Thinning Alternatives for Ponderosa Pine: Tools and Strategies for Family Forest Owners

Paul T. Oester *and* **William H. Emmingham** *(Emeritis), Department of Forest Science, College of Forestry, Oregon State University, Corvallis, Oregon 97331; and* **Pat Larson,** *La Grande, Oregon 97850.*

ABSTRACT: *Density management of ponderosa pine (*Pinus ponderosa*) forests is critical for control of beetles, reducing risk of wildfire and capturing monetary, aesthetic, and ecological values. This case study examined periodic growth response of ponderosa pine 5 and 13 years after installation of a trial including three thinning regimes and an unthinned option in the Wallowa Mountains of northeast Oregon. Family forest owners and their advisors whose management goals include reducing fire and beetle risk and producing timber value can use the results of this case study with the stand density index (SDI) to evaluate thinning options. We analyzed mean tree diameter growth and periodic board foot volume growth of 8-in. diameter and larger trees for the four treatments applied to 85–100-year-old stands. Our treatments were used as a local test for SDI management guidelines and forest vegetation simulator (FVS). As expected, significant increases ($\alpha = 0.05$) were found after 13 years in mean diameter growth of trees and periodic board foot volume growth per tree in the wide and free treatments compared to narrow and control. Thinning to 80 ft^2 of basal area or the lower management zone SDI in previously unmanaged, 85-year-old ponderosa pine stands provided for faster tree growth, lower risk of mortality from mountain pine beetle (*Dendroctonus ponderosae*), and no appreciable sacrifice in value of stand growth. Total wood fiber production was better for narrow and control, but with greatly increased fire and beetle risk. This work substantiates research results that thinning to carefully prescribed stocking levels can increase volume growth per tree (even free selection) and maintain reasonable stand value growth even though cubic volume growth is diminished. The resulting changes in stand structure and reduced beetle and fire threats improve the odds that family forestland will generate their full potential of monetary and ecological benefits. West. J. Appl. For. 20(4):216–223.*

Key Words: Thinning regimes, growth response, stand density index (SDI), bark beetles, density management, forest vegetation simulator (FVS).

Ponderosa pine (*Pinus ponderosa*) is one of the most plentiful species in the western United States, occurring in 15 western states (Oliver and Ryker 1990). As a major commercial species in the Rocky Mountain, Pacific Northwest, and California regions of the west, it ranks second in total value behind Douglas-fir (Western Wood Products Association 2004). Its ability to grow in a variety of site conditions makes it an important species for recreation, water, shelterbelt, and wildlife goals (Morgan 1987). This case study helps validate previous studies and evaluates the use of several thinning alternatives for family forest owners, whose management goals may include reducing wildfire and bark beetle risks, producing large, high-quality timber, and enhancing forage. While thinning can promote economic interests, it has complimentary benefits such as enhancing forest health and sustainability and creating stands closer to historical stand conditions for wildlife and esthetics.

Historically, ponderosa pine and Douglas-fir (*Pseudotsuga menziesii*, var. *glauca*) forest types in the interior West developed under a high-frequency, low-intensity fire regime, although fires of moderate and high intensity also occurred (Agee 1993). Many of these forests are in a weakened, fire-prone, and insect-susceptible condition, created by fire exclusion and management policies favored since the beginning of the last century (Covington et al. 1997, Smith and Arno 1999, Agee 2002). Munger (1917) found most

---

NOTE: Paul T. Oester can be reached at (541) 963-1061; Fax: (541) 963-1036; paul.t.oester@oregonstate.edu. The authors wish to thank Ted and Mary Brown for their cooperation in providing the site and assisting with this research. Thanks also to Larry Larson in helping with data collection.

ponderosa pine forests in Oregon to be open and multiaged with little underbrush or down trees or branches and emphasized that travel through them was easy except for "occasional patches of saplings and fallen trees." Presettlement ponderosa pine forests in Arizona had fewer but larger trees per acre and trees grew in distinct groups (Covington et al. 1997). Harrod et al. (1999) found similar results in Washington, and historical stand density indices (SDIs) were nearly the same as the threshold for serious beetle mortality.

