Invited Paper

INFLUENCE OF MOUNTAIN PINE BEETLE EPIDEMIC ON WINTER HABITAT CONDITIONS FOR MERRIAM'S TURKEYS: MANAGEMENT IMPLICATIONS FOR CURRENT AND FUTURE CONDITION

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Abstract: Understanding response of ponderosa pine (*Pinus ponderosa*) forest development following a mountain pine beetle (MPB; *Dendroctonus ponderosae*) epidemic has important management implications for winter habitat conditions for Merriam's wild turkeys (*Meleagris gallopavo merriami*; hereafter, turkeys). Therefore, we quantified habitat changes over time for turkeys following a widespread MPB epidemic in the Black Hills of South Dakota and evaluated how many years it will take for optimal winter habitat conditions within ponderosa pine forests to recover following such a disturbance. To do so, we used a Habitat Suitability Index (HSI) model developed for Merriam's turkeys and a Forest Vegetation Simulator (United States Forest Service, Fort Collins, CO, USA). Our HSI indicated winter habitat quality decreased following the

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MPB outbreak due to conversion of ponderosa pine >40% canopy cover and trees >22.9-cm diameter at breast height (DBH) to smaller diameter (2.54-cm to 22.9-cm DBH) structural stages. Simulations indicated that time for stands to return to optimal winter habitat conditions after the MPB outbreak varied depending on forest structural stage of residual trees and management action. Intensive timber management, particularly precommercial thinning every 20 years, reduced amount of time for forests to develop optimal winter habitat conditions. Importance of intensive management was more pronounced following 75% mortality in stands due to MPB compared to 50% mortality in stands. In some stands, no management versus intensive management may have at least doubled recovery time. We recommend managers use practices such as precommercial thinning every 20 years or uneven-aged management to substantially reduce time to produce optimal winter habitat conditions for turkeys following a MPB outbreak. Additionally, because our study area historically experienced large-scale wildfires and MPB epidemics, we recommend silvicultural practices that ensure a mosaic of stand structural stages across the Black Hills to create and maintain a landscape that is resilient to these disturbances.

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Merriam's wild turkey (*Meleagris gallopavo merriami*; hereafter, turkey) is a focal species of local concern in the Black Hills National Forest because of their great social and economic value (Flake et al. 2006, Griebel et al. 2007). The United State Department of Agriculture (USDA) Forest Service has adopted policies to implement ecosystem management which involve partnerships, stakeholder involvement, and using the best available science in management decisions (Thomas and Dombeck 1996). Previous research on resource selection by turkeys during winter has been an asset for resource managers in the Black Hills (Rumble and Anderson 1992, 1993, 1996*a*, 1996*b*, 1996*c*; Lehman et al. 2007). However, landscape attributes in the Black Hills have changed considerably following a mountain pine beetle (MPB; *Dendroctonus ponderosaei*) epidemic that began in the mid-1990s.

Mountain pine beetles are endemic to the Black Hills and a substantial mortality agent in unmanaged ponderosa pine stands (Furniss and Carolin 1977). Outbreaks of MPB have killed millions of trees in the Black Hills since the early 1900s (Blackman 1931, Thompson 1975). During the most recent epidemic, beginning in the mid-1990s, considerable tree mortality occurred throughout the Black Hills (Schmid et al. 2007). From 1996 to 2013, an estimated 167,540 ha, or roughly a third of the Black Hills, incurred substantial tree mortality (Howell et al. 2014). This MPB epidemic has affected approximately 18,700 ha in the Mystic Ranger District of the Black Hills National Forest (BHNF) in the central Black Hills of South Dakota (USDA Forest Service, unpublished data, 2014).

Epidemic MPB populations are usually attributed to over-stocked ponderosa pine stands (Thompson 1975, Fettig et al. 2007). Characteristics of trees within stands that are very susceptible to MPB during epidemics include trees ≥15-cm diameter at breast height (DBH) and basal area exceeding 16.1 to 18.4 m^2/ha (Fettig et al. 2007, Schmid et al. 2007). These susceptible trees often have crowns in the mid- and upper canopy, resulting in increased light and resource availability to surviving smaller trees after epidemics. Creation of more growing space also allows regeneration. In the Black Hills, favorable growing conditions and good seed crops often coincide and result in abundant natural ponderosa pine seedling establishment, often ≥1,000 seedlings/ha (Battaglia et al, 2008). Historically, wildfire reduced density of these seedlings (Brown and Sieg 1996, Shepperd and Battaglia 2002), but with active wildfire suppression, using prescribed fire or mechanical treatment to thin forest stands is needed. Without seedling density reduction, competition among the new cohort decreases growth rates of trees (Woodall et al. 2003).

