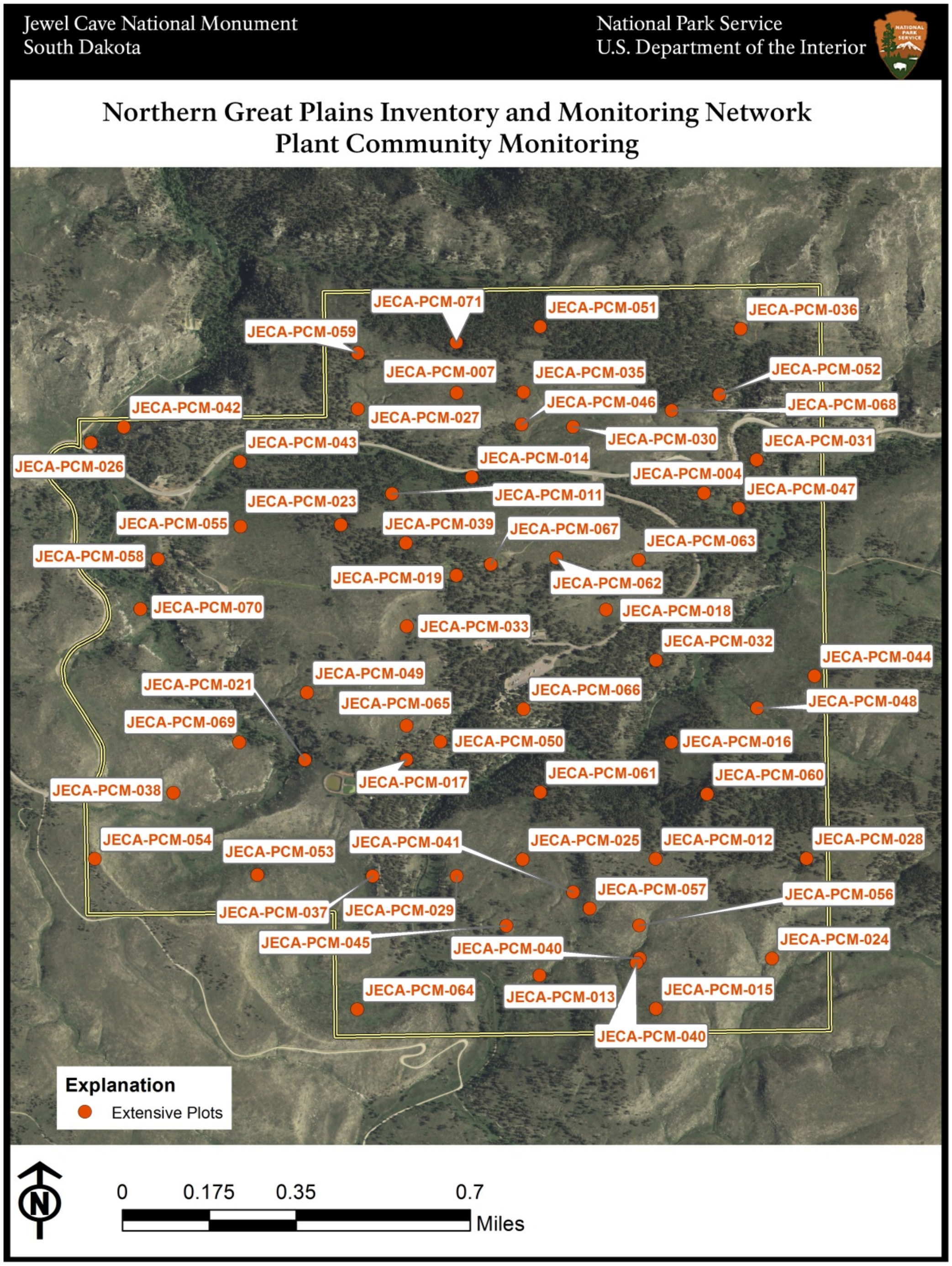


Figure 3. Map of Jewel Cave National Monument and the location of 60 forest monitoring plots.

Plot layout and sampling

At each of 60 sites, we sampled tree regeneration and density in a 10 m radius permanent plot (0.03 ha; Figure 4). All sites were visited in August and September of 2011. Tree and targeted tall shrub species with diameter at breast height (DBH, where breast height = 137 cm) < 2.54 cm (seedlings or samplings) were tallied by species. For all poles species (2.54 cm ≤ DBH ≤ 15 cm), DBH, and status (live or dead) were recorded. Species, DBH, status, and condition (leaf-discoloration, insect-damaged, etc.) were recorded for each tree with DBH > 15 cm. Dead and downed woody fuel load data were collected on two perpendicular, 100-ft (30.49 m) transects centered at the center of the plot following Brown's Line methods (Brown 1974, Brown et al. 1982).

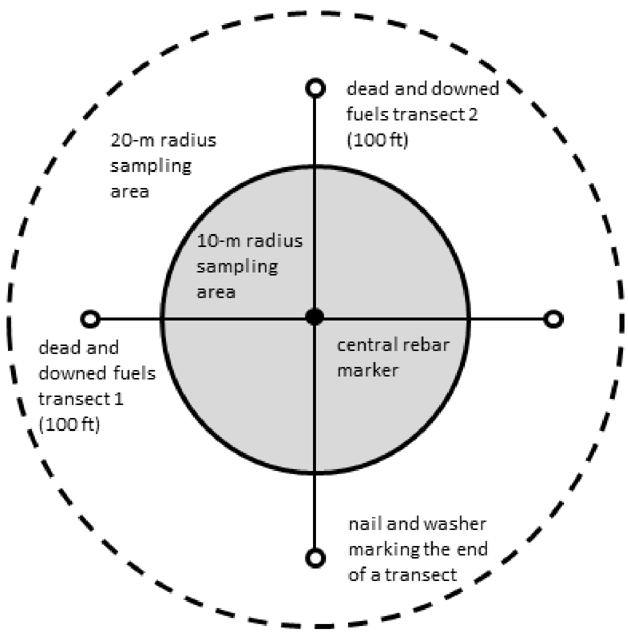


Figure 4. Long-term monitoring plot used for sampling forest structure and fuels in Jewel Cave National Monument.

In a subset of 6 sites, we sampled in the 10 m radius and extended tree sampling to a 50 m x 20 m (0.1 ha) plot. In these 6 sites, trees were mapped and tagged and will be revisited two of every five years on a rotating schedule. The larger sampling frame and greater sampling frequency are consistent with the more comprehensive NGPN vegetation monitoring protocol (Symstad et al. 2011).

At all plots, we surveyed the area for common disturbances and exotic species of management interest (Table 1). Common disturbances included roads, burn piles, animal trails, and fire. For all plots the type, severity, and approximate area of the disturbances were recorded. For each target species that was present at a site, an abundance class was given on a scale from 1 to 5 where 1 = one individual, 2 = few individuals, 3 = cover 1-5% of site, 4 = cover 5-25% of site, and 5 = cover > 25% of site. Where plots had more than one exotic species present, we used the maximum cover class in that plot to describe cover class of all target exotics (rather than by species).

Table 1. Targeted exotic species of management interest in JECA that were surveyed for during the 2011 field season.

