National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Forest Structure and Fuel Loads at Wind Cave National Park

2012 Status Report

Natural Resource Technical Report NPS/NGPN/NRTR—2013/776

Corrections:
12/20/2017 Errors in the database structure were found that likely resulted in over estimations of mature tree density (Table 4). Please use caution when interpreting these results.

ON THE COVER
A view ponderosa woodlands at Wind Cave National Park, 2012
Photograph by: NGPN, NPS

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Isabel W. Ashton[1]
Michael Prowatzke[1]
Stephen K. Wilson[1]
Phil Graeve[2]
Dan Swanson[2]

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

[2]National Park Service
Fire Ecology-Northern Great Plains Park Group
26611 U.S. Hwy 385
Hot Springs, SD 57747

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Executive Summary

The Northern Great Plains Inventory & Monitoring Network and the Northern Great Plains Fire Ecology Program surveyed 90 forested plots in Wind Cave National Park (WICA) in 2012. This effort will be repeated in 2017 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, but for the park as a whole. In this report, we provide a summary of our results from sampling in 2012.

The ponderosa pine forest that covers portions of WICA is an outstanding natural resource with a low abundance of exotic species and a high diversity of native plant species. As of 2012, overall condition of the forest community was good. Mountain pine beetles and exotic species are currently in low abundance within the park but both are expected to increase in future years, causing some concern to park managers. The 2011 Addition to WICA shows slight variations in forest structure compared to the area within the 2010 boundary. Forests within the 2011 Addition are characterized by more Rocky Mountain juniper, thinner forests, less grazing pressure, and fewer exotics species. A trend in forest condition is difficult to discern because few quantitative studies of past conditions were completed. Continued forest monitoring 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 WICA for providing logistical and field support. The 2012 NGPN vegetation and Fire Effects field crew collected all the data included in this report. Data presented in this report were collected by Gretchen Addington, Isabel Ashton, Lauren Baur, Phil Graeve, Valena Hoffman, Daina Jackson, Ryan Manuel, Timothy Pine, Dan Swanson, Mike Prowatzke, Sarah Wakamiya and Ellery Watson.

Introduction

The Black Hills contain 1.5 million hectares (ha) of discontinuous ponderosa pine (*Pinus ponderosa*) forest surrounded by the prairies of western South Dakota and eastern Wyoming. The Black Hills are a unique ecosystem composed of plant species and communities 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 the ponderosa pine forests 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 frequency and intensity of disturbances and drought stress (Allen et al. 2010). In recent years, mountain pine beetle (*Dendroctonus ponderosae*) outbreaks have been of particular note because they are increasing throughout the Black Hills and have caused 100% mortality of ponderosa pines in some areas (Hocking et al. 2010).

Wind Cave National Park (WICA) is located in the southeastern foothills of the Black Hills. Its purpose is to protect the unique Wind Cave resources and preserve and enhance the native plants and wildlife, while providing for the enjoyment of the public. The 13,699 ha of WICA are a mosaic of ponderosa woodlands and mixed-grass prairie (Figure 1), with approximately 30% covered by ponderosa pine woodlands (Cogan et al. 1999). Contiguous ponderosa pine forest is concentrated in the west and northwest of the park.

Figure 1. Wind Cave National Park is characterized by a mosaic of ponderosa pine forest and mixed-grass prairie.

Historically, smaller fires have maintained a relatively stable amount of prairie and woodland in this area of the southern Black Hills (Shinneman and Baker 1997). During the period of 1500 to early 1900, the average number of years between wide-spread fires in the area was estimated at 10-12 years (Brown and Sieg 1999). However, post-settlement times have been quite different. After the early 1900s, fires were much less common, and when they did occur they were smaller in area (Brown and Sieg 1999). At least 82 lightning-caused fires and 24 human-caused fires were suppressed in the park between 1930 and 1987 (Bone and Klukas 1988). Major fires (wildfire and prescribed) have affected WICA in 1964, 1988, 1991, and 2000, burning 4,732 ha within the park boundary, approximately 1/3 of the park's area (USDA 2006). In order to restore the ecological benefits of fire, the NPS implemented prescribed burning in WICA in 1973, when it was largely confined to small research fires (Bone and Klukas 1988). Prescribed burn efforts have increased over time, including the 2010 American Elk Fire which burned 1,396 ha, making it the largest prescribed fire in the history of WICA (Swanson 2010).

Scientifically credible information on the current status and long-term trends of the composition, structure, and function of the forests in WICA is required for sound management. In 2012, the National Park Service Northern Great Plains Inventory & Monitoring Network (NGPN) and the Northern Great Plains Fire Ecology Program (FireEP) sampled 90 forested sites in WICA 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 WICA's forest by sampling and characterizing forest structure, exotic plant prevalence, and fire and fuel dynamics (Gitzen et al. 2010). The long-term monitoring objectives are to: (1) determine park-wide status (at 5-year intervals) and long-term trends of fuel loads and tree density by species, height class, and diameter class, 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. 2012). In this report, we present the results from 2012, our first year of monitoring, which will provide a baseline against which to compare the results of our future efforts.

Methods

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

Sample design

We implemented a protocol to monitor forest structure and fuel loads in WICA using a spatially balanced probability survey design (Generalized Random Tessellation Stratified (GRTS); Stevens and Olsen 2003, 2004). For WICA, we defined the target population as vegetation in the entire park using the 2010 boundary. A 54 x 54 m grid was overlaid on the park to create the sample frame with sampling locations at the center of a random subset of grid cells. We excluded the following areas from the sample frame: administrative areas, bison holding 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 80 randomly located sites (Figure 2). In 2011, WICA acquired the 2,246 ha Casey property. We applied the same process as above in the new property to select 10 randomly located sites. We refer to this area as the “2011 Addition”.

The sample frame for the woody plots in WICA was the whole park because most of the park provides suitable habitat for tree growth, particularly in the absence of fire. However, trees and tall shrubs currently do not occur or are very sparse in a substantial portion of the park. When we visited the 90 randomly located plots, the first step was to determine whether it was appropriate to conduct forest sampling in that selected location. If we found no trees, tall shrubs, or woody fuels within 38 m of the plot center, we designated the site as “dormant” and did not sample at that site. We replaced these dormant sites with the next site drawn using the GRTS design. In 2012, we visited a total of 122 sites (32 were designated as dormant) to reach our target of 90 forested sites. Of the 80 sites within the 2010 boundary, only one plot was greater than 250 m from an area that Cogan et al. (1999) mapped as ponderosa pine forest and woodland, deciduous forest and woodland, tall shrubland, or areas with burned ponderosa pine trees.

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 WICA forests (minus excluded areas). When these sites are revisited in 2017 and every five years thereafter, we will be able report on the change in the condition of WICA forests over time.