Interior forests of today have fewer areas of medium and large trees, are dominated by shade-tolerant conifers, and have increased in area of dense, multilayered forest structures (Hessburg et al. 2000) Mature and old forests have seen a dramatic decline (Everett et al. 1994), especially on small private ownerships where periodic timber harvest income is critical. Current forests are more vulnerable to stand-replacing fires, insects, and pathogens (Quigley et al. 2001, Peterson et al. 2005). Thinning and prescribed burning have been suggested as tools for lowering wildfire risk and bark beetle susceptibility and creating presettlement forest structure in ecosystems dependent on fire (Mutch et al. 1993, Covington et al. 1997, McIver et al. 2003), although following these treatments, fire behavior, understory response, wildlife habitats, and other ecological attributes may vary (Waltz et al. 2003, Metlen et al. 2004).

It is well established that thinning in managed and unmanaged stands of ponderosa pine can improve leave tree diameter growth, increase tree vigor, lower bark beetle susceptibility, improve forage production, accelerate the yield of merchantable wood fiber, and potentially lengthen rotation age (McConnell and Smith 1970, Larsson et al. 1983, Oliver in press). When Cochran and Barrett (1999) compared a range of growing stock levels over a 30-year period in central Oregon, increasing tree density of ponderosa pine increased gross cubic volume yields and basal area, while diameter growth decreased. Similar results were found in stands near Winthrop, Washington (Cochran and Barrett 1998) and the Blue Mountains of Oregon (Cochran and Barrett 1995).

For family forest owners, Oregon's eastern forests are not realizing their economic potential, and in many parts of the region sustainability of wildlife and ecological benefits is in question. Large-scale disturbances from insects, disease, fire, and human influences (Quigley et al. 2001) threaten the ability of owners to capture the values and potentials they hope to or could gain from these forests. Although more of a threat on public lands, uncharacteristically intense wild fires that occur after long periods of fire exclusion may destroy forests that would otherwise be fire resilient (Graham et al. 2004, Peterson et al. 2005). Azuma et al. (2002) estimated that 30% of gross growth is lost annually to mortality on woodland properties in eastern Oregon. Relatively low productivity of eastside forests, a diverse past-use history, a declining sawtimber processing industry, and the high risk of unmanaged stands from insects, disease, and fire create major challenges for forest owners. Too often, they suffer loss of both economic and ecological values due to past unwise management practices (e.g., high grading) or inaction. For family forest owners, simple approaches to management seem to work best (Lankford 1994); however, they need to be based on solid science. With these social, ecologic, and economic pressures comes the need for scientifically based, simply applied density management tools that facilitate the landowner's ability to capture their forests' potential.

SDI (Reineke 1933) is a density management tool, relatively independent of site quality and age, that provides a user-friendly, research-based measure of a site's biological potential (Cochran et al. 1994). Cochran et al. (1994) review the development of and suggest SDI stocking guidelines for plant associations of northeastern Oregon and southeastern Washington. Powell (1999) goes a step further by providing stocking level guides for the Umatilla National Forest by species, plant association, and stand condition, including even-aged, uneven-aged, and irregular structure stands. We believe that many family forests would benefit from thinning regimes based on this simple stand density metric. Forest vegetation simulator (FVS) is a research-based model that provides stand projections, such as time to next thinning, tree sizes, and volume in the future, and how long stands might be resistant to beetles (Wykoff et al. 1982). Knowledge of these predictions can help forest managers make more rational management decisions.

Our case study was oriented to thinning methods that suit woodland owners. We compared three thinning alternatives (narrow low, wide low, and free thinning) with an unthinned control in previously unthinned, unmanaged 85–100-year-old ponderosa pine stands. Treatment effects were monitored on tree growth and mortality and periodic stand yield 5 and 13 years after thinning.

Study Area

Our study was located on private property South of Wallowa-Whitman National Forest's Eagle Cap Wilderness and 30 miles southeast of La Grande, Oregon (45.04° N, 117.63° W). Elevation ranged from 4,150–4,250 ft, and slopes are less than 20% with aspects generally westerly. Moisture comes primarily as snow, and average precipitation levels are 20–25 in. per year (Johnson and Simon 1987). The soil, a klicker silt loam, is moderately deep, well-drained, and formed over basalt bedrock with some loess and volcanic ash mixed on the surface layer (Dykstenhuis and High 1985). Tree age at the time of the thinning ranged from 85–100 years with a 100-year site index of 96 (Meyer 1961, Johnson and Simon 1987) that varied little within the 50-ac study area. The understory vegetation was dominated by elk sedge (*Carex geyeri*), pinegrass (*Calamogrostis rubescens*), common snowberry (*Symphoricarpos albus*), and heartleaf arnica (*Arnica cordifolia*) and averaged 620 pounds of dry matter per acre across the study area. The plant association is Douglas-fir/common snowberry (Johnson and Simon 1987). Ponderosa pine and Douglas-fir regeneration, which varies from light to well stocked, was present in the understory. A light infection of ponderosa pine dwarf mistletoe (*Arceuthobium campylopodum*) was scattered throughout the overstory.

