RESEARCH ARTICLE

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Characteristics of Dry Site Old-Growth Ponderosa Pine in the Bull Mountains of Montana, USA

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ABSTRACT: Increasing public interest in old-growth forests has spurred new research and legislation aimed at managing this resource. The old-growth ponderosa pine (*Pinus ponderosa* var. *scopulorum* Engelm.) forests of central and eastern Montana, USA, are one such resource that requires management information in the face of threats from catastrophic fire and diameter-limit cutting (removal of trees greater than a specified diameter). This study examined five randomly selected old-growth ponderosa pine stands on state-owned land in central Montana for a variety of site-, stand-, and tree-level attributes. For trees ≥ 12.7 cm in diameter (dbh), stand densities ranged from 245 to 410 trees ha^{-1} and basal area ranged from 16.3 to 22.7 m^2 ha^{-1}. Regeneration ranged from 10 to 5078 seedlings (trees > 0.15 m but < 1.4 m tall) per hectare and 133 to 1620 saplings (trees ≥ 1.37 m tall with dbh < 12.7 cm) per hectare. Each site retained four to eight snags per hectare with dbh ≥ 38.1 cm. Across all sites, 94% of sampled live trees ≥ 38.1 cm dbh were ≥ 120 years, while 17% were ≥ 300 years. By site, 56% to 88% of trees ≥ 38.1 cm dbh displayed crown deformities, and 14% to 43% exhibited external fire scars. Areas of old-growth ponderosa pine typically occur along drainage features as a component of uneven-aged forests maintained by low-intensity fires. This study was the first of its kind in central Montana and should aid managers and researchers in identifying and maintaining old growth in the region.

Características de los Sitios Secos de Bosque Maduro de Pino Ponderosa en las Montañas Bull de Montana, USA

RESUMEN: El aumento del interés público en los bosques maduros ha incitado a nuevas investigaciones y legislación orientadas a manejar el recurso. Los bosques maduros de pino ponderosa (Pinus ponderosa var. scopulorum Engelm.) del centro y este de Montana son uno de los recursos que requieren información de manejo en cara a las amenazas de fuegos catastróficos y el diámetro límite de corte (remoción de árboles mayores que un diámetro especffico). Este estudio examina cinco lotes de bosque maduro de pino ponderosa seleccionados al azar en tierras del estado en Montana central, USA, en diversidad de atributos a nivel de sitios, parcelas y árboles. Para los árboles > 12,7 cm de diámetro (dap), la densidad de árboles en pie varió de 245 a 410 árboles ha-1 y el área basal varió de 16,3 a 22,7 m2 ha-1. La regeneración varió de 10 a 5078 plántulas (árboles > 0,15 m pero < 1,4 m de alto) por hectárea y 133 a 1620 vástagos (árboles > 1,37 m de alto con dap < 12,7 cm) por hectárea. Cada sitio tenía de cuatro a ocho nudos por hectárea con dap > 38,1 cm. Entre todos los sitios, 94% de los árboles muestrados > 38,1 cm dap fueron > 120 años, mientras que 17% fueron > 300 años. Por sitios, 56% al 88% de los árboles > 38,1 cm dap mostraron deformaciones en la corona, y 14% al 43% tenían marcas externas de fuego. Áreas de bosque maduro de pino ponderosa típicamente ocurren a lo largo de los drenajes, rasgo componente de bosques de edad dispar, mantenidos por fuegos de baja intensidad. Este estudio fue el primero de este tipo en Montana central y debería ayudar a los encargados e investigadores en la identificación y manutención de bosques maduros en la región.

Index terms: fire, Montana, old-growth forest, *Pinus ponderosa* var. *scopulorum*, uneven-aged forest

INTRODUCTION

Public concern for old-growth forests has been increasing because of the relative scarcity of such tracts and the myriad values associated with them (Tyrrell 1992, Vora 1994, Wells et al. 1998). A prominent old-growth forest type of the inland West is the ponderosa pine (*Pinus ponderosa* Dougl. Ex. Laws.) type. Numerous authors have reported on ponderosa pine occurrence (Steele 1988), size and age-class structure (Cooper 1960, White 1985), relationship to climate and fire (Swetnam and Dieterich 1985, Covington and Moore 1994), successional changes (Pfister et al. 1977, Moir and Dieterich 1988), and vulnerability of old growth to fire (Fischer and Clayton 1983, Arno et al. 1995). Only recently have scientists and managers focused on the old-growth ponderosa pine (*P. ponderosa* var. *scopulorum* Engelm.) resource at the eastern edge of the species' range in Montana, South Dakota, Wyoming, and Colorado, USA (Green et al. 1992, Mehl 1992, Shinneman and Baker 1997, Morgan 1999, Robertson and Bowser 1999). Two recent trends have spurred this research interest: increased harvest of trees based on a minimum diameter (diameter-

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limit cutting) in dry site ponderosa pine forests due to rising stumpage prices, and increased risk of catastrophic wildfire from burgeoning understories. Conservation of the old-growth resource and associated values requires clear descriptions of attributes, ecologically based old-growth indices, and effective management plans. Without description and identification—the first step in obtaining this information—quantifiable management goals for maintaining or restoring old-growth ponderosa pine cannot be set or met.

