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Early settlement forest structure in Black Hills ponderosa pine forests

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Abstract

An ecological and management paradigm in ponderosa pine (*Pinus ponderosa*) forests is that historically recurrent surface fires maintained open forest stands dominated by large, old trees. Land use that accompanied Euro-American settlement in the late 1800s included timber harvest and fire cessation that resulted in loss of larger trees and increased tree density. Here we reconstruct basal areas, densities, ages, and sizes of larger trees ca. 1900 before initial tree harvest from 112 ponderosa pine stands in the Black Hills of the northern Great Plains. Reconstructed large tree basal area (BA) averaged 15.8 m^2 ha^{-1}, although there was a great deal of diversity in density. Approximately 35% of all plots contained 0–10 m^2 ha^{-1} large tree BA but seven plots (∼6%) contained >40 m^2 ha^{-1} large tree BA. Significant differences were found between plots at both local and broad scales. We found no significant differences in BA related to moisture gradients. There also was no significant difference between average BA of the historical and current forests, although historical tree stocking was dominated by larger trees than those present today. Current BA from the Black Hills National Forest Resource Inventory System averages 21.2 m^2 ha^{-1}, ranging from 0 to 49.5 m^2 ha^{-1}. 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. Results largely support previous findings of changes in forest structure in ponderosa pine forests in response to timber harvest and loss of historical fire regimes, although the historical Black Hills landscape apparently contained a greater range of structural variability than ponderosa pine forests of the southwestern US. Our results support restoration of heterogeneity in landscape structure to enhance species habitat requirements and promote ecological resiliency.

Keywords: Fire regime; Historical range of variability; Ponderosa pine; Forest structure

1. Introduction

An ecological and management paradigm in ponderosa pine (*Pinus ponderosa*) forests of western North America is that historically recurrent surface fires maintained open forest stands dominated by large, old trees (Cooper, 1960; White, 1985; Covington and Moore, 1994; Arno et al., 1995; Fulé et al., 1997, 2002; Brown et al., 2001; Allen et al., 2002; Friederici, 2003). Surface burns strongly affected overstory recruitment by killing most seedlings and saplings before they had a chance to reach the canopy (Brown and Wu, 2005). Fire cessation and harvest of larger trees accompanied Euro-American settlement in the latter half of the nineteenth century, with the result that many current forests are much denser and composed of younger and smaller trees (Fulé et al., 1997, 2002). Altered fuel and canopy structures have resulted in severe crown fires occurring more frequently and over larger areas than apparently what occurred historically (Allen et al., 2002). Contemporary management in many areas is directed to restoration of open, low-density stands, often with an ultimate goal of reintroduction of surface fires as a "keystone" ecosystem process (Arno et al., 1995; Brown et al., 2001; Friederici, 2003). In other areas management is directed to reducing fuels and changing canopy configuration to reduce the incident and extent of crown fire or effects of other disturbances, such as bark beetle outbreaks.

Ponderosa pine forests in the Black Hills of southwestern South Dakota and northeastern Wyoming also experienced surface fires that ceased coincident with settlement (Fisher et al., 1987; Brown and Sieg, 1996, 1999; Brown et al., 2000; Brown, 2003; Wienk et al., 2004). This area also has a long history of intensive timber harvest (Graves, 1899; Shepperd and

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Battaglia, 2002). Forest structure apparently responded accordingly to these two impacts. Photographs taken in 1874 during initial Euro-American exploration of the Black Hills show in many locations relatively open stands of large trees that are today covered by dense canopies of smaller trees (Progulske, 1974; Grafe and Horsted, 2002). Reconstructions of historical forest structure compared to current conditions also document shifts in structural elements as a result of fire cessation and logging (McAdams, 1995; Wienk et al., 2004). However, intervals between fires were longer than ponderosa pine forests in the Southwest and elsewhere, and large areas of even-aged and occasionally dense forest were present at settlement (Graves, 1899; Shinneman and Baker, 1997; Brown, 2003). These dense stands may have resulted from large crown fires in the late 1700s and early 1800s (Shinneman and Baker, 1997), although an alternative hypothesis is that optimal climate conditions led to abundant ponderosa pine recruitment opportunities during this period (Brown, 2003). If significant portions of the Black Hills contained dense, even-aged stands, broad-scale restoration of open, multi-aged forests as has been proposed for ponderosa pine forests in the Southwest may be inappropriate (Shinneman and Baker, 1997).

