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Black Hills National Forest

Revised Forest Assessment:

Ecological Integrity of Forested Ecosystems

Black Hills National Forest, photographed from Inyan Kara Mountain in northeastern Wyoming.

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Chapter 1. Introduction

As stated in the Black Hills National Forest Revised Land and Resource Management Plan Phase II Amendment FEIS (USDA Forest Service 2005),

> *The Black Hills is an isolated, unglaciated, and distinctive group of rugged mountains rising above the surrounding plains. It is variously described as an "island on the plains," and species from diverse environments, including the Rocky Mountains, northern coniferous forests, eastern hardwoods, and the surrounding Great Plains, have populated the "island." As such the area forms an "ecological crossroads" and has been described as one of the nation's greatest national treasures (USDA Forest Service 1996a).*

The region is ecologically unique due to its convergence of grasslands, woodlands, forests, and wetlands. The Black Hills functions as a place for intermingling of species from disparate portions of North America. While ponderosa pine dominates the Black Hills, areas exist where other species such as white spruce, aspen, paper birch, and others dominate. The Black Hills is unique due to its location in the center of the continent, highly variable climate, its isolation as a mountainous upthrust surrounded by prairie, and its varied topography (USDA Forest Service 1996a). Many of the species found here, such as paper birch, white spruce, and other plants, are isolated and distant from the rest of their range. Even Black Hills ponderosa pine is at the east edge of its range, isolated from other populations.

Forested ecosystems cover about 88 percent of Black Hills National Forest, with grasslands and shrublands comprising most of the remaining area. Riparian, wetland, aquatic, and cave ecosystems occupy relatively minor areas of the Black Hills National Forest but are nonetheless of considerable importance. This assessment is focused on the forested ecosystems (excluding riparian forest) on the Black Hills National Forest. Other ecosystems are discussed in other assessments, such as the Aquatic, Riparian, and Groundwater-Dependent Ecosystems assessment and Rangeland/Non-Forested Ecosystems assessment.

Humans benefit from and depend on the forested ecosystems in a variety of ways, from regulation of water quality and quantity, carbon sequestration, and pollination, to production of timber and non-timber forest products. Forested ecosystems provide fish and wildlife habitat, plants and places of cultural and tribal importance, recreational opportunities, beautiful scenery, opportunities for solitude and spirituality, and various other ecosystem services. The list of ecosystem services that the forests of the Black Hills support is long. The ecosystem sections in Chapter 2 highlight some of the key ecosystem services provided. Many ecosystem services are described in more detail in other assessments, including wildlife, recreation, range, timber, soil and water, carbon, scenery, and others. Ecosystems with high ecological integrity that are resilient to future disturbances and climate change will continue to provide the ecosystem services that have been historically provided by Black Hills National Forest. Continued production of ecosystem services will be more difficult and less certain if ecosystems have low ecological integrity or experience frequent large-scale disturbances.

Scope and Key Data Sources

This scope of this assessment of ecological integrity involves both describing the natural range of variation to establish a context for whether ecosystems are functioning properly as well as assessing current conditions and recent trends in each ecosystem, specifically changes to forest vegetation condition that have occurred during implementation of the 1997 Revised Land and Resource Management Plan (1997 Forest Plan). It is focused on the major ecosystem drivers, stressors, and key characteristics, as seen in Chapter 2. It is not focused on timber harvest volume and trends in standing inventory, which are described in the Timber assessment.

One key data source used in this assessment to evaluate current conditions is the Forest Inventory and Analysis (FIA) plot data (table 1). FIA is the Forest Service's national program for collecting and reporting information on the status and trend in forest ecosystems. It was chosen for its geographic extent, consistency, systematic, unbiased, and statistically defensible sample design, and rigorous quality control. Given that this data will continue to be collected for the foreseeable future, it can be used to monitor any of the attributes or trends identified in this assessment.

FIA data was summarized using the Black Hills database (with 2017-2019 data) and associated version of the FIA Evalidator reporting tool (USDA Forest Service 2019, https://usfs-public.app.box.com/v/BlackHillsFIAData), unless otherwise noted, to ensure evaluation included the recent spatially and temporally intensified FIA plot data. As described in Graham et al. (2021), this database contains the 2019 (2017 to 2019) FIA data requested by the Black Hills National Forest to address changes in forest conditions[1].

Regarding recent trends, an earlier version of this assessment looked at changes with comparisons made to information in Walters et al. (2013). At that time, as discussed in the draft assessment, additional FIA data had been requested to support a comparison that is representative of change since the signing of the 1997 forest plan and based on repeat measurements only. This data is now available. As such, the recent trends in area by forest type (and a few other trends) have been updated to use this custom subset of FIA data, as described below, instead of Walters et al. (2013).

This custom FIA analysis provides a forest-wide comparison using Forest Inventory and Analysis (FIA) data that was made using: the 2000 periodic inventory for WY and the 2001-2005 annual inventory for South Dakota (Measurement 1); and the 2017-2019 forest-wide inventory (Measurement 2) for forestlands. These inventories represent the earliest and latest FIA inventories available for this period. The Measurement 1 inventory estimates for both SD and WY utilize data that precede the data used in Walters et al. (2013), lengthening the time over which the comparison is made. Comparisons were made using repeat measurements only since this approach is ideal for assessing change over time.

The sampling intensity of the 2017-2019 FIA inventory was doubled per the Forest request to include plots that were measured for the first time to increase sampling precision. Output that is available to the Forest and the public from the 2017-2019 inventory is derived from this intensified sample. Consequently, it was necessary to request custom work by the Rocky Mountain Research Station, Forest Sciences Lab, Interior West FIA, Ogden, UT, to produce comparisons from Measurement 1 to Measurement 2 using repeat measurements only since the new plots established in the recent spatial intensification were not measured in 2000-2005. Output from this comparison was not available when the draft assessment report was released to the public on June 17, 2022.

In addition, where necessary, the public version of FIA's Evalidator and the Forest's spatial vegetation layer (2021 FSVeg Spatial layer) is used (table 1).

[1] Values for the 2019 data came from three sources: (1) plots that were remeasured from previous FIA inventories that fell within the normal measurement cycle (panel base plots); (2) plots that were remeasured from previous FIA inventories but that were measured ahead of schedule (off-panel base plots); and (3) new plots that were installed in 2017 and 2018 field seasons to increase the sample size and spatial extent (one plot every 3,000 acres; 2X PLOTS). The total number of plots – panel base plots, panel off-base plots, and the 2X plots – is 438 plots.

Table 1. Main tabular and spatial data sources used for this assessment.

Data Source	Use	Location
Black Hills FIA database and associated version of FIA's Evalidator. Includes data collected 2017 – 2019, including intensified FIA data	Used for estimates of current forest conditions, with the exception of coarse woody debris estimates.	url: https://usfs-public.app.box.com/v/BlackHillsFIAData
Public version of FIA database and Evalidator.	Public Evalidator used for all coarse woody debris estimates given down wood was not loaded in the Black Hills FIA database listed above.	url: https://apps.fs.usda.gov/Evalidator/evalidator.jsp
Custom FIA analysis done by Rocky Mountain Research Station, Forest Sciences Lab, Interior West FIA	Used to produce comparisons from Measurement 1 (the 2000 periodic inventory for WY and the 2001-2005 annual inventory for South Dakota) to Measurement 2 (2017-2019 forest-wide inventory) using repeat measurements only.	Available on request.
Black Hills NF FSVeg Spatial vegetation layer	Used to examine trends in the habitat structural stage distribution, for some general information about where particular ecosystems are located within the forest, and to estimate the extent of some rare forest types such as lodgepole pine and Douglas-fir.	Available on request.

While table 1 outlines the key quantitative data sources uses, many scientific references were incorporated as well. This includes numerous publications by Peter Brown that are specific to the Black Hills (Brown and Cook 2006, Brown et al. 2008, and others), publications by and communication with Rocky Mountain Research Station scientists (for example, Graham et al. 2021, Shepperd and Battaglia 2002, Tatina and Hanberry 2022), historical accounts such as Graves (1899) and Dodge (1876), numerous reports produced by the Rocky Mountain Region State & Private Forestry and Tribal Relations Forest Health Protection staff evaluating forest condition, previous Black Hills National Forest planning documents created as part of the 1997 forest plan and 2006 phase II plan amendment, and Black Hills National Forest monitoring reports.

In 2023, a decision was made to collect lidar data across the entire Black Hills National Forest to provide additional information for the forest plan revision process and future plan implementation. Lidar, or **li**ght **d**etection **a**nd **r**anging, is a remote sensing technology that actively emits pulses of light to measure distances to target surfaces. By calculating the time it takes lidar pulses to hit a surface and return to the lidar sensor, objects can be precisely located in three-dimensional space. With each pulse, the lidar sensor records several points of contact, and with millions of pulses in a lidar acquisition, the result is a dense point cloud that reveals the forest and the ground beneath it. Lidar data can be used to measure vegetation height, canopy cover, and canopy gaps, as well as to create digital elevation models. Together with field sampling and modeling, we can use lidar to estimate forest structure metrics like basal area, volume, and biomass. In the analysis phase, lidar data could potentially be used to develop detailed maps of vegetation cover, forest structure, and topography. This information could be used to consider different management scenarios and evaluate the potential impacts of those scenarios on various ecological values.

See the following for more information about how the Forest Service uses lidar:

Investing in the Forest Service with Lidar Data (arcgis.com)

url: https://storymaps.arcgis.com/stories/6740fb49099649e78d5ccf543aed4165

Identification of Forested Ecosystems

Forested areas make up about 88 percent[2] of the Black Hills National Forest. The primary forested ecosystems, characterized by their dominant vegetation, are:

- Ponderosa Pine
- White Spruce
- Aspen
- Bur Oak

In addition, this report examines less common forested ecosystems and species in the Forest such as paper birch, Rocky Mountain juniper, limber pine, lodgepole pine, and Douglas-fir.

The extent in acres of the forested ecosystems on the Black Hills National Forest is estimated with the latest Forest Inventory and Analysis (FIA) plot data (table 2a). Forest type definitions come from FIA. The dominant forested ecosystem on the Black Hills National Forest is ponderosa pine, with all other types having much smaller extents. Aspen is the dominant hardwood type in the Forest (table 2a).

Table 2a. Extent of forest land by forest type on the BKNF based on the intensified 2017-2019 Forest Inventory and Analysis (FIA) data.

Forest Type	Acres, 2017-2019 data (sampling error %[3])	Percent (%) of forest land	Number of non-zero plots[4]
Ponderosa Pine	789,803 (3.2%)	71.4%	299
White Spruce	54,282 (21.2%)	4.9%	24
Aspen	70,115 (19.0%)	6.3%	28
Bur Oak	30,292 (29.3%)	2.7%	12
Paper Birch	18,649 (36.2%)	1.7%	9
Rocky Mountain Juniper	17,209 (40.5%)	1.6%	6
Other forested vegetation[5]	30,759 (31.4 – 71.2%)	2.8%	13
Nonstocked[6]	95,449 (15.1%)	8.6%	45
Total	1,106,559 (1.2%)	100.0%	407

The extent of ponderosa pine and other ecosystems in the Forest are showing signs of change since the previous inventory collected in the early 2000s (table 2b). In this case, the 2017-2019 FIA estimates of forest land in each forest type are compared to an earlier estimate (the 2000 periodic inventory for WY and the 2001-2005 annual inventory for SD) using repeat measurements only (a subset of the FIA data

[2] Based on FIA forestland relative to the official Black Hills NF acreage.
[3] Sampling error percent at the 68% confidence level.
[4] Non-zero plots are the plots where the attribute of interest (in this case forest type) was observed to occur.
[5] Other forested vegetation includes areas labelled as mixed upland hardwoods and other hardwoods.
[6] Nonstocked forest land is land that currently has less than 10 percent stocking but formerly met the definition of forest land. Forest conditions meeting this definition have few, if any, trees sampled. In these instances, the algorithm cannot assign a specific forest type (USDA Forest Service FIADB Users Guide).

since new plots established as part of the recent spatial intensification were not measured in 2000-2005), as described in Chapter 1 of this document.

In addition, recent trends as seen in the FSVEG spatial vegetation layer are presented (table 2d). While we recognize that presenting multiple data sets with different acreages can be confusing, these are included to help verify (or not) the trends seen in the FIA data. These are different data sets with different classification methods and as such, can show different trends or higher or lower extents of different forest types. Including this second dataset is also important because it is tied to habitat structural stage (HSS) estimates, estimates in past monitoring reports, and may be used in future parts of the plan revision process.

Looking at the individual forest types in Table 2b, this comparison indicates that some forest types, such as ponderosa pine, are decreasing in extent, while the extent of nonstocked areas and the other hardwood types are increasing. Confidence in these three trends is high given the magnitude of the trend as well as its consistency with trends seen in other data sets (such as the FSVEG spatial vegetation layer, see table 2d) and observations on the Forest. The extent of Rocky Mountain juniper is also increasing in multiple data sets.

Recent trends in other types, such as white spruce, aspen, bur oak, and paper birch are less certain as the trends seen here are not consistent with those seen elsewhere, such as the FSVEG spatial vegetation layer (table 2d) or monitoring reports. FIA data for these types generally have much smaller plot counts and higher sampling errors relative to ponderosa pine.

The extent of each forest type should continue to be monitored to gain more information about these trends.

Looking at the data more broadly in terms of conifer vegetation types, hardwood vegetation types, and nonstocked areas (table 2c), one can see a clear decrease in the conifer vegetation types and a clear increase in hardwood vegetation types and nonstocked areas since the earlier inventory (2000-2005). These three trends are seen in the FSVEG spatial data as well (table 2d).

Table 2b. Trend of forest land by forest type on the Black Hills National Forest based on the Forest Inventory and Analysis (FIA) data (repeat measurements only)

Forest Type	Acres, Measurement 1 (2000 for WY, 2001-2005 for SD)	Acres, Measurement 2 (2017-2019)	Recent Trend[7]
Ponderosa Pine	935,186	819,088	**decrease**
White Spruce	50,495	49,019	decrease*
Aspen	51,323	61,501	increase*
Bur Oak	27,626	19,589	decrease*
Paper Birch	1,454	5,816	increase*
Rocky Mountain Juniper	11,632	17,448	increase
Other forested vegetation[8]	9,411	37,954	**increase**
Nonstocked	77,062	135,405	**increase**
Total	1,164,188	1,145,819	

[7] * Indicates where trends are less certain / are not consistent with those seen elsewhere, such as the FSVEG spatial vegetation layer (table 2d) or monitoring reports

[8] Other forested vegetation includes areas labelled as mixed upland hardwoods and other hardwoods.

Table 2c. Trend of forest land by broad vegetation type on the Black Hills National Forest based on the Forest Inventory and Analysis (FIA) data (repeat measurements only)

Type	Acres, Measurement 1 (2000 for WY, 2001-2005 for SD)	Acres, Measurement 2 (2017-2019)	Recent Trend
Conifer vegetation types[9]	997,313	885,555	**decrease**
Hardwood vegetation types[10]	89,814	124,860	**increase**
Nonstocked	77,062	135,405	**increase**
Total	1,164,188	1,145,819	

Table 2d. Forest land area by forest type, Black Hills National Forest, 1995 to 2021

[Source: 1995 RIS inventory and 2021 FSVeg inventory.]

Forest Type	1995 (acres)	2021 (acres)	Change (acres)
Non-commercial, Aspen	48,225	42,250	-5,975
Non-commercial, Bur Oak	9,190	14,154	4,963
Non-commercial, Conifer/Hardwood Mix	0	7,532	7,532
Non-commercial, Other Hardwoods	690	5,522	4,831
Non-commercial, Other Softwoods	153	159	6
Non-commercial, Paper Birch	2,623	1,757	-866
Non-commercial, Rocky Mountain Juniper	494	1,109	615
Non-commercial, Subtotal	***61,375***	***72,482***	**11,107**
Commercial, Ponderosa Pine	1,017,981	939,693	-78,288
Commercial, White Spruce	21,737	33,700	11,963
Commercial, Subtotal	***1,039,719***	***973,393***	**-66,326**
Non-stocked ponderosa pine	23,502	88,982	65,480
Total	***1,124,596***	***1,134,857***	**10,261**

[9] Includes ponderosa pine, white spruce, and Rocky Mountain juniper.
[10] Includes aspen, bur oak, paper birch, mixed upland hardwoods, and other hardwoods.

Chapter 2. Forested Ecosystems – Conditions and Trends

Ponderosa Pine

Introduction

Ponderosa pine (*Pinus ponderosa* var. *scopulorum* Dougl. ex Laws.) is the dominant tree species and forest type in the Black Hills planning area and occurs from low to high elevations on all soil types and aspects (Shepperd and Battaglia 2002, USDA Forest Service 1996a). Ponderosa pine forests occupy approximately 800,000 acres and more than 70% of the forest land on the Black Hills National Forest (table 2a). Variation in moisture and soils result in 15 different ponderosa pine community types (appendix B). Some of these types are ranked as globally vulnerable and/or locally imperiled or vulnerable in Wyoming.

The ponderosa pine forests of the Black Hills have sustained a viable timber industry for over 100 years. Timber production is an important ecosystem service produced by this ecosystem and it is discussed in more detail in the timber assessment.

Providing wildlife habitat for a variety of species is a key ecosystem service of the ponderosa pine forests of the Black Hills planning area. In one study, the northern hills habitat, with its deciduous understory, had the highest bird species richness, with species such as warbling vireo, dusky flycatcher, yellow-rumped warbler, and ovenbird occurring in relatively high densities in northern hills habitat (Panjabi 2001). Other species, such as the plumbeous vireo and western tanager were detected in southern hills habitat in higher densities. Late-successional pine habitat had the highest densities of brown creeper (Panjabi 2001).

Many species that occur in ponderosa pine in Black Hills National Forest are primarily associated with either conditions favoring a deciduous understory (e.g., broad-winged hawk, Lewis' woodpecker, frigid ambersnail, and Black Hills mountainsnail) or late-successional conditions (e.g., northern long-eared bat, northern goshawk, northern flying squirrel, American Pacific marten, three-toed woodpecker, black-backed woodpecker, pygmy nuthatch, and pahasapa mountainsnail) (Anderson 2003, Buskirk 2002, Frest and Johannes 2002). However, some species such as Cooper's hawks and sharp-shinned hawks utilize dense coniferous stands that have relatively open understories (Stephens and Anderson 2002).

Recent trend data indicates the extent of ponderosa pine is declining (table 2b). This is in line with observations on the Forest. For instance, some areas that experienced high-severity fire are not naturally regenerating and are considered nonstocked. Timber harvest of pine in mixed pine-oak stands increases oak sprouting. Consequently, in some areas treated mixed pine-oak stands are currently (and temporarily) dominated by oak and experiencing delayed pine regeneration. In some cases, when pine is harvested from mixed pine/spruce stands, spruce has become dominant (USDA Forest Service 2015). Spruce is also replacing pine on some sites with fire exclusion or insects and disease that affect pine but not spruce (Alexander and Edminster 1981).

Ecosystem Drivers and Stressors

Ecosystem drivers are factors or processes that affect ecosystem characteristics and contribute to the natural range of variation. Stressors are defined as factors that may directly or indirectly degrade ecosystem composition, structure, or processes in a manner that may impair its ecological integrity (36 CFR 219.19). Many system drivers can be stressors if they are operating in atypical ways, outside of their natural range of variability. Management influences can be drivers or stressors.

Timber Harvest

Timber harvest has been a dominant driver in the ponderosa pine ecosystem on the Black Hills National Forest. In the late 1800s, before the establishment of the Black Hills Forest Reserve in 1897, large tracts were clearcut to yield mine timbers or railroad ties (USDA Forest Service 1996a, Boldt and Van Deusen 1974, Graves 1899). Once established, the Black Hills Forest Reserve was the site of the first federal timber sale. Virtually every operable acre has been harvested at least once. The majority have received repeated partial cuts of one kind or another (USDA Forest Service 1996a). The Forest produces quality ponderosa pine lumber and has sustained a viable timber industry for over 100 years (Graham et al. 2021). The only other commercial timber species in the forest is white spruce, which is a minor contributor to the timber sale program.[11]

In ponderosa pine stands, even-aged management is typically practiced which creates single or two-aged stands. Even-aged ponderosa pine forests result in ecological conditions with lower structural and spatial heterogeneity and reduced resilience to native ecological disturbances such as mountain pine beetle epidemics and wildfire (see footnote next page as well as discussion in the timber assessment). Even-aged conditions are associated with a moderate to low frequency, moderate to high severity disturbance regime. (Kaufmann et al. 2006, Veblen and Donnegan 2005, and Veblen et al. 2012, in Addington et al. 2018).

Uneven-aged management in ponderosa pine is about 5% of the timber management program. This results in higher structural and spatial heterogeneity and higher resilience to fire, insects, and disease relative to even-aged management.[12] Uneven-aged conditions are associated with a high frequency, low severity disturbance regime (Kaufmann et al. 2006, Veblen and Donnegan 2005, and Veblen et al. 2012, in Addington et al. 2018, Reynolds et al 2013).

Past vegetation management and associated planning analysis have been supportive of even-aged management. USDA Forest Service (2005) states how even-aged silviculture is eminently suited to Black Hills ponderosa pine (Boldt et al. 1983). And additionally discusses how the shelterwood method capitalizes on the species' natural tendency to form even-aged stands and how it combines the advantages of continuous vegetative protection of the site; absence of obvious openings; assurance of an adequate, well-dispersed seed supply; fair control over development of competitive ground cover; good control over accumulations of hazardous and unsightly logging residue; and an esthetically acceptable appearance, provided the harvest job is skillfully planned and executed. Given how the natural disturbance regime changes with increasing elevation (as described below), even-aged silviculture has been the most appropriate and suited to the ponderosa pine forest at higher elevations in the Black Hills National Forest.

As discussed in later sections, given how different vegetation conditions are associated with different fire regimes and the mixed-severity fire regime (including both more frequent, lower-intensity surface fires and less frequent, higher-intensity crown fires) that occurred in Black Hills National Forest, a

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[11] Typically, this has been the harvest of white spruce from pine dominated stands and the implementation of meadow and hardwood enhancement projects outside of the white spruce forest type.

[12] The diversity of tree sizes as well as density affect the level of susceptibility to mountain pine beetle and fire. Small trees are susceptible to fire whereas larger diameter trees are less susceptible. Larger diameter trees are susceptible to mountain pine beetle with smaller trees less susceptible. Density also plays a role with lower density stands more resilient to disturbance and drought than dense stands (Negrón et al. 2008, Bottero et al. 2016, Bradford and Bell 2016). In general, uneven-aged management leads to higher resiliency to disturbance relative to even-aged management, particularly when a large portion of the landscape is even-aged and mature, given the latter has a greater continuity of large trees, fewer replacement trees in the understory, greater potential loss of seed source, and higher fuel loads. Variability in stand structure and fuels can result in fine-scale variation in fire effects, with small areas of torching created by moderate or high-intensity fire, as well as unburned or lightly burned areas that still maintain prefire seed producing mature trees, tree saplings, understory plants, and denser cover for wildlife habitat (Stephens et al. 2021).

management regime that includes both uneven-aged and even-aged management could potentially best mimic historical stand and landscape structure.

There has historically been a high demand for wood products from Black Hills National Forest, with the demand greater than the supply (USDA Forest Service 1996a). Supply is limited by some forest plan direction beneficial for other resources and uses, such as the HSS objectives. In addition, the supply is in decline due to a decrease in standing volume, with the standing inventory of ponderosa pine on the Black Hills National Forest peaking around the time of the 1997 Forest Plan Revision effort (Graham et al. 2021).

Two forest-wide vegetation management projects have been authorized and implemented on the Black Hills National Forest since 2012. The first was the Mountain Pine Beetle Response project (MPBR). This 2012 decision intended to reduce the threat to ecosystem components from the existing mountain pine beetle epidemic and help protect local communities and resources from large scale, severe wildfire. This decision authorized a variety of vegetation management activities to reduce stand densities and lower mountain pine beetle risk and wildfire hazard. From fiscal years 2013 through 2021, approximately 76,000 acres have been treated under MPBR. The majority of this has been shelterwood establishment treatments. This project concluded at the end of 2021.

The second vegetation management project was the Black Hills Resilient Landscapes project. Signed in 2018, this project is currently being implemented. Given forest structure, hazardous fuel levels, and concerns about forest resilience, this project was designed to move the landscape-level vegetation conditions towards the objectives in the Forest Plan to increase ecosystem resilience to insect infestation and other natural disturbances, to contribute to public safety and the local economy, and to reduce the risk of wildfire to landscapes and communities. From fiscal years 2018 through 2021, commercial products have been sold from approximately 42,000 acres, with an additional 13,000 acres of commercial treatments planned over the next few years. Most of the commercial treatments have been overstory removal and liberation cuttings, but other treatments such as hardwood enhancement, meadow restoration, and uneven-aged selection have also occurred. Precommercial treatments are under contract on just under 9,000 acres with an additional 17,000 acres planned for the near future.

Natural Disturbances

Ecological disturbances shape forest structural diversity and composition at a range of spatial and temporal scales. Weather (e.g., wind, hail, tornados, and snow), wildfire, insects, parasites, pathogens, and animals individually and in combination kill trees, create openings, and promote vegetative diversity. Each of these natural disturbance agents influence the array of ecosystems on the Black Hills National Forest in different ways. For instance, changes in the abundance of beaver over the past two centuries influenced stream dynamics and riparian conditions but had little impact on uplands while bark beetle outbreaks dramatically influenced pine forest but not oak or aspen forest. Of these disturbances, insects, wildfire, and weather events have been the most noticeable causes of tree mortality (Graham et al. 2021, Shepperd and Battaglia 2002, Graves 1899, Negrón et al. 2008, Brown et al. 2008).

Fire and Fire Exclusion

Fire and fire exclusion have been dominant drivers and stressors in forest ecosystems, particularly the ponderosa pine ecosystem in the Black Hills National Forest.

As described in USDA Forest Service (2005), many ponderosa pine forests of the western United States, including the Black Hills National Forest historically experienced frequent fires resulting in open stands with high understory biomass and diversity (Brown 2003). Frequent, low-intensity fires, whether lightning ignitions or cultural ignitions by native communities of the Black Hills[13], limited stand density, reduced surface fuels, altered understory vegetation, and resulted in high spatial heterogeneity (Brown 2003). While there is agreement that episodic surface fires were a major form of disturbance prior to Euro-American settlement, there is less agreement regarding the role of large, high-intensity wildfires. Shinneman and Baker (1997) suggest it is likely that both low-intensity surface fires and large catastrophic wildfires occurred prior to Euro-American settlement in the Black Hills. Shinneman and Baker (1997) cite descriptions from early expeditions in the Black Hills (Custer Expedition 1874 and Dodge Expedition 1875), forest inventories conducted by Graves from 1891 to 1897, and sizeable areas of even-aged forest on the limestone plateau as evidence of large, stand-replacing fires occurring prior to settlement. In contrast, large patches of even-aged forest structure seen at settlement may have resulted from an extended wet period during the late 1700s and early 1800s seen over much of the Northern Plains rather than the result of large crown fires during this period (Brown 2001, Brown 2003, USDA Forest Service 2005). However, large, severe fires have been documented (see discussion in Shepperd and Battaglia 2002, USDA Forest Service 2005). For instance, as described in Shepperd and Battaglia (2002), evidence of a large-scale fire in 1842 was confirmed by accounts reported by Native Americans that the "entire Black Hills were ablaze" around that time, and the presence of several clusters of 150-year-old trees in the northern Hills. Another example in Shepperd and Battaglia (2002) is an even-aged forest stand around 190 to 200 years old documented by the Forest Service in the 1940s that can be traced to originate after a severe fire in the central Black Hills around 1730 to 1740. Therefore, while there is not complete agreement in the literature, evidence suggests it is likely that a mixed-severity fire regime including both surface fires and crown fires occurred in the Black Hills (Lentile et al. 2005). Similarly, Tatina and Hanberry (2022) conclude that the Black Hills region primarily had a frequent surface fire regime based on General Land Office survey data, Euro-American settlement documentation, and fire reconstructions of surface fire frequencies every 10 to 35 years, but recognize that occasional, high severity fires occurred in dense stands, as detailed in historical accounts and fire chronologies.

As described by Brown and Cook (2006), historical ponderosa pine forests in the Black Hills consisted of a "diverse landscape mosaic that varied from non-forested patches and open stands of few large trees to quite dense stands with many similar-sized and -aged trees." The more open stands/savannahs of ponderosa pine were more typical, with dense patches present and contributing to spatial heterogeneity (Brown and Cook 2006).

Before Euro-American settlement, average wildfire return interval ranged from 5 to 33 years, depending on elevation and moisture availability (Graham et al. 2021, Murphy 2017). Mean fire return intervals (MFRI) increase with increasing elevation from the ponderosa pine savanna (median MFRI=12 years), to the low- to mid-elevation ponderosa pine woodland[14] and forest (median MFRI=21 years), to the high-elevation ponderosa pine and white spruce forest (median MFRI=28 years) (Murphy 2017).