During winter, turkeys in northern regions of the United States have been found to often feed on natural foods, such as ponderosa pine seeds (Rumble and Anderson 1996*a*, Lehman et al. 2007) and waste grains attained from farmsteads (Hengel 1990, Hoffman et al. 1996, Lehman et al. 2007). In years of abundant pine seed production, turkeys in the central Black Hills have selected dense ponderosa pine stands on southerly exposures almost exclusively; greatest pine seed abundance occurred in stands with >70% canopy cover of ponderosa pine and >28-m^2/ha basal area (Rumble and Anderson 1996*a*).

Tree basal areas >23-m^2/ha have been recommended for turkey winter habitat in the northern part of their range (Hoffman et al. 1993, Rumble and Anderson 1996*a*, Lehman et al. 2007). However, as noted above, MPB infestations often occur in these dense forests, reducing numbers of mature trees and possibly making these previously suitable areas unsuitable for turkeys during winter. There is a research need to understand winter resource selection patterns in turkeys (Hoffman et al. 1993); understanding dynamics of ponderosa pine regeneration and growth patterns as it relates to natural disturbance and silviculture is intrinsically connected to winter resources needed by turkeys. Therefore, to better understand effects a dynamic ponderosa pine system may have on winter habitat conditions for turkeys, our objectives were to: (1) quantify changes in winter habitat conditions for turkeys in ponderosa pine stands resulting from a MPB disturbance using Habitat Suitability Index (HSI) modeling (Rumble and Anderson 1995, Junnti and Rumble 2006) and (2) estimate length of time for optimal winter habitat conditions for turkeys in ponderosa pine stands to recover following a MPB disturbance by modeling forest growth.

STUDY AREA

Our study area (1,442 km^2) was within the boundary of the Mystic Ranger District of the BHNF in Custer,

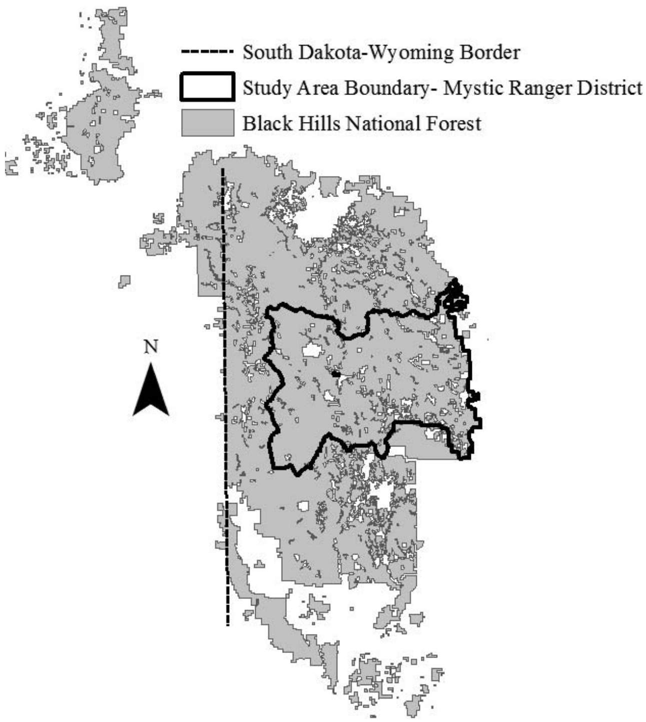

Figure 1. Location of study area to examine ponderosa pine forest response to management after a mountain pine beetle outbreak relative to winter habitat conditions for Merriam's turkeys. This area is the Mystic Ranger District of the Black Hills National Forest in the central Black Hills, South Dakota.