In this study, we reconstruct historical forest structural elements in Black Hills forests. Our goal is to provide baseline information useful for ecological restoration efforts and silvicultural planning at a landscape scale across the Black Hills. Structural elements we reconstruct include size class distributions, tree ages, basal areas, and densities of larger trees (>~30 cm in size) ca. 1900 during the early settlement period but before any initial stand harvest. We compare age and size distributions and basal areas of the historical data with contemporary data from the Black Hills National Forest (BHNF) Resource Inventory System (RIS). A major caveat to this work is that much of the Black Hills has been harvested (often multiple entries in many stands) beginning in the mid-1870s with the result that precise measures of early settlement structure are difficult to reconstruct. We chose 1900 as a point of reference since in many stands we cannot be certain of the date of initial harvest nor how many entries have occurred since then. Data we reconstruct represent estimates of structure before harvest although some of our stands were initially harvested before 1900. Another caveat to this work is that many of the pre-settlement trees we measured were stumps, often missing bark and sapwood because of decay since harvest. Sapwood typically persists at most only a few decades after tree death, although highly resinous heartwood in ponderosa pine can persist well over a century. Smaller trees have proportionally less heartwood and, if harvested long enough ago, have completely decayed and are no longer present for us to sample. We are undoubtedly missing much of the smaller size classes from stands that were harvested early on. Because of these limitations of the historical record, the structural elements we reconstruct here should be viewed in terms of overall trends and ranges of variability of larger trees at a broad spatial scale across the Black Hills, and not as precise targets for restoration efforts or silvicultural prescriptions in individual stands.

2. Study area and past land use

The Black Hills rise over 1000 m above the surrounding relatively flat northern Great Plains. The Black Hills were formed from an intrusive granitic pluton and anticlinal warping of overlying layers of limestones and sandstones has formed a complex topography of canyons, plateaus, and ridges around a central granite core area. The main part of the range is in southwestern South Dakota with a smaller extension, the Bear Lodge Mountains, in northeastern Wyoming (Fig. 1). The main range extends roughly 200 km N–S and 120 km E–W. Elevations range from 1050 to 1350 m on the margins with the Great Plains to the highest point at 2207 m.

The Black Hills support extensive conifer forests in contrast to adjacent mixed-grass prairies (Shepperd and Battaglia, 2002). Ponderosa pine dominates over 95% of the forest. There is a strong moisture gradient from ~740 mm in the northern high elevations of the range to ~480 mm in south. White spruce (*Picea glauca*) and aspen (*Populus tremuloides*) are occasional co-dominants of higher and wetter forests in the northern and central Hills, although in most areas ponderosa pine is the only tree species present.