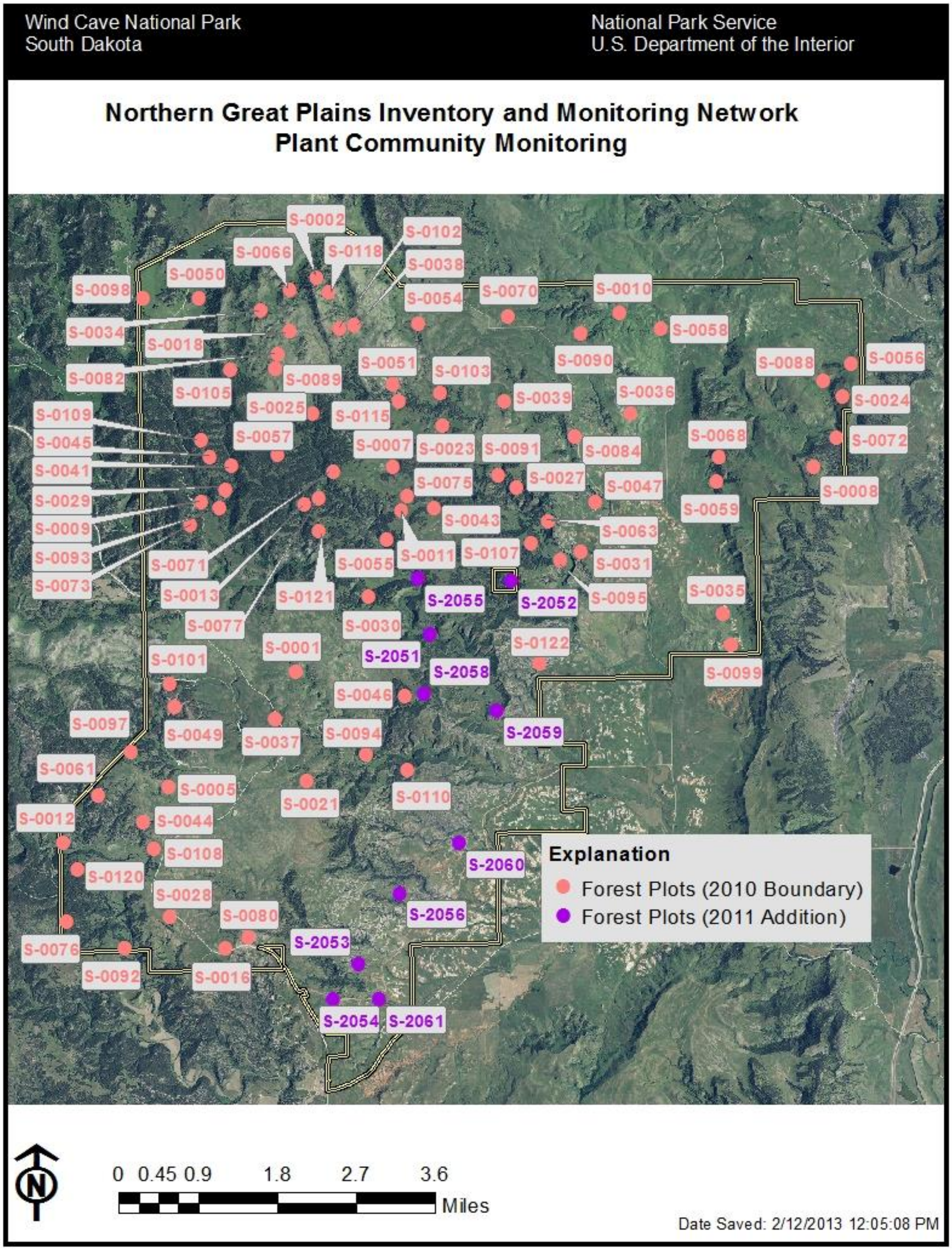

Figure 2. Map of Wind Cave National Park and the location of 90 forest monitoring plots. Ten plots are in the 2011 Addition to the park (purple), and 80 plots fall within the 2010 Boundary (pink).

Plot layout and sampling

At each of 90 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 2012. Tree and targeted tall shrub species with diameter at breast height (DBH, where breast height = 137 cm) < 2.54 cm were tallied by species and classified as seedlings or saplings. Seedlings and saplings are differentiated by height, where saplings are > 137 cm. For all poles (2.54 cm ≤ DBH ≤ 15 cm), DBH and status (live or dead) were recorded by species. 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 (30.48 m) transects centered at the center of the plot following Brown's Line methods (Brown 1974, Brown et al. 1982).

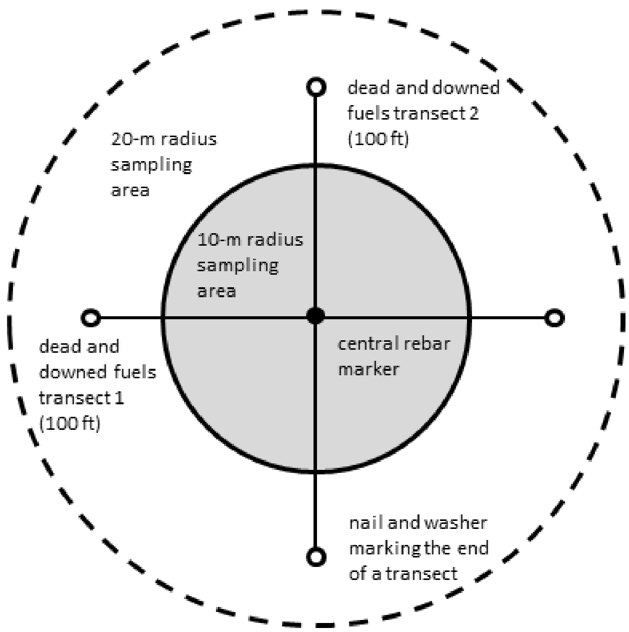

Figure 3. Long-term monitoring plot used for sampling forest structure and fuels in Wind Cave National Park.

In a subset of 7 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 7 sites, trees were mapped and tagged and will be revisited two of every five years on a rotating schedule. The larger plot size and greater sampling frequency are consistent with the more comprehensive NGPN vegetation monitoring protocol (Symstad et al. 2012). In cases where we found fewer than 5 trees or poles within the sampling area, we extended the radius to 20-m and recorded all trees within the larger area.

At all plots, we surveyed the site area defined by 15.5 m (50 ft) radius fuel transects for common disturbances and exotic species of management interest (Table 1). Common disturbances included animal trails, bison wallows, prairie dogs, and fire. The type, severity, and approximate area of the disturbances were recorded. This method was meant as a quick assessment of disturbance and typically took no more than 15 minutes in the field. Thus, the dataset focuses on large scale and obvious disturbances. For each target species that was present at a site, an abundance class on a scale from 1 to 5 was assigned, 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 reported 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 concern at Wind Cave National Park that were surveyed for during the 2012 field season.