The isolated Bull Mountain Range in central Montana offers a unique opportunity to study relatively undisturbed dry site old-growth ponderosa pine near the northeast edge of the species' range. We conducted a study there to: (1) characterize site attributes of old-growth pine stands in the Bull Mountain Range; (2) quantify structural features of these old-growth pine stands, including age and size distributions, tree and snag densities, biomass and volume of downed logs, and morphological characteristics of old-growth trees; and (3) identify the associated stand structure–disturbance regime model, and interpret potential changes given trends in the understory component of these old-growth stands. Description and quantification provide important ecologically based information for use in developing old-growth indices and management strategies for dry-site ponderosa pine forests in central and eastern Montana.

Approaches To Old-Growth Definition

Because of the diversity of ecological attributes associated with different forest types, it is not useful, and is potentially misleading, to create a universal definition of old growth (Hunter 1989, Burgman 1996). Consequently, two general approaches to defining old growth have evolved—structure-based approaches and process-based approaches. A structural approach can readily be employed in the field to identify and quantify old-growth forest stands, if specific old-growth structural parameters are defined. Old-growth forests typically are assumed to contain the following structural features: numerous, widely spaced large diameter trees, often with crown or bole deformities; abundant coarse woody debris (fallen logs); a reverse-J-shape diameter distribution; and standing dead trees (Oliver and Larson 1996, Woodgate et al. 1996). Among federal agencies, old-growth definitions and delineation procedures vary by geographic region and forest cover type, and they typically list structural features and expected quantities of these features (Green et al. 1992, Mehl 1992, Tyrrell 1992, Beardsley and Warbington 1996, Batista and Platt 1997, Greenberg et al. 1997).

Process approaches to defining old growth incorporate stand age and disturbance history (Moir 1992). The length of time required for initiation of old-growth processes is a function of site and climate factors as well as the plant community composition. Woodgate et al. (1996) noted that definitions of old growth ought to be based upon forest growth stage, ecological vegetation classes, and evidence or modeled probability of disturbance, adding that descriptions of old-growth are "snapshots in time" resulting from dynamic and cyclic processes that cause the distribution of old growth to change. Burgman (1996) also noted that ecologically sound definitions of old growth must take into account spatial and temporal scales and severity of disturbance.

Shinneman and Baker (1997) identified two stand structure–disturbance regime models (equilibrium and nonequilibrium) in the Black Hills, South Dakota, that provide insight into old-growth ponderosa pine in general. These two models are based on differences in climate, topography, stand structure, and associated interval and intensity of fire, the dominant disturbance factor in pine ecosystems. The (traditional) equilibrium model is characteristic of dry sites with relatively open forests maintained by frequent, low-intensity surface fires. The nonequilibrium model better represents cooler, moister, and topographically protected sites where relatively dense forests were historically dominated by occasional stand-replacing disturbances like crown fires or mountain pine beetle (*Dendroctonus ponderosae* Hopk.) outbreaks (Shinneman and Baker 1997). Understanding which of these models best describes individual sites would strengthen definition and management of old-growth ponderosa pine east of the Continental Divide.

Recently, several authors have emphasized the need for ecologically based thresholds in old-growth definition and delineation (Duchesne 1994, Burgman 1996, Woodgate et al. 1996, Hunter and White 1997). Duchesne (1994) listed 12 "required" measures for formulation of ecological definitions of old growth, including vertical and horizontal structures, age of oldest trees, dead biomass as snags or logs, and disturbance history, among others. Wells et al. (1998) suggested that indices of old-growth characteristics may be appropriate because of the ability of index methods to account for abundance of certain characteristics in the absence or limited expression of others, predict future old-growth development, and better recognize natural variation. Parker et al. (2000) noted that scales beyond that of the stand and suppression of disturbances are matters that need to be addressed. Clearly, ecologically sound definitions or indices must include not only current structural attributes and ages but also regional climate and disturbance histories that can account for variation and provide spatial, temporal, and abiotic context.

METHODS

Study Area

Old growth in the Bull Mountain Range has not been studied before and is decreasing due to diameter-limit cutting of some stands and recent catastrophic wildfires in the region. We defined trees $\geq$ 120 years at breast height (pith date of 1878 or earlier) as "old" because they became established before Euro-American settlers brought cattle and sheep to the region in the early 1880s (Musselshell Valley Historical Museum 1974, Musselshell Valley Pioneer Club 1974). We defined as potential old-growth sites areas exhibiting the following characteristics: numerous old trees ($\geq$ 120 years old) with respect to the surrounding forest or grassland, large trees showing signs of old age (broken, flat, or misshapen tops, bole defects, large-diameter upper branches), large snags and downed logs, and no evidence of timber harvesting.