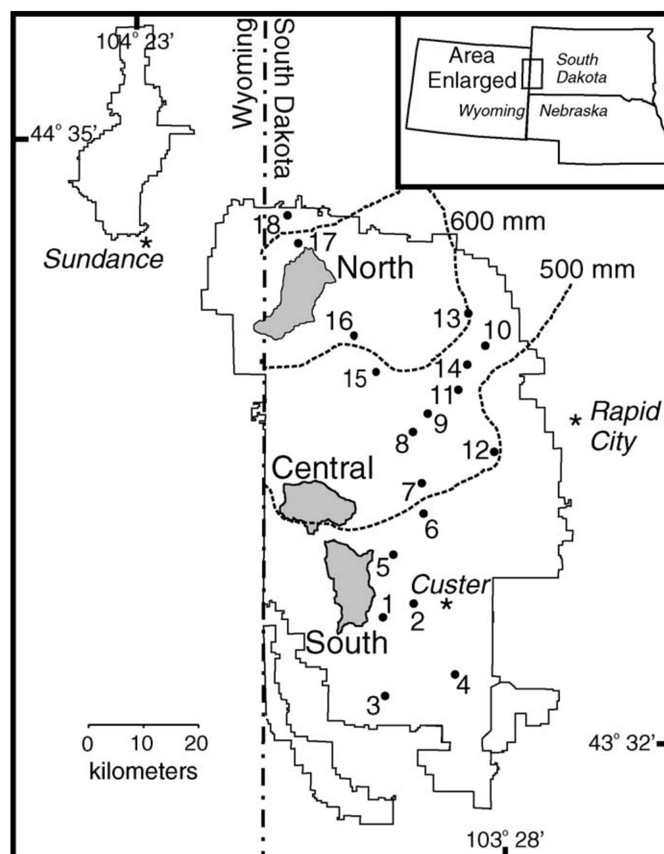

Fig. 1. Locations of plots sampled for reconstruction of pre-settlement forest structure in Black Hills National Forest (solid line = BHNF boundaries). Numbered dots are transects collected for goshawk habitat assessment study, gray areas are landscapes sampled for age structure study (Brown, 2003). Dashed lines are isolines of precipitation used to divide landscapes and goshawk transects for moisture gradient analysis (see text).

Euro-American settlement began after 1874 (Graves, 1899; Progulske, 1974; Grafe and Horsted, 2002). Timber harvest that began with settlement has resulted in large areas of second-growth forest (Shepperd and Battaglia, 2002). The Black Hills National Forest Reserve (today the Black Hills National Forest) was the first federal forest preserve established in the United States in 1897, mainly as a response to intensive and often wasteful timber practices up to that time (Graves, 1899). Timber production is still a major use of much of the landscape. Few areas of unharvested forest exist and most are found on National Park Service lands, isolated or inaccessible areas, and portions of the Black Elk wilderness area.

3. Methods

3.1. Field procedures

Two sets of structural data are reported here. Both sets of data were collected using the same sampling protocols and randomly located across the range of variation in current Black Hills forest structure. The first set was collected for age and stand structure reconstructions as part of a fire history study (Brown, 2003). Plots were established randomly within three ∼100 km^2 landscape study areas on the Limestone Plateau in the western Black Hills (Fig. 1). Thirty-seven plots form this data set, 13 from the northern landscape and 12 each from the central and southern landscapes. The second data set was collected to assess stand structure as part of a goshawk (*Accipiter gentilis*) habitat assessment. Restoring historical forest structure is a major objective in managing habitats for goshawks and their prey in Southwestern ponderosa pine forests (Long and Smith, 2000). Plot transects were established in the vicinities of known goshawk nest sites (Fig. 1). Initial plot centers were chosen close to nest locations with subsequent plots spaced 100 m distance on transects running east of the first plot. Goshawk prefer a range of structural conditions for nesting and foraging requirements and we attempted to capture this variation across sample transects. Four plots were measured on most transects (range 2–5) for a total of 75 plots sampled on 18 transects. All but one plot in the northern landscape on the Limestone Plateau had evidence of harvest in the form of stumps.

Within each plot, we used *n*-tree distance sampling methods (Jonsson et al., 1992; Lessard et al., 2002) to collect data from the nearest 30 pre-settlement trees to each plot center within a maximum plot radius of 40 m (∼0.5 ha circular plot). Most plots were ≤0.25 ha in size. Pre-settlement trees were defined as all remnant trees (stumps, logs, and snags) and living trees that either were not "blackjacks" (younger trees with primarily dark bark) or that were ≥30 cm dbh. Based on extensive prior observation and age sampling of ponderosa pine in the Black Hills, trees tend to have mainly dark bark (blackjacks) until ca. 75–100 years of age, after which it progressively changes to a buff or orange color. We assumed all blackjack trees and trees <30 cm dbh established post-1900. Tree distances and azimuths from plot centers were measured for stand mapping and calculation of tree densities and stocking. Living tree diameters were measured at 10 cm (diameter at sample height: dsh) and breast heights (dbh). Ten centimeter height diameters were measured on remnant trees with an accompanying designation of state of decay, whether bark, sapwood, or heartwood was present. For age structure analyses, increment cores or cross sections were removed from 10 cm height on all trees in the fire history study (Brown, 2003). Increment cores or cross sections were removed from ∼10% of the trees in the goshawk habitat assessment study. We measured ∼3300 trees, all but 12 of which were ponderosa pine, from 112 field plots.