Scientific Name	Common Name
Bromus japonicus	Japanese brome
Bromus tectorum	cheatgrass
Carduus nutans	musk thistle
Centaurea stoebe	spotted knapweed
Cirsium arvense	Canada thistle
Cirsium vulgare	bull thistle
Convolvulus arvensis	field bindweed
Cynoglossum officinale	houndstongue
Elaeagnus angustifolia	Russian olive
Euphorbia esula	leafy spurge
Hyoscyamus niger	black henbane
Hypericum perforatum	common St. Johnswort
Leucanthemum vulgare	oxeye daisy
Linaria dalmatica	Dalmatian toadflax
Linaria vulgaris	yellow toadflax
Marrubium vulgare	horehound
Onopordum acanthium	Scotch thistle
Potentilla recta	sulphur cinquefoil
Rhaponticum repens	Russian knapweed
Salsola tragus	Russian thistle
Sonchus arvensis	perennial sowthistle
Tamarix spp.	tamarisk
Tanacetum vulgare	common tansy
Verbascum thapsus	common mullein

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. Plant species were identified in the field to species level and not to lower taxonomic groupings (e.g., subspecies or variety). 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. Fire Severity data for the American Elk Fire 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. These burn classes were further refined to unburned, low, medium and high severity using field-based Composite Burn Index monitoring performed by the Northern Great Plains FireEP.

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. 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 2011 (Komp et al. 2011).

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).

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

We used a probability-based survey design that allows for unbiased inference from sampled sites (a selection of 90 grid cells) to unsampled elements of the population of interest (the entire sample frame or the set of grid cells that cover WICA 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 WICA included in this discrete sample frame. For ease of interpretation, we hereafter will refer to these means as representing the park-wide status of either the forests in the WICA 2010 Boundary or the 2011 Addition, with an understanding that they do not represent administrative areas, roads, or other areas excluded from the sample frame.

Forest structure and composition varied across WICA in 2012 (Figure 4). The plots we visited included open ponderosa woodlands with few trees, dense ponderosa forest, juniper woodlands, and woody draws with a high density of deciduous shrubs. Despite the variation in forest structure, we encountered very few tree and shrub species. In total, we measured the density of 8 tree and tall shrub species at 90 plots in WICA (Table 3). Ponderosa pine was the most common mature tree found, but we also encountered Rocky Mountain juniper and American elm. Rocky Mountain juniper was more abundant in the 2011 Addition than in the main portion of the park; there were poles or mature junipers occurring in 8 of 10 plots vs. 10 of 80 plots in the 2010 Boundary. We found a larger diversity of seedlings and saplings, including many deciduous species, throughout the park, but ponderosa pine was still the most common (Table 3).

Table 3. Tree and tall shrub species occurrence in 2012 sampling of 90 plots in Wind Cave National Park.

Species Name	Common Name	Number of plots with mature or dead trees (DBH > 15cm)	Number of plots with poles (2.5cm ≤ DBH ≤ 15cm)	Number of plots with saplings (DBH < 2.5cm)	Number of plots with seedlings (height < 137cm)
Pinus ponderosa	ponderosa pine	69	42	27	59
Juniperus scopulorum	Rocky Mountain juniper	14	10	5	14
Prunus virginiana	chokecherry	-	-	4	14
Ulmus americana	American elm	1	1	2	6
Amelanchier alnifolia	western serviceberry	-	-	-	2
Celtis occidentalis	common hackberry	-	-	-	1
Fraxinus pennsylvanica	green ash	-	-	-	1
Prunus americana	American plum	-	-	-	1

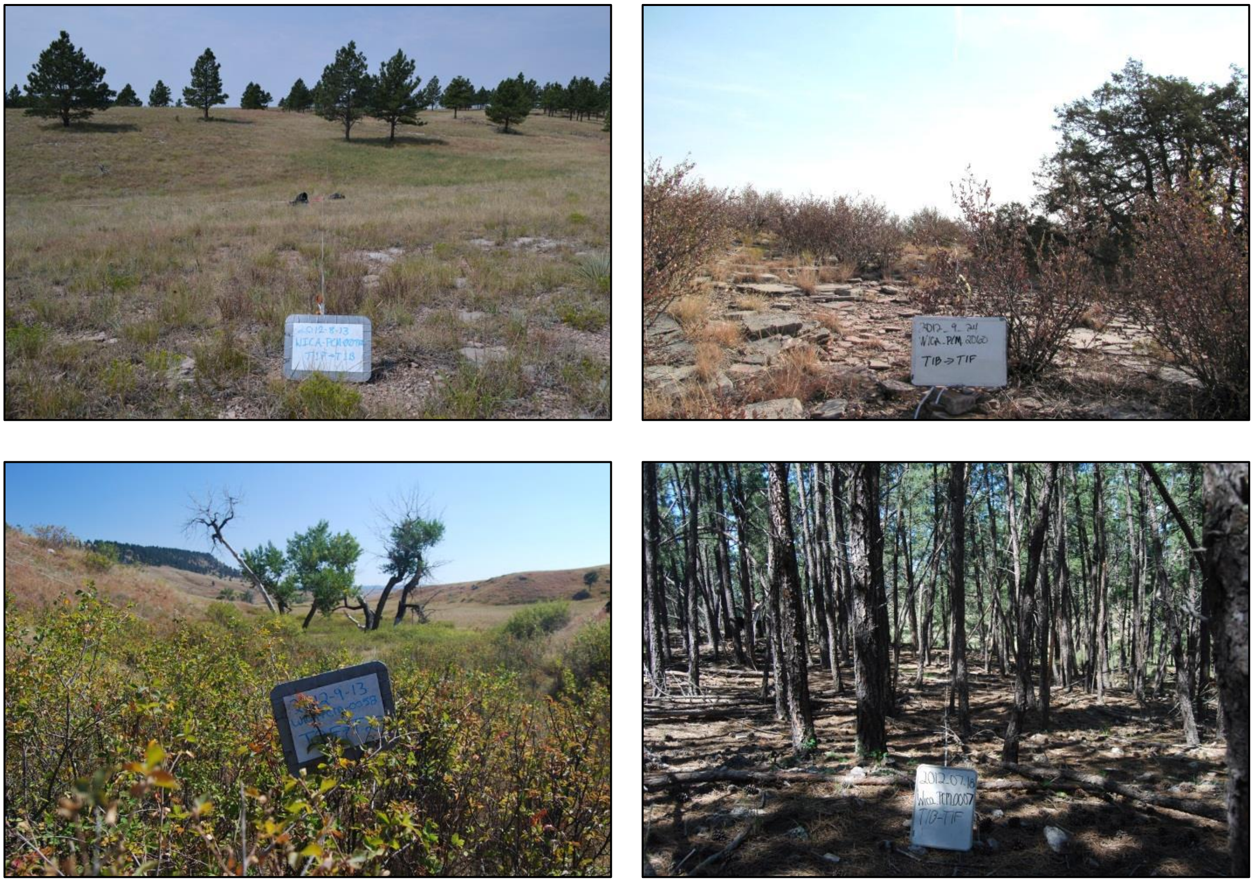

Figure 4. Four long-term forest monitoring plots at Wind Cave National Park that illustrate the diversity of forest structure present in the park. Plot PCM_0080 (top left) is open ponderosa pine woodland, plot PCM_2060 (top right) is an open juniper woodland, PCM_0058 (bottom left) is in a woody draw that hosts chokecherries and other deciduous shrubs, and PCM_0007 (bottom right) is a closed canopy ponderosa pine forest with a high density of younger trees.