Potential sites focused on state-owned lands because foresters at the Montana Department of Natural Resources and Conservation (DNRC) guaranteed access and offered their cooperation. We initially considered approximately 45 state-owned sections in the Bull Mountains. Over half of these sections, however, were completely deforested by the 1984 Hawk Creek wildfire that consumed over 70,000 ha. In 1997 state foresters identified 13 state-owned sections potentially containing areas of old-growth ponderosa pine. We used preliminary, walk-through site examinations to identify old-growth sampling sites because large, old trees were frequently mixed among smaller trees and not readily discernible on aerial photos from large-crowned trees in general. Field reconnaissance of the 13 sections confirmed a total of 10 stands or groves in six different sections as potential old-growth sampling sites. Five sites were then randomly selected for field sampling, with the constraint of no more than one sample site per section.

Sampling

It was difficult to apply the stand concept to old-growth ponderosa pine in this study because of the patchy nature of older trees, a pattern also observed by Robertson and Bowser (1999) along the Colorado Front Range. Because number and arrangement of old trees at the Bull Mountains sites were variable, a sampling method that quantified these features consistently across each grove was preferred over one that required subjectively locating a single large plot or several smaller plots in "representative" portions of each grove.

Sampling was accomplished using a series of parallel strip plots and nested circular plots, with plot spacing scaled to the size of the grove being sampled. We surveyed a baseline along the azimuth of each sample grove's longest dimension. We then established four transects to intersect the baseline at right angles. The first transect was placed 40.2 m (two chains) from the origin of the baseline, and the remaining three transects at were placed at equidistant intervals along the length of the baseline, with a minimum of 20.1 m between the last transect and the end of the baseline. Transects ranged from 53.3 m to 225.6 m in length, with a median length of 118.9 m. Strip plots, 40.2 m wide (20.1 m on either side of the transect), extended the full width of the grove, and within each strip plot, we established a series of sampling points along the transect. The first and last sampling points in each strip plot were located 20.1 m from the beginning and end of the transect, respectively. All other sampling points were spaced equidistantly between the first and last point, with a minimum distance between points of 33.2 m.

At each sampling point, we used a 0.008-ha (0.02-acre) fixed-area plot to sample small trees (dbh < 12.7 cm) and a variable-radius plot to sample trees of dbh ≥ 12.7 cm. Seedlings (trees > 0.15 m but < 1.37 m tall) were counted, while saplings (trees ≥ 1.37 m tall with dbh < 12.7 cm) were counted and measured for diameter. A 10 BAF prism was used to identify "in" trees within each variable-radius plot, and the diameters of all live "in" trees ≥ 12.7 cm were recorded. We constructed stand tables according to Avery and Burkhart (1994), using the tree counts from the variable-radius plots to calculate basal area and trees per hectare by 2.5-cm diameter classes.

Within each strip plot, we recorded the following data for all live trees and snags with dbh ≥ 38.1 cm (hereafter "large trees"): aspect, position on slope, diameter (dbh), total height, bole length, live crown ratio, crown shape, crown vigor class (Hornibrook 1939, Thomson 1940, Keen 1943), type of bole deformity, and presence or absence of external fire scars. Over the five sites, we recorded crown, bole, and other morphological features for a total of 413 large trees and snags. Along each transect, we counted downed logs ≥ 25.4 cm in diameter (at point of intersection with the transect). Length, diameter at intersection, and large-end diameter were recorded for each log, and biomass (metric tons/ha) and volume (m^3/ha) of downed logs were calculated (Howard and Ward 1972, Brown 1974).

We randomly selected 10 to 15 large live trees ≥ 38.1 cm dbh in each strip plot for increment coring at breast height. A subset of four large trees in each strip plot that were sampled for age at breast height were also sampled for age at stump height (30.5 cm to 45.7 cm above ground line). Within a 20.1-m radius of each sample point, the tree nearest the sample point in each 12.7-cm diameter class (dbh < 12.7 cm, 12.7–25.3 cm, and 25.4–38.0 cm) up to 38.1 cm was measured for diameter and cored to determine age at breast height. Increment cores were taken parallel to the contour on all trees to reduce variance, and to avoid fire scars that typically occur on the uphill side of the bole. If an increment core did not appear to be near the pith or appeared to have a fire scar, branch, or other defect, we retained the core but took a second core 180° from the first. Increment cores were air-dried, mounted in grooved boards, and sanded with progressively finer grit sandpaper until individual earlywood cells could be identified using a dissecting microscope (Stokes and Smiley 1968). For each core, all rings (beginning with 1997) were counted and the age of each core was recorded. If a tree was cored twice at breast height, the older age was recorded for the tree.

RESULTS AND DISCUSSION

Site and Stand Attributes

Old-growth ponderosa pine study sites in the Bull Mountain Range are typically quite dry (26.4 to 31.2 cm of precipitation annually), occur at elevations between 1067 m and 1189 m, and are located on a variety of aspects and slopes (Table 1). Sites tend to occur along coulees or entirely within larger drainage features. The ponderosa pine habitat types (climax or potential vegetation associations) of central Montana are among the driest forested areas in the state and are often the first forest zone above grassland (Pfister et al. 1977, Arno 1979). Most of our study sites were classified within the *Pinus ponderosa/Agropyron spicatum* (*Pseudoroegneria spicata* [Pursh] A. Love) (PIPO/AGSP) habitat type

(Pfister et al. 1977), with the exception of Rehder Creek (RC), which was classified as a less droughty *Pinus ponderosa/Prunus virginiana* (PIPO/PRVI) habitat type (Pfister et al. 1977). Regional land use history suggests that all five old-growth sites have experienced some degree of cattle grazing for decades. All sites except Rehder Creek revealed signs of recent grazing (e.g., fresh droppings or cattle present). Rehder Creek probably was not grazed because of steep slopes and the dominance of the shrub component, but an abundance of exposed soil and lack of undergrowth at Sage Top (ST) suggested that site may have been overgrazed.