3.2. Laboratory analyses

3.2.1. Age structure

All of the trees (living and remnant) in the fire history study (Brown, 2003) and ∼10% of the trees collected in the Goshawk study were crossdated to assess landscape patterns of tree age structure (∼750 trees total). Increment cores and cross sections were crossdated against established ring-width chronologies from the Black Hills (Brown, 2003). Crossdating was accomplished using visual cross matching of ring patterns (Stokes and Smiley, 1968) and measured ring widths compared to both locally developed and existing tree-ring chronologies for the Black Hills. We estimated pith dates using overlaid concentric circles on cores that did not reach pith.

3.2.2. Stand structure

Radius of each plot was first calculated as the distance from plot center to center of the farthest tree of the 30 measured. Plot area was determined as a circular plot of the calculated radius and using a bias correction derived by Moore (1954; see also Lessard et al., 2002; Lynch and Wittwer, 2003). Slope corrections were applied to plots over 10% slope (∼60% of all plots) to account for variation in tree basal areas with increasing slopes. To determine tree basal areas (BA) within plots, we first converted dsh measurements on remnant trees to dbh using a regression equation derived from dsh/dbh measurements on living trees: dbh = dsh × 0.8645 ($n = 567$; $R^2 = 0.95$). Historical dbh ca. 1900 for individual trees was then calculated based on empirically derived stem diameter conversion equations. The first conversion applied was to living trees (Fig. 2a). Other conversions applied to stumps were based on state of decay and assumed time of harvest. We assumed that all stumps with only heartwood present today would have been living shortly before or after 1900. This assumption is based on crossdated stumps from the landscape age structure study (Brown, 2003). For these stumps, we used a conversion to estimate dbh in 1900 based on ratio of heartwood diameter to total tree dbh measured in living trees (Fig. 2b). For stumps missing bark we assumed these trees were harvested in the past few decades. We first estimated dbh as sapwood diameter + (sapwood diameter × 0.1 for estimated bark width), then applied the conversion factor for living trees to determine diameter ca. 1900 (Fig. 2a). We applied the same conversion for stumps with intact sapwood and bark, with the assumption these trees had been cut within the last decade or two. We then estimated quadratic mean diameters of trees based on total tree diameters and densities within each plot.

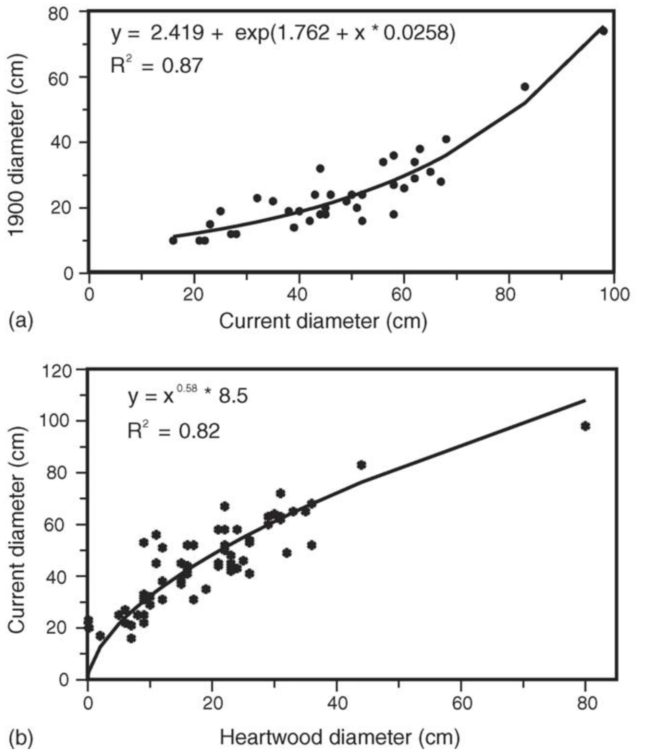

Fig. 2. Empirical correction factors applied to living trees (a) and stumps (b) to estimate stem diameters in 1900.