More specifically, and as described in Murphy (2017), fire history studies generally show evidence of frequent surface fires prior to the 20th century, with a pattern of decreasing fire frequency with increasing latitude and elevation in these communities, as well as a greater incidence of mixed-severity fires on

[13] As synthesized in Murphy et al. (2017), Native Americans contributed to frequent presettlement burning in the Black Hills region but may have done little burning in ponderosa pine woodlands and forests. They used fire seasonally, mostly in the surrounding Great Plains, to manage vegetation and drive game. It is unlikely that Native Americans burned the denser Black Hills forests at all. Accounts suggested that Native Americans were superstitious of the Black Hills and may have avoided the dense portions because game was scarce, hunting and navigating were difficult, and rain and lightning were frequent.

[14] Although the terms woodland and forest are often used interchangeably, the term woodland is commonly associated with forest types in drier climate regions (for example, pinyon-juniper woodlands) or is used to describe a forest with a more open canopy. For example, the Black Hills Community Inventory defines woodlands as open stands of trees with crowns not usually touching (generally forming 25 percent to 60 percent cover) (Marriott and Faber-Langendoen 2000a, Marriott et al. 1999).

mesic sites where relatively long fire-free intervals were part of the record. Occasional mixed-severity fires likely occurred in the two higher elevation community types when, during low-severity surface fires, small patches (less than 250 acres) sometimes burned with high-severity. Frequent fire in ponderosa pine forests and woodlands maintained considerable structural and spatial heterogeneity (Murphy 2017). While this indicates that the areas historically burned by high severity were small (less than 250 acres), there does not appear to be agreement in the literature on this topic. For instance, as summarized by Shepperd and Battaglia (2002), Shinneman and Baker (1997) examined several historical reports of the Black Hills and reported that many fires ranged from 7,500 to 22,000 acres (3,000 to 9,000 ha) in size, with a possibility of a very large fire of 50,000 acres (20,000 ha). Additionally, in 1898, a 20,000-acre (8,100-ha) fire near Crow Peak was caused by lightning (Progulske 1974, in Shepperd and Battaglia 2002 and Shinneman and Baker 1997). Fire exclusion has influenced forest ecosystem composition, structure, and pattern in the Black Hills. Changes in forest conditions due to fire exclusion (and past timber harvest) include an increase in tree density with more small trees and fewer large trees and increased likelihood of crown fire (Brown et al. 2008, Brown and Cook 2006, Murphy 2017, Tatina and Hanberry 2022). Under these conditions, when a fire occurs with very low fuel moisture and high winds, such as the Jasper Fire (2000), there are large patches of mortality due to high-severity fire. Other changes in forest conditions due to fire exclusion include loss of understory species and biomass, reduction in nutrient cycling, and increase in plant transpiration which reduces surface and subsurface hydrological flows (USDA Forest Service 2005, Murphy 2017, Brown et al. 2000).

The effects of timber harvest and fire exclusion collectively have led to a current forest structure that is simpler than it would have been historically, with increased tree density leading to fewer gaps and more even spacing and size distributions within groups, which also leads to higher fuel continuity (Brown and Cook 2006). Current conditions are likely also more homogeneous in terms of patch size. The trend toward homogenization reflects changes in forest structure in other western ponderosa pine forests, although the Black Hills historically had a greater range of structural variability than ponderosa pine forests of the southwestern United States (Brown and Cook 2006). Evidence suggests that restoration of landscape heterogeneity would enhance species habitat and promote ecological resiliency (Brown and Cook 2006).

In addition to changes within ponderosa pine forests, fire exclusion favored expansion of white spruce forest. In the absence of fire, white spruce, which is highly vulnerable to fire, became established in areas historically occupied by ponderosa pine forests (Murphy 2017, USDA Forest Service 1996a). Similarly, forest expansion into grasslands in the West is often attributed to reduced fire frequency, although changes in climate and/or increased livestock grazing may also have contributed to these modifications. Brown and Sieg (1999) found that fire exclusion was likely the major driver of forest expansion into grasslands in the southern Black Hills with grazing and climate having minimal impact (Murphy 2017). Evidence suggests that ponderosa pine would continue to persist in the face of increased fire frequency due to their thick bark and other adaptations that confer resistance to surface fire (King et al. 2013).

Insects and Disease - Mountain Pine Beetle

Insects and disease are disturbance agents that play an integral part in the Black Hills National Forest ecosystem and help produce heterogeneity throughout the forest system. Insects play an important role in pollinating plants, recycling nutrients, decomposing vegetation, and providing food for wildlife. Tree mortality and other impacts of insects and diseases regulate forest vegetation composition, influence stand density and structure; provide wildlife habitat in dead and dying trees and contribute nutrients to soils. Insects are also food for birds and other wildlife.

While insects and disease can have positive impacts on forest ecosystems, they can also negatively affect the forest ecosystem. For example, at endemic levels, individual trees are weakened and killed, resulting in small-scale changes affecting limited areas. Trees weakened by one organism are often susceptible to attacks by other organisms. When conditions such as stand maturity, overcrowding, drought, blowdown, or poor site conditions act independently or in combination to stress large groups or stands of trees, populations of forest insects and pathogens can increase in these stressed trees, resulting in widespread mortality (Bentz et al. 2009, USDA Forest Service 2011). Currently, the insect or disease having the most significant impact on the Black Hills National Forest is mountain pine beetle (*Dendroctonus ponderosae*). The mountain pine beetle is a native bark beetle that occurs in conifer forests of western North America and uses ponderosa pine as one of its hosts (Negrón et al. 2017, Allen et al. 2020). There is a long history of mountain pine beetle outbreaks in the Black Hills (Negrón et al. 2017, Graham et al. 2021, Graham et al. 2016), with varying locations and severity.

Mountain pine beetles were observed in historical accounts. As stated in Graham et al. (2016), "Hopkins (1905) indicated that the Black Hills beetle had been present and killing trees since the 1850s throughout the Rocky Mountains and he also suggested that much of the dead and dying trees that were attributed to wildfires were actually killed by bark beetles (Hopkins 1909).

The first documented epidemic of bark beetles like mountain pine beetle in the Black Hills occurred in 1895, in the northwestern corner, near the Wyoming border where trees were dying in clumps (Blackman 1931). Graves in his reconnaissance of the Black Hills Forest Reserve visited the same area in 1897 and noted that large numbers of trees on several ridges in the vicinity of Crooks Tower and the headwaters of Little Spearfish Creek were dead or dying (Graves 1899)."

In 1901, a team composed of Gifford Pinchot, Andrew D. Hopkins, and an assistant went to the Black Hills to further investigate the beetle activity that Graves described. In four days, Hopkins collected and described 4,363 beetle specimens, described how they attacked trees, described the galleries they left under the bark, and even speculated on using trap trees to control the bark beetle damage (Graham et al. 2016).

While most of the time mountain pine beetle populations occur at endemic levels (Allen et al. 2020), the Black Hills has experienced mountain pine beetle epidemics approximately every twenty years, with notable events in the early 1900s, the late 1960s to the early 1980s, and the most recent epidemic from about 1996 through 2016 (Graham et al. 2021). See images below of figures from Graham et al. 2021, see also Figure 31 in Graham et al. 2016)[15].

[15] Data from the Forest Health Protection, Aerial Detection Survey Program shows that increases in MPB populations were first detected in 1996. The highest year of MPB activity was 2003 based on acres affected. The MPB epidemic peaked in 2013 based on annual tree mortality and returned to endemic levels in 2016. For more information on this data, see the Timber Assessment Appendix, Table 16.

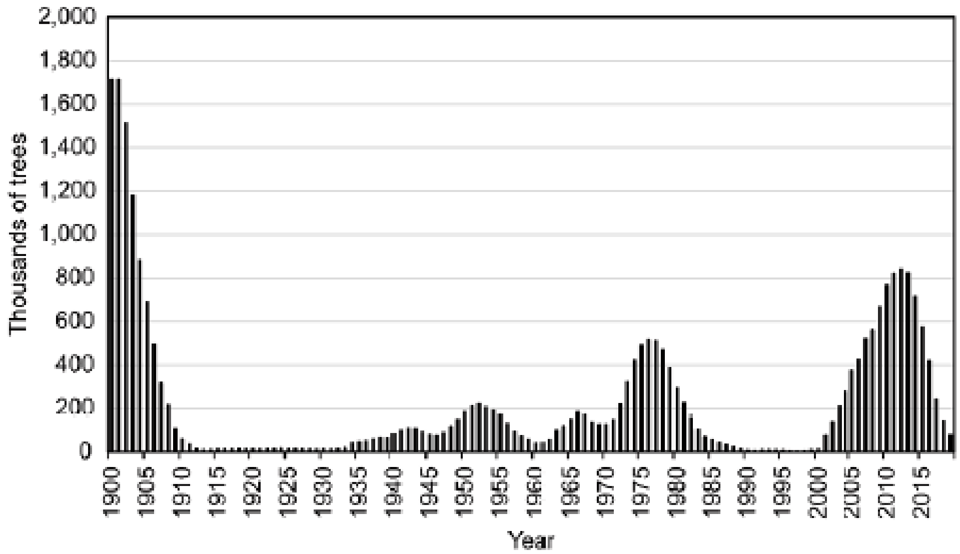


Figure 4—Within the forests of the Black Hills, there has been a continuous endemic and several epidemics of mountain pine beetles over the last 129 years (see Graham et al. 2016, fig. 31). From 2000 through 2017, over 8,000,000 trees were estimated to have been killed. Values reported are the 5-year moving average.

Image 1 - Image of Figure 4 from Graham et al. 2021 that shows a graph with years from 1900 to 2015 on the x axis and Thousands of Trees on the y axis. Peaks are visible from 1900 to 1910, 1950s, 1970s, and 2000-1015. The captions states "Within the forests of the Black Hills, there has been a continuous endemic and several epidemics of mountain pine beetles over the last 129 years (see Graham et al. 2016, fig. 31). From 2000 to 2017, over 8,000,000 trees were estimated to have been killed. Values reported are the 5-year moving average."

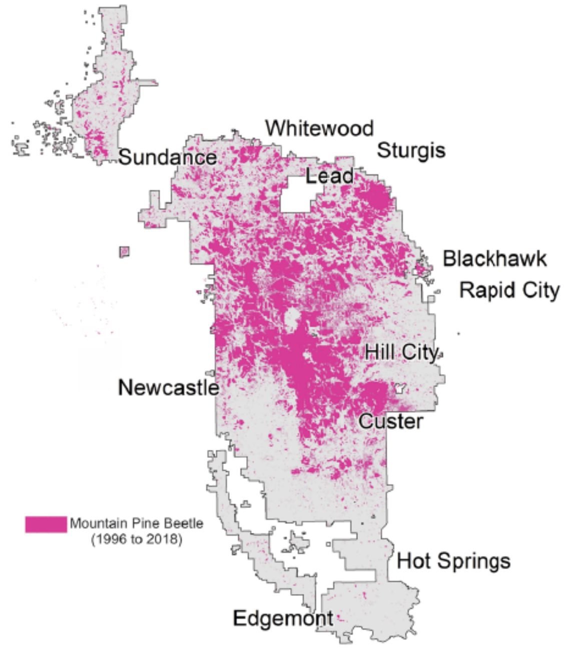


Figure 5—The most recent (i.e., 1998) MPB epidemic started with many isolated areas of endemic MPB populations throughout the Black Hills. As the endemic populations increased in numbers, the MPB spread throughout the central and northern Black Hills. Notably, the MPB infestation was less in Wyoming portions of the Black Hills and Bear Lodge Mountains (see Graham et al. 2016, figs. 65–69, for details on the extent and impact of mountain pine beetles in the Black Hills). This disturbance can have a substantial impact on post-disturbance recovery.

Image 2 - Image of Figure 5 from Graham et al. 2021 that shows a mapped outline of Black Hills National Forest and areas highlighted in pink showing where mountain pine beetle occurred from 1996-2018. The caption states "The most recent (i.e., 1998) mountain pine beetle epidemic started with many isolated areas of endemic mountain pine beetle populations throughout the Black Hills. As the endemic populations increased in numbers, the mountain pine beetle spread throughout the central and northern Black Hills. Notably, the mountain pine beetle infestation was less in Wyoming portions of the Black Hills and Bear Lodge Mountains (see Graham et al. 2016, figures 65-69, for details on the extent and impact of mountain pine beetles in the Black Hills). This disturbance can have a substantial impact on post-disturbance recovery."

While mountain pine beetle activity can be part of a healthy ecosystem, there are forest management objectives regarding the control and suppression of mountain pine beetle epidemics on the Forest (see current plan standards and guidelines 4201, 4205, and 4206). As discussed earlier, the Mountain Pine Beetle Response project (MPBR) was focused on reducing the threat to ecosystem components from the mountain pine beetle epidemic and authorized a variety of vegetation management activities to reduce stand densities and lower mountain pine beetle risk.

Forest stand conditions affect ponderosa pines susceptibility to mountain pine beetle. In particular, stand density and tree size are important factors, with pine beetles preferring larger, sawtimber-sized trees and dense stands (Graham et al. 2021, Graham et al. 2016, Negrón et al. 2008, Negrón et al. 2017). Negrón et al (2008) found that the basal area of ponderosa pine in uneven-aged stands in trees ≥ 25.4 cm (10 inches) diameter at breast height (dbh) and total ponderosa pine stand density index were correlated with mountain pine beetle attack. A more recent study by Negrón et al. (2017) conducted in thinned and unthinned even-aged stands produced similar results indicating that bark beetle susceptibility was greater in unthinned stands that contained higher number of trees ≥ 25.4 cm (10 inches) dbh and higher stand densities in these diameter classes.

Other factors that may affect the shift from endemic to epidemic populations of mountain pine beetle include favorable climatic and stand conditions as well as proximity to an existing beetle population (Gibson et al. 2009). In second-growth ponderosa pine stands in the Black Hills and Rocky Mountains, highly susceptible stands are generally those that are densely stocked (i.e., for average stand diameter of 10-12 inches, greater than 150 square feet basal area per acre), have an average diameter greater than 10 inches, and are even-aged and single-storied (Gibson et al. 2009).

Early susceptibility ratings considered stands with densities in the 80-120 ft^2/acre of basal area range or 80-150 ft^2/acre of basal area range a moderate risk (for examples, see Chojnacky et al. 2000). However, stands with densities in this range are now exhibiting high mortality, indicating a shift in risk since those rating systems were developed. For instance, unthinned stands with an average of 111.1 ft^2/acre of basal area of ponderosa pine experienced 38.2% mortality in terms of basal area (Negrón et al. 2017, Tables 1 and 2).

Given susceptibility to mountain pine beetle is based on stand density and tree diameter, stands can be commercially thinned to reduce density and thus lower the risk of beetle mortality in both even-aged and uneven-aged stands. As described earlier, the Forest initiated the Mountain Pine Beetle Response Project (MPBR) in response to the most recent mountain pine beetle epidemic. Past practice on the Black Hills National Forest was to reduce stand density to 80 ft^2/acre of basal area to reduce susceptibility to mountain pine beetle. Even lower densities (30-60 ft^2/acre of basal area) were later found to be needed to reduce susceptibility to mountain pine beetle. Fire and fuels treatments can be effective at increasing tree resistance to bark beetles, but this effect can vary depending on the treatment (Hood et al. 2016, Fettig et al. 2021).

As discussed more thoroughly in the Timber assessment, even-aged silvicultural practices create conditions that are more conducive and less resilient to severe bark beetle events relative to uneven-aged silvicultural practices.

Mountain pine beetle epidemics cause significant changes in stand structure and composition. Tree mortality caused by mountain pine beetle negatively impacts timber stocking levels, wildlife habitat for some species, and aesthetic and recreation values (Allen et al. 2020). Fire hazard is altered, with increased pine regeneration mixed with heavy surface fuels. In the most recent epidemic, mortality was highly variable across the Forest, with some areas experiencing heavy mortality and others experiencing little to none. More than half (55%) of stands incurred moderate to heavy mountain pine beetle mortality, with about 30% of trees larger than 7-inches dbh (diameter at breast height, measured at 4.5 ft above ground level) killed during the epidemic (Allen et al. 2020).

Other Disturbances

Other disturbances that affect forest structure, diversity, and composition in the ponderosa pine ecosystem include weather events (e.g., wind, hail, tornados, and snow), other insects, parasites, pathogens, and animals (Graham et al. 2021).

The pine engraver beetle or ips beetle (*Ips pini*) is native to the Black Hills and attacks pine trees. Although it is like the mountain pine beetle, the life cycle and management recommendations for occurrences of pine engraver beetle are different. Pine engraver beetles breed in windthrown ponderosa pine trees, trees damaged by wind and snow, and logging slash greater than two inches in diameter (Sheppard and Battaglia 2002). During times of drought, pine engraver beetles have been known to cause high mortality in unthinned young stands (Sheppard and Battaglia 2002). Pockets of pine engraver beetle have been observed recently.

Armillaria (*Armillaria* spp.) is a root disease that can either kill trees by attacking the cambium and inner bark, causing decay over time, or by stressing trees thereby predisposing them to attacks by insects and pathogens. Armillaria also has a propensity to reside in trunks of trees for several decades. This has resulted in a positive correlation between stands where silvicultural treatment has occurred and increased Armillaria infection. This is especially problematic in areas experiencing new growth due to regeneration because new growth does not have the vigor to resist armillaria and other pathogens (Sheppard and Battaglia 2002, Graham et al. 2021).

As described in Graham et al. (2021), the ponderosa pine regeneration in the Black Hills is vulnerable to other root and stem pathogens, such as red rot (*Dichomitus squalens mellea*), western gall rust (*Peridermium harknessii*), and needle cast (*Elytroderma deformans*). Similarly, animals such as mice, cottontail, and jackrabbits can girdle and kill seedlings. Deer, elk, cattle, and sheep also damage and kill ponderosa pine trees by trampling, rubbing, and browsing.

Weather, in the form of wind, snow, ice, tornados, and hail, intermittently damages and kills ponderosa pine trees throughout the Black Hills. Wind kills individual trees yearly and tornados occasionally strike small patches (e.g., 10 to 15 acres) to large areas (e.g., 7,000 acres) of trees. Large hail, wind, and snow can damage sapling- to pole-sized trees (Graham et al. 2021). Weather events, mortality caused by diseases, and animals are significant contributors to tree mortality in the Black Hills (see table below that was published in Graham et al. 2021).

Table 1—Volume mortality rates based on standing live volume of growing stock trees (> 5 inches d.b.h.), throughout the last several decades in the Black Hills region. Values of mortality category (rounded to 2 significant digits) are based on the proportion that each disturbance contributed to the overall total mortality rate. Values might not add up due to rounding.

Year	Mortality rate (%)	Insect (%)	Fire (%)	Disease (%)	Weather (%)	Other (%)	Mortality (%) without insect included
1962[a]	0.15	0.03	0.00	0.08	Not reported	0.03	0.12
1984[b]	0.26	0.03	0.03	0.00	0.17	0.03	0.23
1999[c]	0.27	0.03	0.03	0.03	0.19	0.00	0.24
2011[d]	1.24	0.80	0.13	0.00	0.27	0.04	0.44
2019[e]	3.07	2.60	0.20	0.05	0.20	0.02	0.47

[a]1962: Mortality and standing live volume based on softwoods across all land ownerships in South Dakota on suitable timberlands (data source: Choate and Spencer 1969).

[b]1984: Mortality and standing live volume based on ponderosa pine across all land ownerships in South Dakota on suitable timberlands (data source: Collins and Green 1988). Mortality by disease was 0.002).

[c]1999: Mortality and standing live volume based on ponderosa pine on the Black Hills National Forest (South Dakota and Wyoming) on suitable timberlands (data source: DeBlander 2002). Mortality by disease was 0.025 and fire was 0.025.

[d]2011: Mortality rate was based on ponderosa pine on the Black Hills National Forest in South Dakota on suitable timberlands. Walters et al. 2013 reported mortality of 1.04%, which included Wyoming and South Dakota; however, when FIA provided the values for 2011 by mortality category, it was only for South Dakota lands.

[e]2019: Mortality and standing live volume based on ponderosa pine on the Black Hills National Forest (South Dakota and Wyoming) on suitable timberlands (source: USDA FS 2021).

Image 3 - Image of Table 1 from Graham et al. 2021 that shows a table listing percents for overall mortality rate, and mortality rates for insect, fire, disease, weather, other, and mortality without insect included. These percents are listed for years 1962, 1984, 1999, 2011, and 2019. The caption states "Volume mortality rates based on standing live volume of growing stock trees (>5 inches dbh), throughout the last several decades in the Black Hills region. Values of mortality category (rounded to 2 significant digits) are based on the proportion that each disturbance contributed to the overall total mortality rate. Values might not add up due to rounding.

Invasive Species

Invasive species are a stressor in the ponderosa pine ecosystem. The most common invasive species is Canada thistle (*Cirsium arvense*). However, new invaders are a bigger concern, with priority species such as yellow toadflax (*Lineria vulgaris*) and St. Johnswort (*Hypericum perforatum*) identified in the Invasive Species Action Plan. Ventenata has been recently identified as a growing concern given its presence in the area (but not currently on the Forest) and is on the Black Hills Invasive Plant Partnership Priority Management List. Cheatgrass (*Bromus tectorum*), while present, is not a major concern currently. Additional information regarding invasive species is in the Insects, Disease, and Invasive Species assessment.

Climate Change

Information in this section about the vulnerability of ponderosa pine to climate change is taken directly from the *Climate change vulnerability in the Black Hills National Forest* report (Timberlake et al. 2022).

Ponderosa pine is a drought- and fire-adapted tree. Ponderosa pine ecosystems have moderate vulnerability to climate change in the Rocky Mountain Region, including the Black Hills (Rice et al. 2018).

Given its widespread range, ponderosa pine is adapted to a wide range of moisture availabilities, though decreases in moisture availability may be particularly impactful to regeneration. Drought conditions may also make trees more susceptible to other disturbances, including insects (Rice et al. 2018). Ponderosa pine growth in the Black Hills correlates with snowpack (Gleason et al. 2021).

The typically prolific pine regeneration in the Black Hills is tied to year-round and high levels of growing-season precipitation. Wet periods result in synchronous recruitment of trees across large areas in the Black Hills (Brown 2006). Although mature ponderosa pine are generally drought-tolerant and fire-adapted, the species is particularly sensitive to drought conditions during seed germination and establishment. Mature trees can be sensitive to a lack of moisture availability during cone development and masting periods (Rice et al. 2018). As such, decreases in available moisture due to climate change, particularly during the growing season, could reduce regeneration in the Black Hills.

Climate projections for the Black Hills are generally uncertain for precipitation but suggest that there may be an increase in winter and spring precipitation, which could potentially benefit the ponderosa pine. However, projections show wide variation in future precipitation and increased variability in year-to-year moisture availability and precipitation may be particularly important. Compared to other ponderosa pine forests, the Black Hills generally have consistent periods of reliable moisture promoting seed development and germination. Future variability in moisture availability from year to year may result in increased variability in regeneration and tree growth compared to the present.

While Black Hills ponderosa pine is well north of the southern range limits of the species, suggesting low vulnerability, the Black Hills may lack higher elevation areas for upslope range shifts in ponderosa pine forests. The lower elevation ecotones for ponderosa pine in the Black Hills may also be vulnerable to vegetation type conversion to grasslands, especially following disturbances that remove seed bearing trees.

One study using a global vegetation model parameterized for the Black Hills indicates that ecotonal areas between prairies and woodlands are projected to experience increased fire frequencies underestimated 21st century climate. This study found that ponderosa pine would continue to persist in these areas in the face of increased fire frequency due to their thick bark and other adaptations that confer resistance to surface fire (King et al. 2013). This study’s conclusions countered the findings of climate envelope modelling, which projected a loss of ponderosa pine in the Black Hills region (Rehfeldt et al. 2006).

Mechanistic models like that used by King and others (2013) are generally viewed as more robust than climate envelop modelling (Iverson and McKenzie 2013).

Studies conducted across the West indicate that fire will become more widespread as a result of climate change. Mature ponderosa pine has species functional traits (e.g., thick bark, self-pruning lower limbs) that confer relatively high resistance to fire (Stevens et al. 2020). As such, ponderosa pine may be resilient to climate-driven changes to fire regimes in the Black Hills; however, this will also depend on the specific forest conditions as some conditions, such as high density or heavy fuel loads, will lower resilience.

The effects of drier conditions on post-fire regeneration are another well-documented climate change vulnerability for ponderosa pine forests, particularly following high severity fires that burn large areas. There are limited seed trees in these areas and climate-driven drought conditions make it difficult for trees to establish (Stevens-Rumann et al. 2018). Studies examining the effects of the Jasper Fire, which burned over 80,000 acres in 2000, suggest limited regeneration in areas that burned at high severities (Lentile et al. 2005, Keyser et al. 2008). One study that examined several fires, including Jasper Fire, indicated that climatic stress was one of three factors most strongly associated with post-fire regeneration patterns, along with burn severity and elevation (Korb et al. 2019).

Climate change indirectly and directly affects insect disturbances that affect ponderosa pine ecosystems. Mountain pine beetles are endemic to ponderosa pine forests in the Black Hills; however, warmer winter temperatures facilitate the survival and population growth of mountain pine beetles. Drought stress also increases trees' susceptibility to pine beetles (Bentz et al. 2010; Rice et al. 2018).

Key Ecosystem Characteristics

Diversity of Ponderosa Pine Size, Density, and Age

FIA plot data provides the most current information on the species and size of trees in the ponderosa pine ecosystem (table 3) as well as ponderosa pine trees across the forest (table 12 in appendix A). These data indicate that ponderosa pine trees in the Forest reach up to about 32-inches diameter at breast height (4.5 feet) (dbh). The majority are in the smallest diameter classes, with 76% of the trees less than 7" dbh. Half are in the smallest (1-2.9") dbh class (table 3). Most of the trees in the ponderosa pine ecosystem are ponderosa pine (81%), with the other 19% being paper birch, bur oak, aspen, and other species (figure 1). FIA seedling data (less than 1" dbh) indicate that in the ponderosa pine forest type, there is an average of more than 1,400 seedlings per acre[16], with about half (52%) of those being ponderosa pine seedlings and the rest being seedlings of other species. This varies across site index classes, from 375 seedlings/acre to 2,200 seedlings/acre.

[16] Sampling error percent (68% confidence level) is 8%.

Table 3. Number of live trees, by diameter class, ponderosa pine forest type, on the Black Hills National Forest, based on the 2017-2019 FIA data.

[Sampling error percent (68% confidence level) is highly variable across species and size classes, ranging from 6 to 118%.]

Diameter Class	Ponderosa Pine	Percent of Total Live Trees	Other Species	Percent of Total Live Trees	Total All Species	Percent of Total Live Trees
1-2.9"	110,675,547	37.0%	38,326,324	12.8%	**149,001,871**	**49.8%**
3-4.9"	39,500,224	13.2%	11,157,285	3.7%	**50,657,509**	**16.9%**
5-6.9"	24,348,457	8.1%	4,262,266	1.4%	**28,610,723**	**9.6%**
7-8.9"	24,057,359	8.0%	2,543,952	0.9%	**26,601,312**	**8.9%**
9-10.9"	16,582,972	5.5%	901,864	0.3%	**17,484,836**	**5.8%**
11-12.9"	10,766,363	3.6%	619,964	0.2%	**11,386,327**	**3.8%**
13-14.9"	6,228,337	2.1%	63,260	0.0%	**6,291,597**	**2.1%**
15-16.9”	4,276,335	1.4%	107,133	0.0%	**4,383,468**	**1.5%**
17-18.9”	2,318,705	0.8%	-	-	**2,318,705**	**0.8%**
19-20.9”	1,416,759	0.5%	-	-	**1,416,759**	**0.5%**
21-22.9”	668,959	0.2%	16,491	0.0%	**685,450**	**0.2%**
23-24.9”	157,456	0.1%	36,257	0.0%	**193,713**	**0.1%**
25-26.9”	37,692	<0.1%	-	-	**37,692**	**<0.1%**
27-28.9”	48,070	<0.1%	-	-	**48,070**	**<0.1%**
29-30.9”	18,129	<0.1%	-	-	**18,129**	**<0.1%**
31-32.9”	20,010	<0.1%	-	-	**20,010**	**<0.1%**
Total	**241,121,373**	**80.6%**	**58,034,797**	**19.4%**	**299,156,170**	**100%**

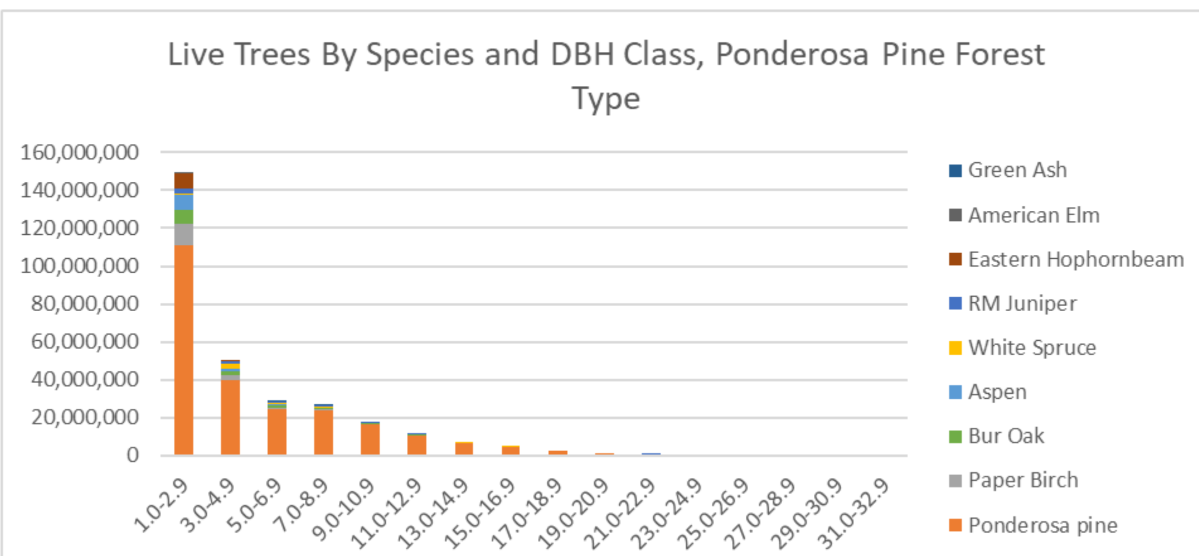
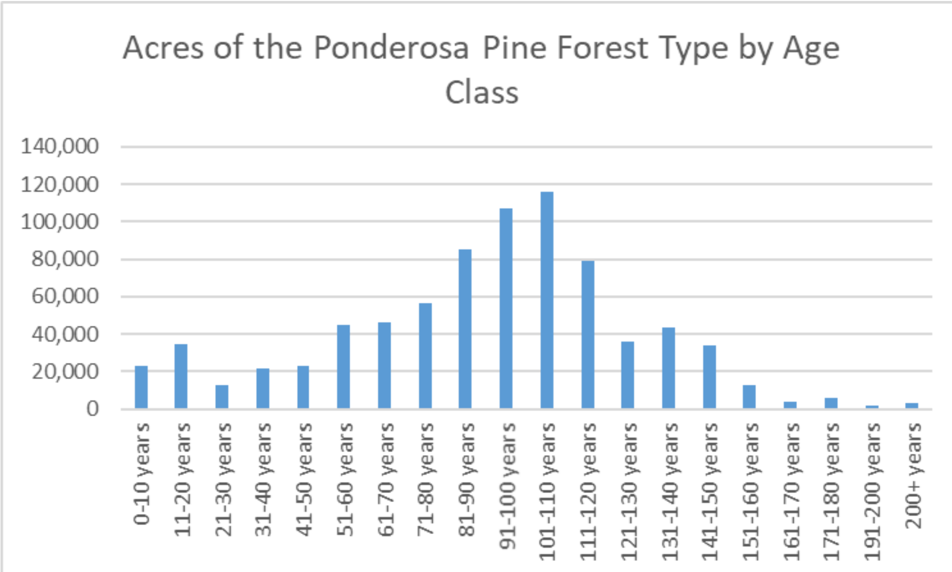


Figure 1. Diameter distribution of live trees, ponderosa pine forest type, by species

The dominant age class of ponderosa pine varies from 0 – 200+ years, as seen in figure 2. The age class distribution shows about half the acres (about 387,000 acres, 49%) are in the 80–120-year age range.