Methods

The landowner used a John Deere 450 crawler tractor with chokers to accomplish the logging in Oct. 1986. Where logging occurred, all unmerchantable tree and logging debris was lopped and left in place within the plot boundaries. The minimum standard for a merchantable sawlog was defined as a log at least 16 ft with a 6-in. inside bark small end diameter. Measurements were taken on 0.2-ac plots centered within 0.5-ac treatment plots. Three replications of wide, narrow, and control treatments were assigned in a randomized design. Three free thin treatment plots were carefully selected in an area thinned by the landowner a month prior to the initiation of the study. For this latter treatment, the landowner harvested trees from all merchantable diameter classes and attempted to leave both small and large trees with good crowns. Preharvest volume for all plots averaged 22 mbf/ac; an analysis of variance (ANOVA) showed no significant differences between pretreatment plots (Table 1). The landowner estimated that approximately 13.0 mbf/ac were removed from the free thinning area. Because the free thinning treatment took more of the larger trees, average log piece size was estimated at 95 bd ft compared to 61 bd ft for the thin from below treatments.

For the low thin options, the target leave trees were dominant and co-dominants with good, well-formed crowns; however, the free thinning treatment left the same quality trees from a variety of crown positions. Thinning removed trees with poor vigor or crowns and dead and dying trees. Thinning guidelines were: (1) wide: 80 trees per acre (tpa), 80 ft^2 of basal area, 22-ft spacing; (2) narrow: 130 tpa, 125 ft^2 of basal area, 18-ft spacing; and (3) free: 100 tpa, 80 ft^2 of basal area, 21-ft spacing.

Dbh of all trees over 4 in. were measured following harvest, and crown class was evaluated according to Oliver and Larson (1996). Total height was measured on five trees in each plot throughout the range of diameters. Tree board foot volumes were calculated based on a local volume table we developed from 50 harvested trees scaled by Official Log Scaling and Grading Rules for eastside logs (logs over 20 ft segmented). Board foot volume = 103.515 –25.492 (dbh) + 1.924 (dbh^2). A quadratic regression equation was the best fit, with an R^2 of 0.92. Cubic volumes were determined using tree volume tariff tables based on a 6-in. top diameter (Turnbull et al. 1970).

Table 1. Mean pretreatment (Pre) and post treatment (Post) trees/ac (tpa), and basal area (ft^2/ac), and Scribner board foot volumes (mbf/ac) for four treatments.

Treatment	Pre	Post	Pre	Post	Pre	Post
	tpa		ft^2		mbf	
Control	310	310	215	215	21.5	21.5
Wide	243	77	187	88	20.7	10.3
Narrow	225	147	206	150	23.7	17.7
Free	–	105	–	78	21.0 (est.)	8.3

Analysis

Data were analyzed for significant treatment effects using ANOVA (Snedecor and Cochran 1967). Mean separations using least significant difference tests are reported at a 0.05 level of significance. Mortality data were tested for homogeneity of variances and computed as a percent of live trees at the end of the period. Mean differences in diameter, volume, and growth between treatments were tested after 5 and 13 years. We included the free thinning treatment in the analysis although the plots were not part of the randomized selection of the other treatments; however, we believe this is not a serious issue based on the case study nature of the study.

We applied our case study treatments as a local test to SDI stocking-level guidelines (Cochran et al. 1994) for the site's plant association and site index, and used FVS Pacific Northwest Region, Blue Mountains variant (version 6.21) (USDA For. Serv. 2005) for estimating how long our stands might be beetle resistant, time to next thinning, and future tree size. SDI is a useful tool for managing stand densities that can assist in regrowing large trees and managing fire, insects, disease, forage, and wildlife (Daniel et al. 1979, Long 1996, McCarter and Long 1986, Filip et al. 1999).

FVS was also used to estimate stand outputs for the warm, dry plant association group (PAG) (Powell and Johnson in press), which includes the Douglas-fir/common snowberry plant association for the Blue and Ochoco Mountains (Johnson and Clausnitzer 1992). We included this comparison because identifying PAG's (aggregates of plant associations) for determining SDI upper and lower management zones simplifies the identification of habitat type and is something woodland owners may consider useful.