3.3. Statistical analyses

We used multivariate analysis of variance (ANOVA; Tabachnick and Fridell, 1983) to assess significant differences in tree BA within and among the goshawk plot transects. We tested for possible spatial variations related to moisture regimes across the Black Hills landscape by comparing reconstructed BA and tree densities among the three Limestone Plateau landscapes and along a moisture gradient in the goshawk plots. The moisture gradient was for plots with >600, 500–600 and <500 mm in precipitation (Fig. 1). We also tested differences in average tree age and size between living trees measured in 1999 and stumps estimated in 1900 for the three Limestone Plateau landscapes. Finally, we used ANOVA to assess differences in tree BA in the 18 polygons in the BHNF RIS database that corresponded to locations of the goshawk plot transects (Fig. 1). Alpha level for all analyses was 0.05.

4. Results

Structural elements varied considerably across the Black Hills landscape (Table 1). Average large tree BA across all 112 plots was estimated to be 15.8 $m^2 ha^{-1}$. All areas we sampled are today forested, but 18 plots were estimated to not have contained large trees or to have had very low large tree density (0–5 $m^2 ha^{-1}$ BA; Fig. 3). An additional 22 plots were reconstructed to have >5 to 10 $m^2 ha^{-1}$ large tree BA, for a total of ~35% of all plots containing 0–10 $m^2 ha^{-1}$ large tree BA before any initial harvest. In contrast, we also found several very dense stands, including 7 plots (~6%) with >40 $m^2 ha^{-1}$ large tree BA. Significant differences were found among plots on 14 of the 18 goshawk plot transects, suggesting that fine-scale structural variability was also present in the unharvested early settlement forest. We often found relatively dense stands 100 m away from relatively open ones.

Table 1
Reconstructed forest structural elements in 1900

Trees ha^{-1}	BA ($m^2 ha^{-1}$)	QMD (cm)
Goshawk plots (n = 75)		
138.9 (12.6)	16.8 (1.4)	48.9 (1.6)
0.0–541.4	0.0–55.1	0.0–85.9
Northern landscape (n = 13)		
50.7 (10.4)	10.7 (3.1)	57.0 (4.2)
16.5–144.7	1.3–35.0	34.2–76
Central landscape (n = 12)		
134.0 (54.7)	15.3 (2.4)	55.0 (4.9)
26.7–710.3	5.2–29.8	30.3–79.3
Southern landscape (n = 12)		
131.4 (24.7)	15.3 (2.7)	48.6 (2.5)
53.7–348.2	3.0–40.1	32.1–60.1
All plots (n = 112)		
127.3 (10.8)	15.8 (1.1)	50.5 (1.3)
0.0–710.3	0.0–55.1	0.0–85.9

All estimates are for ponderosa pine. Standard error of the mean in parentheses with ranges underneath.

We found no significant differences in large tree BA between either the three landscapes on the Limestone Plateau or along the moisture gradient in the goshawk plots (Table 1). The large amount of fine-scale variability between plots within landscapes and along transects was greater than any broader-scale variability that may be related to changes in precipitation amounts.

We found no significant difference between average BA of the historical and current forests in the BHNF RIS database. Contemporary tree BA from the RIS data averages 21.2 $m^2 ha^{-1}$, and ranges from 0 to 49.5 $m^2 ha^{-1}$. Although there is no significant difference in current and historical BA, trees were significantly larger historically compared to the current forests (Table 2, Fig. 4). Historical quadratic mean diameters averaged 50.5 cm, and ranged from 30.3 cm (in plots