Old-growth stand sizes varied between 2.8 ha and 6.3 ha, and large trees or clusters of large trees occurred within a matrix of younger individuals and open, grassy areas. Tree density (dbh ≥ 12.7 cm) ranged from 244 trees ha^{-1} at Hay Coulee (HC) to 409 trees ha^{-1} at Rehder Creek (Table 2). With the exception of Sage Top, all sites revealed an inverse-J diameter distribution (Figure 1), which is typical of uneven-aged old-growth forest stands (Oliver and Larson 1996). All sites had < 2 trees ha^{-1} with dbh ≥ 50.8 cm. Density of trees ≥ 38.1 cm dbh ranged from 16 trees ha^{-1} to 44 trees ha^{-1} among the five sites. Chimney Butte (CB) and Silver Bullet (SB) had the most large trees per hectare, while Sage Top had the fewest. Green et al. (1992) reported that 10 trees ha^{-1} ≥ 43.2 cm was a U.S. Forest Service minimum characteristic for east-side Montana old-growth ponderosa pine stands. Mehl (1992) noted that a minimum of 10 trees ha^{-1} ≥ 40.6 cm (4 trees $acre^{-1}$ ≥ 16 inches) was a standard old-growth attribute of interior ponderosa pine cover types in the Front Range and Black Hills. The numbers of trees ≥ 38.1 cm in the Bull Mountains old-growth stands suggest that large tree densities at these sites (with the exception of ST) meet U.S. Forest Service minimums for old-growth ponderosa pine in the Rocky Mountain Region.

Stand basal area ranged from 16.3 (HC) to 22.7 (RC) m^2 ha^{-1}, and trees with dbh ≥ 38.1 cm accounted for 16 (ST) to 40 (RC) percent of stand basal area by site. The large numbers per hectare of small trees and relatively high proportions of basal area in small trees may be a result of the absence of recent fire in these stands. At all sites, basal area was greatest in the 25.4- to 38.0-cm dbh class (6.2 to 9.0 m^2 ha^{-1}), suggesting that these medium-sized trees are occupying the majority of the stands' growing space and are in position to replace current large, old-growth trees in the near future.

Current regeneration (Table 2) suggests that Chimney Butte, Hay Coulee, and Silver Bullet recently had successful seed crops followed by climatic conditions favoring seedling survival. All sites except Sage Top had over 1800 small trees (seedlings + saplings) per hectare. The extremely low numbers of seedlings and modest numbers of saplings at Sage Top probably were due to trampling by cattle and dry site conditions exacerbated by loss of organic material and soil compaction due to overgrazing.

Large downed logs and snags have been noted as important structural and functional components of old-growth stands, though abundance, size, and rate of deterioration depend upon climate, species composition, and fire history (Moir 1992, Duchesne 1994, Oliver and Larson 1996, Robertson and Bowser 1999). At the Bull Mountains sites, snag density (dbh ≥ 38.1 cm) ranged from a low of 4 snags ha^{-1} at Hay Coulee to a high of 8 snags ha^{-1} at Silver Bullet. Volume and biomass of downed logs (diameter ≥ 25.4 cm) ranged between 4.7 m^3 ha^{-1} and 2.2 metric tons ha^{-1} at Sage Top to 21.3 m^3 ha^{-1} and 10.3 metric tons ha^{-1} at Hay Coulee (Table 3). Abundance of snags (dbh ≥ 38.1 cm) at these sites suggests that the sites would match U.S. Forest Service old-growth descriptions for interior ponderosa pine cover types in the Rocky Mountains, Front Range, Black Hills, and Southwest (Green et al. 1992, Mehl 1992). Values for downed log biomass and volume were not provided by Mehl (1992) or Green et al. (1992). Snag numbers and amounts of downed logs reflect existing conditions in the ab-

Table 1. Attributes of Bull Mountains old-growth ponderosa pine sites. *Pinus ponderosa/ Pseudoroegneria spicata (Agropyron spicatum)* (PIPO/AGSP) and *P. ponderosa/ Prunus virginiana* (PIPO/PRVI) habitat types (climax plant associations) are according to Pfister et al. (1977).

Attribute	Sage Top	Hay Coulee	Chimney Butte	Silver Bullet	Rehder Creek
Habitat type	PIPO/AGSP	PIPO/AGSP	PIPO/AGSP	PIPO/AGSP	PIPO/PRVI
Aspect(s)	SW, S, NW	S,SW,SE	E, N, S	N, NW, NE	N, NE
Slope	17–35%	15–25%	9–15%	5–20%	20–40%
Shape	concave	concave	concave	flat	concave
Elevation	1097 m	1128 m	1067 m	1067 m	1189 m

Table 2. Ponderosa pine stems per hectare by size class at the Bull Mountains old-growth sites.