Pennington, and Lawrence counties in the central Black Hills physiographic region of South Dakota (Flint 1955, Fig. 1). Our study area ranged in elevation from 1,011 to 2,207 m above mean sea level and included the Limestone Plateau (Ensz 1990). Our study area had a continental climate with mean annual precipitation of 53.1 cm and mean annual temperature of 7.3°C during 1981–2014 (National Climatic Data Center 2014). Historically, wildfire and MPB infestations were natural disturbance agents in this region (Brown and Sieg 1996, 1999; Parrish et al. 1996; Shinneman and Baker 1997). Land cover types were primarily ponderosa pine forest (73%), meadows (16%), and aspen (*Populus tremuloides*) and spruce (*Picea glauca*) forest (4%). Within the forests, western snowberry (*Symphoricarpos occidentalis*) and common juniper (*Juniperus communis*) were common shrubs in the understory, while serviceberry (*Amelanchier alnifolia*), bearberry (*Arctostaphylos uva-ursi*), and chokecherry (*Prunus virginiana*) occurred less frequently (Larson and Johnson 1999).

METHODS

Habitat Suitability Index Modeling

We used a HSI model within a geographical information system (GIS) framework (ArcHSI, United States Forest Service, Rapid City, South Dakota, USA; Rumble and Anderson 1995, Junnti and Rumble 2006) to estimate ability of our study area to meet winter habitat requirements for turkeys. We defined suitability as ability of current habitat conditions to provide life requisites of a species (British Columbia Wildlife Habitat Rating Standards 1999). We described vegetation based on dominant vegetation species, DBH (cm), and overstory canopy cover in a GIS coverage (Buttery and Gillam 1983; hereafter referred as vegetation structural stages). Vegetation structural stages in our analyses included grass–forb (meadow), aspen, spruce, and ponderosa pine. We further categorized ponderosa pine as seedling–shrub, pine pole stands (2.54-cm to 22.9-cm DBH; diameter class 3), and pine sawtimber stands (>22.9-cm DBH; diameter class 4) with overstory canopy cover categories in pole and sawtimber stands of 0–40% (canopy class A), 41–70% (canopy class B), and >70% (canopy class C) following descriptions in Rumble and Anderson (1992). We combined the first letter of vegetation type, diameter class, and canopy class as an acronym for vegetation structural stages. For example, a ponderosa pine stand with 41–70% canopy and >22.9-cm DBH would have the acronym P4B.

We calculated a HSI score for our study area by assigning a suitability rating to each vegetation structural stage based on empirical research of winter habitat requirements for turkeys in the central Black Hills (Table 1; Rumble and Anderson 1992, 1993, 1996*a*, 1996*b*, 1996*c*). The ArcHSI construct included 2 basic components: habitat value for forage (FV), and habitat value for cover (CV). This GIS model was deterministic and included values for FV, CV, and HSI for turkeys; we computed $\mathrm{HSI} = \sqrt{\mathrm{FV} * \mathrm{CV}}$. Values for each variable may range from 0 (poor) to 1 (excellent). Using the BHNF Forest Service Vegetation (FSVEG) GIS coverage (BHNF Vegetation Database, unpublished data, USDA Office, Rapid City, South Dakota, 2014), we estimated a winter HSI score before the mid-1990s MPB epidemic and also for conditions post-epidemic, or existing in 2014.

Forest Regrowth Simulation Modeling

We defined ponderosa pine stands representing optimal winter habitat conditions for turkeys as those with mean tree size of >22.9-cm DBH and >40% overstory canopy cover (Hoffman et al. 1993, Rumble and Anderson 1996*a*, Lehman et al. 2007). Hereafter, we refer to optimal winter conditions for turkeys as P4B (>22.9-cm DBH and 41–70% overstory canopy cover) or P4C (>22.9-cm DBH and >70% overstory canopy cover) structural stages. Then, we used the Central Rockies variant of the Forest Vegetation Simulator (FVS v.1321, United States Forest Service, Fort Collins, Colorado, USA; Dixon 2002, 2008) to model forest development after MPB outbreak that occurred within optimal stands. This simulator is a density-dependent simulation model consisting of allometric equations used to estimate tree diameter growth (cm/year), mortality and recruitment, stand density (trees/ha), and basal area (m^2/ha). We initialized FVS with forest structure data obtained through the Forest Inventory Analysis (FIA) database (FIADB v.5.1, http://apps.fs.fed.us/fiadb-downloads/datamart.html) from the USDA Forest Service for BHNF. For experimental units, we used only individual stands that were dominated by ponderosa pine, located on BHNF, and with forest structure that was classified as P4B or P4C (n = 90). Species dominance was based on FIA, and defined by