Park-wide status: forest structure

Ponderosa pine basal areas in the two WICA properties were similar to one another (Table 4). The forests in the 2010 Boundary averaged 14 m^2 per ha (61 ft^2 per acre) while those in the 2011 Addition averaged 10 m^2 per ha (44 ft^2 per acre). We estimated stand density for ponderosa pine trees to be 163 stems per hectare (66 stems per acre) within the 2010 Boundary and 90 stems per hectare (36 stems per acre) in the 2011 Addition (Table 4).

Tree and tall shrub seedling densities were highly variable across plots and ranged from 0 to 74,952 stems per hectare (0 to 30,356 stems per acre). The plot with the highest density had an abundance of chokecherry seedlings (Figure 4, lower left panel). Size class distribution differed between the 2010 Boundary and the 2011 Addition (Figure 6). The 2011 Addition tended to have fewer seedlings and a greater number of poles than plots within the 2010 Boundary. The 2011 Addition also had a lower density of ponderosa snags (Table 5).

Table 4. Tree basal area and density by size class for ponderosa pine, Rocky Mountain juniper, and deciduous trees in Wind Cave. Values are estimated means and standard errors.

Species	Indicator	2010 Boundary	2011 Addition
Ponderosa Pine	Basal Area (m^2/ ha)	14.1 ± 1.6	10 ± 3.2
	Tree Density (stems/ha)	163 ± 19.9	90 ± 40.9
	Pole Density (stems/ha)	332 ± 64.3	690 ± 514.1
	Sapling Density (stems/ha)	233 ± 59.5	353 ± 286
	Seedling Density (stems/ha)	3630 ± 748.2	1970 ± 842
	Snag Density (stems/ha)	29 ± 8.7	6 ± 5.4
Rocky Mountain Juniper	Tree Density (stems/ha)	4 ± 1.9	55 ±15.1
	Pole Density (stems/ha)	23 ± 10.9	152 ± 76.5
	Sapling Density (stems/ha)	1 ± 0.5	25 ± 14.6
	Seedling Density (stems/ha)	58 ± 24.6	255 ± 173.8
Deciduous Tree and Tall Shrubs	Tree Density (stems/ha)	0	3 ± 2.9
	Pole Density (stems/ha)	0	13 ± 11.4
	Sapling Density (stems/ha)	1 ± 0.7	436 ± 261.6
	Seedling Density (stems/ha)	1334 ± 826.5	1553 ± 698

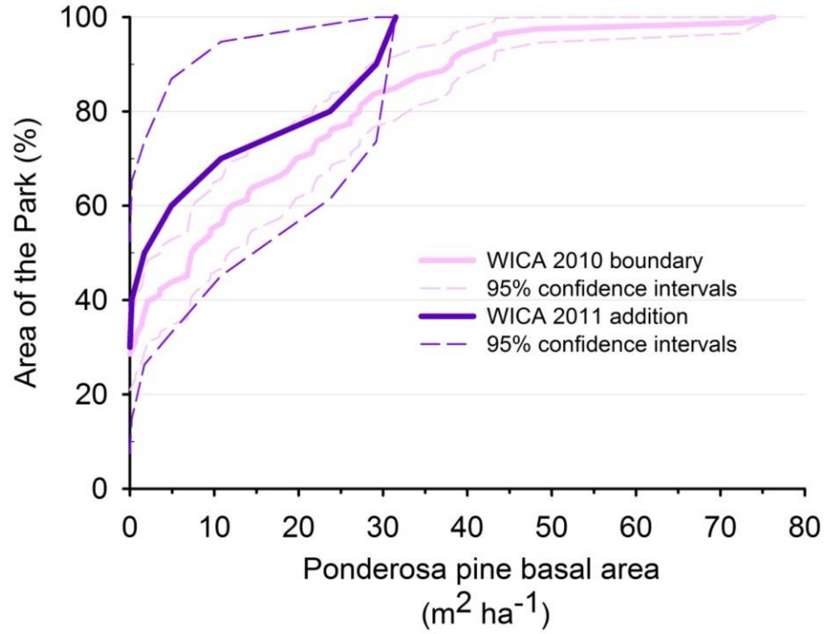

Figure 5. Cumulative distribution function of ponderosa pine basal area in Wind Cave National Park. The pink line indicates the estimated distribution from the 2010 boundary and the purple indicates the estimated distribution in the 2011 addition. The dashed lines are upper and lower 95% confidence intervals.

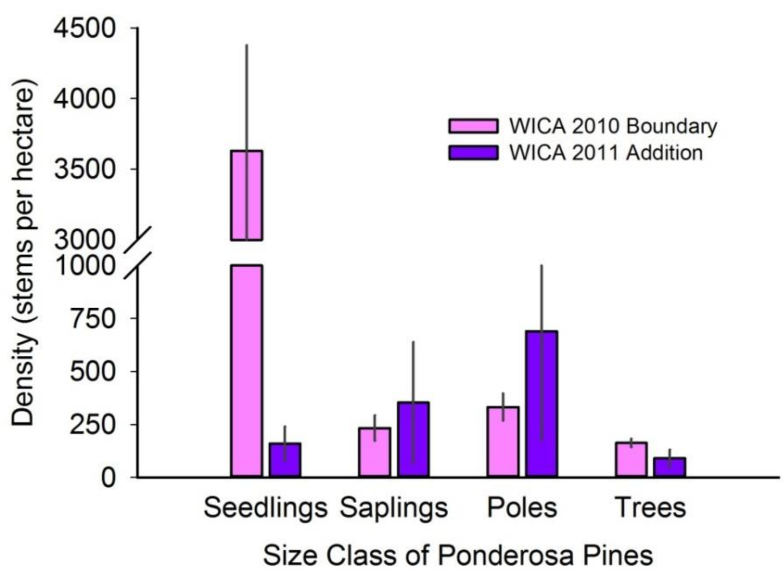

Figure 6. Size class distribution of WICA forests from the 2012 survey. Bars represent means ± standard errors, n = 80 for the plots within the 2010 boundary (pink) and n=10 for the plots within the 2011 Addition (purple).