Size Class	Sage Top	Hay Coulee	Chimney Butte	Silver Bullet	Rehder Creek
Seedlings (height < 1.4 m)	10	3200	5080	1908	939
Saplings (dbh < 12.7 cm)	133	877	1621	657	964
dbh 12.7–25.3 cm	139	108	121	151	261
dbh 25.4–38.0 cm	124	106	90	80	106
dbh 38.1–50.7 cm	16	27	38	40	31
dbh ≥ 50.8 cm	1	3	6	4	11
Total ≥ 12.7 cm	280	244	255	275	409

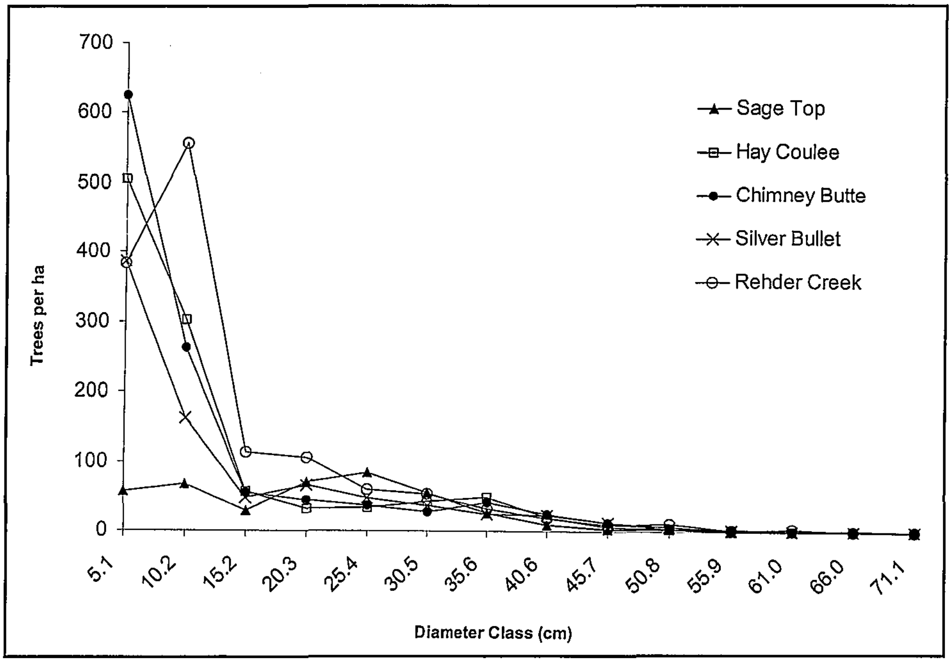

Figure 1. Diameter distribution of trees > 5.0 cm at the Bull Mountains old-growth ponderosa pine sites.

sence of a historically common disturbance, namely, fire. Thus, current numbers of snags and volumes and weights of downed logs may well be higher than historic levels and not necessarily appropriate targets for long-term management of old-growth ponderosa pine on drier sites (Robertson and Bowser 1999).

Age and Size Attributes

Analysis of tree ages indicates that these sites in the Bull Mountain Range readily meet the 180-year and 160-year minimums cited by Green et al. (1992) and Mehl (1992) for old-growth ponderosa pine in eastern Montana and the Black Hills, respectively. Increment cores from 193 large trees and snags (dbh ≥ 38.1 cm) and 200 small (dbh < 38.1 cm) trees were used in age analysis. Across all sites, over 90% of the large trees sampled for age were ≥ 120 years old at breast height, 38% of the large trees were ≥ 200 years, and 17% were ≥ 300 years (Table 4). Only two trees sampled for age were found to be greater than 400 years at breast height.

Table 3. Large snag (dbh ≥ 38.1 cm) and downed log (≥25.4 cm) biomass and volume at the Bull Mountains old-growth sites.

Size Class	Sage Top	Hay Coulee	Chimney Butte	Silver Bullet	Rehder Creek
Snags/ ha	5.4	4.0	5.9	7.9	6.4
Log volume (m^3/ ha)	4.7	21.3	10.4	12.1	10.5
Log weight (metric tons/ ha)	2.2	10.3	5.2	6.1	5.2

Table 4. Percent of aged large live ponderosa pine trees (dbh ≥ 38.1 cm) by breast height age class at the Bull Mountains old-growth sites.

Age Class	Sage Top	Hay Coulee	Chimney Butte	Silver Bullet	Rehder Creek	All Sites
< 120 yrs	0	9	4	5	13	6
≥ 120 yrs	100	91	96	95	87	94
≥ 200 yrs	79	40	29	14	45	38
≥ 300 yrs	39	17	18	9	8	17
≥ 400 yrs	0	3	0	2	0	1

Relative stand ages were determined by comparing the proportions of large trees by age class at each site rather than simply using the age of each site's oldest aged tree. We feel this method provided a more accurate appraisal of relative stand ages given that these were uneven-aged stands, not all trees at each site were aged, and the numbers of aged trees at each site were similar. Both the oldest and youngest large trees aged were located at Silver Bullet. However, because of the low proportion of trees ≥ 200 years old (Table 4), Silver Bullet was considered the youngest of the five old-growth sites. Sage Top was considered the oldest of the Bull Mountains sites with the largest proportion of trees ≥ 200 and ≥ 300 years old.