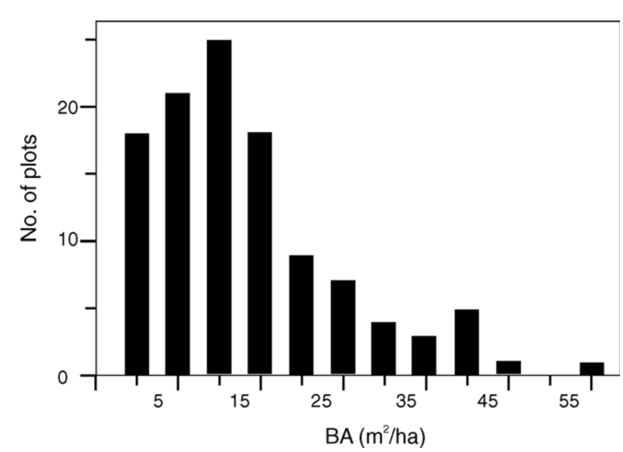

Fig. 3. Distribution of reconstructed basal areas in all plots.

Table 2
Ages and diameters of living trees and stumps

Live trees at 1999		Stumps at 1900	
dbh (cm)	Age (years)	dbh (cm)	Age (years)
Northern landscape			
45.0* (1.3)	180.4 (7.7)	60.9* (1.1)	148.3 (26.3)
12.1–70.4	93–372	17.3–89.9	60–285
Central landscape			
40.7* (1.0)	165.2 (4.8)	58.4* (1.9)	183.8 (10.8)
20.2–64.2	61–229	19.9–100.0	81–503
Southern landscape			
36.4* (0.8)	185.6 (5.8)	50.9* (1.5)	190.2 (11.3)
17.7–62.6	60–461	16.4–106.2	48–708

Standard error of the mean in parentheses with ranges underneath. Live tree averages are based on measured values in 1999. Stump ages and diameters are estimated for 1900.

* Significant differences ($P < 0.05$) between within-row means.

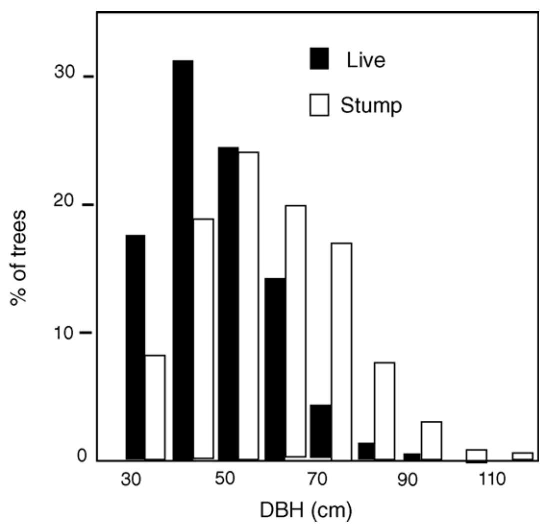

Fig. 4. Percentages of measured live trees (filled bars) and stumps (open bars) by size classes. Live tree dbhs are from trees measured in 1999, while stump dbhs are estimated based on empirical conversions (Fig. 2b) for stem diameters in 1900.

with large trees present in 1900) to over 85 cm. The reduction in average tree diameter appears to be largely a result of harvest, with larger and older stumps preferentially cut (Fig. 5). Many individual trees that were harvested were much older than all

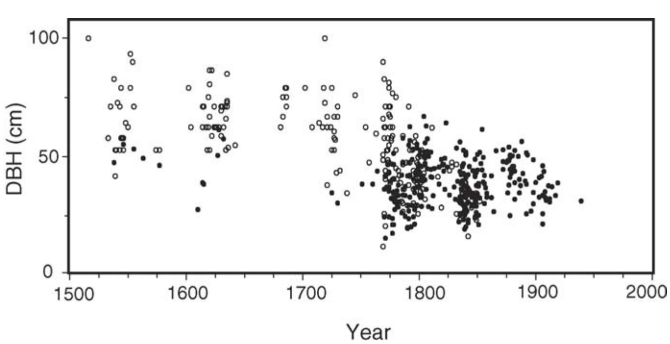

Fig. 5. Establishment dates and dbhs of live trees (filled circles) and stumps (open circles). Establishment dates are pith dates—5 years (Brown, 2003). Live tree dbhs are from trees measured in 1999, while stump dbhs are estimated based on empirical conversions (Fig. 2b) for 1900.

but a few trees living today. However, the average age of trees in 1900 was not significantly different than living trees in 1999 (Table 2), mainly as a result of the abundant establishment that occurred in all stands beginning in the 1770s and continuing through the mid-1800s (Fig. 5; Brown, 2003).