Table 1. Forage value (FV), cover value (CV), and Habitat Suitability Index (HSI) values for vegetation communities computed with an ArcHSI model based on vegetation data from the USDA Forest Service to determine winter habitat suitability for Merriam's turkeys. Proportion (Prop.) and hectares (Ha) of each vegetation community before and after mountain pine beetle epidemic in the Mystic Ranger District of the Black Hills National Forest, South Dakota.

Vegetation community categories[a]				HSI values			Before beetle		After beetle	
Macrohabitat Class	DBH class	Overstory canopy	SS[b]	FV	CV	HSI	Prop.[c]	Ha	Prop.[c]	Ha
Meadow	–	–	GRA	0.1	0.1	0.1	16%	22,387	16%	22,351
Ponderosa pine	seedling-shrub	–	TP2	0.2	0.2	0.2	2%	3,059	2%	3,050
Ponderosa pine	2.54–22.9 cm	0–40	P3A	0.2	0.2	0.2	6%	8,021	6%	9,268
Ponderosa pine	2.54–22.9 cm	41–70	P3B	0.5	0.5	0.5	5%	7,771	5%	6,719
Ponderosa pine	2.54–22.9 cm	71–100	P3C	1.0	1.0	1.0	2%	2,532	2%	2,336
Ponderosa pine	>22.9 cm	0–40	P4A	0.2	0.2	0.2	31%	44,217	34%	49,215
Ponderosa pine	>22.9 cm	41–70	P4B	0.5	0.5	0.5	19%	27,011	16%	22,613
Ponderosa pine	>22.9 cm	71–100	P4C	1.0	1.0	1.0	5%	6,585	4%	6,012
Ponderosa pine	>41.0 cm	0–100	P5	1.0	1.0	1.0	<1%	205	<1%	179
Aspen	All classes	0–100	TAA	0.0	0.0	0.0	3%	4,108	3%	4,108
Spruce	All classes	0–100	SPR	0.0	0.0	0.0	1%	2,058	1%	2,058

[a] Vegetation structural stages were described based on dominant vegetation species, DBH, and overstory canopy cover (Buttery and Gillam 1983).
[b] Structural stage (SS) category acronym.
[c] The study area included 144,198 ha and the approximate area for each category can be estimated as a proportion.

predominance of species based on tree density. At the beginning of the projection, we simulated a mortality event that killed either 75% or 50% of basal area of trees >15.24-cm DBH, concentrating mortality on largest trees first, mimicking documented outbreaks (Sheppard and Battaglia 2002, Schmid et al. 2007). This resulted in changing P4B or P4C stands to P3A, P3B, and P4A stands. We used the Regeneration Imputation Extractor throughout our simulation to add seedling regeneration with densities based on inventory data from BHNF FIA data (Vandendriesche 2010). We modeled forest growth simulations for 200 years.

We focused our simulations on various mechanical management scenarios that would potentially reduce small tree density and increase residual tree growth following the MPB epidemic. These scenarios focused on different thinning intervals and tree size classes. Our no action scenario simulated stand development without any management. Our precommercial thin (PCT) scenario focused on reducing ponderosa pine regeneration density by targeting trees ≤12.7-cm DBH. Within our PCT scenario, we varied frequency by modeling either 1 thinning 10 years post MPB outbreak (PCT once) or thinning every 20 years (PCT every 20 yrs). Our third scenario was an uneven-aged treatment, or BDQ (basal area [BA], diameter distribution, and q ratio). In the BDQ method, we initiated thinning anytime a stand reached a defined threshold BA and thinning then occurred throughout the entire diameter range. The q factor is the ratio between tree density in 1 diameter class and those in the next smaller class. This controlled distribution of tree diameters between larger and smaller target diameter classes (*D*; Alexander and Edminster 1987). We used a q factor of 1.1, which promoted small densities of small trees (DBH < 15.24 cm). For this model, BA referred to residual BA that the growing stock was reduced to following each cutting cycle. For the BDQ scenario, when stands reached 23 m^2/ha, we reduced trees to a residual BA of 18.4 m^2/ha, between all diameter classes up to 61-cm DBH, and a q factor of 1.1. We defined PCT every 20 years and uneven-aged treatments as "intensive management" due to the additional work needed in meeting objectives set for those practices.