Inputs to FVS included the complete tree list for each plot, diameter growth rates, site index, slope, aspect, elevation, and plant association. The maximum density for ponderosa pine for the Wallowa-Snake Douglas-fir/common snowberry plant association is SDI of 416 (125% of full stocking) (D.C. Powell, Umatilla National Forest, Pendleton, OR, 2005). Full stocking for ponderosa pine in this plant association is SDI of 333, with an upper management zone (UMZ) and lower management zone (LMZ) SDI of 234 and 157 (67% of UMZ), respectively, according to the tables and formulas found in Cochran et al. (1994) for sites below Barrett's site index (Barrett 1978) 110. The UMZ and LMZ for the warm, dry PAG are SDI of 124 and SDI of 83, respectively (D.C. Powell, Umatilla National Forest, Pendleton, OR, 2005). Site index was estimated by measuring total tree height and age on dominant trees in the stand (Meyer 1961, Johnson and Simon 1987), then converting this value to Barrett's site index by increasing this value by 110% (Cochran et al. 1994). Maximum density values are used instead of full stocking in the FVS model because they control tree mortality functions.

The SDI values for ponderosa pine were determined using,

$$SDI = (N)(Dq/10)^{1.77}$$

where N is the number of live trees per acre and Dq is the quadratic mean diameter (QMD). An exponent of 1.77 was used for ponderosa pine instead of 1.605, and SDI values were determined for each plot using methods for even-age stands as described in Cochran et al. (1994).

Results

Tree survival overall was good throughout the study. Mortality (trees per acre that died) by treatment after 13 years was: control, 11.3%; wide, 2.6%; narrow, 1.1%; and free, 9.5%. Only leave trees in the intermediate crown class died in the narrow and wide treatments; however, mortality in the free thinning treatment was spread between dominant (18.2%), co-dominant (63.6%), and intermediate/suppressed (18.2%), implying the loss of volume was more severe. The greatest mortality occurred in the control (35 trees per acre), primarily within the intermediate and suppressed crown classes (77% of total mortality). The pine engraver beetle (*Ips pini*) and mountain pine beetle caused most of the mortality.

Diameter distributions by diameter class for 1986 and 1999 (Figure 1) show that the narrow, wide, and free thinning regimes moved trees into larger diameter classes more rapidly and there was a greater proportion of larger trees in these classes than in the control. As expected, there was a more even distribution across diameter classes in control and free treatments.

Diameter growth during the 1986–99 period for wide (2.6 in.) and free (2.7 in.) thinning was significantly greater ($P < 0.05$) than the narrow thin (1.9 in.) treatment and control (1.7 in.) treatment. There was a general upward trend for all treatments for the 13-year period; however, the wide and free treatments proved capable of greater sustained diameter growth. Absolute gain in basal area was lowest for the free treatment (26 ft^2) compared to control (30 ft^2), wide (30 ft^2), and narrow (37 ft^2).

When evaluating growth by crown class, only dominant and co-dominant trees were considered because so few intermediates and suppressed trees remained in the thinning treatments. Mean board foot volume growth per live tree was significantly better ($P < 0.05$) for the wide and free thinning treatments than the same crown classes in control and narrow thinning, and dominant trees appeared to outgrow co-dominant trees for the control and wide treatments (Table 2). Of the suppressed trees in the control treatment, 60% of the trees had no growth and 42% died during the study period.

Scribner board foot volume periodic growth (mbf/acre) of live trees over the 13-year period showed that the wide (6.5) and free (5.7) thinning treatments grew less than the narrow (7.3) and control (7.5) treatments (Figure 2). Total periodic accumulation of cubic foot volume of live trees over the 13-year period by treatment in descending order was: narrow (1,241), wide (985), control (972), and free (889). The low cubic volume growth in control was unexpected. In 1999, free was 46%, wide 52%, and narrow 82% of the control cubic foot volume, which was expected. Board foot volume per tree growth for trees 8 in. dbh and larger during the 13-year period was significantly greater ($P < 0.05$) for trees in the wide and free thinning treatments (Table 3). The rate of growth improved with thinning, and wide- and narrow-spaced trees grew more rapidly after 1991 compared to the other treatments. Average annual growth/acre for trees that averaged 8 in. dbh and larger ranged from a low of 439 bd ft for the free thin treatment to 577 bd ft for the control thinning treatment (Table 4). Mean relative growth rate (South 1995) per tree was greater for the wide and free treatments compared to control and narrow (Table 3).