Park-wide status: surface fuels

Surface fuels were measured at 75 plots in WICA. Fifteen plots did not have sufficient fuels to warrant measurement (e.g., there were no woody debris, pine needles or cones, or juniper needles crossing the two fuels transects). Total fuel loads were similar in the 2011 Addition and the 2010 Boundary (Figure 7) at 6.9 ± 2.3 tons per acre and 9.4 ± 0.9 tons per acre, respectively (note that standard practice for fire management is to report fuels data in English units). The 2011 Addition also had slightly lower total litter and duff depths (0.5 ± 0.14 in) than the park within the 2010 Boundary (0.7 ± 0.05). In both areas, duff and litter made up the majority of total surface fuels (Figure 7). Coarse woody debris totaled 0.9 ± 0.5 tons per acre in the 2011 Addition and 2.4 ± 0.7 tons per acre within the 2010 Boundary.

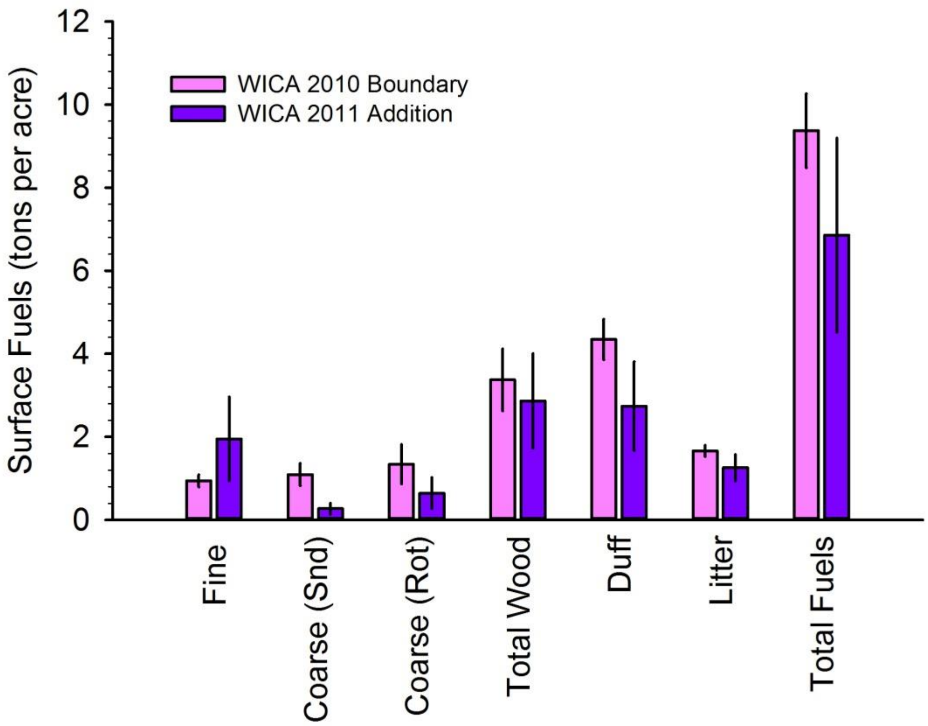

Figure 7. Surface fuels at Wind Cave National Park in 2012. Bars represent means ± standard errors, n = 80 for the plots within the 2010 boundary (pink) and n=10 for the plots within the 2011 Addition. Fine includes 1 to 100 hour fuels, coarse sound (Snd) and rotten (Rot) refers to 1000 hour fuels.

Park-wide status: disturbance

We documented 9 of the targeted exotic species in the park (Table 5). Common mullein and Japanese brome were found in the greatest number of plots. In general, there were fewer exotics found in the 2011 Addition than within the 2010 Boundary. The only plot with target species in the 2011 Addition was PCM_2055. This plot was in the northwestern corner of the new property (Figure 1) but was close to a utility road used to access the power-line. At the scale of the whole park, relative cover of exotic species was low with the maximum cover class averaging less than 1 in the 2011 Addition and 1.3 ± 0.12 in the 2010 Boundary, which is equivalent to only one or two individuals in the plot area.

Table 5. Targeted exotic species found in the 90 forested plots in WICA in 2012.

Scientific Name	Common Name	WICA 2010 Boundary (number of plots where species was present out of 80 possible)	WICA 2011 Addition (number of plots where species was present out of 10 possible)
Bromus japonicus	Japanese brome	20	1
Bromus tectorum	cheatgrass	10	0
Cirsium arvense	Canada thistle	17	0
Cirsium vulgare	bull thistle	3	0
Convolvulus arvensis	field bindweed	2	0
Cynoglossum officinale	houndstongue	9	1
Marrubium vulgare	horehound	7	1
Salsola tragus	Russian thistle	1	0
Verbascum thapsus	common mullein	26	0

At each plot, the forest was surveyed for evidence of natural and human disturbance, and the approximate area of the disturbance was recorded. The survey of disturbance was meant to be a quick assessment and identify the most obvious disturbances. In 2012, the most common disturbances recorded were signs of ungulate activity including animal trails, bison wallows, elk rubs, and animal beds. These were found at 39 of 90 plots. Recent evidence of fire was found at 34 plots, and grazing was apparent at 20 plots. Other disturbances were less common and included prairie dog towns and small mammal disturbance, erosion, off-road vehicle use, and trash. We did not find any evidence of mountain pine beetle activity. Disturbances were less frequent in the 2011 Addition (Table 6) than within the 2010 Boundary. We estimate that 40% of the main portion of the park has evidence of fire compared to 10% in the Addition. Ungulate activity is similar across the two properties, but grazing pressure seems to be higher within the 2010 Boundary (Table 6).

Table 6. Percent area of Wind Cave National Park with evidence of fire, ungulate activity, and grazing in 2012. Values represent means ± standard errors.

Property	Evidence of fire (% of park area)	Signs of Ungulate Activity (% of park area)	Evidence of grazing (% of park area)
2010 Boundary	40 ± 4.1	45 ± 4.5	25 ± 4.0
2011 Addition	10 ± 8.8	30 ± 13.7	0

We explored how disturbance may affect forest structure, surface fuels, and exotic target species presence and cover by comparing plots with and without evidence of disturbance. At WICA, we found no differences in forest structure, fuels, or exotics among plots with ungulate activity and those without. We found no evidence that grazing affected forest structure or cover of exotic species. However, we did find that total fuels were lower in grazed plots than ungrazed plots. The difference was due to a reduction in duff in plots with grazing ($F_{1, 88}$=5.5, P=0.021).