Age structure (20-year classes) of cored trees is depicted in Figure 2 for all five old-growth sites combined. More than half (54.9%) of the large trees were 120 to 200 years old, with few trees younger than 120 years and a gradually decreasing number older than 200 years. The lack of gaps in the age distribution (until the 430-year age class) despite the variable distribution of ages indicates fairly successful, though sporadic, regeneration and survival of large trees across the Bull Mountains sites throughout the past 400 years. Only 3.5% of the small trees were over 200 years old, the smallest of which was 29.2 cm. About a third of the small trees had a dbh < 12.7 cm. Of these, 97% were greater than 20 years old, suggesting that young tree establishment has slowed in the last two decades.

The subset of 51 trees (≥38.1 cm) successfully sampled for age at breast and stump height revealed ages from 80 to 324 years at breast height and 87 to 331 years at stump height. The average breast height

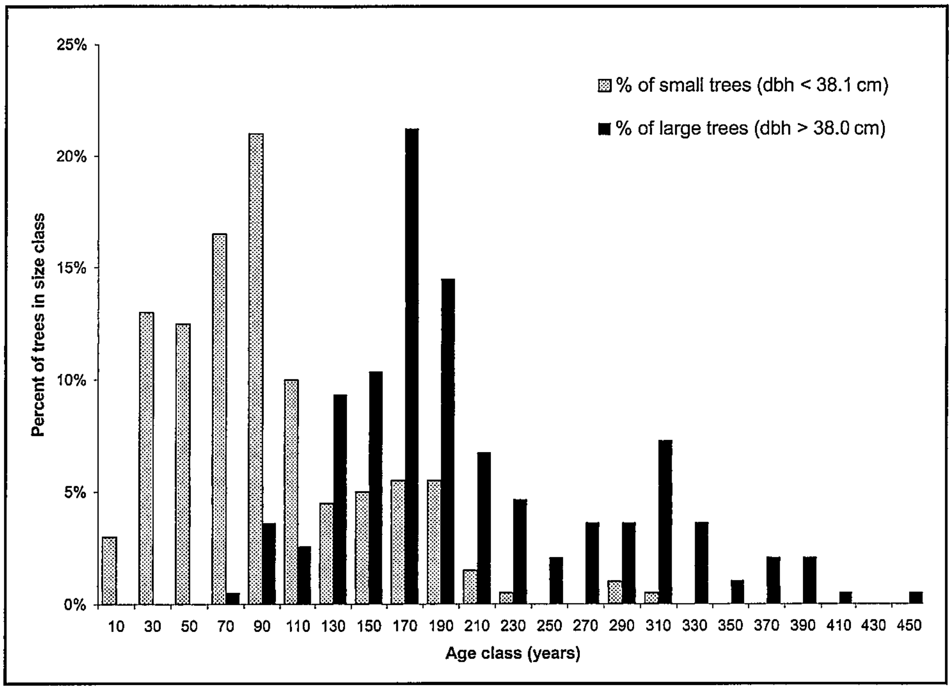

Figure 2. Percent of aged large and small trees by 20-year age classes across the Bull Mountains old-growth ponderosa pine sites.

age was 189.0 (± 62.5 SE) years, and the average stump height age was 205.6 (±62.7 SE) years, for a mean age difference between stump and breast height of 16.6 (±13.8 SE) years. Thus, approximately 10 to 20 years were required for trees to grow from stump height to breast height, indicating approximate early height growth rates of only 4.6 cm to 10.7 cm per year for trees currently ≥ 38.1 cm dbh.

The wide, continuous distribution of tree ages (Figure 3) provides evidence that disturbances were not stand replacing, thus allowing uneven-aged development of stands at each site. The scatter plot of tree age vs. diameter for aged trees at all sites (Figure 3) shows a moderate positive linear relationship (R^2 = 0.58, P< 0.001). Fairly distinct age clusters at several sites may indicate regeneration pulses resulting from abundant seed crops, disturbance events, or favorable climatic conditions. One site (CB) had a single distinct age cluster from 20 to 30 years old. Four sites (ST, HC, SB, and RC) displayed age clusters between 90 and 110 years old, and two sites (HC and SB) also possessed clusters about 200 years old. If these age clusters became established following disturbance events such as fire, their synchrony across several sites may indicate that such disturbances affected areas ≥ 25,900 ha in size. Shinneman and Baker (1997) and Knight (1994) cited evidence of large, landscape-scale fires affecting ponderosa pine forests in the Black Hills region and the mountains of northwest Wyoming in the 1790s and again in the late 1800s. The relatively large number of trees > 200 years old in all five of the Bull Mountains stands reinforces the notion that landscape-scale fires, even if large and synchronous, were not necessarily stand replacing.