Sampling error percent (68% confidence level) is highly variable across age classes, ranging from 14 to 100%.

Figure 2. Extent of ponderosa pine forest type by dominant age class from 2017-2019 FIA data

Looking at the trends since 2000-2005, using repeat measurements only, as described in Chapter 1, is complicated by the fact that total acreage in the ponderosa pine forest type has decreased by a substantial amount (see table 2b and associated reduction in ponderosa pine forest type of approximately 116,000 acres), which makes some trends seem less pronounced. This data indicates an increased acreage in the youngest age classes (0-60 years) of about 42,000 acres and a reduced acreage in the older age classes (60 years +) of about 158,000 acres (appendix A, table 16) since 2000-2005.

FIA data estimates there are 789,803 acres of the ponderosa pine forest type. Most of this acreage (73%) is in the large diameter stand-size class[17], with 10% in the medium diameter stand-size class and 17% in the small diameter stand-size class (table 4).

The density class distribution, based on the FIA data, indicates that there is a relatively even distribution over the four density classes in the ponderosa pine forest type (table 4), but with a little more area in the 41-80 square foot density class and a little less area in the highest density class.

Looking collectively at both the stand-size class and density class distribution, a quarter of the ponderosa pine type is in the large diameter stand-size class and the 41-80 square feet/acre density class and just under a quarter is in the large diameter stand-size class and 81-120 square feet/acre density class.

[17] FIA estimates the stand-size class based on the predominant diameter class of live trees based on stocking. Large diameter trees are at least 11.0 inches diameter for hardwoods and at least 9.0 inches diameter for softwoods. Medium diameter trees are at least 5.0 inches diameter and smaller than large diameter trees. Small diameter trees are less than 5.0 inches diameter (USDA Forest Service FIADB Users Guide).

The variation in stand-size class and density is not surprising given ponderosa pine occurs on a range of ecological sites supporting different growth potential as well as the varied disturbance history across the forest associated with tree harvest, fires, insects, and other factors.

Table 4. Current extent of ponderosa pine forest type by density class and stand-size classes within each density class on the Black Hills National Forest, based on 2017-2019 FIA data.

[Sampling error percent (68% confidence level) is highly variable across categories, ranging from 5 to 108%.]

Density Class based on Live Basal Area	Acres in Small Diameter Stand-Size class	Acres in Medium Diameter Stand-Size Class	Acres in Large Diameter Stand-Size Class	Total Acres (All Stand-Size Classes)
0-40 sqft/acre	100,589 (12.7%)	16,671 (2.1%)	66,232 (8.4%)	**183,492 (23.2%)**
41-80 sqft/acre	30,061 (3.8%)	27,008 (3.4%)	204,133 (25.8%)	**261,202 (33.1%)**
81-120 sqft/acre	2,500 (0.3%)	15,939 (2.0%)	174,884 (22.1%)	**193,322 (24.5%)**
120+ sqft/acre	-	17,710 (2.2%)	134,077 (17.0%)	**151,788 (19.2%)**
Total (All Density Classes)	**133,150 (16.9%)**	**77,328 (9.8%)**	**579,325 (73.4%)**	**789,803 (100.0%)**

Looking at the trends since 2000-2005, using repeat measurements only, indicates a reduced acreage and percentage in the large and medium diameter stand-size classes and an increase in the acreage and percentage in the small diameter stand-size class (approximately 57,000-acre increase, 19% currently vs 10% in 2000-2005) (appendix A, table 17). Looking at the trends since 2000-2005, using repeat measurements only, indicates a larger acreage and percentage in the lower density classes (0-80 BA, approximately 98,000-acre increase) and a lower acreage and percentage in the higher density classes (80+ BA, approximately 214,000 acre decrease) (appendix A, table 18). These recent trends in the age class, stand-size class, and density class distributions would be expected given the high levels of vegetation management on the Forest as well as changes due to natural disturbances such as the mountain pine beetle epidemic.

Habitat Structural Stage Distribution and Late-Successional Forest

Habitat structural stages (HSS) are the several developmental stages of tree stands described in terms of tree size and the extent of canopy closure they create. As defined in the current Black Hills forest plan, they include:

Habitat Structural Stage 1 (Grass/Forb): The grass/forb HSS was historically a product of fires, windthrow or similar disturbances. Under forest management, this stage can be created through harvesting. This stage is dominated by grasses and forbs lasting until tree seedlings become established.

Habitat Structural Stage 2 (Shrub/Seedling): The shrub/seedling HSS consists of shrubs such as chokecherry, rose and serviceberry along with tree seedlings. A stand remains in HSS 2 until the tree seedlings reach one inch diameter at breast height (DBH), which should take less than a decade.

Habitat Structural Stage 3 (Sapling/Pole): The sapling/pole HSS consists of trees with stems one to nine inches DBH. This stage typically persists up to 30 years to age 70. Less than 40 percent canopy closure is 3A; 40 to less than 70 percent canopy closures is 3B; and greater than 70 percent canopy closure is 3C. Understory production is inversely related to overstory pine canopy cover.

Habitat Structural Stage 4 (Mature): The mature HSS begins when trees reach the 9-inch DBH class. Trees remain in this stage until they are about 160 years old. As with HSS 3, understory productivity depends upon the overstory canopy cover. Less than 40 percent canopy closure is 4A; 40 to less than 70 *percent canopy closures is 4B; and greater than 70 percent canopy closure is 4C. The sizes of trees in this stage will vary depending upon growing-site potential and the density of the stand.*

Habitat Structural Stage 5 (Late Succession): This HSS is characterized by very large trees (16+ inches DBH). Trees are at least 160 years in age; ponderosa pine that reach this age are commonly referred to as "yellow barks." Late succession ponderosa pine may occur in dense stands but may also grow in the open or in "parklike" stands (Mehl 1992).

Current plan direction includes the following objective regarding the HSS distribution which applies to five management areas (MAs 4.1, 5.1, 5.4, 5.43, 5.6).

> *4.1-203. *__NEW__. Manage for the following percentages of habitat structural stages in ponderosa pine across the management area in a variety of sizes and shapes.* ***OBJECTIVE***

SS1	5%	SS4A	25%*
SS2	5%	SS4B	25%*
SS3A	10%	SS4C	5%*
SS3B	15%	SS5	5%**
SS3C	5%		

*10% of the structural stage 4 ponderosa pine acreage in the management area will have an average tree size of "very large". Seek opportunities to increase understory shrubs in open-canopy structural stages.

**Active management is allowed, and may be necessary, to provide desired late-successional characteristics.

Image 4 - Image of a table from the current land and resource management plan that show HSS distribution for five management areas (MAs 4.1, 5.1, 5.4, 5.43, 5.6). The table shows SS1 has and objective at 5%, SS2 at 5%, SS3A at 10%, SS3B at 15%, SS3C at 5%, SS4A at 25%, SS4B at 25%, SS4C at 5%, and SS5 at 5%. For SS4A, SS4B, and SS4C, there is an asterisk showing a note stating "10% of the structural stage 4 ponderosa pine acreage in the management area will have an average tree size of "very large." Seek opportunities to increase understory shrubs in open-canopy structural stages." SS5 has a double asterisk directing to a note that states "Active management is allowed, and may be necessary, to provide desired late-successional characteristics.

In addition to the HSS objective mentioned above, which includes late-successional forest as HSS 5, there is also a designated management area (3.7) where the goal is to manage for sustainable late-successional landscapes:

> *3.7-201. Manage each contiguous unit within this management area as a late-successional landscape, so that late-successional structure is always present within some portion of each unit. OBJECTIVE*

A comparison of forest area by HSS for ponderosa pine forest, between the 1995 RIS inventory database and 2021 FSVeg Spatial vegetation layer highlights the following trends (table 5):

- Non-stocked areas (HSS1) and the total area of seedling stands (HSS2) have increased by more than 100,000 acres.
- Open, mature stands (HSS4A), created through the implementation of shelterwood establishment cuts, increased during the implementation of the MPBR and other projects with similar objectives. These treatments reduced the level of the moderately closed to closed mature stands (HSS4B and HSS4C).

- Overall, more than 150,000 acres of moderately closed and closed stand conditions (HSS3B, HSS3C, HSS4B, HSS4C) have changed through either management, mountain pine beetle activity, fire, tornados, or a combination of these disturbances to non-stocked areas and open stand conditions (HSS1, HSS2, HSS3A, HSS4A).
- The level of moderately closed and closed mature stands (HSS4B and HSS4C) has decreased by more than 50,000 acres during this period.
- Late-successional stands (HSS5) have been heavily impacted by mountain pine beetle mortality and fire. Overall, this HSS has declined by 72% since 1995.

Table 5. Change in ponderosa pine extent by habitat structural stage on the Black Hills National Forest, based on the 1995 RIS database and the 2021 FSVeg Spatial layer.

Habitat Structural Stage	1995 RIS database (acres)	2021 FSVeg Spatial Layer (acres)	Change in Acres[18]	Percent of Total Area, 1995	Percent of Total Area, 2021
1 – Grass/Forb	23,502	88,982	65,480	2.3%	8.7%
2 – Shrub/Seedling	10,689	52,938	42,249	1.0%	5.1%
3A – Sapling-Pole (1-9”), 10-40% cover	97,511	95,126	-2,385	9.4%	9.2%
3B – Sapling-Pole (1-9”), 40-70% cover	134,949	54,858	-80,092	13.0%	5.3%
3C – Sapling-Pole (1-9”), > 70% cover	46,767	27,877	-18,890	4.5%	2.7%
4A – Mature (9”+), 10-40% cover	332,392	387,992	55,601	31.9%	37.7%
4B – Mature (9”+), 40-70% cover	258,466	204,145	-54,321	24.8%	19.8%
4C – Mature (9”+), > 70% cover	114,798	110,601	-4,197	11.0%	10.8%
5 – Late Succession (16”+)	22,409	6,156	-16,253	2.2%	0.6%
Total	1,041,483	1,028,675	-12,808	100.0%	100.0%

Looking at the ponderosa pine HSS 4 areas forest-wide, 90,100 acres (13%) have an average tree size of "very large" (16+ DBH) out of the total ponderosa pine HSS 4 acreage (702,738 acres).

Looking more closely at the 6,156 acres of ponderosa pine late-successional habitat (HSS5), the average stand size varies from 1 to 169 acres, with an average of 35 acres. The average slope varies from 0 – 99 percent with an average of 26%. 1,186 acres of this late-successional habitat (19%) is located on slopes greater than 40%. Spatially across the forest, most of it is on the Northern Hills District (54%) and Hell Canyon District (38%), with little to none on the other two districts (none on the Bearlodge District and 8% on the Mystic District). 1,410 acres (23%) is within 200 yards of roads. 1,947 acres (32%) is within 200 yards of roads, motorized trails and non-motorized trails.

Looking more closely at the 110,601 acres of ponderosa pine SS4C, the average stand size varies from 0 to 460 acres, with an average of 28 acres. The average slope varies from 0 – 94 percent with an average of 26%. 18,794 acres (17%) is located on slopes greater than 40%. Spatially across the forest, most of it is on the Northern Hills District (45%) and Bearlodge District (31%), with less on the other two districts (15% on the Hell Canyon District and 9% on the Mystic District). 25,765 acres (23%) is within 200 yards of roads. 37,256 acres (34%) is within 200 yards of roads, motorized trails and non-motorized trails.

[18] In 1995, the threshold between HSS classes 3 and 4 was 8.0 inches dbh. This change in protocol 1995 to 2021 will affect comparisons between areas by size class but not by density class.

Snags and Downed Wood

Snags and downed wood provide numerous benefits such as wildlife habitat, nutrient cycling, and forest structural complexity (Shepperd and Battaglia 2002). Snags provide habitat for many forms of life, including fungi, mosses, lichens, and insects. At least 23 birds and 10 mammal species in the Black Hills depend on snags during a portion of their life history for nest sites, roosts, perches, dens, and foraging substrate (Shepperd and Battaglia 2002). As such, snag availability and recruitment in the ponderosa pine ecosystem is a key element of ecological integrity.

Current plan direction related to snags is as follow:

> *211. *Within a management area in conifer-forested portions of the Forest, provide an average of 3 hard snags greater than 9-inch dbh and 25 feet high per acre, well-dispersed across the Forest, 25 percent of which are greater than 14-inch dbh. (Objective)*
>
> *2301.*
>
> *a. *Retain all snags greater than 20-inch dbh unless a safety hazard. If snag densities within a project area are below Objective 211, retain all snags unless they are a safety hazard. If large snags (>14 in dbh) are not available, retain snags in the largest size class available. This standard does not apply to areas salvaged under Objective 11-03. STANDARD*
>
> *b. *Retain at least six hardwood snags per acre in hardwood stands. Retain all snags in hardwood stands with snag density of less than six per acre. STANDARD*
>
> *2304. a. Prohibit cutting of standing-dead trees for fuelwood, except in designated areas. STANDARD*
>
> *2305. All soft snags should be retained unless they are a safety hazard. STANDARD*

An evaluation of snag abundance within unmanaged stands (Lentile et al. 2000) found no significant differences in snag densities measured in three regions of the Black Hills National Forest (south, central, north). Unmanaged areas in the Forest had mean snag densities (all regions) of 17 per acre for dbh greater than 3 inches, 3.6 snags per acre for dbh greater than 10 inches, and 0.33 snags per acre for dbh greater than 20 inches (Lentile et al. 2000). Lentile et al. (2000) also learned the following:

- Snags less than 8-inch dbh dominated the snag population.
- Forage and cavity use by wildlife increases with snag size although small- diameter snags are used to some degree.
- Some wildlife species depend on large snags[19].
- Snag distribution (per acre) is relatively even, spatially.
- Snag recruitment is uniform through time.
- Median snag persistence is 15 years.

[19] As one example, northern long-eared bats in the Bearlodge Mountains select roosts in areas with larger diameter ponderosa pine snags (Abernethy et al. 2019).

FIA data (2017-2019) was used here to estimate the current number of snags per acre for the ponderosa pine forest type; these data indicate an average of 21 snags per acre (5 inches dbh or larger)[20] (appendix A, table 13).

This FIA data indicates there is currently a higher snag density relative to the snag density in unmanaged areas as reported in Lentile et al. 2000 for snags overall and for snags greater than 10 inches dbh. Current density of snags greater than 20 inches is less than that reported for unmanaged areas for that size range. Current snag densities exceed those described for Black Hills old-growth ponderosa pine (a minimum of 2 per acre at least 10 inches dbh) as described in Mehl (1992). While current snag densities were not broken out in terms of hard and soft snags, they appear to exceed the amounts described in plan objective 211.

Comparing the 2017-2019 FIA estimate of snags per acre (5 inches dbh and larger) to an earlier estimate (the 2000 periodic inventory for WY and the 2001-2005 annual inventory for South Dakota), using repeat measurements only, the earlier estimate is slightly lower at 18 snags/acre relative to current conditions.

Down woody material is an important element of the ecosystem that helps retain moisture, trap soil movement, provides habitat and forage for wildlife (such as American marten and many other species), and provides for the establishment of forbs, grasses, shrubs, and trees.

Current plan direction related to down woody material is as follow:

> *212. In conifer forested portions of a planning unit, provide at least once during a rotation (approximately 100 years) an average of 5 to 10 tons per acre of down, dead woody material at least 3 inches in diameter, provided there is no conflict with fire or pest management objectives. In the shelterwood silviculture system, accomplish this through commercial and precommercial treatments. Provide this tonnage no later than the removal cut (overstory removal) or a combination of removal cut and precommercial thinning of the established stand (thinning to be accomplished within 10 years of the removal cut). (Objective)*
>
> *2307. Leave large woody debris on harvested or thinned sites to help retain moisture, trap soil movement, provide microsites for establishment of forbs, grasses, shrubs, and trees, and to provide habitat for wildlife. GUIDELINE*
>
> *2308. a. *During vegetation management activities on ponderosa pine forested sites, retain an average of at least 50 linear feet per acre of coarse woody debris with a minimum diameter of 10 inches. On white spruce forested sites retain an average of at least 100 linear feet per acre of coarse woody debris with a minimum diameter of 10 inches. STANDARD*

FIA data indicates an average of 5 tons/acre of coarse woody debris[21] (3 inches dbh or greater) in the ponderosa pine forest type[22]. This has likely increased over time as an earlier estimate for the Black Hills National Forest for this size class was less than 2 tons/acre (figure 23 in Walters et al. 2013) and will likely increase into the future as trees killed by mountain pine beetle fall.

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[20] Sampling error percent (68% confidence level) for total snags per acre is 8%.

[21] FIA Coarse Woody Debris (CWD): Pieces or portion of pieces of down dead wood with a minimum small-end diameter of at least 3 inches and a length of at least 3 feet (excluding decay class 5). CWD pieces must be detached from a bole and/or not be self-supported by a root system with a lean angle more than 45 degrees from vertical.

[22] Sampling error percent (68% confidence level) for coarse woody debris is 43%. Estimate was output from the FIA Evalidator public online tool, with 59 FIA plots included.

Regeneration

Regeneration of ponderosa pine on the Black Hills National Forest has historically been prolific (Graham et al. 2021). Most ponderosa pine stands regenerate naturally following timber harvest. Stands that meet desired stocking levels and have been certified are tracked within the Forest Service Activity Tracking System (FACTS database). On average, since 1997, more than 11,000 acres per year of natural regeneration has been certified.[23]

While plentiful, ponderosa pine natural regeneration is variable across the forest. Density of natural regeneration varies by factors such as site productivity, soils, seed source abundance, and competing vegetation. Natural regeneration failures have been rare on the Black Hills National Forest except within large, high severity burn areas (where there is no or distant seed source)[24], areas where other vegetation suppresses seedlings such as bur oak, or highly productive sites where grasses rapidly become the dominant vegetation. Planting has been very limited, except for large, high severity burns such as the Jasper Fire. Portions of the 2000 Jasper Fire (approx. 50,000 – 60,000 acres) have not regenerated. The ongoing planting program in the Jasper Fire burn area, initiated in 2003, treats approximately 400 acres annually.[25]

Research is currently investigating post-wildfire regeneration on the Forest[26]. Large areas of high severity fire limit the availability of seed trees and climate-driven drought conditions make it difficult for trees to

[23] Regeneration is measured from field survey or walk-through survey on forested lands. Stands stocked with a minimum of 150 trees per acre are certified as regenerated (Forest Plan standard 2416b). Forest regeneration needs and the certification of stands that meet minimum stocking standards are tracked annually in the FACTS database (Forest Activity Tracking System). Spatially, regeneration is tied to site index and soils. For example, the Northern Hills has higher site productivity and natural regeneration levels than the southern portion of Hell Canyon. Regeneration is variable from the 100s to 1000s per acre. Tabular FIA data and spatial data have information about site productivity and soils that could be used during future phases of plan revision.

[24] As summarized in Owen et al. (2017), ponderosa pines do not sprout or have serotinous cones, and do not maintain long-lived seed banks; regeneration is dispersal-limited in large patches of high-severity fire and is dependent on surviving seed-sources or residual live trees. Ponderosa pine seeds are morphologically adapted for wind dispersal, but their relatively large seeds rarely travel farther than 30m from seed sources, which limits regeneration in the center of large, high severity burn patches, often greater than 200m from seed sources. Ponderosa pine seed can also be animal dispersed, and long-distance dispersal by birds may be important for regeneration in the interiors of high severity burn patches. However, poor ponderosa pine seed crops, seed predation, and drought can all limit tree regeneration.

[25] An average of 430 acres per year have been planted with ponderosa pine trees in the Jasper Fire burn area since 2003. Generally, areas are targeted based on the pre-burn conditions, forest plan management area direction, and logistics/access. Typically, 400 trees per acre of ponderosa pine are planted, with a target of 250-300 surviving seedlings. There is a requirement to monitor seedling survival rates through first- and third-year surveys. The objective of these surveys is to assess the quality of nursery stock and identify causes of undesirable survival rates so that needed adjustments can be implemented. Survey results and interpretation are reported to the Forest Service Regional Office annually.

[26] Research is currently in progress looking at ponderosa pine regeneration in high-severity fire areas to see how regeneration density is influenced by distance to seed source, topo-climate, and ground layer conditions, which will help inform reforestation activities and post-wildfire management. Preliminary results indicate ponderosa pine seedling regeneration density decreases the further away you get from the edge of a living tree source. Tree regeneration after fires such as the Jasper Fire may only occur where there is still a tree seed source within approximately 50 meters (M. Battaglia, personal communication). Additional research is also looking at the reintroduction of prescribed fire within the Jasper Fire perimeter. This prescribed re-burn resulted in reduced coarse fuel loads and a reduction in ponderosa pine regeneration in both the moderate and high severity areas of the Jasper fire. However, for the moderate severity areas of the Jasper Fire, there was still plenty of ponderosa pine regeneration and the overstory was still alive, providing a seed source. In the high severity portion of the Jasper Fire, regeneration is low, but variable (M. Battaglia, personal communication).

establish (Stevens-Rumann et al. 2016). Studies examining the effects of the Jasper Fire, which burned over 80,000 acres in 2000, suggest limited regeneration in areas that burned at high severities (Lentile et al. 2005). One study that examined several fires, including the Jasper Fire, indicated that climatic stress was one of three factors most strongly associated with post-fire regeneration patterns, along with burn severity and elevation (Korb et al. 2019).

Non-stocked areas are increasing. The increase in non-stocked area is in part due to the 2000 Jasper Fire, with stocking and seed sources lost on more than 50,000-60,000 acres of ponderosa pine forest, the majority of which will not regenerate naturally due to lack of seed source. Some increase in non-stocked area (table 2b) is due to other factors as the changes reflected in this table occurred after the 2000 Jasper Fire.

The typically prolific regeneration in Black Hills National Forest is tied to the year-round and growing-season precipitation experienced, with wet periods resulting in synchronous recruitment of trees across large areas in the Black Hills (Brown 2006). Although mature ponderosa pine is generally drought-tolerant and fire-adapted, the species is particularly sensitive to drought conditions during seed germination and establishment. Mature trees can also be sensitive to a lack of moisture availability during cone development and masting periods (Rice et al. 2018). As such, decreases in available moisture due to climate change, particularly during the growing season, could reduce regeneration in the Black Hills (Timberlake et al. 2022).

In addition, while there may be a benefit for ponderosa pine if there is an increase in winter and spring precipitation, there is wide variation in future precipitation projections and the increased variability in moisture availability from year to year may result in increased variability in ponderosa pine regeneration compared to what is currently experienced (Timberlake et al. 2022).

Natural Range of Variation - Tree Size, Density, and Spatial Heterogeneity and Arrangement

Historical accounts and surveyor notes provide information about what the forest was like in the late 1800s, at the time of Euro-American settlement and the decades following.

Historical accounts and surveyor notes describe a variety of forest conditions, from grasslands to closed, dense stands. For instance, Dodge (1876) states "I estimate that there are, in the two sections, something over four thousand square miles of country covered with pine. Of this, including the Red Valley, the parks, the bare bottoms and valleys of creeks, I estimate that four-tenths are entirely without timber. Another four-tenths are composed of young forests, excellent for railroad ties, small buildings, fencing, etc., but not yet fit for the saw-mill. One-tenth is wind-shaken, or injured by lightning or fire, and one-tenth is good lumber."

Graves (1899) described the forests of the Black Hills during 1897, about 23 years after Euro-American settlement. He states:

> "The forest as it appears today, irregular and broken, and composed in many places of defective and scrubby trees, does not represent what the yellow pine can produce. There are trees of every age and size, and there are large areas where there are no trees at all… The cause of the broken condition of the forest, of the large proportion of defective trees, of the many windbreaks, of the mountain prairies, parks, and bald ridges, has been the destructive forest fires which have swept the Black Hills periodically for years and probably centuries. The natural forest of yellow pine is dense and composed of trees of about the same age. It often comes up in even-aged stands, and the irregular uneven-aged condition as now found is entirely due to external influences. The original forest, uninfluenced by fire or windfalls, is found in but few places in the Black Hills… Taking the forest as a whole, it is composed of

> trees of nearly every age class. The original growth is broken by patches of younger trees varying in extent from a few to several hundred acres. The old timber has an age of 250 – 300 years. It is found chiefly along streams, in ravines and canyons, at the heads of creeks and side draws, and on protected flats and lower slopes."

This text along with the samples provided in Graves (1899) indicate his belief that the natural forest (in this case referring to forest without the influence of fire or windfall) was dense, even-aged, and rare, whereas the irregular and broken condition of the forest, with trees of every age and size and areas with no trees at all, was due to forest fires and windfall.

General Land Office (GLO) surveyors also included brief narratives about the vegetation, or fields, houses, and cut stumps. At various points these notes described changes in the vegetation encountered, including dense timber, heavy timber, medium timber, scattering timber, scattering stunted pine, no timber, second growth, and timber burnt and fallen. Thus, their notes depict a variety of structure (Tatina and Hanberry 2022).

Additionally, as summarized by Tatina and Hanberry (2022), several federal government expeditions report general conditions, encompassing areas burned by fire, blown down timber, dense stands of larger (20 to 30 cm) diameter pine trees, and scattered pine groves and indicate the Black Hills were less covered by trees during 1874 than today based on photographic comparisons to the 1874 Custer Expedition.

In terms of tree sizes, Dodge (1876) states that the forest is composed of trees the "very large majority of which are less than eight inches in diameter" and indicates a scarcity of old forest, large fine sawlogs in very considerable numbers (but rarely in large bodies), scattered old and large trees through the young forest, and occasional fine timber in the bottoms of creeks or in narrow gorges.

Graves (1899) recognizes three classes of old trees. The first is found on rich soil and in protected situations, with trees averaging about 20 inches in diameter and a maximum size of three feet. The second covers the greater portion of the Black Hills is similar in diameter, but not as tall (averaging about 65 to 70 feet in height rather than closer to 80 feet). This second type of forest is found in more exposed situations and more subject to forest fires. The third type of forest is found on ridges and steep slopes and is both smaller and shorter than the other classes, with an average diameter of 14-17 inches and heights less than 60 feet. Graves (1899) also indicates a large amount of young growth scattered throughout the original forest and a great belt almost entirely of second-growth timber. He indicates the forest is composed of trees of nearly every age class. The original growth (at 250 to 300 years) is broken by patches of younger trees varying in extent from a few to several hundred acres. Both Dodge (1876) and Graves (1899) recognize the presence of large pine trees, two to three feet in diameter in an area protected from wind and fire. Tatina and Hanberry (2022) discuss how other historical accounts also noted large trees.