We found evidence that forest structure, surface fuels, and exotic species cover are related to fire history in WICA. Ponderosa pine tree and snag density tended to be higher in the 34 plots where we recorded evidence of fire than in plots with no evidence of fire (trees: $F_{1, 88}$=2.8, P=0.097; snags: $F_{1, 88}$=3.7, P=0.058). This could be a sampling artifact caused by the field crew identifying past fires in forests more readily than in grasslands (e.g. burn scares are more obvious on trees). The density of ponderosa poles tended to be reduced in burned areas ($F_{1, 88}$=2.7, P=0.099). Overall, there was a trend of higher basal areas in burned areas than areas without evidence of fire ($F_{1, 88}$=3.1, P=0.081). The higher ponderosa densities and basal area in burned areas is surprising, but may result from the large number of burned plots that fall in the more forested areas of the park. Total woody fuel loads were higher in burned plots ($F_{1, 88}$=7.1, P=0.009). This difference was driven by coarse woody debris (sound and rotten thousand hour fuels). The maximum cover of target exotic species ($F_{1, 88}$=9.3, P=0.003) and the number of target exotic species present ($F_{1, 88}$=18.0, P<0.0001) was greater in plots that had evidence of fire.

Of the 34 plots where we found evidence of fire in 2012, 15 fell within the bounds of the American Elk Fire perimeter (Figure 8). Only 1 of the plots, PCM_0057, fell within the area of high burn severity, while 4 plots were in areas of moderate severity, and the remaining 2/3 were in areas of low severity (7 plots) or unburned to low severity (3 plots), as determined by the National Burn Severity Project (NPS-USGS 2012) and field-based Composite Burn Index monitoring performed by the Northern Great Plains FireEP. Plots PCM-0013 and PCM-0057 (Figure 9) each recorded more target invasive species (6) than any other plots in the park; both of these were within areas of moderate to high burn severity.

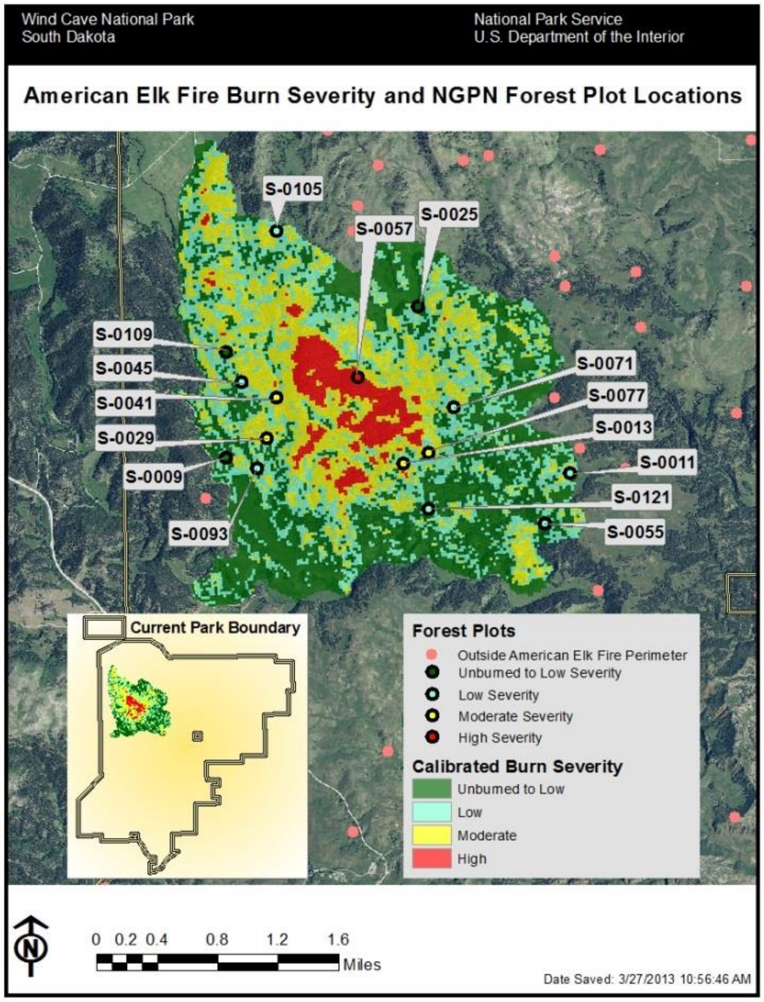

Figure 8. Map of American Elk prescribed fire burn severity and NGPN forest plots.

Figure 9. Long-term monitoring plot PCM_0057 in Wind Cave National Park was within the perimeter of the American Elk Fire in an area of high fire severity.

Discussion

The forests in WICA in 2011 contained 8 species of trees or tall shrubs (Table 3), but were dominated by ponderosa pine, as is typical of the Black Hills region. Average stand density and basal areas were similar to the reconstructed historic forest density and basal area for the southern Black Hills in 1900 (Table 7; Brown and Cook 2006). Forests within the 2010 Boundary are slightly denser and forests in the 2011 Addition are sparser than the estimated forest density from 1900 (131 stems per hectare; Brown and Cook 2006). However, the park-wide estimates include forested areas and more open grassland sites on the edge of woodlands. Only 46 of the 80 monitoring plots in the 2010 Boundary and 4 of the 10 plots in the 2011 Boundary had large ponderosa pines present (≥30 cm DBH). Accounting for this in the analysis and using only the plots with the larger trees provides a more direct comparison to the Brown and Cook (2006) historic density estimates. We found the plots with the larger trees had an average density of 231 ± 28 stems per hectare and an average basal area of 21.8 ± 2.5 m^2 per ha. This suggests that the areas with older trees in WICA are denser than forests during the pre-settlement period.

Forests in the Black Hills National Forest 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). Between 60 and 70% of the park met this criterion (Figure 5), suggesting that seedling recruitment will not be limited by reduced light penetration to the understory. Not surprisingly, seedling establishment varied across the park. While many of the plots exhibiting high seedling density were near the “core” forest in the northwest quadrant of the park, there were some outlying areas in the southwest and the eastern edges of the park that show significant potential for forest encroachment (Figure 10). While differences between areas burned in the American Elk Fire and unburned areas weren’t statistically significant, it is interesting to note that the second and third highest plots by seedling density lie within areas of low and moderate severity burns, indicating that seedling establishment was not suppressed throughout the entire burned area.

Recruitment to pole class (2.54 cm ≤ DBH ≤ 15 cm) shows a different, more defined spatial distribution. In general, the areas with highest pole density appear as a “wave” on the eastern front of the “core” forest, while areas in the eastern canyons of the park also show strong signs of recruitment (Figure 10). Taken together with the seedling density data, continued forest encroachment at the eastern edge of the “core” forest as well as in the area of the eastern canyons could be expected if not checked by fire or other disturbance. The southwest corner of the park may be experiencing this same trend based on seedling density; however pole recruitment is still low relative to other areas of the park.