Scientific Names	Common Names	Management interest
Acroptilon repens	Russian knapweed/hardheads	Early detection
Centaurea diffusa	diffuse knapweed	Early detection
Centaurea jacea	brownray knapweed	Early detection
Centaurea solstitialis	yellow star thistle	Early detection
Centaurea biebersteinii	spotted knapweed	Early detection
Cirsium arvense	Canada thistle	Eradication
Cynoglossum officinale	houndstongue	Eradication
Euphorbia esula	Leafy spurge	Eradication
Tanacetum vulgare	common tansy	Early detection
Verbascum thapsus	mullein	Eradication

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 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 their original source 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/or the FFI database as needed.

Summaries were done using FFI reports and query functions and statistical summaries were done using R software (version 2.11.0). We used the R package 'spsurvey' (Kincaid and Olsen 2011) to adjust the survey site weights to account for replacing non-target or non-accessible sites with overdraw samples. The code used for analysis can be found in Appendix A. Fire Severity data were accessed from the National Burn Severity Mapping Project (NPS-USGS 2012) and the center point of each plot was used to determine burn class.

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 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 basal area, 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 2.

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

We chose a set of 6 indicators that can describe the condition of JECA forests and the status of exotic plant invasions. Reference values were based on descriptions of historic forest condition, past studies completed in the park, management targets, or the natural resource condition assessment completed in 2009 (Narumalani et al. 2009). Current park condition was compared to these reference values and status was scored as good, caution, or significant concern based on this comparison. Good was applied to values that fell within the range of the reference value and significant concern was applied to conditions that fell well 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 estimates 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. Confidence was calculated by averaging the scores for each of the three categories based on definitions given in Table 3. High confidence was given to indicators with an average score of >4, medium with a score ≥2 and ≤4, and low was items with a score <2.

Table 3. Key to calculating confidence values reported in the Natural Resource Condition Table. Confidence is based on relevance to the park unit, data quality, and temporal scale.

Confidence score	**Relevance to the park unit**	**Data quality**	**Temporal scale of reference value (where applicable)**
High (5)	Data are from multiple locations within the park that are representative of the resource. The best examples are studies with statistical inference to the entire resource or a survey of the entire park resource.	Data derived from published and peer-reviewed protocols with results appearing in peer-reviewed publications. Data and metadata are available.	Long-term data (e.g. >15 years)
Medium-high (4)	Data are from several locations within the park or a regional study with multiple locations in and around the park. Alternatively, one to two sites that represent a greater area (e.g. sampling that captures an entire airshed or watershed)	Data derived from established peer-reviewed protocols. Gray literature or thesis work exists but not many peer-reviewed publications have been derived from the data.	6-15 years
Medium (3)	Data are from one to two locations within the park; a regional study with multiple sites near the park; data from multiple locations for the same resource type (e.g. a global survey of caves)	Data derived from established protocols with known inconsistencies (e.g. SNOTEL temperature data) or few publications.	3-5 years
Medium-low (2)	Data are from one nearby location (<100mi); a regional study with no sites (<100mi) to the park	Data with concerns regarding consistency or quality (e.g. many citizen science projects) with or without formal protocols established.	2-3 years
Low (1)	Data are from a global or US scale study that is not specific to the resource (e.g. global temperature trends)	Unknown methods used to acquire data. There are significant concerns regarding consistency or quality of data.	Data from 1 year

Results

We used a probability-based survey design that allows for unbiased inference from sampled sites (a selection of 60 grid cells) to unsampled elements of the population of interest (the entire sample frame or the set of grid cells that cover JECA minus select administrative areas, power line corridors, and roads). Consequently, the results we present below are estimated means (or other metrics) of forest vegetation in JECA included in this discrete sample frame. For ease of interpretation, we hereafter will refer to these means as representing the park-wide status of JECA forests, with an understanding that they do not represent administrative areas, roads, or other areas excluded from the sample frame.

In 2011, we measured density of 7 tree and tall shrub species at 60 plots in JECA (Table 4). Ponderosa pine was the only species to occur in all plots, but we found live trees in only 48 plots. Western serviceberry and chokecherry seedlings were common, but we found no mature trees. Aside from ponderosa pine, the most common mature trees we encountered were Rocky Mountain juniper.

Table 4. Tree and tall shrub species occurrence in 2011 sampling of 60 plots in Jewel Cave National Monument.

Species Name	Common Name	Number of plots with mature or dead trees	Number of plots with seedlings or saplings	Total number of plots where species occurred in 2011
Pinus ponderosa	ponderosa pine	59	26	60
Amelanchier alnifolia	western serviceberry	-	31	31
Prunus virginiana	chokecherry	-	16	16
Juniperus scopulorum	Rocky Mountain juniper	6	1	7
Populus tremuloides	quaking aspen	-	2	1
Cercocarpus montanus	mountain mahogany	-	1	1
Betula papyrifera	paper birch	1	-	1

Park-wide status: tree density and basal area

In 2011, we estimated stand density for mature trees (poles and trees) to be 201 stems per hectare (81 stems per acre, Table 5). Ponderosa pine is the dominant component of the forest and only a small fraction of the average (~1 stem per hectare) is made up of other species (Table 5). Approximately, 60% of the park has stem densities below the reconstructed forest density in 1900 (Brown and Cook 2006) which was estimated to be 131 stems per hectare (53 stems per acre, Figure 5). Seedling densities were highly variable across plots and ranged from 0 to 57,670 stems per hectare (0 to 23,356 stems per acre). The average stem seedling density across the park was 7,060 stems per hectare (2,859 stems per acre). Western serviceberry and chokeberry made up the majority of these seedlings. Basal area of forests in JECA is quite low, averaging only 7.5 m^2 per hectare (33 ft^2 per acre, Table 5). Ponderosa pine accounts for most of the basal area in JECA. Approximately 75% of the area of JECA has stands of ponderosa pine that are less than 15.3 m^2 per hectare (66.6 ft^2 per acre), which is the estimated basal area of the forest in 1900 (Figure 6, Brown and Cook 2006). The basal area is composed of a mix of seedlings, poles and trees, with relatively few saplings (Figure 7).

Table 5. Estimated means, errors, and confidence intervals for select indicators of Jewel Cave National Monument forests

Indicator	N	Estimated Mean	Standard Error	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Mature Tree Density (stems/ha)	60	201	38.9	125	277
Ponderosa Pine Tree and Pole Density (stems/ha)	60	200	38.8	125	277
Total Basal Area (m^2/ ha)	60	7.5	0.97	5.7	9.5
Ponderosa Pine Basal Area (m^2/ ha)	60	7.5	0.97	5.6	9.4
Snag Density (stems/ha)	60	82	12.8	57.2	107.5
Seedling density (stems/ha)	60	7060	1195.6	4716	9403