Shinneman and Baker (1997) concluded that large stand-replacing disturbances produced patches of dense, even aged trees with closed canopies in the northern and central Black Hills. In contrast, the warmer and drier southern Black Hills, south-facing slopes, and exposed areas may have been dominated by frequent, low-intensity surface fires and other small disturbances that maintained open-canopy forests. There is also indication that some large patches of even-aged forest structure seen at settlement may have resulted from an extended wet period rather than the result of large crown fires during this period (Brown 2001, Brown 2003, USDA Forest Service 2005, Brown 2006).

As described in Brown and Cook (2006) and Murphy (2017), ponderosa pine forests in the Black Hills historically[27] consisted of a diverse landscape mosaic that varied from nonforested patches and open stands of very few large trees to quite dense stands with many similarly sized and similarly aged trees.

[27] Brown and Cook (2006) use 1900 as their point of reference.

Although much of the forest was relatively open, dense patches occurred and contributed to considerable spatial heterogeneity. Heterogeneity was present not only across the Black Hills but also within smaller patches sampled for the goshawk habitat assessment study. Historical photographs and written accounts document this highly diverse landscape containing abundant openings and meadows, open stands of larger ponderosa pine trees, and closed canopy stands of younger and smaller trees. Brown and Cook (2006) suggest,

> "restoration and maintenance of large openings, woodlands and open forest stands, retention of existing large trees wherever they are found, as well as large patches of dense even-aged trees. Such a mosaic of age and habitat structural classes would be expected to provide the most diverse habitats for a broad spectrum of understory plant and wildlife species, including species such as the northern goshawk and its prey (Long and Smith, 2000). Patches of denser forest structure and smaller trees are present across much of the Black Hills, but what is largely missing from the contemporary forest are the mosaics of different spacing, especially those containing larger and older trees, that were present in the historical forest."

Historical tree surveys during Euro-American settlement offer information about the natural range of variation. Recent research (Tatina and Hanberry 2022) compared tree compositions and densities from historical General Land Office (GLO) records (years 1878 to 1915) and current FIA tree surveys (years 2011 to 2016) in the Black Hills Highlands of South Dakota. They found ponderosa pine currently is smaller in mean diameter by 7.4 cm (2.9 inches) than historically and found that tree densities have increased two- to more than four-fold. They found that although the Black Hills landscape overall was savannas and woodlands, the spectrum from grasslands to dense stands occurred historically.

Preliminary research results comparing Black Hills forest structure in 2014 to historical forest structure (M. Battaglia, personal communication) indicate that:

- Forest basal area was slightly higher in 2014 than it was historically.
- Tree density is 3x higher than historically and quadratic mean diameter is about 4 inches smaller than historical conditions.
- Historically, uneven-aged forest structure was ubiquitous whereas current management supports even-aged stands.
- Historically, there was evidence of aggregation of trees in groups, single trees, and openings. Also evidence of randomly distributed trees. No evidence of uniformly distributed trees.

This ongoing research supports the idea that in the past, the forest was dominated by larger trees than those currently present. There has also been a simplification in structure within stands and at broader spatial extents, as the structure of the ponderosa pine forest has shifted to a landscape dominated by even-aged structure and with the current increased tree density leading to fewer gaps and more even spacing and size distributions within groups. Current forest conditions are more homogeneous, with higher tree density and with more continuous canopies and greater fuel continuity, increasing the likelihood of crown fire (Brown et al. 2008, Brown and Cook 2006, Murphy 2017).

Current conditions and the even-aged management that is typically practiced support a more homogeneous patch size distribution. Given the mixed-severity fire regime (including both more frequent, lower-intensity surface fires and less frequent, higher-intensity crown fires) that occurred in the Black Hills, a management regime that includes both uneven-aged and even-aged management could potentially best mimic historical stand and landscape structure. This is because, as described earlier, even-aged conditions are associated with a moderate to low frequency, moderate to high severity disturbance regime while uneven-aged conditions are associated with a high frequency, low severity disturbance regime. As discussed earlier, this is tied to elevation and moisture availability, with occasional mixed-severity fires likely occurring in areas of higher elevation and mesic sites (Murphy 2017).

In some areas, fires would have regulated the expansion of ponderosa pine forest. Management is currently done in some areas to reduce pine encroachment into aspen, oak, and grassland areas (for instance, as part of the Black Hills Resilient Landscapes project). This is also integrated into the current forest plan (see Objective 205, Standard 2107).

Understory and Variation in Understory

Given competition for light, nutrients, and water, overstory density affects understory productivity and composition in ponderosa pine forests. Dense ponderosa pine stands support little or no understory vegetation. In contrast, stands that are more open support varying amounts of graminoids, forbs, and shrubs depending on site characteristics. In general, as ponderosa pine overstory density increases, understory plant biomass and species diversity decrease (Shepperd and Battaglia 2002).

Historically, many ponderosa pine woodlands occurred in open, park-like stands with an understory of shrubs and/or grasses. In the northern Black Hills, where mean annual precipitation is higher, ponderosa pine grows in denser stands with fewer shrubs and a more herbaceous understory (Murphy 2017).

With the onset of fire exclusion and forest management a century ago, ponderosa pine forests in the Black Hills became denser, changing the herbaceous and shrub communities of the Black Hills (Shepperd and Battaglia 2002). Increased density led to substantial loss in diversity and biomass of understory species (Murphy 2017).

While the diversity of understory species may be highest in more open, less dense stands, total diversity would be highest if a variety of stocking levels were present and distributed across the landscape; conditions that were common historically. The heterogeneous forest conditions and resulting understory diversity would provide the most benefit for wildlife (Shepperd and Battaglia 2002, Uresk and Severson 1998).

Additional Information from Shepperd and Battaglia (2002)

As discussed more fully in Shepperd and Battaglia (2002), soil properties in conjunction with overstory density and precipitation influence understory production in the Black Hills. One study found that canopy cover was the most important independent variable for predicting understory production and that Stovho and Virkula soils had the highest production potential of 1,600 lbs. per acre with no cover and normal May to June precipitation, but with Stovho soils producing more graminoids and Virkula producing more forbs. Sawdust soils had the lowest production with only 490 lb. per acre under similar conditions, with hardly any forbs. The Pactola soil sites had different understory production and composition based on aspect.

Shepperd and Battaglia (2002) also describe how several studies in the Black Hills have investigated how ponderosa pine crown cover influences understory production for livestock and wildlife grazing. Dense ponderosa pine stands have little or no understory vegetation but stands that are more open have varying amounts of graminoids, forbs, and shrubs depending on site characteristics. Generally, herbage production decreases with an increase in crown cover in ponderosa pine forests. Examples ranged from total herbage production in a clearcut of 2,160 lb. per acre to 40 lb. per acre with 70 percent crown cover. Another example reported total herbage production for an open stand (0-20 percent crown coverage) at 1,428 – 1,784 lb. per acre, with less (638 lb. per acre) for an intermediate cover class (30–60 percent), and 244 lbs. per acre for the dense canopy cover class (~85 percent crown coverage).

In 1963, a long-term study was initiated in the ponderosa pine/bearberry habitat type within the Black Hills Experimental Forest to determine the effects various growing stock levels (GSL) and size class of ponderosa pine had on forage production and diversity. While more details can be found in Shepperd and Battaglia (2002), the GSL affects the production of herbage in the understory. Generally, the production of graminoids, forbs, and shrubs is similar between sapling and pole stands. Total understory production is highest in the clearcuts and lowest in the unthinned stands, except for years of drought, in which case total annual production of understory vegetation was actually higher in the GSL 20 ft2 per acre plot and not the clearcut, possibly due to the overstory lowering the soil temperature and evapotranspiration. In general, understory production was greatest when density was less than GSL 100 ft2 per acre in sapling stands and when density was less than GSL 60 ft2 per acre in pole stands.

In terms of functional groups, generally forb production is relatively low compared to shrub and graminoid production in understories of ponderosa pine forests in the Black Hills. The production of forbs is negatively affected by overstory canopy coverage and basal area. For both sapling and pole-sized stands, forb production is highest where overstory density is low and decreases substantially as the density increases. Forb diversity is highest in areas without canopy coverage.

Graminoids are more sensitive to changes in canopy coverage and basal area than are forbs or shrubs. Several studies report a sharp decrease in graminoid production with an increase in ponderosa pine canopy coverage and basal area. One study reported up to 1,730 lb. per acre of graminoid production in a clearcut compared to 25 lb. per acre under canopy coverage greater than 70 percent.

Shrub production is less sensitive to ponderosa pine canopy coverage and basal area. Shrubs make up 35 to 50 percent of total understory production in clearcuts and up to 70 percent in dense stands. Estimates of shrub production vary between studies. Shrub diversity under different ponderosa pine densities varied with study site, but in general, within a study site, diversity did not differ, although dominance did differ.

Summary of Ecological Integrity

To assess the ecological integrity of each ecosystem, it is helpful to first describe what that ecosystem would be like if it had high ecological integrity, based on the natural range of variation, ecosystem drivers, and key ecosystem characteristics described previously. This provides a reference for comparison with current ecosystem conditions and illuminates why an ecosystem may have high, low, or moderate ecological integrity.

Ponderosa pine ecosystems with high ecological integrity experience frequent fires of low to mixed severity. Given mountain pine beetles are a natural part of the ecosystem, they experience mountain pine beetle activity, with low levels of mortality enhancing forest complexity and heterogeneity and with the severity of these events low enough that desired forest conditions can be maintained. They are structurally diverse, including open stands of very few trees (most of them large), but also nonforested areas and some dense stands with many trees. The ecosystem exhibits high spatial heterogeneity within stands, with a variable spacing of dense groups of trees, scattered individual trees, and openings. Adequate ponderosa pine regeneration occurs following disturbance. Forests include a range of age classes and sufficient snags and downed wood to support wildlife species and other ecosystem services. Larger trees are abundant.

Given the mixed-severity fire regime (including both more frequent, lower-intensity surface fires and less frequent, high-intensity crown fires) that occurred in Black Hills National Forest, a management regime that includes both uneven-aged and even-aged management could potentially best mimic historical stand and landscape structure. The current ecological integrity of ponderosa pine is compromised by significant change in the type, size, and severity of ecological disturbances and by the current forest structure. The higher density of trees, the smaller size of those trees, increased surface fuel loads, and more homogeneous spatial pattern result in higher likelihood of high-severity crown fire. Low resilience of current forest conditions will interact with climate change and current forest management practices to maintain the current simplified forest structure.

The ecological integrity of the ponderosa pine ecosystem is low and will likely continue to be low in the future, assuming even-aged vegetation management continues to be the dominant practice, given the following:

- The extent of ponderosa pine on the Black Hills National Forest has recently been declining while nonstocked areas have been increasing. If these trends continue and uncharacteristic fire becomes more widespread as a result of climate change, more areas may be converted to nonstocked. When high severity fires burn large areas, there are limited seed trees and climate-driven drought conditions make it difficult for trees to establish. Additionally, fire policy is also a factor here. As discussed in the fire and fuels assessment, fire exclusion has led to uncharacteristically heavier surface fuel loads and denser understories of young ponderosa pine, which can lead to more severe fire potentially damaging soils and killing overstories.
- Even-aged silvicultural practices create conditions that are more conducive and less resilient to severe bark beetle events relative to uneven-aged silvicultural practices.
- Forest structure across the landscape has been simplified and is not as diverse as the historical structure. Patch sizes are more homogenous and tree density is higher but composed of smaller trees. Current forest conditions are more uniform and continuous, with fewer gaps and more even spacing, increasing the likelihood of crown fire. This is dissimilar to the uneven-aged and spatially heterogeneous forest structure found historically. These conditions compromise forest resilience and delivery of ecosystem services.
- There is a clear decline in late-successional habitat resulting from the recent mountain pine beetle mortality and fire. Additionally, timber management, mountain pine beetle activity, fire, tornados, or a combination of these have converted more than 150,000 acres of moderately closed and closed stands to non-stocked areas and open stand conditions.
- Regeneration is generally prolific (when seed sources are present and competing vegetation is not a limiting factor), but high intensity fires and climate change will likely lead to more areas that do not regenerate and considerably more variable regeneration.

White Spruce

Introduction

White spruce (*Picea glauca* (Moench) Voss) in Black Hills National Forest is at the extreme southern end of its range (figure 3). It is disjunct from its primary range by several hundred miles (Burns and Honkala 1990, USDA Forest Service 1996a). As described in the 1997 Land and Resource Management Plan and Phase II amendment FEISs (USDA Forest Service 2005, USDA Forest Service 1996a), white spruce is the most shade tolerant of the Black Hills National Forest tree species, enabling regeneration and growth under closed forest canopies. It is a relatively slow growing, long-lived species in the Black Hills. White spruce occurs as the climax species on cool mesic sites such as high elevations, north aspects, and cool canyon bottoms of the Forest. It is found in locally dense stands on the limestone plateau, Black Fox Canyon, and Spearfish Canyon and extensive stands occur as far south as the Harney Range and Custer State Park. Seral associates in white spruce communities include ponderosa pine, aspen, and paper birch (Shepperd and Battaglia 2002).

Unique habitats are a key ecosystem service of the white spruce forests on the Black Hills. The cool, moist environments of white spruce stands provide habitat diversity in a ponderosa pine dominated landscape. Late-successional white spruce with its associated structural complexity (i.e., increased understory vegetation, downed woody debris, and snags), provides habitat for several Forest wildlife species (USDA Forest Service 2005). Wildlife species that rely on white spruce include American marten and several rare snails. Several bird species have been found almost exclusively in white spruce forests of the Black Hills and others were found in higher densities in spruce stands relative to other types (Panjabi 2001). Spruce forests are also used by species such as elk for summer-fall range and thermal and hiding cover (Shepperd and Battaglia 2002).

The disjunct nature of the Black Hills white spruce population (figure 3) really highlights how unusual and exceptional this species' presence in the Black Hills is and its distinctive role and contribution to the broader landscape. It represents a unique element of biodiversity which extends to its understory associates.

Figure 3. Range map of white spruce (*Picea glauca*), digital representation of "Atlas of United States Tree" by Elbert L. Little Jr., U.S. Geological Survey

Black Hills National Forest white spruce community types are described in appendix B. These community types are all globally imperiled or critically imperiled, as ranked by NatureServe. White spruce as a species and some community types are also ranked as imperiled in Wyoming (Natureserve 2022).

Current plan direction regarding white spruce is a Landscape Vegetative Diversity (LVD) objective:

> *239-LVD. *NEW. Manage for 20,000 acres of spruce across the Forest using active management to achieve multiple-use objectives. Treat spruce within 200 feet of buildings, where spruce has encroached into hardwoods, and for emphasis species management.*

As reported in table 2a, white spruce is estimated to occupy 54,282 acres on the Black Hills National Forest (2017-2019 FIA data). Recent trends in this type are inconsistent across datasets (see tables 2b and 2d). Expansion of the white spruce ecosystem was documented in past monitoring (USDA Forest Service 2015). Historical estimates (from the late 1800s) of white spruce in the Black Hills National Forest are much lower, at 15,000 acres (Graves 1899, USDA Forest Service 1996a). Consequently, evidence indicates white spruce has expanded since then and currently exceeds the 20,000-acre objective that is part of the current forest plan. White spruce is absent on the Bearlodge District. The majority occurs on the Northern Hills District (2021 FSVeg).

Two white spruce habitat types occur on Black Hills National Forest. Pure spruce stands have always been dominated by spruce with varying, disturbance driven levels of ponderosa pine, aspen, and other hardwoods as minor components. These forest types occupy a small niche on the moister, northern aspects, and are dominant near riparian areas.

The second type of white spruce forest is considered a mixed species type. These areas would have had higher levels of pine and hardwoods under a more frequent fire regime.

Ecosystem Drivers and Stressors

Key drivers and stressors in the white spruce ecosystem include fire and fire exclusion, insects and disease such as bark beetles and root disease, and climate change.

Timber harvest has historically been a very minor activity in this type and is not a major driver or stressor. Harvest of white spruce has generally been limited and tied to treatments in pine dominated stands and the implementation of meadow and hardwood enhancement projects outside of the white spruce forest type. However, a spruce vegetation management project is currently under analysis.

Fire and Fire Exclusion

Fire and fire exclusion is a driver in white spruce ecosystems. Historically, this species was especially susceptible to mortality from fire due to its thin bark and persistent lower limbs. White spruce forest occurs as a mosaic with pine forest. They naturally have a longer fire return-interval than pine[28] and likely burned with mixed-severity and with a greater proportion of stand-replacing fires (USDA Forest Service 1996a, Murphy 2017, Landfire 2020). As such, historical fire limited its extent. Accounts from the late 19th century estimate white spruce occupied approximately 15,000 acres in the Black Hills, occurring in densely stocked stands of 12- to 18-inch dbh trees (Graves 1899, USDA Forest Service 1996a). Fire exclusion during the last century has promoted climax spruce forests and allowed white spruce to expand its distribution and increase in abundance and density within stands in the Black Hills (Parrish et al. 1996, USDA Forest Service 1996a, Tatina and Hanberry 2022).

Historically, other types such as mixed conifer, which were a mix of spruce, pine, and other species such as aspen and paper birch, were likely more prevalent, and these areas have succeeded to spruce in the absence of fire. Expansion likely occurred more frequently on gentler slopes and drier sites as these sites would have experienced more frequent fire and this would have favored pine and other species over white spruce, maintaining the areas as mixed species. Fire exclusion has likely led to additional larger, more contiguous areas of white spruce.

Recent expansion may also occur when spruce increases in abundance after pine harvest or pine mortality due to mountain pine beetle in mixed pine/spruce stands (USDA Forest Service 2015).

Insects and Disease

The most frequent damaging biological agents to spruce are bark beetles, such as spruce beetle (*Dendroctonus rufipennis*) or spruce engraver beetles (*Ips* spp.) and root diseases, such as Armillaria (*A. solidipes* and *A. sinapina*). White spruce in the Black Hills National Forest is also relatively susceptible to internal decay caused by red ring rot (*Porodaedalea pini*) (Allen et al. 2019, Allen et al. 2021).

[28] While there is limited information specific to white spruce in the Black Hills, as discussed earlier in the ponderosa pine section, mean fire return intervals (MFRI) increase with increasing elevation and the high-elevation ponderosa pine and white spruce forest has a median MFRI of 28 years (Murphy 2017).

While bark beetles have killed trees in large numbers across other parts of white spruce's range, and spruce is susceptible to root diseases that can lead to tree decline and death, recent aerial and ground surveys detected only scattered spruce mortality in the Black Hills National Forest. White spruce on the Black Hills National Forest appears to be in good health with very little recent mortality (about 1 to 2% mortality per year, which is similar to natural or expected mortality levels (Allen et al. 2019, Allen et al. 2021).

Surveys found no groups or pockets of mortality, but more single, scattered dead trees. Most of the recently dead trees had evidence of both *Ips* spp. And *Armillaria* root rot. Evidence of spruce beetle was found but was less common (Allen et al. 2019, Allen et al. 2021). Around 25% of mature trees sampled had some level of internal decay from red ring rot or other decay organisms. These decays can cause tree failures as they become more extensive over time (Allen et al. 2021).

Currently, mortality from insects or diseases do not raise concern about the future integrity of white spruce ecosystems on the Black Hills National Forest (Allen et al. 2019).

Climate Change

Information about white spruce that is specific to Black Hills National Forest is much less common than information about this species that was collected in other parts of its range, such as the boreal forests in Canada and Alaska. As described more fully in the recent climate vulnerability assessment, Timberlake et al. (2022), research indicates that white spruce is not well-adapted to drought and a lack of moisture availability limits its growth.

Black Hills National Forest white spruce ecosystems represent a spatially disjunct population of the species occurring far south from the rest of the species' range, suggesting the population may be particularly vulnerable as suitable climate for the species shifts northward. However, it may be that the colder, wetter sites that white spruce occupies in the Black Hills will continue to function as refugia for the species into the future (Timberlake et al. 2022).

White spruce is vulnerable to fire as it has relatively thin bark and branches near the ground. More widespread fire because of climate change thus may reduce the prevalence of white spruce, particularly in places where the species has expanded due to fire exclusion, including drier meadows. However, if fires do not reach colder, wetter sites, these sites may continue to function as refugia (Timberlake et al. 2022).

Key Ecosystem Characteristics

Connectivity

The white spruce forests of Black Hills National Forest provide high quality habitat for various wildlife species, but particularly for American marten, which were re-introduced into the Forest in the 1980s and 90s. Two core areas support American marten, one in the Northern Hills and one in the Norbeck Wildlife Preserve/Black Elk Wilderness in the central Black Hills. Connectivity between these two areas is important for dispersal between sub populations. This is recognized in the current forest plan, which states:

> *3215. *In areas identified as important connectivity corridors for marten, maintain canopy closure of at least 50 percent. STANDARD*

A range of vegetation treatments are allowed in these corridors, but maintenance of at least 50% canopy closure is key. While corridors need to be forested, hardwoods or other forest types besides spruce can provide the cover needed.

Diversity of White Spruce Size, Density, and Age Classes

FIA plot data provides the most current information regarding the white spruce forest type[29] (table 6, figure 4). In this type, trees reach up to 25-inch dbh. Unsurprisingly, most of the trees present in areas classified as white spruce are white spruce (73%), with ponderosa pine (15%), aspen (8%), and paper birch (4%) also present.

FIA seedling data (less than 1-inch dbh) for the white spruce forest type estimates, on average, more than 800 seedlings/acre[30], with about half of those (51%) white spruce seedlings and the rest being seedlings of other species. White spruce seedlings can be found underneath existing canopies. It is the most shade tolerant of the Black Hills tree species, enabling growth and survival under closed forest canopies. There are currently enough seed sources and regeneration that this species can sustain itself. Recent forest health surveys have also found abundant regeneration in white spruce stands, dominated by white spruce, with no noticeable death or decline in the regeneration (Allen et al. 2019, Allen et al. 2021).

[29] Plot counts are listed in Table 2. Given the distribution of vegetation on the Black Hills National Forest, with ponderosa pine covering most of the Forest, other forest types such as white spruce are represented with a lower number of plots, leading to higher sampling errors and less precise estimates.

[30] Sampling error percent (68% confidence level) is 27%.

Table 6. Number of live trees, by diameter class, white spruce forest type, on the Black Hills National Forest, based on the 2017-2019 FIA data.

[Sampling error percent (68% confidence level) is highly variable across species and size classes, ranging from 23 to 118%.]

Diameter Class	White Spruce	Percent of Total Live Trees	Ponderosa Pine	Percent of Total Live Trees	Paper Birch	Percent of Total Live Trees	Aspen	Percent of Total Live Trees	Total All Species	Percent of Total Live Trees
1-2.9”	4,867,225	25.6%	789,974	4.2%	619,026	3.3%	562,193	3.0%	**6,838,419**	**35.9%**
3-4.9”	3,801,245	20.0%	824,460	4.3%	-	-	393,287	2.1%	**5,018,993**	**26.4%**
5-6.9”	1,462,146	7.7%	496,478	2.6%	124,094	0.7%	254,854	1.3%	**2,337,572**	**12.3%**
7-8.9”	1,233,298	6.5%	270,030	1.4%	13,450	0.1%	194,532	1.0%	**1,711,310**	**9.0%**
9-10.9”	809,449	4.3%	56,988	0.3%	13,450	0.1%	60,175	0.3%	**940,063**	**4.9%**
11-12.9”	485,877	2.6%	43,538	0.2%	-	-	31,535	0.2%	**560,950**	**2.9%**
13-14.9”	549,961	2.9%	67,779	0.4%	-	-	-	-	**617,740**	**3.2%**
15-16.9”	311,322	1.6%	132,061	0.7%	-	-	-	-	**443,383**	**2.3%**
17-18.9”	225,688	1.2%	67,779	0.4%	-	-	-	-	**293,467**	**1.5%**
19-20.9”	61,476	0.3%	66,186	0.3%	-	-	16,491	0.1%	**144,152**	**0.8%**
21-22.9”	67,633	0.4%	41,945	0.2%	-	-	-	-	**109,577**	**0.6%**
23-24.9”	-	-	16,491	0.1%	-	-	-	-	**16,491**	**0.1%**
Total	**13,875,319**	**72.9%**	**2,873,711**	**15.1%**	**770,020**	**4.0%**	**1,513,068**	**8.0%**	**19,032,118**	**100.0%**

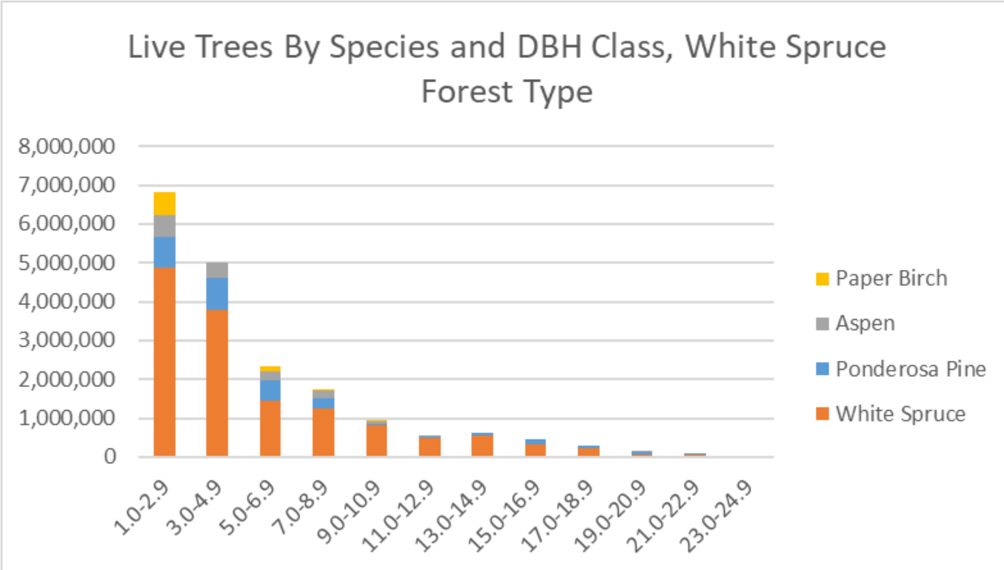
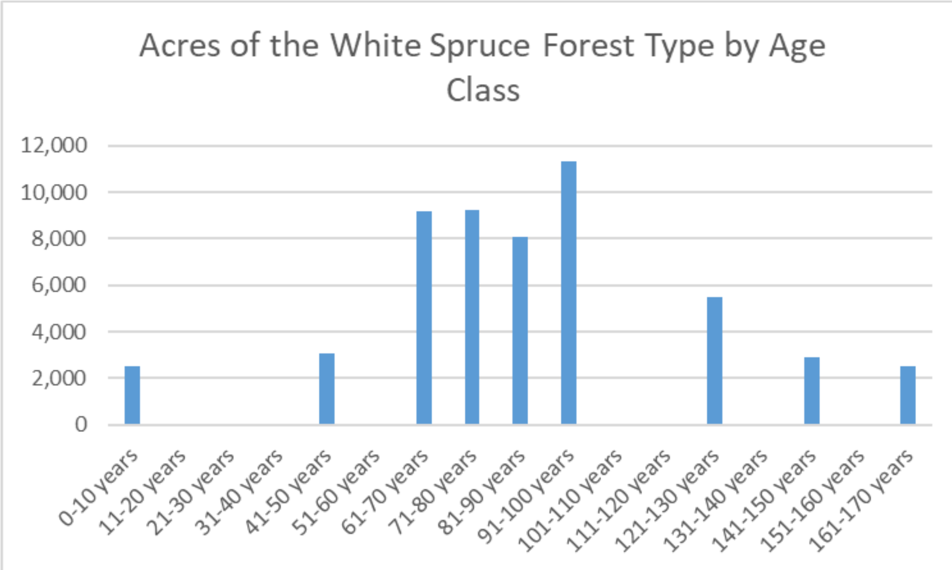


Figure 4. Diameter distribution of live trees, white spruce forest type, by species

White spruce forest age classes range from 10 years or younger up to 170 years, with most of the acreage in the 60–100-year age range (figure 5). Very little area is in the youngest age classes. This supports the idea that there are two white spruce habitat types on the forest: pure spruce stands that are older and are in their historical ecological niche and a second type (mixed species spruce areas) that are currently dominated by white spruce but would have had higher levels of pine and hardwoods under a more frequent fire regime. These would be the younger areas, established following the introduction of fire suppression in the early 20th century. The fact that there is no white spruce older than 170 years old agrees with observations by Peter Brown that it is difficult to locate older white spruce and most individuals are less than 150 years old and many established since fire exclusion began (Murphy et al. 2017). The lack of younger age classes is likely due to the lack of recent stand replacement disturbance in white spruce. As mentioned above, recent forest health surveys have also found abundant regeneration in white spruce stands, dominated by white spruce, with no noticeable death or decline in the regeneration (Allen et al. 2019, Allen et al. 2021).



Sampling error percent (68% confidence level) varies by age class and ranges from 46 to 108%.

Figure 5. Extent of white spruce forest type by dominant age class from 2017-2019 FIA data

Currently 54,282 acres of the white spruce forest type occur on the Black Hills National Forest based on FIA. Most of the ecosystem (76%) is in the large diameter stand-size class, with much smaller amounts in the small (16%) and medium diameter stand-size classes (8%) (table 7).

The density class distribution, based on the 2017-2019 FIA data, indicates that most of the white spruce forest type is in the 41-80 or 81-120 square feet/acre density classes (table 7).