Wide and free treatments were slightly below the LMZ (SDI of 157) immediately after thinning, and after 13 years were still below the UMZ (SDI of 234) for this plant association (Table 4). The narrow thinning and control treatments began the period above the UMZ (SDI of 234) with the control growing to maximum density (SDI 414) and narrow growing close to full stocking (SDI of 311) for this plant association (Cochran et al. 1994) by 1999 (Table 4). Assuming QMD growth rates and trees/acre remain stable after 1999, we estimate (by calculating the QMD for SDI of 234 and dividing by the diameter growth rate, 1986–99) that the wide and free thinning treatments would remain beetle resistant for 24 and 27 years, respectively.

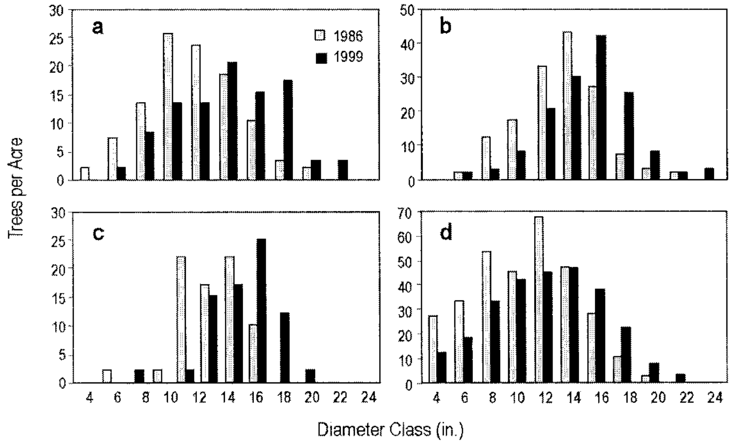

Figure 1. Diameter distributions by treatment for posttreatment 1986 and 1999: (a) free, (b) narrow, (c) wide, and (d) control.

Table 2. Periodic net Scribner board foot growth/tree by treatment over the 1986–99 period for an average tree in the dominant, co-dominant, and combined crown classes.

Treatment	Dominant	Co-dominant	Dom. and co-dom.[a]
	bd ft/tree		
Control	47.3a	24.7a	35.9a
Wide	119.9b	58.5b	89.2b
Narrow	48.2a	45.6b	46.8a
Free	85.0b	68.2b	76.6b

[a]Statistically different means between treatments in the same column are represented by different letters.

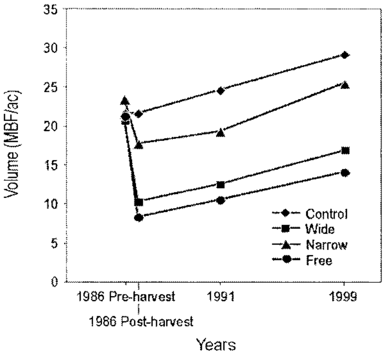

Figure 2. Periodic board foot volume growth/ac of live trees by treatment from 1986 to 1999 for trees 8 in. and larger.

FVS outputs estimate reaching the same SDI would take 30 years for free and 40 years for wide. FVS output showed that to reach a 20 in QMD it would take 80 years for the control treatment, 50 years for narrow and free, and 30 years for the wide treatment. For both the wide and free thinning treatments, the model indicated one thinning would occur during the first 50 years and annual periodic board foot volume growth/acre/year (including thinning volumes) was 546 and 539, respectively. As a comparison, when we used SDI of 124 (UMZ) and SDI of 83 (LMZ) for the warm, dry PAG, FVS thinned twice in the first 50 years and annual periodic growth was 63 and 65% (thinning volume included) of the wide and free estimates, respectively, for the Douglas-fir/common snowberry plant association. FVS outputs for percent annual mortality are close to our case study results except for the control treatment, which is three times higher (Table 4).

Table 3. Mean live tree Scribner board foot volume growth/tree and mean relative growth rate by treatment for trees 8 in. dbh and larger from 1986 to 1999.[a]

Treatment	1986 post-harvest	1991	1999	Growth 1986–99	Mean relative growth rate[b]
	bd ft/tree				
Control	95	108	124	29a	2.1
Wide	140	173	229	89b	3.8
Narrow	127	135	179	52a	2.7
Free	92	114	153	61b	4.0

[a]Statistically different means between treatments are represented by different letters.

[b]Mean relative growth rate = (ln $W_2 - W_1$)/($t_2 - t_1$), where W_1 and W_2 are the biomass at the beginning (t_1) and end (t_2) of the sampling period and ln is the natural logarithm.