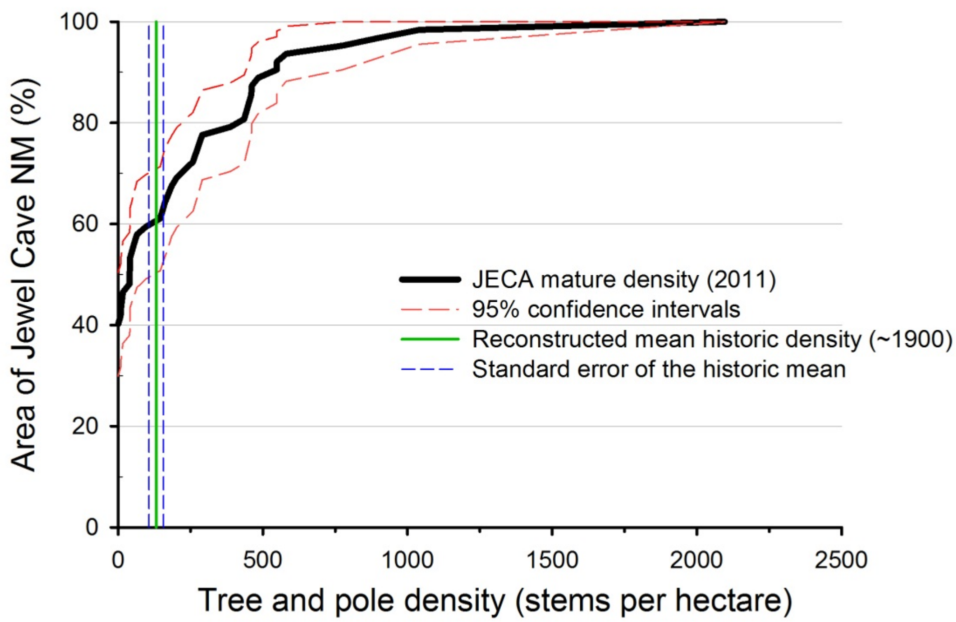


Figure 5. Cumulative distribution function of mature tree density in Jewel Cave National Monument. The black line indicates the estimated distribution, the red dashed lines are upper and lower 95% confidence intervals, the green line is the historic value (Brown and Cook 2006), and the blue dashed line indicates the standard error around the mean historic basal area. This graph indicates that as of 2011, approximately 60% of JECA was at or below the forest density found in 1900.

Snag density averaged 82 stems per hectare across the park (Table 5). Old growth forests in the Black Hills have been described as having at least 10 live trees per acre (24.7 trees/ha) that are larger than 16 inches (40.6 cm) DBH and at least two dead, standing trees per acre (4.9 trees/ha) that are larger than 10 inches (20.5 cm) DBH and trees that are at least 160 years old (Mehl 1992). We have no data on the age of trees in JECA and our small plot sizes do not accurately reflect stand-level snag densities, but by a count of live trees that meet the DBH requirement, 14 plots or 22% of JECA met the definition of old growth. These plots were concentrated in the northern section of the monument.

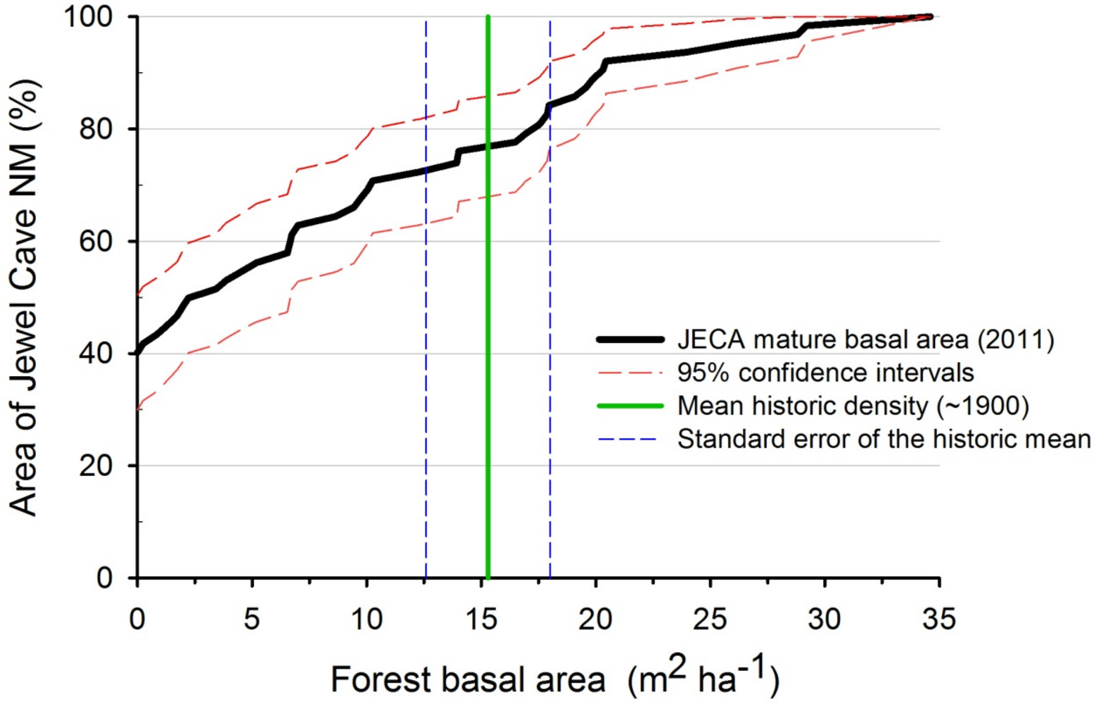


Figure 6. Cumulative distribution function of mature basal area in Jewel Cave National Monument. The black line indicates the estimated distribution, the red dashed lines are upper and lower 95% confidence intervals, the green line is the historic value (Brown and Cook 2006), and the blue dashed line indicates the standard error around the mean historic basal area. This graph indicates that as of 2011, about 75% of JECA was below the basal areas found in 1900.

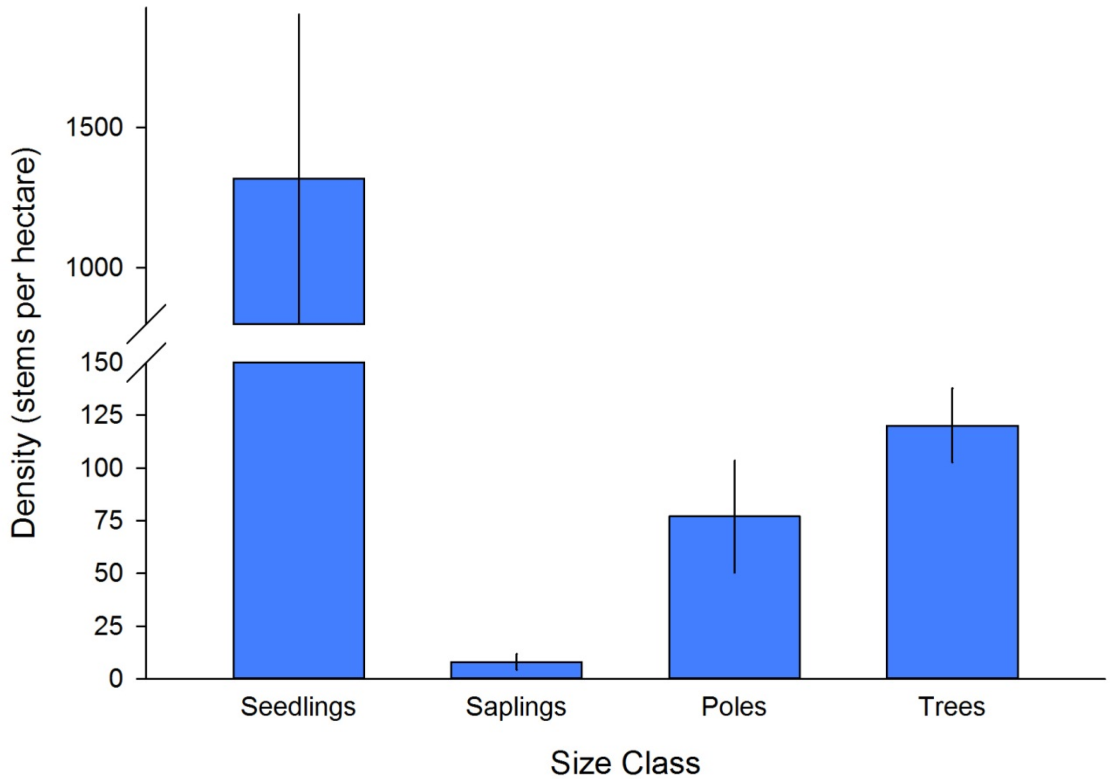


Figure 7. Size class distribution of JECA forests from the 2011 survey.