Looking collectively at both the stand-size class and density class distribution, a quarter of the white spruce type is in the large diameter stand-size class and the 41-80 square feet/acre density class and just over a quarter is in the large diameter stand-size class and 81-120 square feet/acre density class.

Table 7. Current extent of white spruce forest type by density class and stand-size classes within each density class on the Black Hills National Forest, based on 2017-2019 FIA data.

[Sampling error percent (68% confidence level) is highly variable across categories, ranging from 24 to 118%.]

Density Class based on Live Basal Area	Acres in Small Diameter Stand-Size class	Acres in Medium Diameter Stand-Size Class	Acres in Large Diameter Stand-Size Class	Total Acres (All Stand-Size Classes)
0-40 sqft/acre	3,125 (5.8%)	-	2,740 (5.0%)	**5,865 (10.8%)**
41-80 sqft/acre	5,389 (9.9%)	2,235 (4.1%)	13,342 (24.6%)	**20,967 (38.6%)**
81-120 sqft/acre	-	2,235 (4.1%)	15,519 (28.6%)	**17,754 (32.7%)**
120+ sqft/acre	-	-	9,697 (17.9%)	**9,697 (17.9%)**
Total (All Density Classes)	**8,514 (15.7%)**	**4,470 (8.2%)**	**41,298 (76.1%)**	**54,282 (100.0%)**

Snags and Downed Wood

Snags and downed wood provide numerous benefits such as wildlife habitat, nutrient cycling, and forest structural complexity (Shepperd and Battaglia 2002).

Current plan direction related to snags indicates that in conifer areas, there is an objective of an average of 3 hard snags greater than 9-inch dbh and 25 feet high per acre, well-dispersed across the Forest, 25 percent of which are greater than 14-inch dbh as well as a focus on retention of soft snags and snags greater than 20-inch dbh.

FIA data (2017-2019) indicate an average of about 28 snags/acre (5-inch dbh and larger) in the white spruce forest type[31]. The amount and size distribution of these snags (table 14) indicates that snag levels in the white spruce type likely exceed those described in the above-mentioned forest plan objective.

Down woody material is an important element of the ecosystem that helps retain moisture, trap soil movement, provides habitat for wildlife (such as American marten), and provides for the establishment of forbs, grasses, shrubs, and trees.

The current Black Hills National Forest plan directs retention of coarse woody debris during vegetation management. On white spruce sites, this plan standard requires retention of at least 100 linear feet per acre of coarse woody debris with a minimum diameter of 10 inches. There is also an objective that in conifer forested portions of a planning unit, that at least once during a rotation, an average of 5 to 10 tons per acre of down, dead woody material at least 3 inches in diameter should be provided.

Given fire exclusion and the very limited management in white spruce, down woody material is likely near-natural levels or higher.

When down wood data was queried by forest type using the public Evalidator website (2/4/22), no data for the white spruce forest type was present.

Summary of Ecological Integrity

To assess the ecological integrity of each ecosystem, it is helpful to first describe what that ecosystem would be like if it had high ecological integrity. This provides a reference for comparison with current ecosystem conditions and illuminates why an ecosystem may have high, low, or moderate ecological integrity.

The ecological integrity for the white spruce ecosystem would be high if this ecosystem occupied its ecological niche of cool mesic sites (high elevations, north aspects, and cool canyon bottoms) and occupied an area similar to its historical extent of 15,000 acres. Fires would occur as they did historically, burning with mixed-severity and a longer fire return-interval with a higher proportion of stand-replacing fires than pine. Insects and disease would occur at endemic levels. The ecosystem is diverse in terms of tree sizes, density, and age, and downed wood and snags are present in sufficient quantities to support wildlife species and other ecosystem services. Species composition would be dominated by white spruce with incidental levels of pine and hardwoods.

Pure Spruce Areas

Areas of mostly pure spruce, where it existed historically on cool mesic sites, currently exhibit moderate to high ecological integrity. These pure spruce stands have always been dominated by spruce with varying, disturbance driven levels of ponderosa pine, aspen, and other hardwoods as minor components. These forest types occupy a small niche on the moister, northern aspects, and are dominant near riparian

[31] Sampling error percent (68% confidence level) for total snags per acre is 28%.

areas. The ecological integrity of the white spruce ecosystem on these sites will likely be at least moderate in the future if current management levels and forest plan direction continues. These areas, given their longer fire return intervals and greater presence of stand-replacing fire, would be less impacted by fire exclusion. The white spruce on the Black Hills National Forest appears to be in good health with mortality that is in the realm of natural or expected mortality levels (Allen et al. 2019, Allen et al. 2021). Climate change compromises the status of white spruce ecosystems and therefore the future trend may be toward moderate ecological integrity.

Spruce – Mixed Species Areas

The second type of white spruce forest is a mixed species type. These areas would have higher levels of pine and hardwoods under a more frequent fire regime that is consistent with the natural range of variation. Many mixed species areas that have succeeded to spruce due to fire exclusion occur on gentler slopes and drier sites. These stands currently exhibit moderate to low and declining ecological integrity given that, while currently classified as spruce, they historically would have had a different species composition and are departed from that. These sites would have higher ecological integrity if restored to their historical species composition (pine with spruce and other species such as aspen and paper birch) and structure, with fire acting in its natural role and preventing these areas from succeeding to spruce.

Additional Information

In terms of diversity of white spruce ecosystem size, density, and age classes, most of the white spruce ecosystem on the Black Hills National Forest is in the large diameter stand-size class and 60-100 years old. Tree size class and seedling plot data indicate there are many small trees and suggest that white spruce regeneration and recruitment is occurring. There are enough seed sources and regeneration that this species can sustain itself.

Current data indicates an abundance of snags in the white spruce forest type. Given fire exclusion and the very limited management that is done in white spruce, down woody material should be at near-natural levels or higher.

White spruce, with its isolated population in the Black Hills, is likely more vulnerable to changes in climate. It is not well-adapted to drought conditions and more widespread fire may reduce the prevalence of this species on the landscape. Even so, Black Hills National Forest may continue to support refugia population of this species, particularly in colder, wetter locations, assuming fires do not reach these areas.

White spruce provides habitat diversity in a landscape dominated by ponderosa pine. Late-successional white spruce with its associated structural complexity (i.e., increased understory vegetation, downed woody debris, and snags), provides habitat for several Forest species and many rare plants in the Black Hills. These and other ecosystem services will likely continue to be provided in the future given the current and likely future ecosystem integrity of white spruce on the Black Hills National Forest.

Aspen

Introduction

Quaking aspen (*Populus tremuloides* Michx.) is the most widely distributed tree species in North America. It's an early colonizing, sprouting, clonal species that depends on periodic disturbances, primarily fire, for regeneration and to reduce competition. Aspen forests are scattered throughout the Black Hills National Forest, but are more predominant in higher, more mesic northwestern portions of the

Forest and in the Bear Lodge Mountains (Shepperd and Asherin 2004). Aspen is a short-lived species, typically living for less than 80 to 100 years.

Aspen forests in Black Hills National Forest provide a variety of ecosystem services. They add ecological diversity, provide forage and cover for various wildlife species, are an important component of watersheds, and have high aesthetic value (Blodgett et al. 2020). Aspen patches function as natural fuel breaks during wildfires (Howard 1996).

As described in the Black Hills Phase II Amendment FEIS (USDA Forest Service 2005), forage production in aspen and other hardwood communities is three to six times higher than typical conifer stands and is comparable to some grasslands (Burns and Honkala 1990). Hardwood stands also have higher diversity of understory species than do pine stands (USDA Forest Service 1996a). Hardwood forests, with their associated understory shrub components, are an important source of forage for all browsing ungulates, especially white-tailed deer.

Aspen stands often support an abundance and diversity of bird species. Panjabi (2001) detected high densities of 23 bird species in Black Hills aspen stands. Several Forest species are dependent on aspen for forage, including ruffed grouse and beaver (Shepperd and Battaglia 2002). Other species, such as Black Hill's redbelly snake and northern leopard frog, capitalize on the moist site conditions where aspen is found (SAIC 2003b).

There are four aspen community types in the Black Hills: aspen/beaked hazel, aspen/bracken fern, aspen/spiraea, and aspen/chokecherry which are discussed further in appendix B. Three of these are ranked as critically imperiled, imperiled, or vulnerable in Wyoming by NatureServe (NatureServe 2022).

The main plan direction regarding aspen is a Landscape Vegetative Diversity (LVD) objective:

> *201. *Manage for a minimum of 92,000 acres of aspen (double current aspen acres), and 16,000 acres of bur oak (approximately 33 percent increase) in current bur oak during the life of the Plan. The highest priority for hardwood restoration is where conifers (e.g., spruce and pine) have out-competed aspen adjacent to riparian systems that once supported beaver. Increases in bur oak will be focused away from the Bear Lodge Mountains.*

Aspen is estimated to occupy 70,115 acres in the Forest (table 2a). Recent trends are inconclusive as the FIA analysis indicates an increase in this forest type (table 2b), while other data indicates otherwise (table 2d, USDA Forest Service 2015). For instance, there is evidence that in some areas, prolific pine regeneration has contributed to the decrease in aspen and aspen stands have been replaced by pine and spruce on parts of the Forest (USDA Forest Service 2015).

Ecosystem Drivers and Stressors

Key drivers and stressors in aspen include succession, fire and fire exclusion, forest management that traditionally favors pine regeneration over aspen, browsing from livestock and wild ungulates, insects and disease, the loss of beavers, and climate change. These drivers and stressors interact with one another providing the opportunity to influence the integrity of aspen ecosystems.

Fire and Fire Exclusion

Aspen generally is a fire-induced successional species that frequently dominates soon after fire (Mueggler 1985, USDA Forest Service 1996a). While aspen can either be seral to other forest types or climax/stable aspen (Mueggler 1985), most aspen forests are seral. While stable aspen communities have been documented in the Black Hills (Severson and Thilenius 1976), aspen in the Black Hills is considered successional and rarely occurs in stable stands that will not be replaced by other tree species in the absence of disturbance (Shepperd and Asherin 2004).

In these seral aspen stands, as described in the 1997 Land and Resource Management Plan FEIS (USDA Forest Service 1996a):

> Once the aspen canopy is established, conifers that are more shade tolerant trees begin to grow in the understory. Through time, as the conifers establish dominance in the overstory, aspen gets crowded out, eventually disappearing (Mueggler 1985). As long as disturbances continue, seral aspen can be maintained indefinitely, assuming no other clonal mortality. Aspen stands can even be regenerated by a few residual individuals in a conifer stand (Johnston and Hendzel 1985). In the Black Hills there is considerable evidence that ponderosa pine is replacing seral aspen through succession.

Fire exclusion during most of the 20th century limited disturbance, resulting in a trend of decreasing aspen on the Black Hills National Forest. Aspen is being replaced by ponderosa pine and spruce on part of the Forest. Given fire exclusion has favored ponderosa pine over aspen and other hardwoods, it is reasonable to assume that the acreage of aspen was more extensive prior to 1874 than it is today (Parrish et al. 1996).

The fire regime of quaking aspen is highly variable across the Mountain West (Shinneman et al. 2013). Given its limited extent in Black Hills National Forest, it is believed the fire regime is similar to the rest of the Forest, and as described in the earlier section on ponderosa pine. Given the early colonizing, sprouting nature of aspen, fire and other disturbances lead to the maintenance of this species on the landscape (Shepperd and Asherin 2004, Keyser et al. 2005). The severity of that fire is key, however. Keyser et al. (2005) found that aspen clones affected by high severity fire are most likely to persist on the Black Hills landscape. The combination of the removal of the aspen overstory, increased sprout production, and the significant reduction of competing pine in and around the clone create conditions conducive to future growth and expansion of aspen. These clones are likely to experience pine invasion in the future; however, high severity fire was effective at maintaining aspen dominance for another generation and allows for the future expansion of the overstory core area. Low severity fire was ineffective at decreasing competition from overstory aspen and pine, which will likely lead to the further suppression and eventual death of developing sprouts. Without future stand-replacing disturbance, low severity clones are likely to continue the current successional pathway and succeed to ponderosa pine.

Forest Management

Given the need for disturbance to maintain aspen on the landscape, forest management practices that have favored management and regeneration of pine over management and regeneration of aspen have also had an effect on this ecosystem and its extent. Aspen is not a commercial timber species on the Black Hills National Forest. Therefore, harvest and regeneration of aspen has not historically been part of the timber program. Aspen restoration has been a minor component of management and is done at a much smaller scale than management of ponderosa pine. These treatments are termed hardwood restoration: conifers are removed from existing aspen stands or patch cutting is employed around aspen clones to reduce competition and favor sprouts. Aspen/hardwood restoration treatments increased with implementation of the Black Hills Resilient Landscapes project and other smaller projects. However, together these treatments are small in scale, at 100s to up to 1,000 acres per year. Smaller aspen restoration treatments (removing conifers from within and adjacent to small (less than 5 acres) aspen clones within commercial timber units) also occur in the Forest.

Browsing

Browsing from livestock and wild ungulates can be a stressor in aspen ecosystems. Aspen shoots are palatable, and overgrazing can result in the complete loss of an aspen clone (Parrish et al. 1996). One study suggested browsing was not a serious detriment to regeneration and that aspen was not in severe decline on the Black Hills National Forest but did recognize regeneration failures (Shepperd and Asherin 2004). Extensive and atypical browsing of aspen sprouts was observed in the Jasper Fire area in 2004 in clones top-killed in the fire, suggesting immediate management action may have been needed to avoid the loss of the aspen clones (Shepperd and Asherin 2004). Observations of the Forest indicate that browsing by cattle and wild ungulates reduces aspen cover and regeneration. Fencing and similar measures to prevent this browsing are difficult to implement at large scales. Aspen restoration treatments include hinging, which creates a physical barrier to prevent browsing. Instead of cutting pine completely down, hinging fells the tree while maintaining the stem's connection to the stump. This deters browsing from cattle and wildlife but is visually unappealing and leads to higher fuel loads than pine removal. Alternatively, during thinning prescriptions, slash heights are left a little higher to reduce browsing on sprouting stems, but this also equates to higher fuel loads.

Surveys evaluating aspen health on the Black Hills National Forest find browsing and canker damage represent two common damage agents in aspen regeneration, however they showed no correlation with decreasing numbers of regeneration (Blodgett et al. 2017). Cankers were frequently associated with browse damage, suggesting browsing is an important infection route for the damaging canker fungi (Blodgett et al. 2020).

Insects and Disease

As aspen stands age, they become more susceptible to insects and disease (Parrish et al. 1996). As described in USDA Forest Service (2005), aspen can host a wide variety of insects including defoliators, borers, and suckers (Burns and Honkala 1990). Some insect species in the Black Hills that target aspen include tent caterpillar, large aspen trorix, and aspen leaf beetle (USDA Forest Service 1996a). In most cases, native insects are a natural part of the ecosystem and diverse, vigorous forests inhibit serious infestations (USDA Forest Service 1996a).

Recent aspen mortality from insects and disease has been low on the Black Hills, with no significant broad scale tree mortality occurring, though some individual stands had higher mortality (Blodgett et al. 2020). Endemic levels of observed tree mortality were due to three damage agents: aspen trunk rot, sooty bark canker, and Cytospora canker. The most common boring insects, poplar borer and bronze poplar borer, were uncommon in 2019 and other minor damage agents included Ganoderma root disease and other canker diseases.

Beaver and the Loss of Beavers

The drastic reduction in beaver populations using the riparian aspen forests on the Black Hills National Forest is a stressor. Aspen is a preferred food and building material for beavers. Beaver activities stimulate aspen regeneration, both through cutting and restoring hydrologic function in riparian areas. Reintroducing beavers can restore riparian processes, increase aspen growth and diversity, and buffer ecosystem sensitivity to extended drought (Bennett et al. 2019).

Climate Change

Climate change functions as a system stressor and driver in the forested ecosystems in the Black Hills National Forst. As described more fully in Timberlake et al. 2022, key aspects of aspen exposure to climate change include changes in moisture availability, increasing durations and severity of drought, and extreme temperatures (Rice et al. 2017). In general, moisture stress is a significant driver of aspen mortality, and severe drought events are associated with aspen dieback. Aspen in more xeric sites is particularly vulnerable (Frey et al. 2004; Worrall et al. 2013). In Black Hills National Forest, current aspen distribution is correlated with moisture availability, and thus may change as climate change reduces moisture availability (Shepperd and Battaglia 2002). High temperatures also directly affect aspen and its photosynthesis.

Aspen stands in Black Hills National Forest are primarily located on north-facing aspects or in sites that otherwise have wetter conditions (Severson and Thilenius 1976). These types of sites may continue to support aspen under warmer drier future climates; however, the fact that the species already occupies the upper elevational range of the Black Hills and its preference for these moist sites suggests aspen ecosystems on portions of the Forest may be vulnerable to drier future conditions.

Fire generally promotes aspen as the species resprouts following disturbance and frequent fires reduce conifer competition (Rice et al. 2017). Aspen may benefit from ongoing and projected increases in area burned due to climate change, especially if these trends include an increase in area burned at high severity. However, aspen is vulnerable to severe drought that also drive increases in fire (Rice et al. 2017; Worrall et al. 2013). Aspen expansion resulting from more widespread fire may thus be moderated by drought-caused mortality.

Key Ecosystem Characteristics

Diversity of Aspen Size, Density, and Age Classes

FIA plot information (2017-2019) provides the most current estimate of size and species of trees within the aspen type (table 8, figure 6). FIA plot data indicates aspen trees within aspen ecosystems reach about 13 inches dbh and ponderosa pine trees reaching 27 inches dbh. Most trees in aspen stands are aspen (59%), with ponderosa pine (27%), bur oak (12%), paper birch (1%), white spruce (less than 1%), and Rocky Mountain juniper (less than 1%) being the other species present.

FIA seedling data (less than 1 inche dbh) indicates on average about 2100 seedlings/acre[32] in aspen stands, but only about a third of those (37%) are aspen seedlings; the majority are seedlings of other species, such as serviceberry (26%), bur oak (18%), and ponderosa pine (13%). Another source (Blodgett et al. 2020) found that aspen regeneration, on average, was 296 stems per acre in 2019. Competing woody vegetation (and possibly non-woody vegetation) explains the low aspen regeneration, with aspen making up only 66% of the regeneration. A few stands' regeneration was also damaged by Marssonia leaf blight. Overall, the number of aspen seedlings and saplings has declined on the Black Hills National Forest and this decreasing trend continued into 2019. Looking at sapling data (1-5 inches dbh), 62% are aspen while 38% are other species.

[32] Sampling error percent (68% confidence level) is 24%.

Table 8. Number of live trees, by diameter class, aspen forest type, on the Black Hills National Forest, based on the 2017-2019 FIA data.

[Sampling error percent (68% confidence level) is highly variable across species and size classes, ranging from 25 to 101%.]

Diam. Class	Aspen	Per-cent of Total Live Trees	Ponderosa Pine	Per-cent of Total Live Trees	Bur Oak	Per-cent of Total Live Trees	Paper Birch	Per-cent of Total Live Trees	White Spruce	Per-cent of Total Live Trees	Rocky Mtn. Juniper	Per-cent of Total Live Trees	Total All Species	Percent of Total Live Trees
1-2.9”	9,463,598	35.0%	3,885,132	14.4%	1,913,490	7.1%	-	-	-	-	-	-	**15,262,220**	**56.5%**
3-4.9”	3,791,369	14.0%	1,067,137	4.0%	902,957	3.3%	205,220	0.8%	-	-	-	-	**5,966,683**	**22.1%**
5-6.9”	1,196,444	4.4%	682,534	2.5%	276,395	1.0%	87,558	0.3%	16,491	0.1%	-	-	**2,259,422**	**8.4%**
7-8.9”	981,971	3.6%	441,673	1.6%	81,553	0.3%	84,092	0.3%	16,491	0.1%	-	-	**1,605,780**	**5.9%**
9-10.9”	500,602	1.9%	522,363	1.9%	-	-	-	-	52,748	0.2%	16,491	0.1%	**1,092,203**	**4.0%**
11-12.9”	40,776	0.2%	296,326	1.1%	-	-	-	-	36,257	0.1%	-	-	**373,360**	**1.4%**
13-14.9”	-	-	178,859	0.7%	-	-	-	-	-	-	-	-	**178,859**	**0.7%**
15-16.9”	-	-	87,367	0.3%	-	-	-	-	-	-	-	-	**87,367**	**0.3%**
17-18.9”	-	-	123,230	0.5%	-	-	-	-	-	-	-	-	**123,230**	**0.5%**
19-20.9”	-	-	-	-	-	-	-	-	-	-	-	-	**-**	**-**
21-22.9”	-	-	16,491	0.1%	-	-	-	-	-	-	-	-	**16,491**	**0.1%**
23-24.9”	-	-	18,129	0.1%	-	-	-	-	-	-	-	-	**18,129**	**0.1%**
25-26.9”	-	-	18,129	0.1%	-	-	-	-	-	-	-	-	**18,129**	**0.1%**
Total	15,974,761	59.2%	7,337,370	27.2%	3,174,395	11.8%	376,869	1.4%	121,986	0.5%	16,491	0.1%	**27,001,871**	**100.0%**

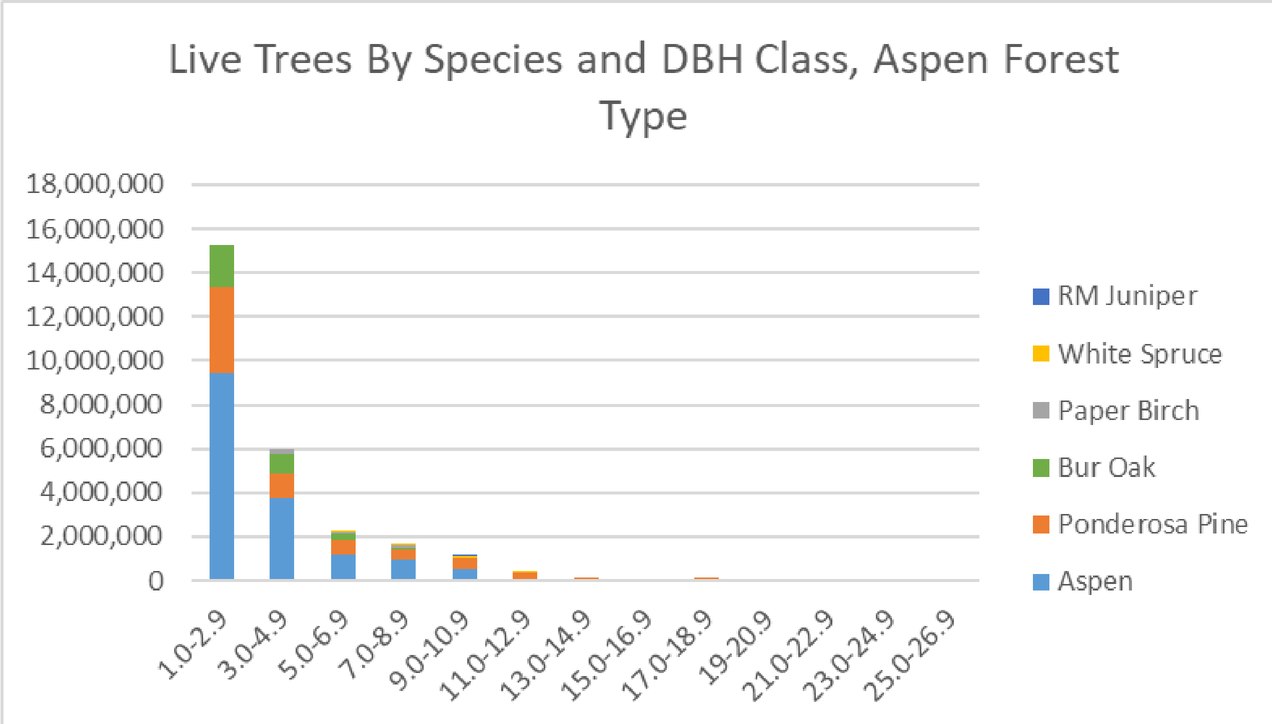
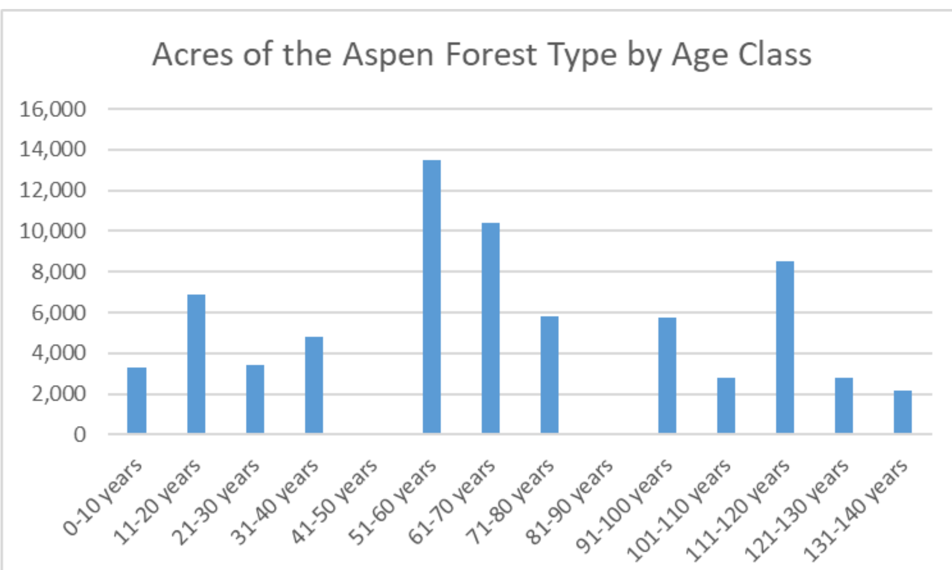


Figure 6. Diameter distribution of live trees, aspen forest type, by species

The age class of aspen varies from 0 to 140 years (figure 7). While the 50–70-year age class dominates, the distribution is generally uniform. The age structure suggests that about half the aspen is at or nearing the end of its typical life span, with 55% estimated at 60 years or older. Only about 25% is in the youngest age classes (0-40 years).



Sampling error percent (68% confidence level) is highly variable across age classes, ranging from 45 to 101%.

Figure 7. Extent of aspen forest type by dominant age class from 2017-2019 FIA data

FIA data estimates 70,115 acres of the aspen forest type. About half of this acreage is in the small diameter stand-size class (36,220 acres) and about half of this is in the medium diameter stand-size class (33,895 acres) (table 9).

The density class distribution, based on the FIA data, indicates that most of the aspen type is in the 0-40 and 41-80 square foot density classes and a small amount (12%) in the 81-120 square foot density class (table 9).

Table 9. Current extent of aspen forest type by density class and stand-size classes within each density class on the Black Hills National Forest, based on 2017-2019 FIA data.

[Sampling error percent (68% confidence level) is highly variable across categories, ranging from 27 to 75%.]

Density Class based on Live Basal Area	Acres in Small Diameter Stand-Size Class	Acres in Medium Diameter Stand-Size Class	Acres in Large Diameter Stand-Size Class	Total Acres (All Stand-Size Classes)
0-40 sqft/acre	18,011 (25.7%)	13,560 (19.3%)	-	**31,571 (45.0%)**
41-80 sqft/acre	14,099 (20.1%)	16,021 (22.8%)	-	**30,120 (43.0%)**
81-120 sqft/acre	4,110 (5.9%)	4,314 (6.2%)	-	**8,425 (12.0%)**
Total (All Density Classes)	**36,220 (51.7%)**	**33,895 (48.3%)**	**-**	**70,115 (100.0%)**

Snags and Downed Wood

Plan direction related to snags has been discussed previously in the ponderosa pine section. Of note here is that current plan direction for hardwood stands such as aspen is to:

> *b. *Retain at least six hardwood snags per acre in hardwood stands. Retain all snags in hardwood stands with snag density of less than six per acre. STANDARD*

FIA data (2017-2019) indicates an average of about 32 snags/acre (5 inches and larger)[33] in the aspen forest type. This exceeds the six snags per acre in hardwood stands described in the standard above.

FIA data estimates an average of 2.4 tons/acre of downed wood (coarse woody debris only, 3 inches or more)[34] in the aspen forest type.

Summary of Ecological Integrity

To assess the ecological integrity of each ecosystem, it is helpful to first describe what that ecosystem would be like if it had high ecological integrity. This provides a reference for comparison with current ecosystem conditions and illuminates why an ecosystem may have high, low, or moderate ecological integrity.

Aspen systems with high ecological integrity experience high severity fire, adequate regeneration, historical levels of insect and diseases, and, in riparian areas, are supported by the activity of beaver. Aspen systems with high ecological integrity are diverse in terms of tree sizes, stand density, and age classes, support native, diverse understories, and downed wood and snags are present. Healthy aspen

[33] Sampling error percent (68% confidence level) is 14%.

[34] Sampling error percent (68% confidence level) is 33%. Estimate was output from the FIA Evalidator public online tool, with 9 FIA plots included.

systems (across the landscape) will have area in young size classes (without encroachment) as well as older stands.

The ecological integrity of the aspen ecosystem in the Forest is moderate. Integrity is declining and will likely be low in the future as summarized here.