We tested years to grow to structural stage P4B or P4C for each management scenario within a structural stage for significant differences using SAS version 9.3 (SAS Institute, Cary, North Carolina, USA). We used the Shapiro-Wilk test for normality and each management scenario was found to fail the normality test, so we used a non-parametric Kruskal-Wallis One Way Analysis of Variance on Ranks to test for differences on median values. We used the Dwass, Steel, Critchlow-Fligner Method (DSCF) method for pairwise multiple comparisons. The null hypothesis was that years to grow back to optimal turkey habitat did not differ among management scenarios. Our response variable was number of years and main effects were management scenarios. Significance was determined at $\alpha = 0.05$.

RESULTS

Habitat Suitability Index Modeling

Winter HSI values before the MPB epidemic were qualitatively greater (mean = 0.44, SE = 0.005) than HSI value in 2014 following the MPB epidemic (mean = 0.36, SE = 0.005). Decreased winter HSI values resulted from loss of ponderosa pine >40% canopy cover in trees >22.9 cm DBH (Table 1). About 4% of better quality winter habitat (≥0.5 HSI) was altered by the MPB epidemic.

Forest Regrowth Simulation Modeling

Fifty Percent Tree Mortality Simulation

Most stands that were in P4B or P4C structural stage were converted to P3A (n = 34) or P4A (n = 29), with