Diameter distributions at individual sites (Figure 1), viewed with age distributions (Figure 3), suggest that trees at all five old-growth sites have existed for over 300 years in relative equilibrium with relatively frequent, low- to moderate-intensity disturbances that were not stand replacing. Age structure and stand densities across all sites suggest that sufficient numbers of relatively large (25.4–38.0 cm), middle-aged trees are available as recruits to sustain old growth throughout the Bull Mountains in the future, provided these trees are not lost to catastrophic fire or selective removal in timber harvest. Still, recruitment of large, old trees in the distant future is uncertain even if these stands escape fire indefinitely. This uncertainty stems from low regeneration numbers at Sage Top, in particular, and lack of knowledge about the developmental dynamics of excessive numbers of saplings and trees < 25.4 cm at all sites.

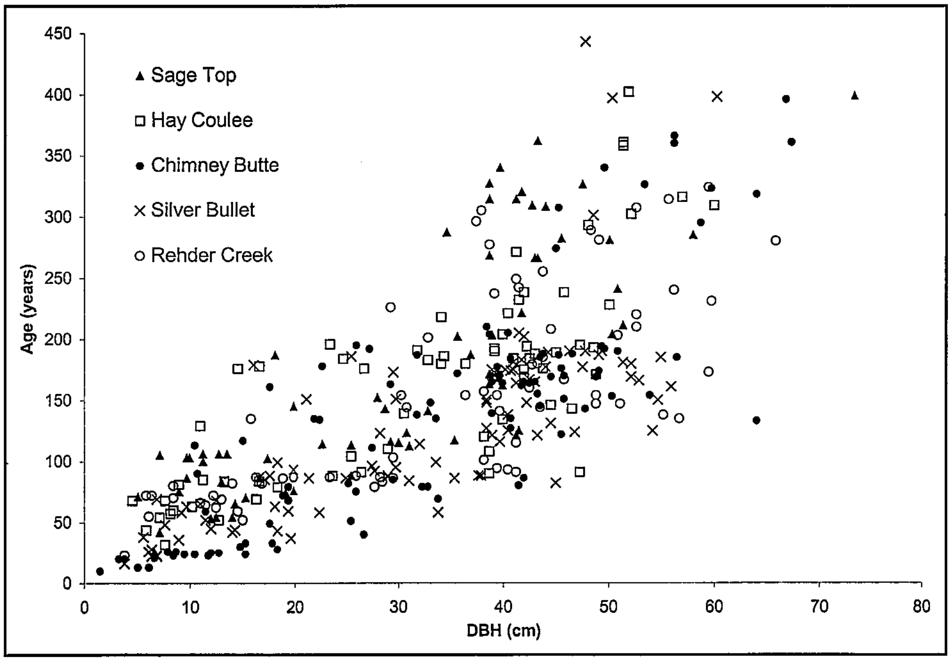

Figure 3. Tree age at breast height vs. diameter at breast height for Bull Mountains old-growth ponderosa pine sites.

Morphological Attributes

A majority of the large trees at each site showed signs of old age in the form of crown or bole deformities (Table 5). Crown deformities included flat, broken, forked, or spiked tops and lean, sweep, or crook of the bole. Across all five sites, 62% of trees with dbh ≥ 38.1 cm had one or more crown deformities. There was a moderate positive correlation between tree age and crown deformity. The most common crown deformity was a flat top, present in 76% of the trees with crown deformities. A flattened top seems to occur in older trees that attain maximum height relatively early in life but are unable to maintain apical dominance due to such factors as ice, wind, biological agents, or water conductance limitations (Ryan and Yoder 1997).

Bole deformities were present in just over half of the old-growth trees at four of the five sites. The lone exception was Rehder Creek, where only 29% of large trees manifested a bole deformity. The lower incidence of deformity at this site may be due to its location on the landscape—a concave topographic position on a moderately steep north to northeast aspect protected from the prevailing southwesterly winds.

The frequency of external fire scars on large trees varied by site (Table 5). Across all five sites, 22% of trees ≥ 38.1 cm dbh had at least one external fire scar, while 9% had multiple scars. Sage Top and Hay Coulee, the two driest sites, revealed the lowest (14%) and highest (43%) proportions of fire scarring, respectively. Neither fire scarring nor bole scorching was observed on trees < 30.5 cm dbh at any of the sites, suggesting the absence of recent fires at all locations. The relative abundance of large trees with fire scars, coupled with the presence of multiple scarring, further supports the hypothesis that these were equilibrium sites frequented by low-intensity surface fires. However, a cross-dated fire history of the Bull Mountains would be required to validate this interpretation.

"Hidden" fire scars were found in increment cores from 10 trees ≥ 38.1 cm; none were found in cores from trees < 38.1 cm. The low number of hidden scars probably was a result of taking increment cores parallel to the contour, which was purposely done to extract undamaged increment cores by avoiding the commonly scarred uphill side of the tree. Chimney Butte and Silver Bullet had four trees each with hidden scars, and Hay Coulee and Rehder Creek each had one. No hidden scars were discovered on cores from trees sampled at Sage Top. The scarcity of external and hidden fire scars at Sage Top provides further evidence that this site historically supported lower tree densities and corresponding lower fuel loads than the other sites.