Park-wide status: surface fuels

Surface fuels were measured at 60 plots in JECA. We found the estimated mean of total surface fuels in JECA to be 24.8 ± 2.23 tons per acre (Figure 7). The estimated mean of total fine fuel loads (1-100 hr fuels) was 4.8 ± 0.49 and total litter and duff depth in the park was 0.6 ± 0.04 in. Woody debris made up the majority of total surface fuels.

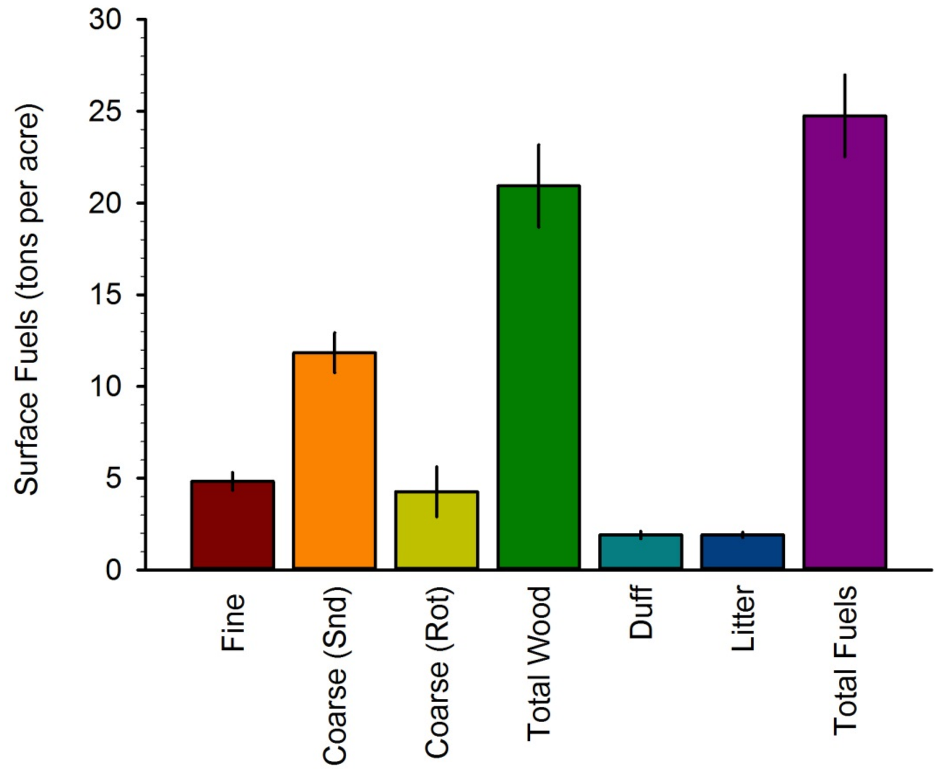


Figure 8. Surface fuels at Jewel Cave National Monument in 2011. Bars represent means ± standard errors, N = 60. Fine includes 1 to 100 hour fuels, coarse sound and rotten refers to 1000 hour fuels.

Park-wide status: disturbance

We documented 4 of the target exotic species (Table 1) in the park including houndstongue (2 plots), leafy spurge (2 plots), Canada thistle (31 plots), and common mullein (18 plots). Twenty three plots had no target species present. At the scale of the whole park, relative cover of exotic species was low cover class averaging 1.4 ± 0.2, which is equivalent to one or two individuals in the plot area.

At each plot, the forest was surveyed for evidence of storm damage (including snow, ice, and water), animal trails or excavations, old roads, and damage from insects or other disease. With the exception of fire, we found too few disturbances to make park-scale estimates of the area affected. We found 4 plots with significant wind or storm damage and 5 plots with evidence of small mammal excavations. Other disturbances that were evident at 2 or fewer plots included: animal trails, garbage (from the highway), powerline right-of-way, herbicide, deer rubs, erosion, and old roads. We found no evidence of mountain pine beetles in any of the plots we visited.

We found evidence of fire at all plots or 100% of the park. Severity of fire differed on the ground, but this was not captured from the field data. Instead, we linked plot locations with burn severity data from the Jasper Fire in 2000 (Figure 8). We found that only 17% of the park was unburned or very low severity and the remaining 83% is classified as burned at low, moderate or high severity (Table 6).

Table 6. Area of Jewel Cave National Monument classified by Jasper Fire (2000) burn severity classes

Burn Severity	Park area (%)	Park area (ha)
Unburned to Low	17 ± 4.1	77.2
Low	33 ± 4.6	154.7
Moderate	21 ± 4.4	96.9
High	29 ± 5.2	135.2