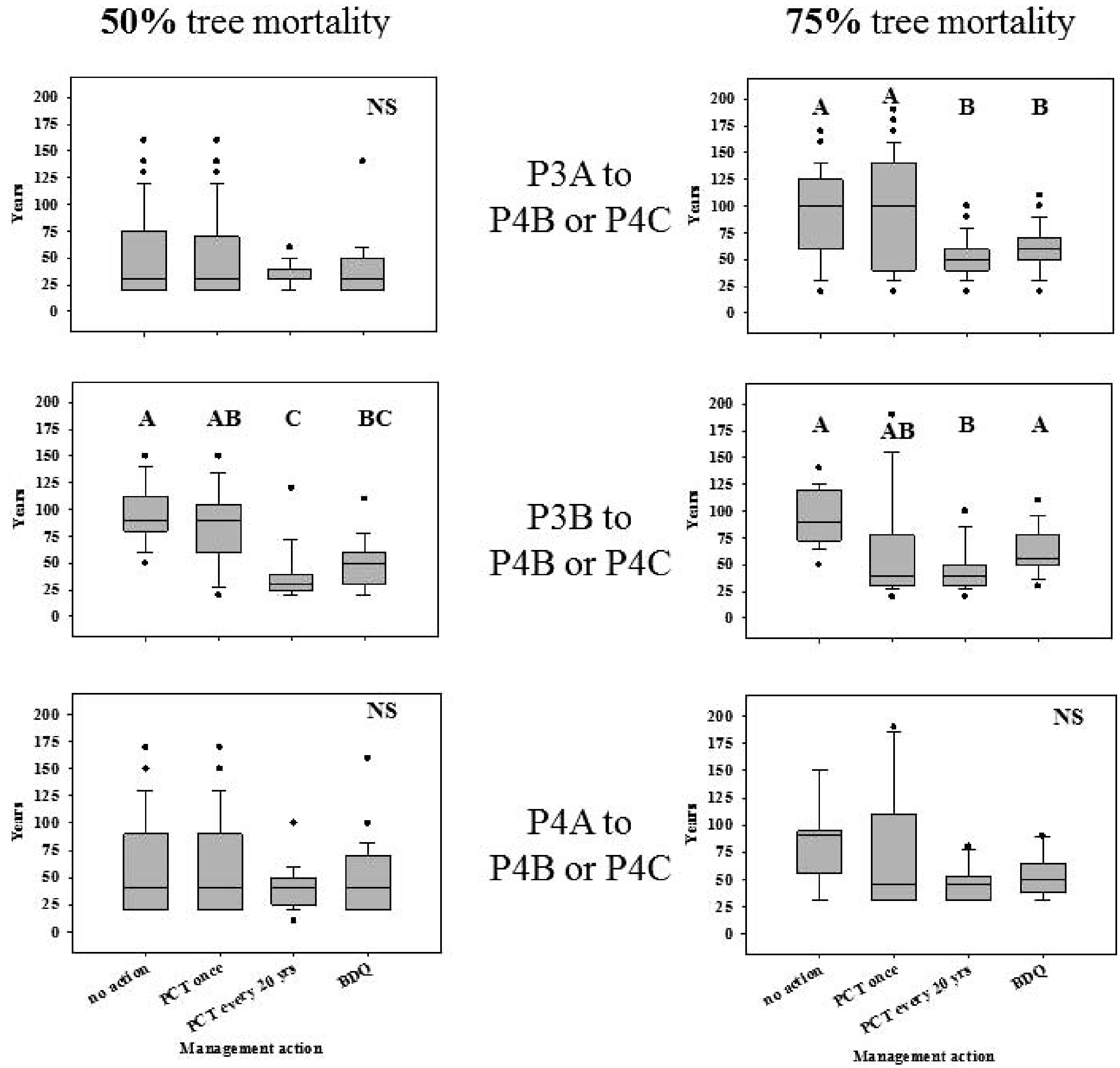

Figure 2. Years for each habitat structural stage to grow into P4B or P4C (ponderosa pine trees ≥22.9-cm DBH with overstory canopy cover ≥41%) under various management actions following a mountain pine beetle epidemic in the Black Hills of South Dakota. We simulated ponderosa pine stands to have experienced 50% or 75% mortality of trees >15.24-cm DBH. In each box plot, the heavy line is the median, boxes represent the 1st and 3rd quartiles, whiskers are 10th and 90th percentiles, and closed circles indicate outliers. Different letters denote significance at $P < 0.05$ from pairwise multiple comparisons using the Dwass, Steel, Critchlow-Fligner Method. Management actions included (1) no action, (2) precommercial thinning once 10 years post epidemic (PCT once), (3) precommercial thinning every 20 years post epidemic (PCT every 20 yrs), and uneven-aged thinning when stands reached a threshold of 23-m^2/ha basal area (BDQ).

some converting to P3B ($n = 14$) after simulating 50% mortality. Time for stands to grow back to a P4B or P4C structural stage post-MPB beetle outbreak varied with pre-MPB structural stage and management action.

We estimated that median value of stands converted to P3A structural stage will take 30 to 40 years to recover to P4B or P4C structural stage regardless of management actions ($\chi_3{}^2 = 0.24$, $P = 0.97$). However, variability in recovery time was influenced by management. For example, outer quartiles (25% and 75%) of no action and PCT once management ranged between 20 and 75 years, while outer quartiles of the PCT every 20 years and BDQ ranged between 30 to 40 years and 20 to 50 years, respectively (Fig. 2).

Intensive management decreased time for stands converted to P3B structural stage following the MPB epidemic to recover to P4B or P4C structural stages (Fig. 2; $\chi_3{}^2 = 28.2$, $P < 0.01$). If no management activity occurred, we estimated that about 90 years would be required to grow from P3B to P4B or P4C structural stage. PCT once also had a median value of 90 years, but with more variability, ranging between 50 and 105 years for outer quartiles compared to 80 and 115 in outer quartiles from no action. More intensive management, such as PCT every 20 years, decreased time to recover to P4B or P4C structural stages to 30 years, with a range of 25 to 40 years for outer quartiles. PCT every 20 years in a P3B stand reduced amount of time to reach P4B or P4C structural stages over that of no action (DSCF = 5.99, P < 0.01) and PCT once (DSCF = 4.70, P = 0.03). Uneven-aged thinning BDQ method also reduced time to reach P4B or P4C over that of no action (DSCF = 5.68, P < 0.01); it took 50 years to recover to P4B or P4C structural stages with a range of 30 to 60 years in outer quartiles.

Stands converted to P4A took a median value of 40 years to recover to P4B or P4C structural stage regardless of management action ($\chi_3{}^2 = 2.40$, P = 0.49; Fig. 2). However, range of time among management actions varied. No action and PCT once management actions first and third quartiles ranged between 20 and 90 years, while estimated time of PCT every 20 years and BDQ in these quartiles only ranged between 25 and 50 years, and 20 to 70 years, respectively.