5. Discussion

5.1. Historical forest structure

Ponderosa pine forests in the Black Hills historically consisted of a diverse landscape mosaic that varied from non-forested patches and open stands of very few large trees to quite dense stands with many trees (Table 1). Although much of the forest was relatively open, dense patches also were present and contributed to considerable spatial heterogeneity. Heterogeneity was present not only across the Hills but also within smaller patches present along transects sampled for the goshawk habitat assessment study. Photographs and written accounts from the late nineteenth century also document a highly diverse landscape containing abundant openings and meadows, open stands of larger ponderosa pine trees, and closed canopy stands of younger and smaller trees (Graves, 1899; Progulske, 1974; Shinneman and Baker, 1997; Grafe and Horsted, 2002).

The current forest contains about the same basal area on average as the historic forest, but historic basal area was dominated by larger trees than those present today (Table 2, Fig. 4). This suggests that there has been a simplification in structure at stand to landscape scales, with increased tree density leading to fewer gaps and more even spacing and size distributions within groups (Long and Smith, 2000). Repeat photographs from the late twentieth century of photographs originally taken in 1874 show relatively homogeneous and for the most part continuous canopies in many areas that were formerly more structurally diverse (Progulske, 1974; Grafe and Horsted, 2002). Relative increases in tree density and simplification of structure have contributed to greater vertical and horizontal fuel continuity, and thus increased likelihood for incidence and extent of crown fire (Fulé et al., 2002). More pole-sized trees within stands also increases the likelihood of bark beetle outbreaks, especially a concern in the Black Hills where mountain pine beetles (*Dendroctonus ponderosae*) have been a major disturbance agent during the 20th century (Shepperd and Battaglia, 2002).

Changes from historic to current forest structure at both stand and landscape scales parallel those seen in ponderosa pine forests throughout the western United States (Covington et al., 1994; Arno et al., 1995; Fulé et al., 1997, 2002; Long and Smith, 2000; Brown et al., 2001; Friederici, 2003; Brown and Wu, 2005). Fulé et al. (1997) found similar pre-settlement average tree densities (148.0 trees ha^{-1}), basal areas (12.9 m^2 ha^{-1}), and QMD (41.6 cm) in a 700 ha ponderosa pine forest in northern Arizona as averages we found in the Black Hills (Table 1). Similarly, Fulé et al. (2002) reconstructed comparatively low average tree densities (140–246 trees ha^{-1}) and BA (9.1–28.5 m^2 ha^{-1}) at sites in Grand Canyon National Park that are again consistent with estimates we found in the

Black Hills. Both of the Fulé et al. studies found that current forests are much denser and composed of younger and smaller trees than what occurred historically.