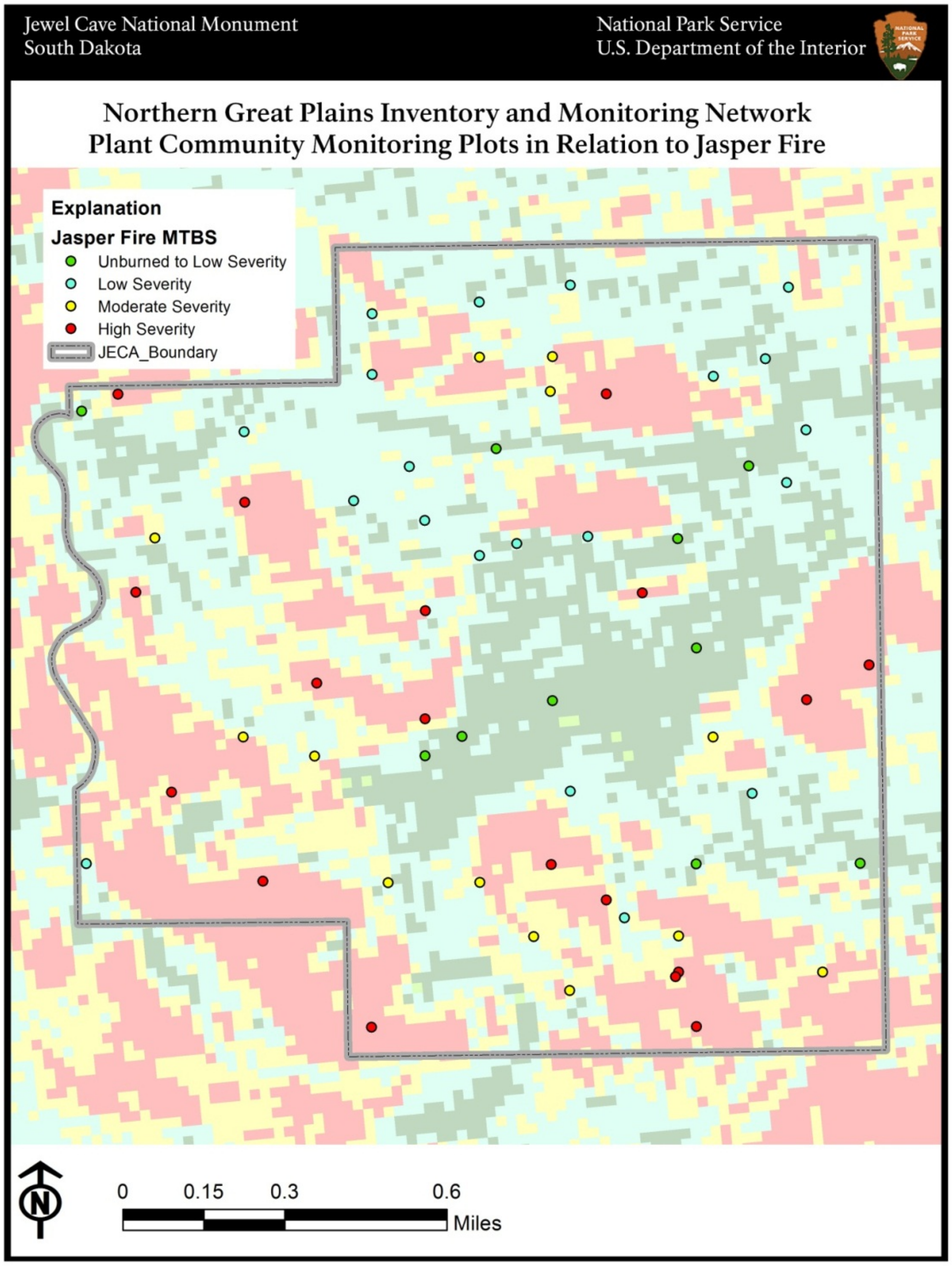


Figure 9. Location of forest monitoring plots in Jewel Cave National Monument in relation to the 2000 Jasper Fire burn severity classes.

Plot-based estimates of fire disturbance

Plots in areas with moderate or high burn severity had significantly lower basal areas than areas that were unburned or experienced low severity burns (Figure 9; $F_{3,56}$=13.4, *P*<0.001). We found no difference in ponderosa pine pole density among severity classes, but a large difference in tree density ($F_{3,56}$=11.0, *P*<0.001). This suggests that the difference in basal area is driven by the loss of large trees in the Jasper Fire. Total surface fuels also differed across burn severities (Figure 9; $F_{3,56}$=4.4, *P*=0.007). In this case, total surface fuel loading was significantly higher in areas that experienced severe burning in 2000 when compared to unburned areas (Figure 9). This difference was driven by an increase in the amount of woody fuels in the high severity burns (Figure 10). We found no difference in the cover of exotic species, seedling densities, or litter depth across burn severity classes.

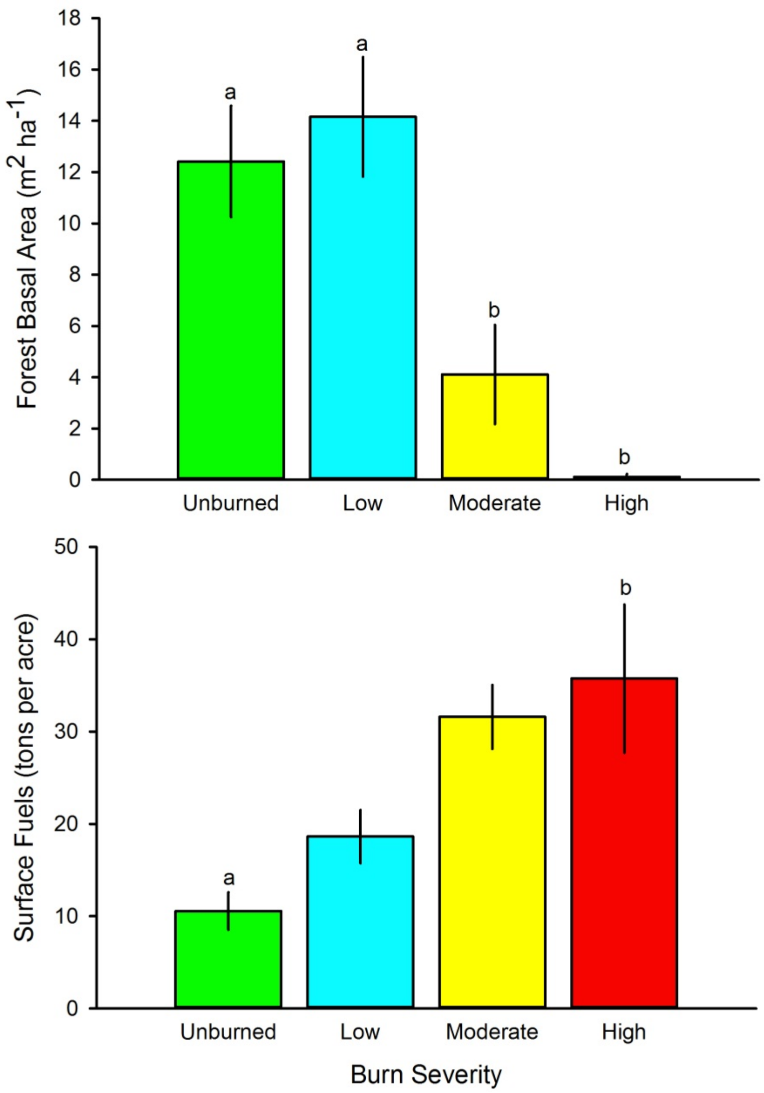


Figure 10. Differences in basal area (top panel) and surface fuels (bottom panel) in Jewel Cave National Monument among different classes of burn severity from the 2000 Jasper Fire. Bars represent means and standard errors, different letters represent means that are significantly different at *P*<0.05.