Seventy-Five Percent Tree Mortality Simulation

Seventy-five percent tree mortality converted most stands that were P4B or P4C structural stage to P3A (n = 61), with fewer to P3B (n = 16) or P4A (n = 10) following MPB infestation. Estimated time for stands to grow back to a P4B or P4C structural stage post MPB beetle outbreak varied with starting structural stage and management action.

Management activities in stands converted to P3A after the MPB outbreak reduced amount of time for these stands to grow into a P4B or P4C stand ($\chi_3{}^2 = 53.5$, P < 0.01). Stands converted to P3A took about 100 years to grow back to P4B or P4C after 75% mortality for both no action and PCT once management scenarios (Fig. 2). Variability in time for recovery was great for both management scenarios; outer quartile range under no action ranged between 60 to 125 years. PCT once had a wider outer quartile range of 40 to 140 years. More intensive management, such as PCT every 20 years (DSCF = 8.05, P < 0.01) and BDQ (DSCF = 7.03, P < 0.01), substantially reduced time for stands to grow to P4B or P4C structural stages (Fig. 2). Precommercial thin every 20 years took 50 years with an outer quartile range of 40 to 60 years. BDQ took 60 years, with an outer quartile range of 50 to 70 years.

Similarly, management in stands converted to P3B structural after the MPB outbreak grew back P4B or P4C structural stage in 40 to 50 years compared to less intensive management ($\chi_3{}^2 = 22.1$, P < 0.01). No action increased time to recover to 90 years with an outer quartile range of 72 to 120 years. PCT every 20 years had the smallest outer quartile range of 30 to 50 years.

In the few stands (n = 10) that were converted to P4A structural stage after the outbreak with 75% tree mortality, no action had a median time of recovery of 90 years, while this was 45–50 years for intensively managed stands. However, due to variability and small sample size (Fig. 2) this did not differ ($\chi_3{}^2 = 5.72$, P = 0.13) among management activities.

DISCUSSION

The MPB epidemic reduced good quality winter habitat conditions for turkeys in the Black Hills. Mortality induced from MPB affected stand structure by reducing both the large tree (>22.9-cm DBH) component, stand BA, and associated canopy cover. Larger trees and greater overstory canopy cover are required for optimal winter habitat conditions for turkeys (Hoffman et al. 1993, Rumble and Anderson 1996*a*, Lehman et al. 2007).

Many stands affected by the MPB were even-aged and great in tree density. Under both tree mortality simulation scenarios, BA was substantially reduced by the MPB infestation. Residual living trees that survived the infestation or those too small to be attacked by MPBs remained for forest structure. Number and size of ponderosa pine that were left alive determined rate of forest recovery relative to optimal winter habitat conditions for turkeys. In most simulated recovery times, intensive management facilitated recovery to P4B or P4C structural stages.

Residual trees capitalize on increased growing space after MBP infestations, but there are limits to how fast trees can grow to reach 22.9-cm DBH (Alexander and Edminster 1981). The other needed component of winter habitat for turkeys is large BA or increased canopy cover of larger trees and BA >23 m^2/ha or >40% canopy (Hoffman et al. 1993, Rumble and Anderson 1996*a*, Lehman et al. 2007). While larger trees have greater individual BA, BA of stands also includes a tree density factor. Considerable time will be required for regeneration that occurs after the MPB-induced mortality event to contribute substantially to stand DBH and BA. However, manipulating regeneration should reduce time for recovery to optimal winter habitat conditions for turkeys.

In our simulations of 50% mortality from MPB, intensive management did not significantly increase development rates for forests in P3A and P4A structural stages. However, inherent variability in stand structure made discerning differences in management actions difficult. Regardless, more intensive forest treatments reduced competition among younger regenerated tree cohorts to allow faster growth and shorter recovery time. The BDQ method was intermediate in forest regeneration because it reduced density in smaller trees and some larger trees that were contributing to the large tree component needed for optimal winter habitat.