Aspen is estimated to occupy 70,115 acres in Black Hills National Forest (table 2a). Recent trends are inconclusive as the FIA analysis indicates an increase in this forest type (table 2b), while other data indicates otherwise (table 2d, USDA Forest Service 2015). For instance, there is evidence that in some areas, prolific pine regeneration has contributed to the decrease in aspen and aspen stands have been replaced by pine and spruce on parts of the Forest (USDA Forest Service 2015).

Fire exclusion has reduced disturbance in this type, affecting the vigor of existing stands as a consequence of uninterrupted forest succession. Aspen restoration treatments occur at a small scale and are not contributing significantly to the ecological integrity of aspen; Prescribed fire benefits aspen ecosystems and increases ecological integrity of aspen. However, as described in the fire and fuels assessment, prescribed fire is not implemented at a pace and scale to have a broad impact.

Browsing from livestock and wild ungulates can be a stressor in the aspen ecosystem and fencing and other similar measures to prevent this browsing are difficult to do at large scales. However, as stated in the Rangeland Assessment, the Forest works with permittees to achieve proper use of the forage resource and maintain harmony with other resources and uses. Working with grazing permittees to reduce stressors on aspen saplings could and should be addressed during annual permittee grazing meetings. The reduction in beavers in the riparian aspen forests on the Black Hills National Forest is a stressor given beavers stimulate aspen regeneration and restore ecosystem processes.

There is some concern about aspen regeneration. One recent forest health protection report found that the number of aspen seedlings and saplings has declined on the Black Hills National Forest and this decreasing trend continued into 2019 (Blodgett et al. 2020). Only about 25% of the acreage is in the youngest age classes (0-40 years). And while there are aspen seedlings in the aspen forest type, the majority are seedlings of other species. Given aspen is short-lived, the age class distribution indicates that about half the aspen is at or nearing the end of its typical life span, with 55% estimated at 60 years or older.

Under a changing climate, as described more fully in Timberlake et al. 2022, there will be both beneficial and detrimental effects to aspen on the Black Hills National Forest. Aspen resprouts after fire and will likely benefit if fire becomes more prevalent in the future. But the species is also vulnerable to moisture stress and severe drought conditions, which are tied to higher aspen mortality. Aspen in more xeric sites is particularly vulnerable. Increases in temperature may be challenging for aspen as well.

Bur Oak

Introduction

Bur oak (*Quercus macrocarpa*) is a drought and fire tolerant tree. In Black Hills National Forest, bur oak is at the western most extent of its range (Burns and Honkala 1990; Shepperd and Battaglia 2002). Bur oak, often in association with ponderosa pine, can be found in large stands in the northern and eastern parts of the Black Hills (Marriot et al. 1999). Along the edges of the Black Hills, relatively large bur oak trees are found in ravines and in riparian areas (USDA Forest Service 1996a). Bur oak can regenerate by seed or by root or stump sprouting, and fire is an important factor in oak establishment (USDA Forest Service 1996a).

Key ecosystem services provided by the bur oak ecosystem include wildlife habitat and forage and cultural value. Bur oak is important habitat and forage for many wildlife species, including Merriam's turkey (Shepperd and Battaglia 2002), white-tailed deer (Sieg and Severson 1996, Severson and Kranz 1978), and red-eyed vireo (Panjabi 2001). Native Americans ground acorns into meal to make mush, soup, or bread. Bark from the roots of bur oak was medicinal for bowel trouble and the bark was also used to make an astringent to treat wounds, sores, insect bites, poison oak, and other ailments. A compound with wood and bark was also used to expel pinworms (Larson and Johnson 2007, USDA NRCS plant guide for bur oak).

Three upland community types have been identified for bur oak in the Black Hills: bur oak/chokecherry – western snowberry woodlands, bur oak/sedge woodlands, and bur oak/ironwood forest (Marriott and Faber-Langendoen 2000a, Hall et al. 2002, Marriott and Faber-Langendoen 2000b) and are described in appendix B. Some Black Hills Region 2 sensitive species, such as bloodroot (*Sanguinaria canadensis*), are associated with the bur oak-ironwood community type (Hall et al. 2002). All three of these community types are globally vulnerable, imperiled or critically imperiled as well as imperiled or critically imperiled in Wyoming based on NatureServe rankings (Natureserve 2022). As a species, bur oak is ranked as imperiled in Wyoming. However, it appears to be doing well in the Bear Lodge Mountains.

There are geographic differences in bur oak across Black Hills National Forest. Bur oak in the northwest part of the Forest (Bear Lodge Mountains) tends to be scrubby and smaller in stature. Bur oak areas in the northern and eastern part of the Forest tend to have larger trees. These larger bur oak trees tend to be more beneficial for wildlife. While the shrub form of bur oak will produce acorns if they grow large enough, acorn production is higher with larger bur oaks. In addition, the scrubby bur oak in the Bear Lodge Mountains heavily dominates without much other plant diversity.

The main plan direction relevant to bur oak are two Landscape Vegetative Diversity (LVD) objectives:

> *201. *Manage for a minimum of 92,000 acres of aspen (double current aspen acres), and 16,000 acres of bur oak (approximately 33 percent increase) in current bur oak during the life of the Plan. The highest priority for hardwood restoration is where conifers (e.g., spruce and pine) have out-competed aspen adjacent to riparian systems that once supported beaver. Increases in bur oak will be focused away from the Bear Lodge Mountains.*
>
> *203. Manage 30 to 50 percent of each bur oak stand for 100-plus year-old trees.*

The amount of bur oak is currently estimated at 30,292 acres (table 2a). Recent trends are inconclusive as the FIA analysis indicates a decrease in this type (table 2b) while other information suggests it is increasing on the Forest (table 2d, USDA Forest Service (2015)). Of the 30,292 acres of bur oak, 10,520 acres (35%) is in Wyoming on the Bearlodge District.

One reason for potentially changing extent of bur oak is that in the Bear Lodge Mountains, timber harvest of pine in mixed pine-oak stands increases oak sprouting. In many cases planned silvicultural treatments in mixed pine-oak stands result in these areas being temporarily dominated by oak and experiencing delayed pine regeneration.

Ecosystem Drivers and Stressors

Key drivers and stressors influencing the distribution and abundance of bur oak include stand development, fire and fire exclusion, livestock grazing, increasing deer and elk populations, timber harvest of pine in mixed pine-oak areas, invading exotic competitors (Shepperd and Battaglia 2002, Ripple and Beschta 2007, Gucker 2011), and climate change.

Bur oak is relatively intolerant of shade, and therefore may be displaced by more shade-tolerant associates (Shepperd and Battaglia 2002, Sieg 1991). In addition, bur oak is fairly cold and drought tolerant (Natureserve 2021). Literature indicates historical hybridization between bur oak and Gambel oak in the

Black Hills (Schnabel and Hamrick 1990, Maze 1968), which may explain the two different forms of bur oak that are seen in the Black Hills.

In general, there are few insects or disease that cause serious damage to bur oak (Natureserve 2021), and this is more specifically true on the Black Hills[35].

Given its relative shade intolerance, bur oak tends to be seral to conifers in the Black Hills. Whether or not this occurs is highly dependent on the presence or absence of fire and pine harvest. Bur oak is very fire tolerant. Older trees have thick, fire-resistant bark and younger trees re-sprout after fire. In mixed pine-oak stands, if the pine is not managed, it tends to shade out the oak and leads to the loss of the oak component.

Given the rapid sprouting of bur oak after fire, and the need for large canopy gaps necessary for seed establishment following disturbance, frequent fire or other disturbance is necessary for bur oak persistence in many habitats. Loss of bur oak is much more likely through succession in undisturbed areas (Gucker 2011), which in the Black Hills would lead to an increase in ponderosa pine.

Fire regimes in bur oak savannas are characterized by frequent, low-severity surface fires at intervals of less than 25 years. Crown fires and severe surface fires are extremely rare, occurring at intervals of over 1,000 years. In addition, burning by Native Americans may have played a role in the maintenance of bur oak in the area. The Oglala Lakota, utilizing fire to drive and kill animals, used fire more frequently than other tribes, leading to a noticeable increase in fire frequency in the prairie-forest mosaic, including bur oak, around Devil's Tower National Monument (Gucker 2011, Fisher et al. 1986).

Accordingly, reduced fire frequencies due to fire exclusion associated with European settlement have been detrimental to bur oak. Fire exclusion over the past century has likely led to conifer encroachment in bur oak stands and a decrease in the acreage of bur oak in the Black Hills. As stated in Parrish et al. (1996), "It is reasonable to conclude that the acreage of the upland deciduous forest was greater prior to 1874 than it is today, although no data are available."

Current management in bur oak in the Forest includes some prescribed fire to reduce fuels and/or benefit wildlife. Use of prescribed fire improves seedbeds and stimulates oak sprouting (Shepherd and Battaglia 2002). One concern with prescribed burning in bur oak is that the timing of prescribed fire is often different than the natural fire regime. Whereas historically fires would have occurred in the hotter drier parts of the year, current prescribed burns occur in the shoulder seasons, when it's cooler, and this may be allowing sprouts to grow and oak to outcompete other species. In general, prescribed fire is supporting the ecological integrity of bur oak in the Forest though likely not at a pace and scale to have a meaningful impact.

Additional stressors in this ecosystem can include grazing by livestock and wild ungulates and nonnative invasive species, if they lead to reduced or no bur oak recruitment (Ripple and Beschta 2007, Gucker 2011). However, as discussed below, data do not indicate a concern regarding oak regeneration and recruitment on the Forest.

As described more fully in Timberlake et al. 2022, several climate change vulnerability assessments conducted for the Midwest indicate that bur oak will remain stable or increase under climate change, suggesting that the species will tolerate warmer conditions and drier growing seasons (Swanston et al.

[35] The FY13-14 Black Hills National Forest monitoring report did not identify insect and disease damage to bur oaks (USDA Forest Service 2015). Recent communication with local forest health protection staff indicates that Armillaria root rot is the most noticeable insect and disease found in bur oak in the Forest. Four bur oak stands were examined in Wyoming in the Black Hills and while Armillaria was present and causing mortality in all four stands, they noted that Armillaria acts as a thinning agent but isn't killing a large number of trees. Other insects were also feeding on leaves and causing small galls on leaves, but were causing very minor damage (James Blodgett, email communication).

2011, Janowiak et al. 2014, Handler et al. 2014, Brandt et al. 2014). Bur oak is fire tolerant due to its thick bark, and its ability to resprout after burns suggests that it may fare well even under increased fire conditions (Sieg 1991, Swanston et al. 2011). Precipitation extremes leading to drought and flood events may also affect bur oak health. Although bur oak is a relatively drought-tolerant species, historical evidence suggests that drought, in combination with severe winters and grazing, can contribute to bur oak decline (Sieg 1991). Bur oak is sensitive to flooding (Kabrick et al. 2012, Gucker 2011).

The forest has invasive species that are impacting the bur oak ecosystem. A common invasive species in this type is houndstongue (*Cynoglossum officinale*) given its high shade tolerance. The degree of invasive species varies with whether bur oak is shrubby or tree form given this is associated with the amount of shade, amount of ground cover, location in drainage bottoms, and disturbance from grazing.

Key Ecosystem Characteristics

Diversity of Bur Oak Size

FIA plot data (2017-2019) provides the most current information on the species and size of trees in the bur oak ecosystem (table 10) as well as bur oak trees across the forest (table 15 in appendix A). These data indicate bur oak trees in the forest reach up to 15”, with the majority in the smallest diameter classes.

Most of the trees in the bur oak ecosystem are bur oak (72%), with 15% being ponderosa pine and 13% being other species - eastern hophornbeam, paper birch, green ash, Rocky Mountain juniper, and quaking aspen (table 10, figure 8).

Table 10. Number of live trees, by diameter class, bur oak forest type, on the Black Hills National Forest, based on the 2017-2019 FIA data.

[Sampling error percent (68% confidence level) is highly variable across species and size classes, ranging from 35 to 101%.]

Diameter Class	Bur Oak	Percent of Total Live Trees	Ponderosa Pine	Percent of Total Live Trees	Other Species	Percent of Total Live Trees	Total All Species	Percent of Total Live Trees
1-2.9”	6,640,572	45.4%	908,962	6.2%	1,272,357	8.7%	8,821,891	60.3%
3-4.9”	2,113,754	14.4%	-	-	451,479	3.1%	2,565,233	17.5%
5-6.9”	1,330,045	9.1%	448,369	3.1%	52,749	0.4%	1,831,162	12.5%
7-8.9”	270,290	1.8%	200,389	1.4%	87,368	0.6%	558,046	3.8%
9-10.9”	143,390	1.0%	184,142	1.3%	52,748	0.4%	380,280	2.6%
11-12.9”	54,386	0.4%	87,611	0.6%	-	-	141,996	1.0%
13-14.9”	36,257	0.2%	154,968	1.1%	-	-	191,225	1.3%
15-16.9”	-	-	69,239	0.5%	-	-	69,239	0.5%
17-18.9”	-	-	36,257	0.2%	-	-	36,257	0.2%
19-20.9”	-	-	34,619	0.2%	-	-	34,619	0.2%
Total	10,588,695	72.4%	2,124,557	14.5%	1,916,699	13.1%	14,629,949	100.0%

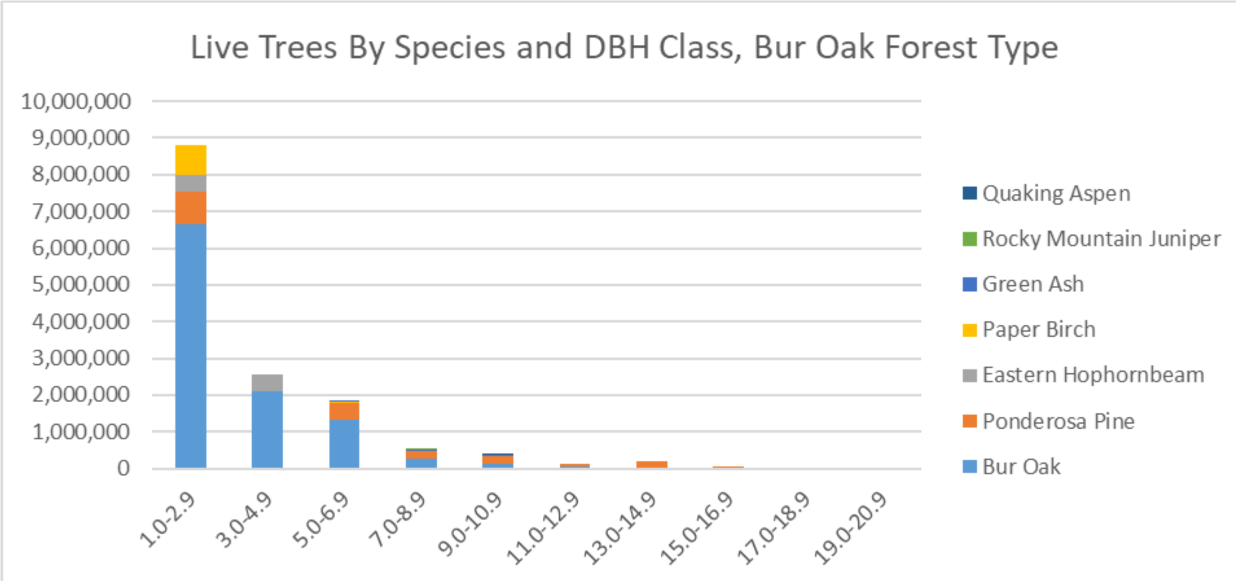


Figure 8. Diameter distribution of live trees, bur oak forest type, by species

Past studies, such as Sieg (1991), have indicated a lack of bur oak seedlings and saplings. While there may be a concern that this species is becoming replaced by more shade-tolerant species in some areas, Sieg (1991) also summarized how some bur oak stands on the western part of its range were regenerating in both western North Dakota and South Dakota. The most current data available as to the size distribution of bur oak in the Forest is the FIA plot data. This data indicates that the majority of the bur oak trees in the Forest are in the smallest diameter classes (table 10, table 15) and do not indicate a concern regarding oak regeneration and recruitment. FIA seedling data for the bur oak forest type indicates an average of just under 7000 seedlings/acre[36], with the majority being bur oak seedlings (65%) and the rest being other species such as chokecherry, paper birch, serviceberry, eastern hophornbeam, aspen, and ponderosa pine.

Mast Production

Mast production is a vital ecosystem service and is critical for some wildlife species dependent on this type of food.

Detailed research specific to bur oak acorn production over time and space is generally lacking. Bur oak is a masting species, producing large acorn crops in most but not all years. Age at first reproduction for bur oak is reported as 35 years (Guyette et al. 2004). Bur oak is a long-lived tree and can live 300 to 400 years (Gucker 2011, Guyette et al. 2004). While bur oak may still produce seeds at older ages, the optimum seed-bearing years are reported as 75 to 150 (Gucker 2011).

Given the distribution of bur oak tree diameters and age-size relationship found in Sieg (1991)[37], one would conclude that the bur oak trees in the Forest do reach a size/age that will support mast production.

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[36] Sampling error percent (68% confidence level) is 24%.

[37] Sieg (1991) examined bur oak in the foothills of the Black Hills at Fort Meade Recreation Area, south of the town of Sturgis. The bur oak age distribution shown by this data was uneven, with peaks occurring in the 40- to 45-year-old class and in the 80- to 85-year-old class. The average diameter of bur oak trees in this study was 7.5 inches (19.0

Snags and Downed Wood

Plan direction related to snags has been discussed previously in the ponderosa pine section. Of note here is that current plan direction for hardwood stands such as bur oak is to:

> *b. *Retain at least six hardwood snags per acre in hardwood stands. Retain all snags in hardwood stands with snag density of less than six per acre. STANDARD*

FIA data (2017-2019), though limited, indicates an average of about 10 snags/acre (5 inches and larger)[38] in the bur oak forest type.

FIA data also indicates an average of about 3.1 tons/acre of downed wood (coarse woody debris only, 3 inches and larger)[39] in the bur oak forest type.

Summary of Ecological Integrity

To assess the ecological integrity of each ecosystem, it is helpful to first describe what that ecosystem would be like if it had high ecological integrity. This provides a reference for comparison with current ecosystem conditions and illuminates why an ecosystem may have high, low, or moderate ecological integrity.

Bur oak systems with high ecological integrity experience frequent fire, have adequate bur oak recruitment, which leads to sufficient mast production, a diversity of bur oak in terms of tree sizes, and the presence of downed wood and snags.

The ecological integrity of the bur oak ecosystem in Black Hills National Forest is high and will likely continue to be high in the future. Data indicate no issue with regeneration and recruitment and there is no concern about significant impacts from insects or disease. Trees appear to be of sufficient size for mast production. It's well-adapted to fire, with its thick bark and ability to re-sprout after fire, and tolerant to drought, which will help maintain the species in Black Hills National Forest even under a changing climate. Given this, we anticipate no issues with maintaining bur oak on the landscape and maintaining ecosystem services it provides, such wildlife habitat and forage and cultural value. In fact, it may have an advantage under a changing climate.

While limited in acreage, the bur oak ecosystem on the Black Hills National Forest is an important one given the wildlife species it benefits, the diversity it adds to the landscape, and the cultural importance of this species. In addition, the bur oak-ironwood community type supports rare plant species such as bloodroot.

Rare Ecosystems and Species

While the forested ecosystems described above cover most of the forested areas on the Black Hills National Forest, several rare ecosystems and tree species occur on the Forest and are discussed here. While limited in area and amount, these species are vitally important to the diversity and ecological integrity of the Black Hills National Forest as a whole and tie to the requirement that the revised plan

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cm). Given the age at first reproduction for bur oak is reported as 35 years (Guyette et al. 2004) and the fact that bur oak trees in the Forest reach sizes larger than 7.5 inches (reaching up to 15 inches), one would conclude that the bur oak trees in the Forest do reach a size/age that will support mast production.

[38] Sampling error percent (68% confidence level) is 59%.

[39] Sampling error percent (68% confidence level) is 48%. Estimate was output from the FIA Evalidator public online tool, with only 6 FIA plots included.

must include plan components to maintain or restore the diversity of native tree species similar to that existing in the plan area 36 CFR 219.9.

Current plan direction related to these types is a Landscape Vegetative Diversity (LVD) objective:

> *204. *Conserve and manage birch/hazelnut, lodgepole pine, limber pine, and Douglas-fir.*

Paper Birch (*Betula papyrifera*)

Outside of quaking aspen and bur oak, paper birch is the most common hardwood tree found on the Black Hills National Forest.

Paper birch is a shade-intolerant, early seral hardwood. This medium-sized, fast-growing tree is typically short-lived, rarely living more than 140 years (Safford et al. 1990). It is more common in the northern parts of the Black Hills National Forest, with some scattered trees and small stands in the southern part of the Forest (Blodgett et al. 2018).

While paper birch is sometimes found in ponderosa pine and other forest types, paper birch/beaked hazel forest is a unique, montane dry riparian type found at upper elevations in the forest. As described in USDA Forest Service (2005), paper birch/beaked hazel forests tend to have dense canopies dominated by paper birch. They occur in drainage bottoms (with or without streams) and on slopes with northern aspects (Marriott and Faber-Langendoen 2000b). Emergent white spruce and ponderosa pine may be present in these areas. Shrub diversity can be high, but beaked hazel often dominates the shrub layer. Common herbaceous species include wild sarsaparilla, Lindley's aster, mayflower, fairy bells, and baneberry (Marriott and Faber-Langendoen 2000b). The paper birch/beaked hazel ecosystem provides ecological conditions that support several plant species including bristle-stalk sedge (*Carex leptalea*) and large round-leaf orchid (*Platanthera orbiculate*) (SAIC 2003b). This community type is ranked as globally imperiled and critically imperiled in Wyoming (NatureServe 2022).

Current estimate of paper birch on the Black Hills NF is 18,649 acres (table 2a). Recent trends in paper birch are inconclusive (see tables 2b and 2d). Paper birch trees on the Black Hills National Forest are generally small, reaching up to 13 inches in diameter (FIA).

As described in Timberlake et al. (2022), assessments done outside of the Black Hills National Forest indicate that suitability for paper birch will decrease, or severely decrease with a changing climate. Paper birch is adaptable due to its ability to regenerate after fire, to disperse readily, and to live in a wide range of habitats. However, it is vulnerable to top-kill by fire, as well as its shade and drought intolerance (Butler-Leopold et al. 2018). While paper birch can persist in a wide variety of precipitation regimes (Safford et al. 1990), it is likely moisture limited in the Black Hills (Sieg 1990), and further declines in moisture availability will decrease suitability. Climate change may affect post-fire paper birch regeneration. Post-fire paper birch recruitment may be negatively impacted by warming temperatures and increased fire frequency combined with warming temperatures may decrease birch abundance (Timberlake et al. 2022).

Paper birch in the Black Hills National Forst exists as a small, disconnected population in the southernmost portion of its central U.S. range, suggesting that it would be difficult for the species to expand to adjacent locations with a changing climate (Timberlake et al. 2022).

Recent focused surveys done in birch stands by Forest Health Protection indicated dense stands with small trees (mean diameter of 5.6 inches, mean live basal area of 44.8 ft2/acre, mean overstory of 1402 trees/acre). Mean stand age was 70 years and ranged from 47-124 years (Blodgett et al. 2018). Birch lifespan is likely between 90 to 130 years in the Black Hills. Although birch is a short-lived species, many of the stands still have a few years before they express significant age associated mortality (Blodgett et al. 2018). These surveys also indicated low mortality. Birch regeneration was not abundant given the dense overstories and lack of management. While there were no observations of bronze birch borer (*Agrilus amius*) in the most recent survey (Blodgett et al. 2018), mortality from insects such as bronze birch borer are expected to increase under climate change as trees become more drought-stressed (Timberlake et al. 2022).

Paper birch is also vulnerable to some root rotting pathogens such as *Armillaria* and white mottled rot (*Ganoderma applanatum;* Safford et al. 1990, Lockman et al. 2016). These fungi make trees susceptible to toppling and may also reduce growth (Safford et al. 1990, Lockman et al. 2016). Although Armillaria root disease is likely the most common damage agent in birch in the Black Hills, mortality of the overstory trees is well within expectations; thus, *Armillaria* is helping with the natural thinning of the relatively dense overstory (Blodgett et al. 2018). However, negative effects from pathogens such as these may increase with climate change where trees are already drought stressed (Lockman et al. 2016).

Paper birch, along with white spruce, are two species with isolated populations in the Black Hills located well south of the remainder of their species range. As such, these two species are more vulnerable to changes in climate. Even so, the Black Hills may continue to support refugia population of these species, particularly in colder, wetter locations (Timberlake et al. 2022).

Paper birch, while rare in Black Hills National Forest, provides forest diversity, with some wildlife species favoring birch habitat (Mills et al. 2000). Like white spruce, its disjunct distribution indicates the Black Hills population represents a unique element of biodiversity which extends to its understory associates.

Rocky Mountain Juniper (*Juniperus scopulorum*)

Rocky Mountain juniper is a drought-tolerant species that grows in dry climates. In the Black Hills, there are Rocky Mountain juniper woodlands, and the species is also found in some ponderosa pine dominated forests.

As described in Timberlake et al. (2022), Rocky Mountain juniper is a drought-tolerant species and will likely not be adversely affected by reduced soil moisture resulting from climate change. High temperatures can negatively impact Rocky Mountain juniper growth and regeneration (Halofsky et al. 2018). Climate change effects on fire are more likely to affect Rocky Mountain juniper. Although mature Rocky Mountain juniper can survive low-intensity fires, Rocky Mountain juniper younger than around 20 years are particularly susceptible to fires. More frequent fires resulting from climate change may thus have significant adverse effects on Rocky Mountain juniper (Halofsky et al. 2018).

Current estimate of the extent of Rocky Mountain juniper on the Black Hills National Forest is 17,209 acres (table 2a). This is an increase from an earlier estimate (table 2b). Fire is a major factor controlling the distribution of Rocky Mountain juniper. In general, it is believed that reduced fire frequency, along with climate change and introduction of grazing, accounts for the expansion of Rocky Mountain juniper woodlands into meadows, grasslands, and other types that began in the late 1800s. Prior to this time, more frequent fires probably maintained low density in woodlands and often restricted Rocky Mountain junipers to rocky sites (Scher 2002, USDA Forest Service RMRS 2021).

Limber Pine (*Pinus flexilis*)

Limber pine is a long-lived, slow-growing tree of small to medium size (Steele 1990). In South Dakota, it occurs in isolated areas scattered over a small geographic area of about 2 square miles in the Black Elk Wilderness of the Black Hills National Forest and adjacent Custer State Park (Blodgett 2020). Recently many of these pines were killed by mountain pine beetle (*Dendroctonus ponderosae*) and white pine blister rust (*Cronartium ribicola*), an exotic, invasive disease of 5-needle pines (Blodgett 2020, Blodgett

2019). There are 32 documented live limber pine in the Forest, most of which are seedlings or saplings (Blodgett 2019). Limber pine is ranked as critically imperiled in South Dakota by NatureServe.

A variety of management activities have been done to help ensure persistence of this species in the Forest. This includes branch pruning for white pine blister rust, bulk seed collections, verbenone pouches for mountain pine beetle protection, individual "mother tree" seed collections and planting (Blodgett 2019).

A new limber pine population was established in 2017 in the Norbeck Wildlife Preserve of the Black Hills National Forest. Two-year-old limber pine seedlings were planted in 2017 and in 2018 at 7 areas in the preserve. Additional planting was completed in 2021[40] for a total of 455 planted seedlings. Seedling survival rate is 95% (Blodgett 2022). Observations of these new seedlings suggest limber pine grows better on "good" sites with deep soil and no competition, versus harsh, rocky, thin-soil sites (Blodgett 2020). Seedlings are still showing good growth (Blodgett 2022).

Lodgepole Pine (*Pinus contorta*)

Lodgepole pine is a native species found primarily on the Northern Hills Ranger District in the Swede Gulch area. Harvest has taken place in these stands. Lodgepole pine is regenerating but not prolifically. Some mature lodgepole pine were attacked by mountain pine beetle during the most recent epidemic, but most were not (USDA Forest Service 2015).

As mentioned in the assessment covering areas of tribal importance, lodgepole pine has tribal significance as tipi poles were made of lodgepole pine harvested in the Black Hills National Forest, with approximately 19-21 poles needed for a single structure.

Lodgepole pine is a very small component of the forest, estimated at less than 100 acres (FSVeg Spatial 2021). Lodgepole pine is ranked as imperiled in South Dakota by NatureServe (NatureServe 2022).

Current plan direction simply states to conserve and manage lodgepole pine. Range maps for this species indicate that lodgepole pine in the Black Hills National Forest is at the extreme eastern edge of its range, disjunct from rest of its range, and naturally rare in the Black Hills.

Douglas-Fir (*Pseudotsuga menziesii*)

Douglas-fir is not native to the Black Hills and was planted in past decades. Some of the Douglas-fir in the Sunday Gulch area on Hell Canyon Ranger District, planted in the 1930s, was cut in favor of aspen (USDA Forest Service 2015).

Douglas-fir is a very small component of the forest, estimated at less than 100 acres (FSVeg Spatial 2021).