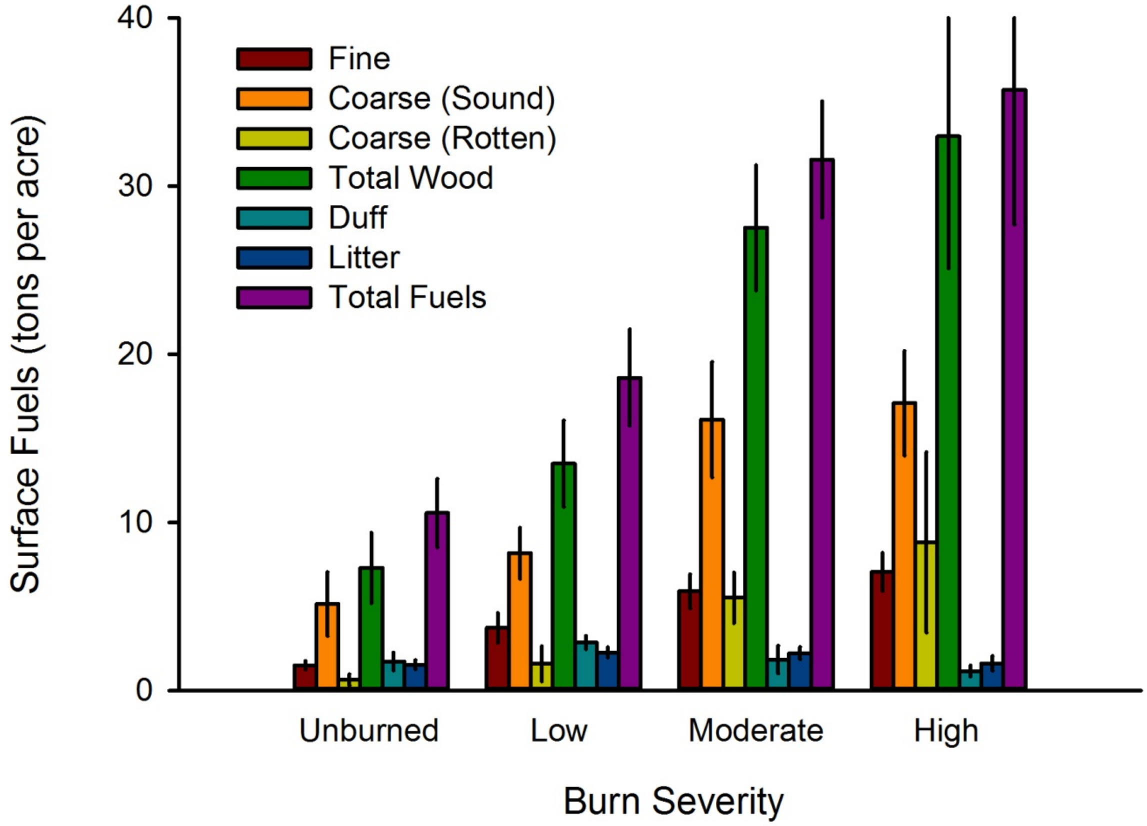


Figure 11. Differences in the composition of surface fuels in Jewel Cave National Monument among different classes of burn severity from the 2000 Jasper Fire. Bars represent means and standard errors.

Discussion

The forests in JECA in 2011 contained 7 species of trees or tall shrubs (Table 4), but were dominated by ponderosa pine, as is typical of the Black Hills region. Western serviceberry and chokecherry seedlings were common and occurred in many of the plots. Average stand density of mature trees (DBH > 15 cm) in the park was estimated at 201 stems per hectare (Table 5). Basal area across the park averaged 7.5 m^2 per hectare. These values are much lower than the 15.3 m^2 hectare historic basal areas (Figure 6; Brown and Cook 2006). This is not unexpected because the 2000 Jasper Fire burned large areas of the park and at the landscape scale the fire caused more than 50% of the trees to be lost to fire-injury (Lentile et al. 2005). Areas that experienced high severity burning in the 2000 Jasper fire had much lower basal areas than unburned areas (Figure 9). Basal areas prior to the Jasper Fires averaged between 12.9 and 24.6 m^2 per hectare (Marriot and Hartment 1986). In the short-term, such a large reduction in basal area is of moderate concern because it differs substantially from historic forests and can reduce available wildlife habitat (Table 7). However, fire is a natural driver of forest change in the Black Hills and such a mosaic of forest structure is similar to historic descriptions.

Forests in the Black Hills are generally managed to keep an initial basal area of < 14 m^2 per hectare to allow pine seedlings to establish in the understory and to maximize understory productivity to sustain periodic timber harvests (Shepperd and Battaglia 2002). About 75% of the park met this criterion (Figure 6), suggesting that seedling recruitment will not be limited by light penetration to the understory.

High ponderosa stand density and basal area can increase susceptibility to attack by mountain pine beetles (Negrón et al. 2008). Less than 5% of the park area has basal areas that are considered high enough to have an increased risk of mountain pine beetle infestation (> 27.6 m^2 per hectare) (Schmid et al. 1994). In 2011, we found no plots in the park that had evidence of mountain pine beetles, indicating a good condition (Table 7). However, in 2010, 16.2 ha area was found to be infested with mountain pine beetles and park management cut, limbed, chunked and dried the trees to kill any larvae (Stark et al. 2011). In 2011, 66 trees infested with mountain pine beetles were cut and chunked (Figure 12; R. Ohms, Physical science technician at JECA, electronic communication, 3/2012). Our survey did not find beetle infested trees and all trees the park found were greater than 27 m from our plot center (the distance for which we surveyed disturbances). Clearly, despite our survey results, mountain pine beetles are a ongoing threat to the park. The number of fading trees detected in the Black Hills from aerial surveys doubled from 22,000 acres to 44,000 acres between 2009 and 2010 (Harris and R2staff 2011) and increased to 67,000 acres in 2011 (USDA 2012).

All the plots visited had some evidence of historic fires, but severity differed (Figure 8). Fire severity was correlated with increased coarse woody fuel loads (Figure 10) and lower basal areas (Figure 9) but there were no relationships between seedling density or exotic cover and severity.

To date, JECA has had effective exotic plant management and has maintained a low cover of exotic plants (Table 7). The average cover in our plots of targeted exotics was less than 2 individuals. The most common exotic species was Canada thistle. Mullein, houndstongue, and leafy spurge were also found.