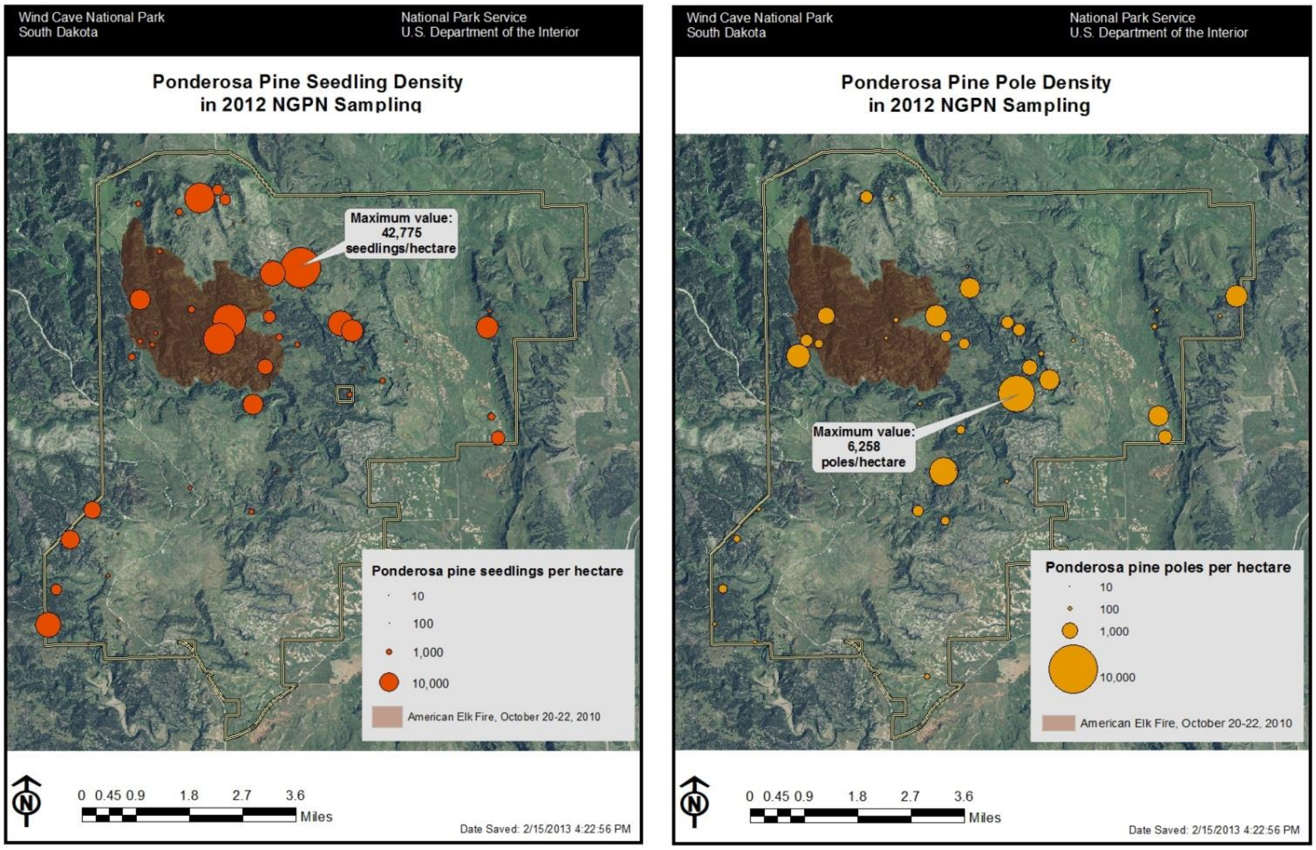

Figure 10. Ponderosa pine seedling and pole density in 2012 NGPN sampling. Sizes of dots are proportional to density, but scale differs between maps.

High ponderosa stand density and basal area can increase susceptibility to attack by mountain pine beetles (Negrón et al. 2008). Approximately 15% of the park area has basal areas that are considered high enough to have an increased risk of mountain pine beetle infestation based on density (> 27.6 m^2 per hectare) (Schmid et al. 1994). Using vegetation map classes, WICA considers only 2.5% of the park to be at high risk of mountain pine beetle infestation but an additional 15% is at moderate risk (WICA 2012 MPB Risk Assessment and Response, *unpublished*). Pine beetles are endemic to the park, but when there is greater than 1 infested tree per hectare infestations are considered to be at epidemic levels (Schmid et al. 2007). In 2012, we found no plots in the park that had evidence of mountain pine beetles. Despite our survey results, mountain pine beetles may be an increasing management concern to the park in areas where maintaining ponderosa pine is desired or where affected trees may become hazardous (e.g. around the Visitor Center). 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). Mountain pine beetles were active on 31,000 acres in 2012 (USDA 2013). According to aerial surveys, only 11.68 acres of forest within WICA had current year tree mortality (USDA 2013). The areas affected are most apparent in the northwest corner of the park (Figure 11). None of NGPN's 90 plots intersected infested areas as identified by the Forest Service overflights.

Downed wood and surface fuels provide foraging habitat and refugia for small wildlife species, as well as substrate for mosses and fungi. Downed wood also sometimes provide "nursery" logs for vascular plant establishment. However, when surface fuels are too abundant in a forest they can increase the risk of high intensity fires. Ideally, a healthy forest will have a mosaic of conditions that range from open areas with low fuel loads to denser areas. The Northern Great Plains FireEP has developed a management target for surface fuels: the goal is to keep a range between 2 and 10 tons per acre within the Black Hills parks. In 2012, we found that surface fuels at WICA fell within this management target (Table 7). Brown and colleagues (2003) defined an optimum range of coarse woody debris for warm and dry ponderosa forests of 5 to 20 tons per acre. This optimum range of coarse woody debris is thought to provide an acceptable risk of fire hazard while still providing benefit to wildlife and soils. Within WICA, coarse woody debris was less than 3 tons per acre (coarse woody debris was 2.4 tons per acre when only plots with mature ponderosa are included in the analysis). This suggests there is a low fire hazard but a lower than optimal benefit to forest soils and wildlife.

To date, WICA 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. While their cover was generally very low, target exotic species were common throughout the park. The most common exotic species were mullein, Japanese brome, and Canada thistle (Table 5). Areas where there was evidence of fire had more exotic target species present, and covers were typically higher. This suggests that exotic removal efforts focusing on recently burned areas might be one effective way to reduce the spread of exotic species. At the present time, exotic species are not common in the 2011 Addition (there was only one plot with exotic target species present). While doing field work, we noticed that that most of the exotic species in the 2011 Addition were concentrated along roadsides, power lines, and in the large underground pipeline disturbance created in 2010. Focusing removal efforts along these corridors may be an effective strategy for reducing the spread of exotics into the rest of the property.