Summary of the Assessment of Ecosystem Integrity of Forested Ecosystems

The Black Hills region is ecologically unique due to its convergence of grasslands, woodlands, forests, and wetlands. It functions as a place for intermingling of species from disparate portions of North America. Many of the species found here, such as paper birch and white spruce, are isolated and distant

[40] Seed used to produce the seedlings for the 2021 planting were collected in 2018 from Custer State Park. Seeds were divided into two groups for storage: seed collected from mother-trees that had WPBR, and seed collected from mother-trees with no WPBR. A consistent planting pattern was used to monitor seedlings for potential WPBR resistance.

from the rest of their range. While the landscape is dominated by ponderosa pine, there is a high amount of biodiversity provided by other tree species and their understory associates.

Below is a summary of the ecological integrity of the four main ecosystems (table 11). Additional details can be found in earlier sections.

Table 11. Summary of terrestrial ecosystem integrity and trends

Ecosystem	Current Ecosystem Integrity	Likely Future Ecosystem Integrity Under Current Management and Direction
Ponderosa Pine	Low	Low
White Spruce – Pure Spruce	Moderate to High	Moderate
White Spruce – Mixed Species	Moderate to Low	Low
Aspen	Moderate	Low
Bur Oak	High	High

The ecological integrity of the ponderosa pine ecosystem is low and will likely continue to be low in the future, assuming even-aged vegetation management continues to be the dominant practice, given the following:

- The extent of ponderosa pine on the Black Hills National Forest has recently been declining while nonstocked areas have been increasing. If these trends continue and uncharacteristic fire becomes more widespread because of climate change, more areas may be converted to nonstocked. When high severity fires burn large areas, there are limited seed trees and climate-driven drought conditions make it difficult for trees to establish. Additionally, fire policy is also a factor here. As discussed in the fire and fuels assessment, fire exclusion has led to uncharacteristically heavier surface fuel loads and denser understories of young ponderosa pine, which can lead to more severe fire potentially damaging soils and killing overstories.
- Even-aged silvicultural practices create conditions that are more conducive and less resilient to severe bark beetle events relative to uneven-aged silvicultural practices.
- Forest structure across the landscape has been simplified and is not as diverse as the historical structure. Patch sizes are more homogenous and tree density is higher but composed of smaller trees. Current forest conditions are more uniform and continuous, with fewer gaps and more even spacing, increasing the likelihood of crown fire. This is dissimilar to the uneven-aged and spatially heterogeneous forest structure found historically. These conditions compromise forest resilience and delivery of ecosystem services.
- There is a clear decline in late-successional habitat resulting from the recent mountain pine beetle mortality and fire. Additionally, timber management, mountain pine beetle activity, fire, tornados, or a combination of these have converted more than 150,000 acres of moderately closed and closed stands to non-stocked areas and open stand conditions.
- Regeneration is prolific, but high intensity fires and climate change will likely lead to more areas that do not regenerate and considerably more variable regeneration.

The ecological integrity of the white spruce ecosystem is tied to its ecological niche and historical extent. Key factors include:

- As a result of fire exclusion and other factors, the extent of white spruce has expanded and is currently more than 50,000 acres compared to 15,000 acres historically.

- Areas of mostly pure spruce, where it existed historically on cool mesic sites, currently exhibit moderate to high ecological integrity. The ecological integrity of the white spruce ecosystem on these sites will likely be at least moderate in the future if current management levels and forest plan direction continues. These areas, given their longer fire return intervals and greater presence of stand-replacing fire, have been less impacted by fire exclusion. The white spruce on the Black Hills National Forest appears to be in good health with mortality that is in the realm of natural or expected mortality levels. Climate change compromises the status of white spruce ecosystems and therefore the future trend may be toward moderate ecological integrity.
- White spruce mixed species areas would have had higher levels of pine and hardwoods under a more frequent fire regime that was consistent with the natural range of variation. Many mixed species areas that have succeeded to spruce due to fire exclusion occur on gentler slopes and drier sites. These stands currently exhibit moderate to low and declining ecological integrity given that, while currently classified as spruce, they historically would have had a different species composition and are departed from that. These sites would have higher ecological integrity if restored to their historical species composition (pine with spruce and other species such as aspen and paper birch) and structure, with fire acting in its natural role and preventing these areas from succeeding to spruce.
- Tree size class and seedling plot data indicate there are many small trees and suggest that white spruce regeneration and recruitment is occurring. There are enough seed sources and regeneration that this species can sustain itself.

The ecological integrity of the aspen ecosystem is moderate and will likely be low in the future assuming current management and direction.

Key factors in this moderate rating and its decrease to low in the future are:

- Fire exclusion has reduced disturbance in this type. Aspen restoration treatments and prescribed fire are on a small scale, and they are not contributing to the ecological integrity of aspen to the degree needed to maintain or increase this species on the landscape.
- Given this species is short-lived, the age class distribution indicates that about half the aspen is at or nearing the end of its typical life span, with 55% estimated at 60 years or older. Only about 25% is in the youngest age classes (0-40 years).

A larger emphasis on aspen restoration treatments and prescribed fire would help change this trend.

The ecological integrity of the bur oak ecosystem is high and will likely continue to be high in the future.

Key factors in this high rating are:

- Data indicates no issue with regeneration and there is no concern about significant impacts from insects or disease. Trees appear to be of sufficient size for mast production.
- It’s well-adapted to fire, with its thick bark and ability to re-sprout after fire, and tolerant to drought, which will help maintain the species in the Forest even under a changing climate.

Chapter 3. Input for Plan Development

A variety of comments were received on this assessment, many of which led to additions, corrections, and improvements in the revised assessment.

Some comments are more appropriately considered in the next phases of the plan revision process – plan development and the analysis of forest plan alternatives. Those are outlined here.

- Areas with high ecological value have been identified on the forest spatially and should be considered as management areas with associated direction defined.
- Comments in support of a diameter limit cap for commercial timber harvesting to address loss of larger, older trees. Also, potentially delaying harvest beyond the time of CMAI (culmination of mean annual increment) to allow stands to recover ecologically from recent disturbances. Support for sustainable timber harvest levels. Support for larger trees in more complex arrangements.
- Support for increasing the amount of heterogeneity within and between ponderosa pine stands, increasing the amount of uneven-aged management, more prescribed fire, and sustaining the existing late successional habitat and taking actions to develop late successional habitat over time. In contrast, there were also many comments that the assessment is pre-decisional and biased towards uneven-aged management or that mechanical treatment may be needed before reintroduction of fire.
- Comments were received to manage spruce to benefit wildlife species that use this habitat type and to maintain or increase the amount of this type on the forest. In contrast, we also heard that some are concerned that the number of SCCs (species of conservation concern) proposed in spruce habitats will be at odds with reducing spruce acreage to its historical level.
- Support for the idea that we may need more than five habitat structural stages. However, there was also concern about revisiting the current HSS classification system and that the current objectives will be relaxed.
- Support for reforestation, particularly using native seed sources.
- Support for an adaptive management framework given changing conditions and new information.
- Support for restoring prescribed fire treatments for aspen stands, excluding herbivores in clones that are impaired or in decline, and revisiting current classification objectives.
- Support for plan components to control and reduce expansion of juniper into native grassland.
- Support for reintroduction of beavers.
- Support for more accurate monitoring, particularly of forest types and their extents.
- Suggestion to discontinue the practice of “reducing competition with forbs to enhance regeneration of pine trees” to strengthen forbs and resistance to invasive plant species.
- Support for additional or more complex/spatially nuanced analyses of insect and wildfire risk, old growth/late-successional habitat, potential future old growth, interior forest, and ecological integrity.
- Many comments in support of management to reduce mountain pine beetle epidemics and their effects.
- We also heard that we should identify desired conditions for the various management areas and for the Forest as whole in enough detail that management strategies can be developed to achieve those desired conditions. This would be a precursor to work on management strategies,

measurable objectives, and standards and guidelines, all of which can be developed, analyzed, and compared in various forest plan alternatives. Additionally, we should consider latitude and elevation when determining desired conditions to accommodate climate change risks in a more fine-tuned approach. And the desired conditions should focus on landscape patterns, i.e., composition, size, habitat structural stage, and abundance of ecosystem patches, based on NRV landscape patterns, and be designed to limit the ability of stressors, such as insect epidemics and stand-replacing crown fires, to disrupt the ecosystem. Forest Plan goals must emphasize, prioritize, protect, and improve ecosystem health. When developing goals and desired conditions and other plan content, coordinate with county government and their management plan priorities, which include encouraging active management of forest resources, promoting forest health, reducing disease and insect infestation, reducing wildfire impacts, and supporting the economy.

Chapter 4. Potential Need for Forst Plan Changes

Best available science and historical documentation indicate a need for forest plan revision for each of the ecosystem types described in this assessment.

Ponderosa pine

- Focus on a desired forest structure in ponderosa pine that is more uneven-aged and spatially heterogeneous as was found historically. Given the mixed-severity fire regime (including both more frequent, lower-intensity surface fires and less frequent, high-intensity crown fires) that occurred in the Black Hills, a management regime that includes both uneven-aged and even-aged management could potentially best mimic historical stand and landscape structure.
- Focus on restoring more frequent surface fire across the ponderosa pine ecosystem. (See also the Need for Change section of the Fire and Fuels assessment and the need for reasonable guidance for natural fire.) While it varies across the Forest and situation, in some cases, mechanical timber harvest or hand thinning may make implementing prescribed fire easier and lead to less overstory mortality.
- Have an emphasis on sustaining the existing late successional habitat and take actions to develop late successional habitat over time.
- Focus on increased reforestation via planting, where appropriate, but in particular in high-severity fire areas that are not regenerating due to lack of a seed source and factoring in desired conditions and objectives as defined in the forest plan.
- Revisit the current HSS classification system, which is most applicable for even-aged, single species stands rather than uneven-aged and mixed-species stands and is rather subjective. Future classification system should be appropriately tied to desired conditions for species habitat requirements. This may mean having a more informative HSS system with additional classes.
- Revisit how HSS are included in the plan in a way that is flexible and enables adaptive management given changing conditions and new information.

White Spruce

- Revisit the white spruce plan direction (239-LVD). This direction indicates to manage for 20,000 acres of spruce across the Forest using active management to achieve multiple-use objectives. There is a need to revisit desired conditions for white spruce and re-assess thresholds needed for species habitat. Current white spruce direction is simple and may need to be more nuanced in terms of how different types of spruce-dominated forest in different areas across the Forest is managed.
- Include monitoring of white spruce to keep track of what is happening to this species, given its uniqueness and vulnerability to climate change.

Aspen

- Continue with the emphasis on increasing the extent of the aspen ecosystem. A higher emphasis on aspen restoration treatments and prescribed fire is needed, particularly given about half of the aspen is at or nearing the end of its typical life span.
- Focus on identifying aspen clones that are in decline or those that are in need of immediate treatment (see earlier description of aspen/hardwood restoration treatments in the Forest Management section) as that is important to maintaining aspen on the Black Hills National Forest.
- Revisit the current objective of 92,000 acres of aspen. Additional direction tied to maintaining a variety of aspen age classes, restoring a particular amount per year, or establishing particular areas to focus on may be desirable.
- Maintain an emphasis on reintroduction of beavers and restoration of conditions that favor beavers given their beneficial impacts on aspen regeneration, diversity, and ecosystem processes.

Bur Oak

- Revisit the current plan objective regarding bur oak. It may need to be more nuanced in terms of desired conditions and needs to adequately factor in the different bur oak forms and/or communities.
- Revisit the plan direction regarding managing a portion of each bur oak stand for 100-plus year-old trees. It is difficult to track progress towards this plan objective. One potential need for change would be to adjust this objective to something that is more easily tracked with FIA data or another data source.

Rare Ecosystems and Species

- Current plan direction simply states to conserve and manage birch/hazelnut, lodgepole pine, limber pine, and Douglas-fir.
- Given the desire to maintain this paper birch, there is a need to more explicitly describe how this species will be managed. Birch regeneration could be facilitated by clearcutting or burning in and around stands or removing conifers around birch stands. Coppice cuts, if desired, could be done in the near term given current stand ages and given that older trees produce few sprouts (Blodgett et al. 2018).
- There is also a need to describe how limber pine will be conserved and/or managed to ensure its continued existence in the Forest. This may include, among other management approaches, branch pruning to control white pine blister rust spread and to prevent the diseases from reaching

the main stems (thus killing trees) and/or cone collections in good cone bearing years (Blodgett 2019).

- Given the desire to maintain native tree species, there is a need to more explicitly describe how lodgepole pine will be conserved and/or managed to ensure its continued existence in the Forest.
- Current plan direction simply states to conserve and manage Douglas-fir. Given this species is not native to the Black Hills, there is a need to more explicitly describe how Douglas-fir will be conserved, managed, or removed.

References Cited

Abernethy, I., E. Whittle, and A. Chalfoun. 2019. Maternity Roost Selection by Northern Long-eared Bat (Myotis septentrionalis) On the Black Hills National Forest, Wyoming. Final Report. Challenge Cost Share Agreement Supplement 17-CS-11020000-005. Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming, Laramie, Wyoming.

Addington, Robert N.; Aplet, Gregory H.; Battaglia, Mike A.; Briggs, Jennifer S.; Brown, Peter M.; Cheng, Antony S.; Dickinson, Yvette; Feinstein, Jonas A.; Pelz, Kristen A.; Regan, Claudia M.; Thinnes, Jim; Truex, Rick; Fornwalt, Paula J.; Gannon, Benjamin; Julian, Chad W.; Underhill, Jeffrey L.; Wolk, Brett. 2018. Principles and practices for the restoration of ponderosa pine and dry mixed-conifer forests of the Colorado Front Range. RMRS-GTR-373. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 121 p.

Allen, K., J. Blodgett, K. Schotzko, and A. Dymerski. 2019. Conditions in White Spruce Stands on the Black Hills National Forest. Report RCSC-19-05. USDA Forest Service, Rocky Mountain Region, Forest Health Protection.

Allen, K., K. Schotzko, and A. Dymerski. 2020. Estimated Tree Mortality Caused by the Mountain Pine Beetle During the 1997-2015 Epidemic on the Black Hills NF. Report RCSC-20-04. USDA Forest Service, Rocky Mountain Region, Forest Health Protection.

Allen, K., J. Blodgett, and K. Schotzko. 2021. Conditions in White Spruce Stands in the PAR Project Area. Report RCSC-21-01. USDA Forest Service, Rocky Mountain Region, Forest Health Protection.

Alexander, R. R.; Edminster, C. B. 1981. Management of ponderosa pine in even-aged stands in the Black Hills. Res. Pap. RM-228. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 10 pp.

Anderson, T. 2003. Conservation assessment for the woodpeckers in the Black Hills National Forest, South Dakota and Wyoming. U.S. Forest Service, Rocky Mountain Region, Black Hills National Forest. Custer, South Dakota. http://www.fs.fed.us/r2/blackhills/projects/planning/assessments/woodpeckers.pdf

Bennett, S., N. Bouwes, and P. C. Rogers. 2019. Beaver and aspen: synergy among keystone species. Western Aspen Alliance. Utah State University, Logan, UT. WAA Brief #6.

Bentz, Barbara; Logan, Jesse; MacMahon, Jim; Allen, Craig D.; Ayres, Matt; Berg, Ed; Carroll, Allan; Hansen, Matt; Hicke, Jeff; Joyce, Linda; Macfarlane, Wallace; Munson, Steve; Negron, Jose; Paine, Tim; Powell, Jim; Raffa, Ken; Regniere, Jacques; Reid, Mary; Romme, Bill; Seybold, Steven J.; Six, Diana; Tomback, Diana; Vandygriff, Jim; Veblen, Tom; White, Mike; Witcosky, Jeff; Wood, David. 2009. Bark beetle outbreaks in western North America: Causes and consequences. Bark Beetle Symposium; Snowbird, Utah; November, 2005. Salt Lake City, UT: University of Utah Press. 42 p.

Bentz, B.; Régnière, J.; Fettig, C.; [et al.]. 2010. Climate change and bark beetles of the western United States and Canada: Direct and indirect effects. Bioscience. 60: 602–613.

Blodgett, J. T. 2022. Limber Pine Planting in the Black Hills National Forest (2021 Update). Report RCSC-22-10. USDA Forest Service, Rocky Mountain Region, Forest Health Protection.

Blodgett, J. T. 2020. Limber Pine Planting in the Black Hills National Forest. Report RCSC-20-09. USDA Forest Service, Rocky Mountain Region, Forest Health Protection.

Blodgett, J. T. 2019. Black Elk Limber Pine: 2019. Report RCSC-20-02. USDA Forest Service, Rocky Mountain Region, Forest Health Protection.

Blodgett, J. T., K. K. Allen, K. Schotzko, A. Dymerski. 2020. Aspen Health on National Forests in the Northern Rocky Mountain Region (2008/2009 to 2019). Biological Evaluation RCSC-20-06. USDA Forest Service, Rocky Mountain Region, Forest Health Protection.

Blodgett, J. T., K. K. Allen, K. Schotzko, A. Dymerski. 2018. Paper Birch in the Black Hills National Forest. Report RCSC-18-05. USDA Forest Service, Rocky Mountain Region, Forest Health Protection.

Blodgett, J. T., K. K. Allen, K. Schotzko, A. Dymerski. 2017. Aspen Health on National Forests in the Northern Rocky Mountain Region. Report RCSC-17-06. USDA Forest Service, Rocky Mountain Region, Forest Health Protection.

Boldt, Charles E.; Van Deusen, James L. 1974. Silviculture of ponderosa pine in the Black Hills: The status of our knowledge. Res. Pap. RM-124. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 45 pp.

Bottero, Alessandra; D'Amato, Anthony W.; Palik, Brian J.; Bradford, John B.; Fraver, Shawn; Battaglia, Mike A.; Asherin, Lance A. 2017. Density-dependent vulnerability of forest ecosystems to drought. Journal of Applied Ecology. 54(6): 1605-1614. https://doi.org/10.1111/1365-2664.12847.

Bradford, J.B. and Bell, D.M. (2016). A window of opportunity for climate-change adaptation: easing tree mortality by reducing forest basal area. Front Ecol Environ. doi: 10.1002/fee.1445.

Brandt, Leslie; He, Hong; Iverson, Louis [et al.]. 2014. Central Hardwoods ecosystem vulnerability assessment and synthesis: a report from the Central Hardwoods Climate Change Response Framework project. Gen. Tech. Rep. NRS-124. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 254 pp.

Brown, P.M. and C.H. Sieg. 1999. Historical variability in fire at the ponderosa pine – northern Great Plains prairie ecotone, southeastern Black Hills, South Dakota. Ecoscience 6(4): 539-547.

Brown, P.M., M.G. Ryan and T.G. Andrews. 2000. Historical surface fire frequency in ponderosa pine stands in research natural areas, central Rocky Mountains and Black Hills, USA. Natural Areas Journal 20:133-139.

Brown, P.M. 2001. Landscape age structure of ponderosa pine stands, Limestone Plateau, Black Hills National Forest: Final report. Challenge Cost Share Agreement No. CCS-11020399-23 between Rocky Mountain Tree-Ring Research, In. and USDA Forest Service Black Hills National Forest.

Brown, P.M. 2003. Fire, climate, and forest structure in ponderosa pine forests of the Black Hills. PhD Dissertation, Colorado State University, Fort Collins. 103 pp.

Brown, P.M. 2006. Climate effects on fire regimes and tree recruitment in Black Hills ponderosa pine forests. Ecology. 87(10): 2500-2510.

Brown, P. M., and B. Cook. 2006. Early settlement forest structure in Black Hills ponderosa pine forests. Forest Ecology and Management 223:284–290.

Brown, Peter M.; Wienk, Cody L.; Symstad, Amy J. 2008. Fire and forest history at Mount Rushmore. Ecological Applications. 18(8): 1984–1999.

Burns, R.M., and B.H. Honkala. 1990. Silvics of North America. Vol. 2 Hardwoods. Agriculture Handbook 654. USDA Forest Service, Washington Office. Washington, D.C. 877 pp.

Buskirk, S.W. 2002. Conservation assessment for the American marten in the Black Hills National Forest, South Dakota and Wyoming. U.S. Forest Service, Rocky Mountain Region, Black Hills National Forest. Custer, South Dakota. http://www.fs.fed.us/r2/blackhills/projects/planning/assessments/marten.pdf

Butler-Leopold, P.R.; Iverson, L.R.; Thompson, F.R., III [et al.]. 2018. Mid-Atlantic forest ecosystem vulnerability assessment and synthesis: a report from the Mid-Atlantic Climate Change Response Framework project. Gen. Tech. Rep. NRS-181. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 294 pp.

Chojnacky, David C.; Bentz, Barbara J.; Logan, Jesse A. 2000. Mountain pine beetle attack in ponderosa pine: Comparing methods for rating susceptibility. Res. Pap. RMRS-RP-26. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 10 p.

Dodge, R.I. 1876. The Black Hills. James Miller and Company, New York, NY.

Fettig, C.J., S.J. Hood, J.B. Runyon, and C.M. Stalling. 2021. Bark beetle and fire interactions in western coniferous forests: Research findings. Fire Management Today 79: 14-23.

Fisher, R. F.; Jenkins, M. J.; Fisher, William F. 1986. Fire and the prairie-forest mosaic of Devils Tower National Monument. The American Midland Naturalist. 117(2): 250-257.

Frest, T.J. and E.J. Johannes. 2002. Land snail survey of the Black Hills National Forest, South Dakota and Wyoming, Summary report, 1991-2001. Final report contract # 43-67TO-8-1085. USDA, Forest Service, Black Hills National Forest. 127 pp. plus appendices.

Frey, B.R.; Lieffers, V.J.; Hogg, E.H.; Landhausser, S.M. 2004. Predicting landscape patterns of aspen dieback: mechanisms and knowledge gaps. Canadian Journal for Forestry Research. 34: 1379-1390.

Gibson, K., S. Kegley, and B. Bentz. 2009. Mountain Pine Beetle. US Forest Service, Forest Insect and Disease Leaflet 2:12 p.

Gleason, K. E., J. B. Bradford, A. Bottero, A. W. D'Amato, S. Fraver, B. J. Palik, M. A. Battaglia, L. Iverson, L. Kenefic, and C. C. Kern. 2017. Competition amplifies drought stress in forests across broad climatic and compositional gradients. Ecosphere 8(7):e01849. 10.1002/ecs2.1849

Gleason, K. E., J. B. Bradford, A. W. D'Amato, S. Fraver, B. J. Palik, and M. A. Battaglia. 2021. Forest density intensifies the importance of snowpack to growth in water-limited pine forests. Ecological Applications 31(1): e02211. 10.1002/eap.2211

Graham, Russell T.; Battaglia, Mike A.; Jain, Theresa B. 2021. A scenario-based assessment to inform sustainable ponderosa pine timber harvest on the Black Hills National Forest. Gen. Tech. Rep. RMRS-GTR-422. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 61 p. https://doi.org/10.2737/RMRS-GTR-422

Graham, Russell T.; Asherin, Lance A.; Battaglia, Michael A.; [et al.]. 2016. Mountain pine beetles: A century of knowledge, control attempts, and impacts central to the Black Hills. Gen. Tech. Rep. RMRS-GTR-353. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 193 pp.

Grafe, E. and P. Horsted. 2002. Exploring with Custer: The 1874 Black Hills expedition. Golden Valley Press. Custer, South Dakota.

Graves, H.S. 1899. The Black Hills Forest Reserve. Extract from the Nineteenth annual report of the survey, 1897-1898. Part V. Forest Reserves. U.S. Geological Survey.

Gucker, Corey L. 2011. Quercus macrocarpa. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: https://www.fs.usda.gov/database/feis/plants/tree/quemac/all.html [2021, November 24].

Guyette, Richard P.; Muzika, Rose-Marie; Kabrick, John; Stambaugh, Michael C. 2004. A perspective on Quercus life history characteristics and forest disturbance. In: Spetich, Martin A., ed. Upland oak ecology symposium: history, current conditions, and sustainability: Proceedings; 2002 October 7-10;

Fayetteville, AR. Gen. Tech. Rep. SRS-73. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 138-142.

Hall, J.S., H.J. Marriott, and J.K. Perot. 2002. Ecoregional conservation in the Black Hills. Final report: 2002. The Nature Conservancy. Minneapolis, Minnesota.

Halofsky, Jessica E.; Peterson, David L.; Ho, Joanne J.; Little, Natalie, J.; Joyce, Linda A., eds. 2018. Climate change vulnerability and adaptation in the Intermountain Region. Gen. Tech. Rep. RMRS-GTR-375. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Part 1. pp. 1–197.

Handler, S.; Duveneck, M.J.; Iverson, L.; [et al.]. 2014. Minnesota forest ecosystem vulnerability assessment and synthesis: a report from the Northwoods Climate Change Response Framework project. Gen. Tech. Rep. NRS-133. Newtown Square, PA; U.S. Department of Agriculture, Forest Service, Northern Research Station. 228 pp.

Hood, S.M., S. Baker, and A. Sala. 2016. Fortifying the forest: Thinning and burning increase resistance to a bark beetle outbreak and promote forest resilience. Ecological Applications 26: 1984-2000.

Howard, Janet L. 1996. Populus tremuloides. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: https://www.fs.fed.us/database/feis/plants/tree/poptre/all.html [2021, November 24].

Iverson, L.R.; McKenzie, D. Tree-species range shifts in a changing climate: detecting, modeling, assisting. Landscape Ecology. 28: 879-889.

Janowiak, M.K.; Iverson, L.R.; Mladenoff, [et al.]. 2014. Forest ecosystem vulnerability assessment and synthesis for northern Wisconsin and western Upper Michigan: a report from the Northwoods Climate Change Response Framework project. Gen. Tech. Rep. NRS-136. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 247 pp.

Johnston, B. C., and L. Hendzel. 1985. Examples of aspen treatment, succession, and management in western Colorado. USDA Forest Service, Range Wildlife Fisheries and Ecology. Denver, CO. 164 pp.

Kabrick, J.M.; Dey, D.C.; Van Sambeck, J.W.; Coggeshall, M.V.; Jacobs, D.F. 2012. Quantifying flooding effects on hardwood seedling survival and growth for bottomland restoration. New Forests 43: 695-710.

Kennedy. P.L. 2003. Northern Goshawk (Accipiter gentiles atricapillus): A technical conservation assessment. USDA Forest Service, Rocky Mountain Region. http://www.fs.fed.us/Region 2/projects/scp/assessments/northerngoshawk.pdf

Keyser, T.L., Smith, F.W., Shepperd, W.D., 2005. Trembling aspen response to a mixed-severity wildfire in the Black Hills, South Dakota, USA. Can. J. For. Res. 35, 2679–2684

Keyser, Tara L., Leigh B. Lentile, Frederick W. Smith, and Wayne D. Shepperd. Changes in Forest Structure After a Large, Mixed-Severity Wildfire in Ponderosa Pine Forests of the Black Hills, South Dakota, USA, Forest Science, Volume 54, Issue 3, June 2008, Pages 328–338. https://www.fs.fed.us/rm/pubs_other/rmrs_2008_keyser_t001.pdf

King, D.A.; Bachelet, D.M.; Symstad, A.J. 2013. Climate change and fire effects on a prairie-woodland ecotone: Projecting species range shifts with a dynamic global vegetation model. Ecology and Evolution 3: 5076–5097.

Korb, J.E.; Fornwalt, P.J.; Stevens-Rumann, C.S. 2019. What drives ponderosa pine regeneration following wildfire in the western United States? 454: 117663.

Krzic, M., H. Page, R.F. Newman, and K. Broersma. 2004. Aspen regeneration, forage production, and soil compaction on harvested and grazed boreal aspen stands. BC Journal of Ecosystems and Management 5(2):30–38.

Landfire BPS documentation. 2020. Landfire Biophysical Setting Model Description for 2910480 – Northwestern Great Plains Highland White Spruce Woodland.

Larson, G.E. and J.R. Johnson. 2007. Plants of the Black Hills and Bear Lodge Mountains. South Dakota State University, 2nd edition. 608 pp.

Lentile, L.B., F.W. Smith, and W.D. Shepperd. 2000. Snag management in the Black Hills National Forest 2000. Study report to the Black Hills National Forest.

Lentile, L.B., F.W. Smith, and W.D. Shepperd. 2005. Patch structure, fire-scar formation, and tree regeneration in a large mixed-severity fire in the South Dakota Black Hills, USA. Can. J. For. Res. 35: 2875–2885.

Lockman, I.B.; Kearns, H.S.J., eds. 2016. Forest root diseases across the United States. Gen. Tech. Rep. RMRS-GTR-342. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 55 pp.

Marriott, H.J. and D. Faber-Langendoen. 2000a. Black Hills community inventory. Volume 2: Plant community descriptions. The Nature Conservancy, Midwest Conservation Center. Minneapolis, Minnesota. 326 pp.

Marriott, H.J. and D. Faber-Langendoen. 2000b. Riparian and wetland plant communities of the Black Hills. The Nature Conservancy Midwest Conservation Science Center and Association for Biodiversity Information. Minneapolis, Minnesota.

Marriott, H.J., D. Faber-Langendoen, A. McAdams, D. Stutzman, and B. Burkhart. 1999. The Black Hills community inventory.

Maze, Jack. 1968. Past hybridization between *Quercus macrocarpa* and *Quercus gambelii*. Brittonia. 20: 321-333.

Mehl, S.M. 1992 Old-growth descriptions for the major cover types in the Rocky Mountain Region. In: GTR-RM-213. Old-growth forests in the Southwest & Rocky Mountain regions, proceedings of a workshop. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Mills, T.R., M.A. Rumble, and L.D. Flake. 2000. Habitat of birds in ponderosa pine and aspen/birch forest in the Black Hills, South Dakota. J. Field Ornith. 71:2. pp. 187-206.