For stands with slightly more residual trees, or the P3B structural stage, intensive management reduced recovery time. When the MPB thinned these forests, overstory density was reduced to levels that were still dense enough to have optimal canopy cover (41–70%), but not DBH (22.9 cm). Because density was great, overstory trees grew slower to reach the 22.9-cm DBH threshold. This overstory tree competition was compounded by a competition effect of the new regeneration cohort that initiated after the MPB attack. In those stands that had intensive management of reducing regeneration density several times (PCT every 20 yrs) and reducing overstory/regeneration density, growth time to P4B or P4C was reduced substantially.

Recovery time for affected stands to progress into optimal winter habitat conditions for turkeys following 75% mortality of mature trees killed by MPB was substantially reduced with more intensive management. Stands recovery was the result of 2 primary factors. Increased growing space for the residual living trees created conditions for trees to increase diameter growth and a reduction in regeneration densities reduced inter-tree competition.

It was not surprising few stands were converted to P4A following MPB disturbance. These stands contained trees >22.9-cm DBH and such trees are targeted by MPBs during large epidemics (Fettig et al. 2007, Schmid et al. 2007). We surmise that lack of significance in management actions within this structural stage was most likely related to great variability along with the small sample size of only 10 stands.

Trees that are killed by MPB will be standing snags for less than 5 years and will contribute to increased coarse woody debris on the ground (Schmid et al. 2009). This will add substantially to surface fuel loads, which could lead to high intensity surface fires with long residence time and difficulty for firefighting operations (Page et al. 2013). Increased fuel loading increases visual obstruction at the ground level, and turkeys select areas of decreased visual obstruction for winter feeding (Lehman et al. 2007). Turkeys select such areas for visual detection of predators and less woody debris also allows for ease of scratching for pine seeds at the ground surface (Lehman et al. 2007).

Growth rates and recovery times of ponderosa pine within the Black Hills are unique, as germination rates of seedlings are robust due to timing of optimal temperature and precipitation during the growing season, leading to unique productivity and tree regeneration success (Shepperd and Battaglia 2002). Therefore, our simulations were based on these specific conditions. We hesitate to recommend specific silvicultural practices to be implemented broadly across the western United States based on this unique situation. However, we do recommend that forest growth simulations calibrated to the regeneration potential and site productivity of specific regions of interest be used in evaluating management practices to maintain and enhance ponderosa pine stands for turkeys in other regions. Our findings can be applied as a template to other ponderosa pine systems in the western United States where wildlife biologists and managers are interested in what silvicultural practices may produce desirable winter habitat conditions for turkeys.

MANAGEMENT IMPLICATIONS

In the Black Hills, PCT every 20 years and BDQ management substantially reduced simulated time to provide optimal winter habitat conditions for turkeys following a MPB epidemic. Judicious thinning of trees ≤12.7-cm DBH can increase growing space for residual living trees, resulting in increased diameter growth rate and reduced tree densities that also reduces inter-tree competition. Although it may seem counter intuitive, in some cases management with harvest of timber will allow faster attainment of stands to BA >23-m^2/ha and trees >22.9-cm DBH following a MPB infestation. We recommend timber management that allows for a mosaic of stand structures across the Black Hills to provide areas less susceptible to large stand-replacing fires and MPB epidemics that lead to large contiguous areas of tree mortality. A mosaic of ponderosa pine structural stages with varying ages and stocking densities will not optimize the landscape for turkeys, but will reduce loss of dense and mature forests to MPB, thus sustainably providing winter habitat conditions needed by turkeys in the future. Future research should focus on collecting vital rate information of turkeys as it relates to MPB epidemics and changing landscape conditions.

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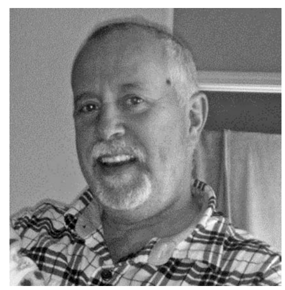

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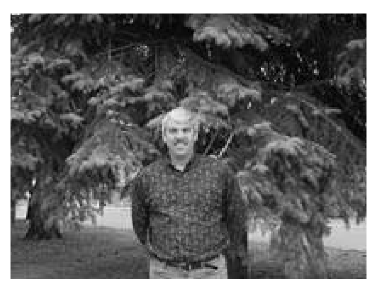

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