In conclusion, WICA’s ponderosa pine woodlands are an outstanding natural resource with a low abundance of exotic species and a high diversity of native plant species. As of 2012, overall condition of the forest community was good, however in some areas of the park the forests have high basal areas and densities compared to historic conditions. This is likely a legacy of widespread fire suppression during the last century. The 2011 Addition to WICA shows slight variations in forest structure compared to the area within the 2010 boundary. Forests within the 2011 Addition are characterized by more Rocky Mountain juniper, thinner forests, less grazing pressure, and fewer exotic species. The higher juniper density in the 2011 Addition may be due to a difference in geological context between the two properties. Limestone close to the soil surface is often associated with the mountain mahogany and juniper shrublands (Larson and Johnson 2007) that seem more widespread in the new property. A trend in forest condition is 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.

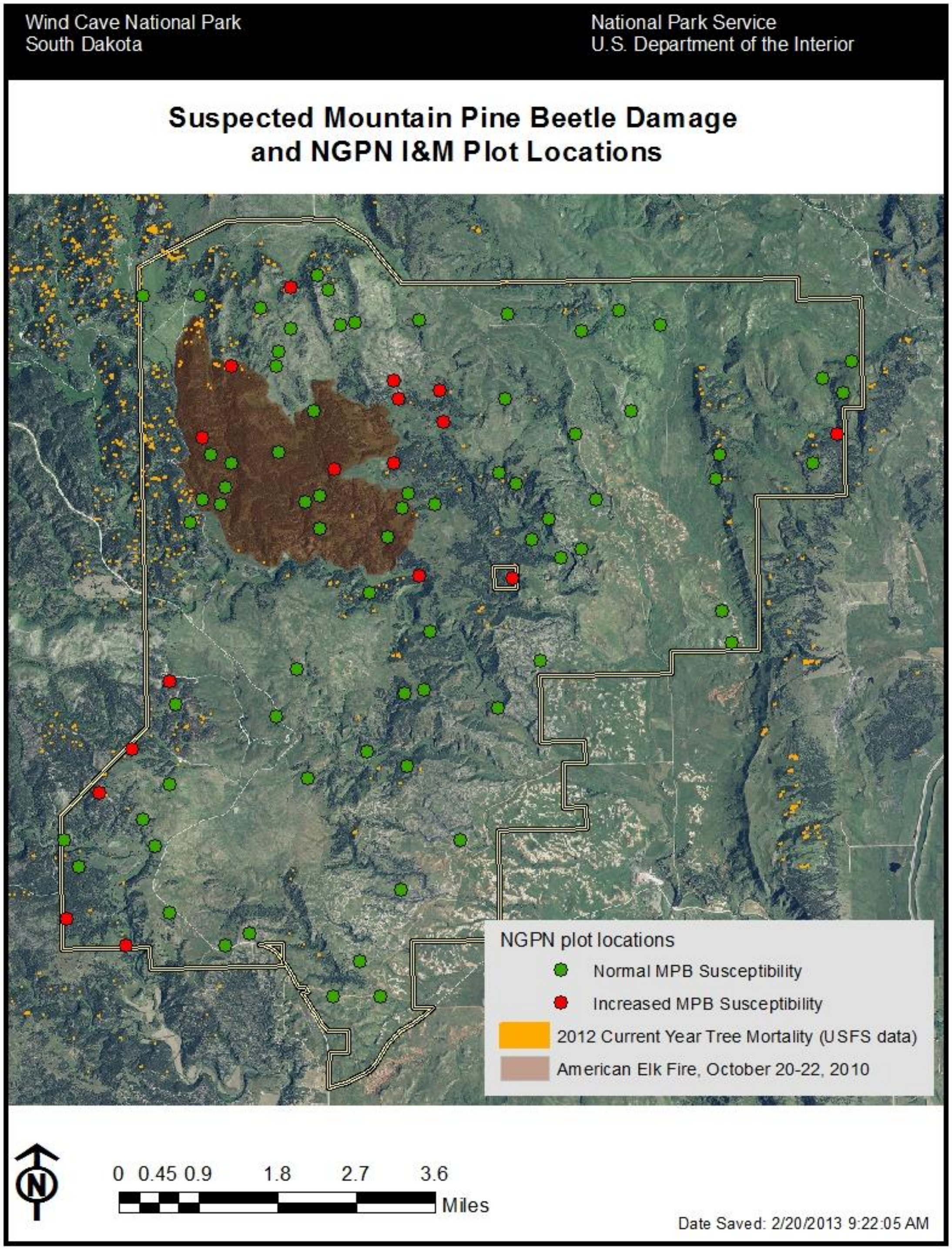

Figure 11. Suspected mountain pine beetle (MPB) infestation (current year tree mortality) in Wind Cave National Park in 2012. Plots identified as having increased MPB susceptibility are those having basal areas >27.6 m^2/ha (Schmid et al. 1994). Note that the area affected by beetles is exaggerated on this map for illustrative purposes. Polygons used to make the map were quite small, and a border was applied to make them visible. Tree mortality data comes from US Forest Service over-flights in 2012, and not all tree mortality may be due to beetle activity. Also note that not all areas of tree mortality may be visible from the air.

Table 7. Natural resource condition summary table for forest structure and fuels in WICA in 2012.

Indicators of Condition	Specific Measures	2010 Boundary (mean ± SE)	2011 Addition (mean ± SE)	Reference Value	Condition Status/Trend	Rationale
Exotic Plant Early Detection	Average maximum cover class of targeted exotic species (0-5)	1.3 ± 0.12	0.3 ± 0.18	Between 0 and 3 (< 5% cover)		To date, WICA has had effective exotic plant management and has maintained a low cover of exotic plants. The 2011 Addition typically has a lower cover of exotic species than within the 2010 Boundary.
Upland Plant Communities	Ponderosa pine basal area	14.1 ± 1.6 m^2 ha^{-1}	10.2 ± 3.2 m^2 ha^{-1}	15.3 ± 2.7 m^2 ha^{-1}		As of 2012, overall condition of the forest community was good, however in some areas of the park the forests have high basal areas and densities compared to historic conditions (Brown and Cook 2006). When considering only the forest plots with large diameter ponderosa pines, basal areas are closer to 22 m^2 acre and densities are 231 stems per ha. This is likely a legacy of widespread fire suppression during the last century.
	Ponderosa pine density	163 ± 19.9 stems ha^{-1}	90 ± 40.9 stems ha^{-1}	131 ± 24.7 stems ha^{-1}		
Fire and Fuel Dynamics	Total fuel loads	9.4 ± 0.9 tons per acre	6.9 ± 2.3 tons per acre	Between 2 and 10		The current fire ecology program aims to maintain fuel loads of less than 10 tons per acre. Both WICA properties have fuel loads below this management threshold.

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

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