Mueggler, W.F. 1985. Vegetation associations. Aspen: Ecology and Management in the Western United States. General Technical Report RM-119. Norbert V. DeByle and Robert P. Winokur (ED). USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO pp. 45-55.

Murphy, Shannon K. 2017. Fire regimes of ponderosa pine communities in the Black Hills and surrounding areas. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). Available: https://www.fs.fed.us/database/feis/fire_regimes/Black_Hills_ponderosa_pine/all.pdf

NatureServe. 2021-2022. Explorer. Web based application. accessed September 2021 and April 2022.

https://explorer.natureserve.org/

https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.689584/Quercus_macrocarpa_-_Ostrya_virginiana_Forest

https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.158441/Quercus_macrocarpa

Negrón, Jose F.; Allen, Kurt; Cook, Blaine; [et al.]. 2008. Susceptibility of ponderosa pine, Pinus ponderosa (Dougl. ex Laws.), to mountain pine beetle, Dendroctonus ponderosae Hopkins, attack in uneven-aged stands in the Black Hills of South Dakota and Wyoming USA. Forest Ecology and Management 254(2): 327–334.

Negrón, Jose F.; Allen, Kurt K.; Ambourn, Angie; [et al.]. 2017. Large-scale thinnings, ponderosa pine, and mountain pine beetle in the Black Hills, USA. Forest Science 63(5): 529–536.

Panjabi, A. 2001. Monitoring the birds of the Black Hills: Year 1 final report. Rocky Mountain Bird Observatory. Fort Collins, Colorado. http://www.fs.fed.us/r2/blackhills/projects/wildlife/index.shtml

Parrish, J.B., D.J. Herman, D.J. Reyher, and Black Hills National Forest. 1996. A century of change in the Black Hills forest and riparian ecosystems. USDA Forest Service Agricultural Experiment Station, USDA, South Dakota State University. 13 pp.

Rehfeldt, G.E.; Crookston, N.L.; Warwell, M.V.; [et al.]. 2006. Empirical analyses of plant-climate relationships for the western United States. International Journal of Plant Science 167: 1123–1150.

Reynolds, Richard T.; Sánchez Meador, Andrew J.; Youtz, James A.; Nicolet, Tessa; Matonis, Megan S.; Jackson, Patrick L.; DeLorenzo, Donald G.; Graves, Andrew D. 2013. Restoring composition and structure in Southwestern frequent-fire forests: A science-based framework for improving ecosystem resiliency. Gen. Tech. Rep. RMRS-GTR-310. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 76 p.

Rice, J.; Bardsley, T.; Gomben, P.; Bambrough, D.; Weems, S.; Huber, A.; Joyce, L.A. 2017. Assessment of aspen ecosystem vulnerability to climate change for the Uinta-Wasatch-Cache and Ashley National Forests, Utah. Gen. Tech. Rep. RMRS-GTR-366. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 67 pp.

Rice, J.R.; Joyce, L.A.; Regan, C.; Winters, D.; Truex, R. 2018. Climate change vulnerability assessment of aquatic and terrestrial ecosystems in the U.S. Forest Service Rocky Mountain Region. Gen. Tech. Rep. RMRS-GTR-376. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 216 pp.

Ripple, W.J., and R.L. Beschta. 2007. Hardwood tree decline following large carnivore loss on the Great Plains, USA. Frontiers in Ecology and the Environment 5(5):241-246.

Safford, L.O.; Bjorkbom, J.C.; Zasada, J.C. 1990 Betula papyrifera Marsh. Paper birch. In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America. Vol 2. Hardwoods. Agriculture Handbook 654. Washington, DC: U.S. Department of Agriculture Forest Service: 158-171.

Scher, Janette S. 2002. Juniperus scopulorum. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: https://www.fs.usda.gov/database/feis/plants/tree/junsco/all.html [2022, February 10].

Science Applications International Corporation (SAIC). 2003b. Management approaches for emphasis species and biological elements of viability concern, Black Hills National Forest Phase II Plan Amendment. Science Application International Corporation. SAIC project number 01-0209-04-4456-103.

Schnabel, Andrew; Hamrick, J. L. 1990. Comparative analysis of population genetic structure in Quercus macrocarpa and Q. gambelii (Fagaceae). Systematic Botany 15(2): 240-251.

Severson, K.E., and J.J. Kranz. 1978. Management of bur oak on deer winter range. Wildlife Society Bulletin 6(4):212-216.

Severson, Kieth E.; Thilenius, John F. 1976. Classification of Quaking Aspen Stands in the Black Hills and Bear Lodge Mountains. U.S. Department of Agriculture, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station Forest Service, Research Paper RM-166, 24 pp.

Shepperd, W.D., and L.A. Asherin. 2004. Assessment of aspen clonal conditions on the Black Hills National Forest. Final Report. USDA Forest Service, Rocky Mountain Research Station. Fort Collins, CO.

Shepperd, W.D., and M.A. Battaglia. 2002. Ecology, silviculture, and management of Black Hills ponderosa pine. Gen. Tech. Rep. RMRS-GTR-97. USDA Forest Service, Rocky Mountain Research Station. Fort Collins, CO.

Shepperd, W.D. 1993. The effects of harvesting activities on soil compaction, root damage, and suckering in Colorado aspen. West. Jour. Appl. For. 8:62-66

Shinneman, D.J. and W.L. Baker. 1997. Nonequilibrium dynamics between catastrophic disturbances and old growth forests in ponderosa pine landscapes of the Black Hills. Conservation Biology 11(6):1276-1288.

Shinneman, D.J., W.L. Baker, P.C. Rogers, and D. Kulakowski. 2013. Fire regimes of quaking aspen in the Mountain West. For. Ecol. Manage. 299:22-34.

Sieg, C. H. 1991. Ecology of bur oak woodlands in the foothills of the Black Hills, South Dakota. Lubbock, TX: Texas Tech University Dissertation, 185 pp.

Sieg, C.H., and K.E. Severson. 1996. Managing habitats for white-tailed deer: Black Hills and Bear Lodge Mountains of South Dakota and Wyoming. General Technical Report RM-GTR-274. Rocky Mountain Forest and Range Experiment Station. Fort Collins, Colorado.

Steele, R. 1990. Pinus flexilis James. Limber Pine. In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America. Vol 1. Conifers. Agriculture Handbook 654. Washington, DC: U.S. Department of Agriculture Forest Service.

Steen-Adams, M.M.; Abrams, J.A.; Huber-Stearns, H.R.; Bone, C.; Moseley, C. 2021. Leveraging administrative capacity to manage landscape-scale, cross-boundary disturbance in the Black Hills: What roles for federal, state, local, and nongovernmental partners? Journal of Forestry.

Stephens, R.M. and S.H. Anderson. 2003. Conservation assessment for the broad-winged hawk in the Black Hills National Forest, South Dakota, and Wyoming. U.S. Forest Service, Rocky Mountain Region, Black Hills National Forest. Custer, South Dakota. http://www.fs.fed.us/r2/blackhills/projects/planning/assessments/broad_winged_hawk.pdf

Stephens, S.L., M.A. Battaglia, D.J. Churchill, B.M. Collins, M. Coppoletta, C.M. Hoffman, J.M. Lydersen, M.P. North, R.A. Parsons, S.M. Ritter, and J.T. Stevens. 2021. Forest restoration and fuels reduction: convergent or divergent? BioScience 71: 85–101.

Stevens, J.T.; Kling, M.M.; Schwilk, D.W.; Varner, J.M.; Kane, J.M. 2020. Biogeography of fire regimes in western U.S. conifer forests: A trait-based approach. Global Ecology and Biogeography 29: 944-955.

Stevens-Rumann, C.S.; Kemp, K.B.; Higuera, P.E.; Harvey, B.J.; Rother, M.T.; Donato, D.C.; Morgan, P.; Veblen, T.T. 2018. Evidence for declining forest resilience to wildfires under climate change. Ecology Letters 21: 243-252.

Stone, D.M. 2001. Sustaining aspen productivity in the Lake States. Pp 47-59 IN: Shepperd et al. Editors. Sustaining Aspen in Western Landscapes: Symposium Proceedings. Proceedings RMRS-P-18. Fort Collins, CO. USDA Forest Service, Rocky Mountain Research Station, 460 pp.

Swanston, C.; Janowiak, M.; Iverson, L.; [et al.]. 2011. Ecosystem vulnerability assessment and synthesis: a report from the Climate Change Response Framework Project in northern Wisconsin. Gen. Tech. Rep. NRS-82. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station, 142 pp.

Tatina R.E., Hanberry B.B. (2022). Historical forests of the Black Hills, South Dakota, USA, determined using General Land Office surveys. Silva Fennica vol. 56 no. 3 article id 10754. 17 p.

Timberlake, T.J.; Halofsky, J.E.; Joyce, L.A.; Peterson, D.L. 2022. Climate change vulnerability in the Black Hills National Forest. U.S. Department of Agriculture, Forest Service, Western Wildland Environmental Threat Assessment Center. Unpublished report.

Uresk, D. W.; Severson, K. E. 1998. Response of understory species to changes in ponderosa pine stocking levels in the Black Hills. Great Basin Naturalist 58(4): 312–327.

USDA Forest Service. 1996a. Final Environmental Impact Statement for the Revised Land and Resource Management Plan for the Black Hills National Forest. USDA Forest Service, Black Hills National Forest. Custer, South Dakota.

USDA Forest Service. 2005. Final Environmental Impact Statement for the Phase II Amendment to the 1997 Revised Land and Resource Management Plan for the Black Hills National Forest. USDA Forest Service, Black Hills National Forest. Custer, South Dakota. Available online: https://www.fs.usda.gov/detail/blackhills/landmanagement/planning/?cid=fsm9_012673

USDA Forest Service. 2011. Review of the Forest Service Response: The Bark Beetle Outbreak in Northern Colorado and Southern Wyoming. USDA Forest Service, Rocky Mountain Region and Rocky Mountain Research Station at the request of Senator Mark Udall.

https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5340736.pdf

USDA Forest Service. 2013. Black Hills National Forest FY 2012 Monitoring and Evaluation Report. USDA Forest Service, Black Hills National Forest. Custer, South Dakota.

USDA Forest Service. 2015. Black Hills National Forest FY 2013-14 Monitoring and Evaluation Report. USDA Forest Service, Black Hills National Forest. Custer, South Dakota.

USDA Forest Service, Forest Inventory and Analysis Program. 2019. MyEVALIDator Version 1.8.0.01. St. Paul, MN: U.S. Department of Agriculture, Forest Service, Northern Research Station. Available at https://usfs-public.app.box.com/v/BlackHillsFIAData

USDA Forest Service, Forest Inventory and Analysis Program. 2021. The Forest Inventory and Analysis Database: Database Description and User Guide for Phase 2 (version 9.0.1). https://www.fia.fs.fed.us/library/database-documentation/current/ver90/FIADB%20User%20Guide%20P2_9-0-1_final.pdf

USDA Forest Service, Rocky Mountain Research Station. 2021. Science You Can Use Bulletin - Between a Rock and a Hard Place: Understanding and Managing Pinyon and Juniper Woodlands in a Changing Climate. July/August 2021, Issue 49. https://www.fs.usda.gov/rmrs/sites/default/files/documents/SYCU_Bulletin_PinyonJuniper_0.pdf

USDA Natural Resources Conservation Service. Bur Oak Plant Guide. Bur Oak Plant Guide (usda.gov) (Accessed October 2021).

Walters, Brian F.; Woodall, Christopher W.; Piva, Ronald J.; [et al]. 2013. Forests of the Black Hills National Forest 2011. Resource Bull. NRS-83. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 36 pp.

Worrall, J.; Rehfeldt, G.; Hamann, A.; [et al.]. 2013. Recent declines of Populus tremuloides in North America linked to climate. Forest Ecology and Management 299: 35–51.

Appendix A: Additional Tables

The ponderosa pine trees described in table 12 occur predominantly in the ponderosa pine forest type, but a small amount occur in aspen or other forest types.

Table 12. Diameter distribution of ponderosa pine trees on the Black Hills National Forest, based on the 2017-2019 FIA data.

[Sampling error percent (68% confidence level) for total number of ponderosa pine trees is 7% and is variable across diameter classes, from 6% to 100%.]

Diameter class	Number of live trees on forest land, on the Black Hills NF, ponderosa pine species	Percent (%)
1-2.9"	119,641,473	45.4%
3-4.9"	43,646,756	16.6%
5-6.9"	27,366,944	10.4%
7-8.9"	26,072,006	9.9%
9-10.9"	18,073,631	6.9%
11-12.9"	11,691,421	4.4%
13-14.9"	6,828,024	2.6%
15-16.9”	4,683,903	1.8%
17-18.9”	2,643,514	1.0%
19-20.9”	1,550,546	0.6%
21-22.9”	727,395	0.3%
23-24.9”	230,214	0.1%
25-26.9”	55,820	<0.1%
27-28.9”	48,070	<0.1%
29-30.9”	18,129	<0.1%
31-32.9”	20,010	<0.1%
Total	263,297,855	100.0%

Table 13. Diameter distribution of snags in the ponderosa pine forest type on forest land on the Black Hills National Forest, based on the 2017-2019 FIA data.

[Sampling error percent (68% confidence level) for total standing dead trees is 8% and is variable across diameter classes, from 11% to 73%.]

Diameter class	Number of standing dead trees on forest land, on the Black Hills National Forest, ponderosa pine forest type	Percent (%)	Number of standing dead trees per acre, on forest land of the Black Hills National Forst, ponderosa pine forest type
5-6.9"	3,909,545	23.6%	4.95
7-8.9"	4,429,912	26.7%	5.61
9-10.9"	2,802,530	16.9%	3.55
11-12.9"	2,272,524	13.7%	2.88
13-14.9"	1,605,300	9.7%	2.03
15-16.9”	909,597	5.5%	1.15
17-18.9”	434,251	2.6%	0.55
19-20.9”	184,141	1.1%	0.23
21-28.9”	33,172	0.2%	0.04
Total	16,580,972	100.0%	20.99

Table 14. Diameter distribution of snags in the white spruce forest type on forest land on the Black Hills National Forest, based on the 2017-2019 FIA data.

[Sampling error percent (68% confidence level) for total standing dead trees is 35% and is variable across diameter classes, from 30% to 108%.]

Diameter class	Number of standing dead trees on forest land, on the Black Hills NF, white spruce forest type	Percent (%)	Number of standing dead trees per acre, on forest land of the Black Hills NF, white spruce forest type
5-6.9"	434,360	28.8%	8.00
7-8.9"	325,164	21.6%	5.99
9-10.9"	232,529	15.4%	4.28
11-12.9"	177,357	11.8%	3.27
13-14.9"	165,189	11.0%	3.04
15-16.9”	106,771	7.1%	1.97
17-18.9”	28,494	1.9%	0.52
19-20.9”	15,044	1.0%	0.28
21-28.9”	22,648	1.5%	0.42
Total	1,507,556	100.0%	27.77

Table 15. Diameter distribution of bur oak trees in the Black Hills National Forest, based on the 2017-2019 FIA data.

Diameter class	Number of live trees on forest land in the Black Hills NF, bur oak species	Percent (%)
1-2.9"	17,892,236	65.7%
3-4.9"	5,111,500	18.8%
5-6.9"	2,690,605	9.9%
7-8.9"	980,221	3.6%
9-10.9"	343,622	1.3%
11-12.9"	184,410	0.7%
13-14.9"	36,257	0.1%
Total	27,238,852	100.0%

Table 16. Age class trends, ponderosa pine forest type, on the Black Hills National Forest, based on FIA data (repeat measurements only).

Age class	Acres - Measurement 1 (2000 for WY, 2001-2005 for SD)	Acres - Measurement 2 (2017-2019
0	10,302	29,823
20	5,816	13,797
40	58,160	72,599
60	142,136	61,068
80	326,532	240,426
100	225,210	202,476
120	87,059	121,012
140	40,712	28,421
160	5,816	40,295
180	20,356	0
200	13,086	9,169
Total	935,186	819,088

Table 17. Stand-size class trends, ponderosa pine forest type, on the Black Hills National Forest, based on FIA data (repeat measurements only).

Stand-size class	Acres - Measurement 1 (2000 for WY, 2001-2005 for SD)	Acres - Measurement 2 (2017-2019
Small	96,723	154,180
Medium	110,504	77,328
Large	727,958	587,579
Total	935,186	819,088

Table 18. Density class trends, ponderosa pine forest type, on the Black Hills National Forest, based on FIA data (repeat measurements only).

Density Class (basal area in sq. ft/acre)	Acres - Measurement 1 (2000 for WY, 2001-2005 for SD)	Acres - Measurement 2 (2017-2019
0	9,127	26,883
20	60,965	105,227
40	105,225	138,802
60	151,911	154,567
80	225,173	108,309
100	142,492	104,630
120	82,246	82,877
140	101,342	39,633
160	23,264	29,080
180	21,810	14,540
200	4,362	8,724
220	5,816	5,816
260	1,454	0
Total	935,186	819,088

Appendix B: Black Hills Community Types

The Black Hills community types are described below, as they were in the Black Hills Phase II Amendment FEIS (USDA Forest Service 2005).

Black Hills Ponderosa Pine Community Types

Marriott and Faber-Langendoen (2000a) identified 13 ponderosa pine community types that occur in upland forests/woodlands of the Black Hills and two community types that occur as sparse vegetation. Most pine forests at lower elevations of the black hills are classified within the dry coniferous forest and woodlands ecological group. Pine forests occurring in moist habitat of lower elevations and at higher elevations are considered within the mesic coniferous forest and woodlands ecological group (Marriott and Faber-Langendoen 2000a). Pine communities that exist in association with limestone outcrops and scree slopes are classified within the Black Hills sparse vegetation ecological group (Marriott and Faber-Langendoen 2000a). Ponderosa pine community types, grouped by ecological group, are listed in table 19.

Table 16. Ponderosa pine ecological groups and community types

[Sources: Marriott et al. 1999, Marriott and Faber-Langendoen 2000a]

Ecological Group	Community Type	NatureServe Ranking[41]
Dry Coniferous Forests and Woodlands	Ponderosa Pine/Bearberry Woodland	G4-Apparently Secure, S3 – Vulnerable (Wyoming), S4-Apparently Secure (South Dakota)
Dry Coniferous Forests and Woodlands	Ponderosa Pine/Sedge Woodland	G3-Vulnerable, S2S3-Imperiled (Wyoming)
Dry Coniferous Forests and Woodlands	Ponderosa Pine/Rocky Mountain Juniper Woodland	G4-Apparently Secure, S2S3 - Imperiled (Wyoming)
Dry Coniferous Forests and Woodlands	Ponderosa Pine/Oregon Grape Forest	G3-Vulnerable
Dry Coniferous Forests and Woodlands	Ponderosa Pine/Western Wheat Grass Woodland	G3-Vulnerable, S2S3-Imperiled (Wyoming)
Dry Coniferous Forests and Woodlands	Ponderosa Pine/Bluebunch Wheat Grass Woodland	G4-Apparently Secure, S3?-Vulnerable (Wyoming)
Dry Coniferous Forests and Woodlands	Ponderosa Pine/Little Bluestem Woodland	G3-Vulnerable, S2? -Imperiled (Wyoming), S4-Apparently Secure (South Dakota)
Mesic Coniferous Forests and Woodlands	Ponderosa Pine/Common Juniper Woodland	G4-Apparently Secure, S3?-Vulnerable (Wyoming)
Mesic Coniferous Forests and Woodlands	Ponderosa Pine/Rough-leaf Rice Grass Woodland	G3-Vulnerable
Mesic Coniferous Forests and Woodlands	Ponderosa Pine/Mountain Ninebark Forest	G3 – Vulnerable, S2? - Imperiled (Wyoming)
Mesic Coniferous Forests and Woodlands	Ponderosa Pine/Chokecherry Forest	G3 – Vulnerable
Mesic Coniferous Forests and Woodlands	Ponderosa Pine/Bur Oak Woodland	G3-Vulnerable, S3-Vulnerable (Wyoming)

[41] https://explorer.natureserve.org/

Ecological Group	Community Type	NatureServe Ranking[41]
Mesic Coniferous Forests and Woodlands	Ponderosa Pine/Snowberry Forest	G4-Apparently Secure, S2? - Imperiled (Wyoming)
Black Hills Sparse Vegetation	Ponderosa Pine Limestone Cliff	G4-Apparently Secure
Black Hills Sparse Vegetation	Ponderosa Pine Scree Slope	G4-Apparently Secure

Dry Coniferous Forests and Woodlands

Dry coniferous forests and woodlands are relatively open forests with less than 50-percent canopy cover. This ecological group dominates in the Black Hills (Marriott and Faber-Langendoen 2000a). Ponderosa pine/bearberry, ponderosa pine/sedge, and ponderosa pine/little bluestem comprise most of the dry coniferous forest cover at higher elevations. Ponderosa pine/sedge, ponderosa pine/little bluestem, and ponderosa pine/western wheat grass communities are the most extensive types at lower elevations. Three other ponderosa pine types—ponderosa pine/Rocky Mountain juniper, ponderosa pine/bluebunch wheat grass, and ponderosa pine/Oregon grape—are locally significant at lower elevations of the Black Hills; much of it occurs on private lands not administered by the Forest (Marriott and Faber-Langendoen 2000a). Detailed environmental and vegetation descriptions of community types are provided in Marriott and Faber-Langendoen (2000a).

Mesic Coniferous Forests and Woodlands

Mesic coniferous forests dominate at higher elevations of the Black Hills. These forests typically have canopy cover greater than 60 percent. The most extensive high-elevation types are ponderosa pine/bearberry, ponderosa pine/common juniper, and ponderosa pine/rough-leaf rice grass. Ponderosa pine/mountain ninebark and ponderosa pine/chokecherry types occur in scattered locations in the southern and central Black Hills, and ponderosa pine/bur oak is relatively common at middle and lower elevations of the northern and eastern Black Hills (Marriott and Faber-Langendoen 2000a).

Black Hills Sparse Vegetation

Marriott and Faber-Langendoen classify sparse vegetation in the Black Hills based on vegetation and rock substrate. Two ponderosa pine types are categorized within this ecological group: ponderosa pine/limestone cliff and ponderosa pine/scree slope. Ponderosa pine/limestone cliff type occurs in scattered patches on the limestone plateau and the Minnekahta Hills, and the ponderosa pine/scree slope type exists in limited locations off National Forest System (NFS) land in the central-core area (Marriott and Faber-Langendoen 2002a).

Black Hills White Spruce Community Types

There are two white spruce upland community types recognized in the Black Hills: white spruce/twinflower (*Picea glauca/Linnaea borealis*) and white spruce/grouseberry (*Picea glauca/Vaccinium scoparium*) (Marriott and Faber-Langendoen 2000a, Shepperd and Battaglia 2002). Marriott et al. (1999) and Marriott and Faber-Langendoen (2000b) also recognized a riparian-type, white spruce alluvial Black Hills forest as a third community.

The white spruce/twinflower community type is ranked as G2-Imperiled and S2 -Imperiled (Wyoming) by NatureServe. It is generally found at elevations of 5,800 to 6,400 feet within high, wet habitats on northwest to northeast aspects. Important understory shrubs in this community type include common juniper (*Juniperus communis*); prickly rose (*Rosa acicularis*); russet buffaloberry (*Shepherdia* *canadensis*); and white coralberry (*Symphoricarpos albus*). Grasses and forbs include Kentucky bluegrass (*Poa pratensis*); rough-leaved rice grass (*Oryzopsis asperifolia*); wild strawberry (*Fragaria virginiana*); sweet-scented bedstraw (*Galium triflorum*); American sweetvetch (*Hedysarum alpinum*); and longspur violet (*Viola adunca*). Mosses and lichens are common (Shepperd and Battaglia 2002, Marriott and Faber-Langendoen 2000a). Grouseberry is absent from this community type (Shepperd and Battaglia 2002).

The white spruce/grouseberry community typically occurs at elevations ranging from 5,700 to 6,700 feet in cooler, moist habitats on loamy, calcareous soils (Shepperd and Battaglia 2002). It is ranked as G1-Critically Imperiled and S2-Imperiled (Wyoming) by NatureServe. Besides grouseberry, other understory shrubs in this community type include bearberry; Oregon grape (*Mahonia repens*); common juniper; prickly rose; wild spiraea (*Spiraea betulifolia*); and white coralberry. Common grasses and forbs include rough-leaved ricegrass, Kentucky bluegrass, yarrow (*Achillea millefolium*), and pussytoes (*Antennaria* spp.) (Marriott and Faber-Langendoen 2000a, Shepperd and Battaglia 2002).

Marriott et al. (1999) gathered information on eight occurrences of the white spruce alluvial Black Hills forest community type, which is ranked as G2-Imperiled by NatureServe. This type occurs in very mesic drainages at high elevations on the limestone plateau and the central core and at lower elevations in wetter portions of the northern Black Hills (Marriott et al. 1999, Marriott and Faber-Langendoen 2000b). The understory is highly variable. Small spruce, aspen, ponderosa pine, boxelder (*Acer negundo*), and paper birch (*Betula papyrifera*) often form a sub-canopy (Marriott and Faber-Langendoen 2000b). Some sites have an understory of riparian shrubland and wet meadow types with species such as beaked (Bebb's) willow (*Salix bebbiana*), water birch (*Betula occidentalis*), Canadian reed grass (*Calamagrostis canadensis*) and Nebraska sedge (*Carex nebrascensis*) (Marriott and Faber-Langendoen 2000b). Other common understory species include Wood's rose (*Rosa woodsii*), baneberry (*Actaea rubra*), red-osier dogwood (*Cornus sericea*), wild sarsaparilla (*Aralia nudicaulis*), fringed loosestrife (*Lysimachia ciliata*), several species of violets (*Viola* spp.), and horsetails (*Equisetum* spp.) (Marriott and Faber-Langendoen 2000b).

Black Hills Aspen Community Types

There are four aspen community types in the Black Hills: aspen/beaked hazel, aspen/bracken fern, aspen/spiraea, and aspen/chokecherry (Marriott et al. 1999). Aspen/beaked hazel is ranked as G3-Vulnerable and S1S2 – Critically Imperiled (Wyoming) by NatureServe. Aspen/chokecherry is ranked as G3-Vulnerable and S2S3-Imperiled (Wyoming). Aspen/bracken fern is ranked as G4 – Apparently Secure. Aspen/spiraea is ranked as G4 – Apparently Secure but is listed as S3 – Vulnerable in Wyoming.

The aspen/chokecherry type is a dry riparian[42] community type. The other community types are found in uplands at higher elevations and are best developed in the Central Core, Limestone Plateau, higher Minnekahta Foothills, and Bear Lodge Mountains (Marriott et al. 1999). Aspen also occurs in association with white spruce, ponderosa pine, and ironwood, although these are not distinct community types (Marriott et al. 1999). Common understory species in aspen stands include beaked hazel, paper birch, bur oak, western serviceberry, Oregon grape, wild honeysuckle, chokecherry, pink shinleaf, prickly rose, red raspberry, wild spirea, white coralberry, wild sarsaparilla, Lindly's aster, wild strawberry, sweet-scented bedstraw, and wild lily-of-the-valley (Marriott et al. 1999).

[42] Dry riparian associations differ from other riparian plant associations because they typically occur in moist areas on the lowermost slopes and bottoms of drainages and may not be associated with open water or a stream (Marriott and Faber-Langendoen 2000b).

Black Hills Bur Oak Community Types

Three upland community types have been identified for bur oak in the Black Hills: bur oak/chokecherry - western snowberry woodlands, bur oak/sedge woodlands, and bur oak-ironwood forest (Marriott and Faber-Langendoen 2000a, Hall et al. 2002).

Bur oak/chokecherry - western snowberry occurs along the northern periphery of the Black Hills (Marriott and Faber-Langendoen 2000a). It is ranked as G3-Vulnerable and S2S3-Imperiled (Wyoming) by NatureServe. Other tree species such as green ash, American elm, ponderosa pine, and paper birch often occur in the understory of this community type along with several shrub and forb species that include Oregon grape, chokecherry, red raspberry, poison ivy, dryspike sedge, Kentucky bluegrass, and bedstraw (Marriott and Faber-Langendoen 2000a). The bur oak/sedge community is found on the outermost hogback in the northern and northeastern Black Hills, primarily on private lands (Marriott and Faber-Langendoen 2000a). it is ranked as G1-Critically Imperiled and S1-Critically Imperiled (Wyoming) by NatureServe.

The bur/ironwood is a low-elevation dry riparian type. It is ranked as G2-Imperiled and S2-Imperiled (Wyoming) by NatureServe. Bur oak/ironwood forests occur in mesic drainage bottoms, with or without flowing streams, and usually do not occur immediately adjacent to streams (Marriott and Faber-Langendoen 2000b, Marriott et al. 1999). The overstory canopy tends to be open (25- to 60-percent cover), with the sub-canopy often closed (60- to 100-percent cover). The understory is variable; the most common shrub species are western snowberry and chokecherry (Marriott and Faber-Langendoen 2000b). Some Black Hills Region 2 sensitive species, such as bloodroot (*Sanguinaria canadensis*), are associated with this community type (Hall et al. 2002).