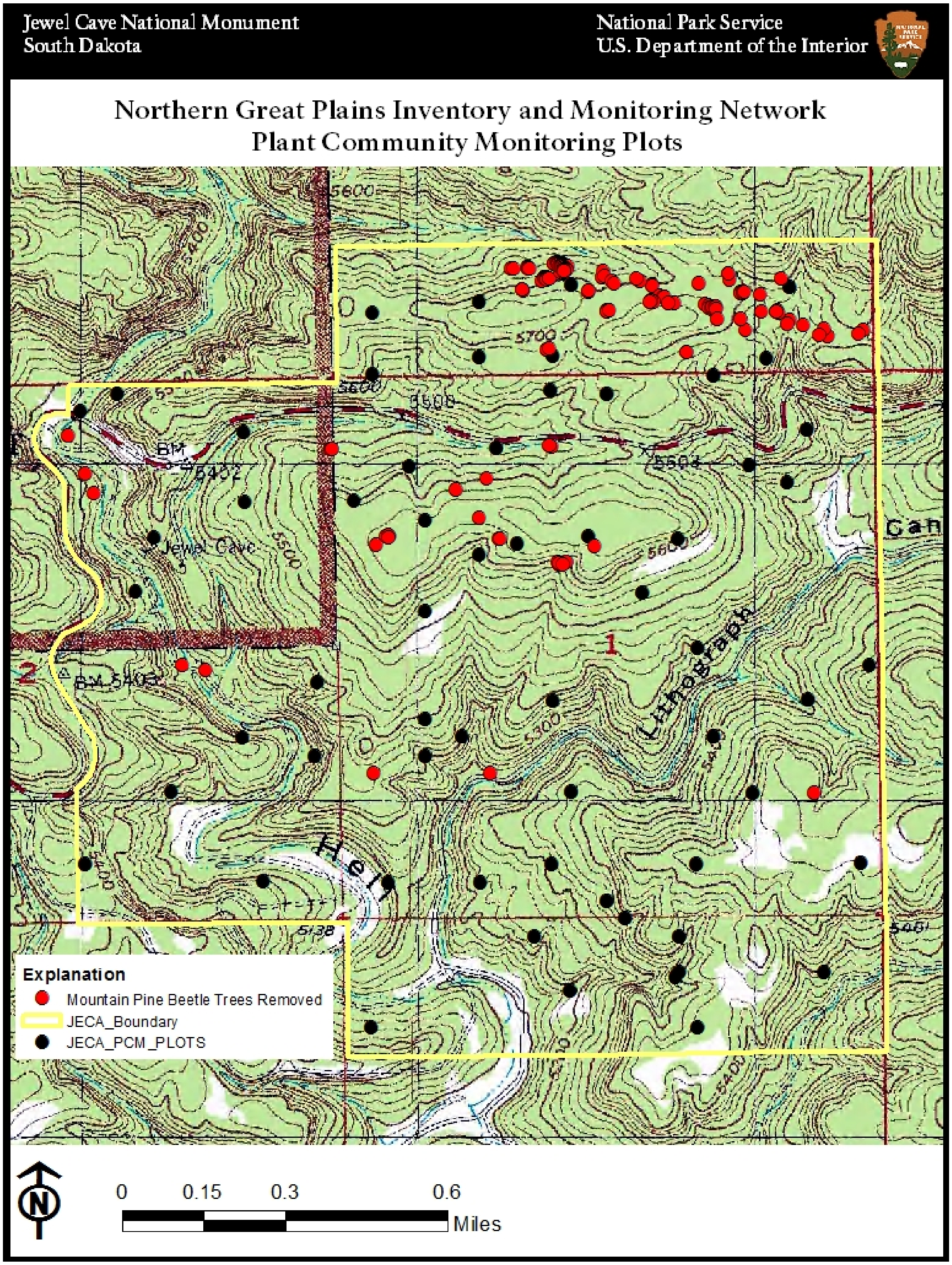


Figure 12. Map of Jewel Cave National Monument showing the location of the monitoring plots and the locations of trees that were cut and chunked because of mountain pine beetle infestations by JECA in March 2011.

Sixteen percent of JECA had densities of large ponderosa pine and snags that is consistent with old growth forest in the Black Hills (Mehl 1992). These areas were concentrated in the northern section of JECA and near the visitor center, and none were in areas of high severity burning during the 2000 Jasper Fire. Unfortunately, since we have no data on ages of these trees, we cannot confirm that these areas are old growth. Moreover, our small plot sizes (0.03 ha) may not be the most appropriate method to measure stand densities. Still, areas of old-growth may exist in JECA and this fact is consistent with other reports (Brown and Sieg 1996). The presence of old-growth forest in the park warranted a rating of good condition (Table 7); however it is unclear how this compares to historic values. It is possible that as much as 25% of the area was unlogged (Marriot and Hartment 1986), but we could not find any quantitative assessments of the area covered by old-growth forests in JECA to compare our data to. In five years, when we revisit these plots, we will be able to determine if there is a change in potential areas of old-growth forest.

In conclusion, the ponderosa pine forest that blankets JECA is an outstanding natural resource with a low abundance of exotic species and a high diversity of plants. As of 2011, overall condition of the forest community was good. The Jasper Fire in 2000 reduced forest density and basal area but patches of old growth forest remain. Of moderate concern is the large amount of coarse woody debris resulting from high tree mortality caused by the fire. Resource trends are difficult to discern because few quantitative studies of past conditions were completed but continued forest surveys will allow us to discern changes in the future.

Table 7. Natural resource condition summary table for forest structure and fuels in JECA.

Indicators of Condition[a]	Specific Measures	2011 Value (mean ± SE)	Reference Value[b]	Scale of Assessment[c]	Condition Status[d]	Trend[e]	Condition Status/Trend Symbol	Rationale
Exotic Plant Early Detection	Average cover class of exotic species (0-5)	1.4 ± 0.2	Between 0 and 3 (< 5% cover)	Park-wide	Good	Insufficient Data		To date, JECA has had effective exotic plant management and has maintained a low cover of exotic plants.
Upland Plant Communities	Forest basal area (m^2/ha)	7.5 ± 0.97	15.3 ± 2.7	Park-wide	Caution	Insufficient Data		Current forest basal area is less than and density is slightly greater than the historic range in 1900 (Brown and Cook 2006). The Jasper Fire in 2000 killed many mature trees causing a large reduction in basal area. Not unexpectedly, the trees of the current forests are smaller than those found historically.
	Overstory Density (stems/ha)	201 ± 38.9	131 ± 24.7	Park-wide	Good	Insufficient Data		
	Percent of park that meets structural definition of old growth (%)	22 ± 4.5	TBD	Park-wide	Good	Insufficient Data		A portion of the park area has forest structure that includes large trees consistent with old growth forests (Mehl 1992). Lack of data on tree age and stand-level snag density reduces the confidence of the estimate. There is little information about old growth forests in JECA, but future surveys will be able to use 2011 as a baseline reference.
Fire and Fuel Dynamics	Total fuel loads (tons/acre)	24.8 ± 2.23	Between 2 and 10	Park-wide	Caution	Insufficient Data		The current fire ecology program aims to maintain fuel loads of less than 10 tons/acre. The Jasper Fire in 2000 has led to 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 fuels is only of moderate concern.
Forest Insects and Disease	Percent of park with mountain pine beetle infestations >1 infested tree per hectare (%)	0	0	Park-wide	Good	Deteriorating		While there was no indication of mountain pine beetles in plots visited in 2011, they have increased from endemic levels to epidemic levels in many parts of the Black Hills and are continuing to spread (USDA 2012).

[a]based on the Vital Signs Framework (http://science.nature.nps.gov/im/monitor/VitalSigns.cfm); [b]Reference Value is the numeric value used in against which current values and conditions are measured, interpreted, and reported; [b]Spatial scale of inference. Scale is described as a sample size of plot-level data, park-wide, or regional; [d]Condition refers to the current status of a resource in relation to the reference value. Condition is described as good, caution, or significant concern; [e]Trend refers to the direction of change in condition of a resource. Trend is described as improving, unchanging, or deteriorating. Insufficient data is used when there are fewer than 5 years of data or the quality of the data is not appropriate for trend analyses.