Post-settlement increases in tree densities have been largely attributed to cessation of surface fire regimes. Surface fires ceased coincident with settlement primarily as a result of widespread sheep and cattle grazing that reduced grass and herbaceous fuels through which fires spread (Swetnam and Betancourt, 1998; Brown and Sieg, 1999). Prior to settlement, temporally episodic recruitment in many ponderosa pine forests resulted in uneven-aged stands typified by distinct cohort structure (Peet, 1981; White, 1985; Savage et al., 1996; Grissino-Mayer and Swetnam, 2000; Brown, 2003; Brown and Wu, 2005). The historical Black Hills forest also was uneven-aged and dominated by cohorts of tree establishment (Fig. 5). Broad areas of pulsed establishment in the Black Hills have been argued to be the result of large crown fires in the 1700s and 1800s opening up stands for recruitment to occur (Shinneman and Baker, 1997). However, cohort timing also was contemporaneous with longer intervals between surface fires and optimal climatic episodes for tree regeneration and growth (Brown, 2003). Many trees in the Black Hills established in the late 1700s during the wettest 40-year-long pluvial since at least 1260 (Stockton and Meko, 1983; Meko, 1992; Gray et al., 2004). These cohorts also are contemporaneous with abundant recruitment in the Bighorns and Little Belt Mountains to the west of the Black Hills (Leiberg, 1900; Leiberg, 1904; Brown, unpublished data), further suggesting regional climate synchronization of tree recruitment (Brown and Wu, 2005). Furthermore, this prolonged wet period followed a severe, extended drought in the northern Great Plains and Black Hills from ca. 1753 to 1762 (Stockton and Meko, 1983; Meko, 1992; Gray et al., 2004). It is likely that the mid-1700s drought opened up stands via both direct mortality and possibly drought-related outbreaks of bark beetles, which then provided abundant opportunities for trees to establish during the climatically optimal late 1700s pluvial (Brown, 2003). It is possible that broad-scale even-aged forest structure in Black Hills ponderosa pine forests has little if anything to do with variations in fire severity causing widespread mortality, but rather relate to climate variations that contributed to episodic and broad-scale recruitment opportunities (Brown, 2003).

5.2. Management implications

A "one-size-fits-all" approach to forest management is rarely appropriate even within specific forest types (Allen et al., 2002; Schoennagel et al., 2004). Variation in environmental conditions and climate regimes contribute to variations in fire behavior, timing, and spatial patterning. However, multiple, repeated studies from throughout the range of ponderosa pine consistently point to the prevalence of recurrent surface fires as a dominant, keystone disturbance process that strongly affected forest structure and related ecosystem conditions (Cooper, 1960; White, 1985; Covington and Moore, 1994; Arno et al., 1995; Fulé et al., 1997, 2002; Brown et al., 2001; Allen et al., 2002; Brown, 2003; Friederici, 2003; Brown and Wu, 2005). Fire scars caused by surface burns are ubiquitous in ponderosa pine stands. Mature ponderosa pine trees also are well adapted to survive surface burning, with thick bark that protects vascular cambium from girdling and high crowns that reduce the likelihood of fatal crown scorch. Ponderosa pine also have large, heavy seeds that are not well adapted to rapid re-colonization after extensive crown fires, further arguing for surface fire as a dominate form of disturbance in ponderosa pine forests.

Much of the historical fire regime and resulting forest structure that has been reconstructed from the Black Hills fits with a dominant model of ponderosa pine ecosystems largely developed from the Southwest (e.g., Allen et al., 2002; Friederici, 2003). In this model, surface fires were a common mode of disturbance and resulted in broad areas of open, multi-aged forest stands often composed of larger and often older trees than those found today because of timber harvest (Fulé et al., 1997). Longer intervals between fires in the Black Hills apparently contributed to a coarser-scale mosaic of dense to open stands and a greater range of variation in forest structure than what was present in the Southwest where fire intervals were typically shorter, but the overall end result was similar. Severe drought followed by an extended wet period in the latter half of the eighteen century also apparently contributed to abundant tree establishment that resulted in dense, even-aged stands over large areas in the Black Hills (Brown, 2003). These dense stands were still present at settlement, and likely contributed to extensive patches of crown fire noted by early explorers and scientists during the latter half of the 1800s (Graves, 1899; Shinneman and Baker, 1997). However, over longer time scales, the dominate fire regime consisted of recurrent surface fires that maintained multi-aged and open structure over large portions of the landscape.

Forest management in the Black Hills should take into account the combined effects from both transient and persistent historical processes in future forest planning. Historical structural patterns reconstructed by this study and documented in historic photographs justify 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 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. Increasing the area burned in prescribed fires and mechanical thinning to change stand and landscape configuration should be considered as complementary means to maintain or restore structural characteristics that promote structural diversity. However, at the same time management planning must recognize that climate change will undoubtedly lead to unforeseeable and extreme events in the future. Forest managers cannot easily manage for unpredictable events, but by being aware of the possibilities they can target management practices to promote ecosystems that are resilient enough to withstand impacts of future events when they occur.

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