Because of the danger of losing old growth to stand-replacing disturbances including insect or disease outbreaks, a measure of stand health—susceptibility / resiliency to such disturbances—could help managers locate and prioritize stands for treatment. Abundance of full-vigor (A) and medium-vigor (B) trees and scarcity of weak-vigor (D) trees (Keen 1943) across the five sites (Table 6) indicated that the stands (with the possible exception of ST) were relatively healthy. Although stand density at Sage Top was low relative to the other sites (Table 2), this site had the lowest proportion (6.1%) of large trees with full vigor and no trees of full vigor with an open-grown or "wolf" appearance (vigor class AA, Thomson [1940]). Sage Top also had the greatest proportion (54.6%) of large live trees in the low (C) and weak vigor classes combined, and the highest proportion of large dead trees. Although Silver Bullet had the highest proportion (7.4%) of weak-vigor trees, it had relatively high proportions of large trees with full and medium vigor, indicating better health. The relative abundance (48.5%) of low-vigor trees at Sage Top may have been typical historically at this dry site or might indicate potential decline brought about by recent periods of drought or impacts from cattle grazing (i.e., soil compaction, mechanical injury, etc.). At the other four sites, small tree densities, which probably are high relative to historic levels, could cause declining vigor and reduced growth in older trees (Biondi 1996, Fiedler 2000).

CONCLUSIONS

This study describes structural, morphological, and disturbance characteristics of

Table 5. Percent of large ponderosa pine trees (≥38.1 cm) displaying damage at the Bull Mountains old-growth sites.

Damage Type	Sage Top	Hay Coulee	Chimney Butte	Silver Bullet	Rehder Creek
Crown deformity	88	56	56	58	67
Bole deformity	58	54	54	52	29
External fire scar	14	43	33	28	30

Table 6. Percent of large ponderosa pine trees (≥38.1 cm) by vigor class at the Bull Mountains old-growth sites. Classes AA through D computed as number in class divided by total number alive at each site. Percent dead (X) calculated as number dead divided by total number of alive and dead at each site.

Vigor Class	Sage Top	Hay Coulee	Chimney Butte	Silver Bullet	Rehder Creek
AA	0.0	4.2	9.6	3.7	12.2
A	6.1	16.7	34.6	21.3	37.8
B	39.4	50.0	31.7	45.4	32.4
C	48.5	25.0	21.2	22.2	13.5
D	6.1	4.2	2.9	7.4	4.1
X (Dead)	25.0	14.3	12.6	14.3	11.9

old-growth ponderosa pine sites in the Bull Mountains of Montana, providing a better understanding of the ecology, structure, and processes near the northeastern edge of the species' range that can be incorporated into regional definitions of old growth and management strategies. The wide, continuous distribution of tree ages, coupled with the presence of moderate numbers of trees > 300 years old at each site, provide the basis to classify all five sites as equilibrium old-growth sites in Shinneman and Baker's (1997) vernacular. The failure of a stand (i.e., ST) with many of the oldest trees in this study to meet current regional structural minimums for old growth—number of trees > certain dbh per hectare, or snags per acre (Green et al. 1992, Mehl 1992)—does not disqualify it as old growth. Rather, such failures expose the inadequacy of rigidly fixed minimum criteria for defining old growth, and the need for criteria to be based on ecological attributes that account for natural variability among sites, stands, climate, and disturbance regimes (Parker et al. 2000). Thus, we agree with Wells et al. (1998) that index methods of old-growth determination would be better able than minimum criteria methods to (1) account for the abundance of certain characteristics (e.g., age) in the absence or limited expression of others (e.g., snags per hectare), (2) recognize natural variation, and (3) predict future development of old growth.

The continued existence of old growth in the Bull Mountains, as throughout the inland West, is at risk from catastrophic fire and selective removal of old trees by high-grade logging. High densities of trees < 38.1 cm dbh at four of the five study sites pose a fundamental and immediate threat to the historic stand structure–disturbance regime. Should wildfire occur in these stands, the result probably would be a stand-replacement event signaling the transition from an equilibrium to nonequilibrium stand structure–disturbance regime. However, as evidenced by the largely unregenerated 70,000-ha wildfire of 1984 in the Bull Mountains, the result of such fires may be long-term deforestation. The other immediate threat to old-growth trees is diameter-limit cutting, the traditional approach to timber harvesting in the Bull Mountains. Diameter-limit harvesting—in essence high-grading—will not maintain the quantity, quality, or spatial distribution of large trees characteristic of uncut old-growth sites and does not reduce small tree densities sufficiently to protect potential old-growth sites from crown fire.

Only through a more complete understanding of the history and dynamics of dry site ponderosa pine and reduction of threats from fire and high-grade logging can efforts to sustain the old-growth resource be developed. Dendrochronological studies, spatially explicit fire histories, and detailed inventories of snags and coarse woody debris would provide important insights into old-growth ponderosa pine dynamics in eastern Montana. Until such investigation can be completed, management of existing old-growth pine in the Bull Mountains should focus on prioritized treatment of high-risk stands and sites with the greatest potential for future development of old growth. Proactive restoration treatments aimed at reducing densities in the sapling and pole-size diameter classes, reducing fuel loads, and maintaining the larger and older trees should sustain the old-growth resource as research continues.

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