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Appendix A: R code used for adjusting weights and analyzing JECA survey data

```
# File: JECA_GRTSDataAnalysisRcode_2012.r
# Purpose: JECA weight adjustment for whole park: Uses adjwgt function from spsurvey and
# then data analysis
# Programmer: Isabel Ashton
# Date: 20120202

# For complete instructions on how to start R, load the design library, etc. see:
# http://www.epa.gov/nheerl/arm/analysispages/software.htm or the Cran R site

library (spsurvey) # load spsurvey library

# Start R and set path to where input files are: change this path to your needs
setwd("N:/Monitoring/Plant_Community/JECA/ANALYSIS/Extensives")
getwd()

# Input files:
# For adjwgt: "JECA_GRTSextframe_2011.csv"
# Includes: all original design file fields
# Includes: site evaluation attributes as added during implementation of the design
# Add Target Status for each site in the frame
# Target = TS (target sampled), TO (target office), and NS (non sampled but target)
# NT = non target
# NN = not needed or evaluated
#Add a column “Resource” where all sites get “Park”

# Step one: read, QA and modify input file
# Reads in data from .csv file into SiteEvalJECA data.frame and displays field names and table
of sites by mdcaty
# Input file is described above
SiteEvalJECA <- read.csv('JECA_GRTSextframe_2011.csv')
names(SiteEvalJECA) <- tolower(names(SiteEvalJECA))
names(SiteEvalJECA)
nrow(SiteEvalJECA)
head(SiteEvalJECA)

## Create equal area coordinates for display and later variance estimation
tmp <- marinus(SiteEvalJECA$xcoord, SiteEvalJECA$ycoord)
SiteEvalJECA$xmarinus <- tmp[,'x']
SiteEvalJECA$ymarinus <- tmp[,'y']
# plot sites to visually QA the design extent and distribution
plot(SiteEvalJECA$xmarinus,SiteEvalJECA$ymarinus, pch='+')
# Step two: assign attributes used for adjwgt
```

```
#uses all park T* sites
sites1 <- !(SiteEvalJECA$status_2011 == "NN" | SiteEvalJECA$status_2011 == "NT")
sites1

#wgt is the initial weight (inverse of the sample inclusion probability) for each site
wgt1 <- SiteEvalJECA$wgt
wgt1

#wtcat is weight adjustment category name for each site = mdcaty.
wtcat1 <- SiteEvalJECA$resource
wtcat1

framesize=464 # this is the sum of the areas of the original grid cells/sample frame that the
#GRTS draw came from: 4637331 sq meters; 464 ha
names(framesize) <- c("Park")
framesize

# calls adjwgt function with all attributes as created above and adds a new field #
"adjwt2010_wholepark" to SiteEvalJECA that has the adjusted weights
# for the whole park and all years implemented to date:
SiteEvalJECA$adjwt2011_wholepark <- adjwgt(sites1, wgt1, wtcat1, framesize)
SiteEvalJECA$adjwt2011_wholepark

summary(SiteEvalJECA$adjwt2011_wholepark)
tapply(SiteEvalJECA$adjwt2011_wholepark, list(SiteEvalJECA$resource), sum)
plot(SiteEvalJECA$wgt, SiteEvalJECA$adjwt2011_wholepark, pch="+")

#outputs table with all adj weights
write.table(SiteEvalJECA,'JECA_AdjustedWeights.csv',sep=',',col.names=NA)

#Append these adjusted weights, x,y, and resource to the file with the data. The file is set up with
#all sites (including non-target & overdraws) as rows, each metric is a column.
# Missing data points should be left blank

####################
# Data Analysis
####################

# Read in Whole park data file with design, evaluation and data
JECAdata <- read.csv('JECA_Forest_2011.csv')
names(JECAdata)
nrow(JECAdata)
head(JECAdata)
table(JECAdata$panel)
```

```
# Keep only target sampled site...retain this code incase data file ever includes non TS samples

samp1 <- JECAdata$status_2011 == 'TS'
Wholesampled <- JECAdata[samp1, ]
nrow(Wholesampled)

# check to see that all Whole sites are unique

table(duplicated(Wholesampled$siteid)) # if duplicated sites check why

#sites is a data frame consisting of two variables: the first variable is site IDs, and the second
# variable is a logical vector indicating which sites to use in the analysis. If spsurvey.obj is not
# provided, then this argument is required. The default is NULL.

Wholesites <- data.frame(Wholesampled$siteid, Wholesampled$status_2011 == 'TS')
names(Wholesites) <- c('siteID','Use')
Wholesites

# design: a data frame consisting of design variables.
# repeat of code from SiteEval code, must be run in same session

# Whole:

Wholedesign <- data.frame(siteID=Wholesampled$siteid,
                          wgt=Wholesampled$wgt_final,
                          xcoord=Wholesampled$xmarinus,
                          ycoord=Wholesampled$ymarinus,
                          stratum=Wholesampled$resource)


# data.cont: a data frame of continuous response variables. The first variable is site IDs.
# Subsequent variables are response variables. If psurvey.obj is not provided, then this argument
# is required. The default is NULL.

Wholedata.cont <- data.frame(siteID=Wholesampled$siteid,
          Wholesampled[,c
( "OneHr_tonacre","TenHr_tonacre",
"HunHr_tonacre","FineWood_tonacre","ThSound_tonacre", "ThRotten_tonacre",
"TotalCoarse_tonacre",
"TotalWood_tonacre","Duff_tonacre","Litter_tonacre","TotalFuels_tonacre","DuffDep_in","Litt
Dep_in","TotDep_in",
"ALL_Snags_stemsha" , "ALL_TreePole_stemsha" , "TotalBasal_m2ha" ,
"PIPO_TreesPoles_stemsha", "PIPO_Snag_stemsha" , "PIPO_BasalArea_m2ha" ,
"AMAL2_Seed_stemsha" , "PIPO_Sap_stemsha" ,
```

```
"PIPO_Seed_stemsha","PRVIM_Seed_stemsha" , "PIPO_Tree_stemsha" ,
"PIPO_Pole_stemsha" ,"TargetSp_Max_Cover" ,"ALL_Seed_stemsha" )])

#data.cat: a data frame of categorical response variables. The first variable is site IDs.


Wholedata.cat <- data.frame(siteID=Wholesampled$siteid,
                 Wholesampled[,c ("Wfire_Disturbance")])

#subpops: a data frame describing sets of populations and subpopulations for which estimates
# will be calculated. The first variable is site IDs. Each subsequent variable identifies a Type of
# population, where the variable name is used to identify Type. A Type variable identifies
# each site with one of the subpopulations of that Type. If spsurvey.obj is not provided, then this
# argument is required. The default is NULL.

Wholesubpop <- data.frame(siteID=Wholesampled$siteid, allpark=Wholesampled$resource)
#allpark field has "allpark" in all cases
names(Wholesubpop) <- c('siteID','allpark')
Wholesubpop

popsize_whole <- list(allpark=c(allpark=464)) #used frame size for JECA

Allpark_continuousVars <- cont.analysis (sites = Wholesites, subpop=Wholesubpop,
design=Wholedesign, data.cont=Wholedata.cont, popsize=popsize_whole, vartype="Local",
conf=95, pctval=c(5,10,25,50,75,90,95))

#write output
write.table(Allpark_continuousVars$CDF,'JECA_continuousVars.CDF_2012.csv',sep =
",",col.names=NA)
write.table(Allpark_continuousVars$Pct,'JECA_continuousVars.Pct_2012.csv',sep =
",",col.names=NA)

#rough CDF plots of all variables in pdf file
cont.cdfplot("JECA_continuousCDFs_2012.pdf", Allpark_continuousVars$CDF, ylbl.r="Area
(hectares)")

Allpark_catVars <- cat.analysis(sites = Wholesites, subpop=Wholesubpop, design=Wholedesign,
data.cat=Wholedata.cat, popsize=popsize_whole, vartype="Local", conf=95)

#write output
write.table(Allpark_catVars, file = "JECA_catVars_2012.csv", sep = ",",col.names=NA)
```

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