Discussion

Results from thinning regimes in this case study parallel many responses found in long-term tree spacing studies (Oliver in press). Our results for QMD growth, net basal area growth, and total cubic volume were similar to those reported in Cochran and Barrett (1995, 1998, and 1999) for eastern Oregon and Washington. Additionally, Scribner board foot volume/acre growth and total volume at the end of the period was similar to that found in central and northeast Oregon (Cochran and Barrett 1995, 1999), but the reverse of trends reported by Cochran and Barrett (1998) in eastern Washington. One reason for these differences may be that the Washington study was on low site quality (site index 62, Meyer 1961) and expected suppression-related mortality did not occur. Contrary to the results of Cochran and Barrett (1995, 1998, and 1999), our annual cubic volume/acre growth at the highest density (control) was less than both the narrow and wide thinning treatment. We believe this was due primarily to high mortality in the control treatment (Table 4), but variability in site quality across the study area could be a contributing factor.

We observed that periodic (net) cubic volume/acre growth in our three thinning regimes captured 92–128% of the growth in the unthinned control for a 13-year period. On a site in Washington, Cochran and Barrett (1998) found that thinning to an even wider range of spacings provided periodic (net) cubic volume growth between 70 and 105% of the unthinned control during a 35-year period. In central Oregon, Cochran and Barrett (1999) showed that after 30 years spacing at 39% of full stocking lost 34% of cubic and Scribner board foot/acre growth compared to densities at 72% of full stocking; however, this wider spacing produced a 42% faster QMD growth rate. Similarly, our study showed that wide spacing (45% of full stocking) lost 21% of the cubic foot and 11% of the board foot growth, but gained a 44% faster QMD growth rate compared to the narrow treatment spacing (77% of full stocking). The free thinning treatment (42% of full stocking) lost 28% of the cubic foot volume and 22% of the board foot growth with a 33% better QMD growth rate than the narrow treatment. Our results also showed that Scribner board foot/acre growth begins to plateau at the narrow treatment density, which indicates that this density is growing near maximum for this stand. Thinning close to the LMZ allows for better diameter growth rates than thinning to the UMZ without forfeiting too much volume, especially board foot volume.

The application of Cochran et al. (1994) SDI guidelines provided good diameter growth and beetle protection in the wide thinning treatment (Table 4). Thinning to the same level, but leaving a variety of size classes (as long as leave trees have adequate crowns), showed similar benefits in the free thinning treatment; however, it will take longer to reach larger diameters and volume growth is less. This treatment experienced higher mortality in all crown classes, perhaps by chance. If so, this thinning method may conceivably show better growth in needed follow-up studies.

Table 4. Case study and FVS by treatment for the study area.

	Control	Wide	Narrow	Free	Control	Wide	Narrow	Free
	Case study measurement				FVS estimate			
1986 QMD (in.)	11.3	14.4	13.7	11.7	11.3	14.3	13.7	11.5
1999 QMD (in.)	12.6	17.0	15.5	14.1	13.5	17.4	16.1	14.7
1986 BA (ft^2/ac)	215	88	150	78	215	84	150	77
1999 BA (ft^2/ac)	245	118	187	104	205	121	181	124
1986 SDI	385	149	257	139	376	133	243	134
1999 SDI	414	192	311	172	334	177	275	195
Stand vol. mbf/ac 1986	21.5	10.3	17.7	8.3	17.4	8.3	14.1	6.4
Stand vol. mbf/ac 1999	29.0	16.8	25.0	14.0	21.7	15.4	22.0	13.4
Growth (bf/ac/yr 1986–99)	577	500	562	439	331	546	608	539
Mort. (%/yr 1986–99)	2.7	<1	<1	<1	7.9	<1	1.5	<1

The narrow treatment spacing represents what landowners may experience when stands are not thinned wide enough, because the initial postthinning SDI exceeded the upper basal area and UMZ SDI recommended for keeping mountain pine beetle mortality low (Sartwell and Larson 1975, Barrett 1979, Cochran et al. 1994). Landowners should be aware that mountain pine beetle attack behavior is sometimes unpredictable, and not fully understood; however, when mortality does occur larger trees are more frequently attacked and volume losses can be great (Cochran et al. 1994, Cochran and Barrett 1995). Additionally, if beetles begin infesting unmanaged stands, this could cause lower stand and individual tree growth than if stands had been mechanically thinned because beetles kill trees in patches, which leaves an uneven distribution of growing space among remaining trees (Cochran and Barrett 1995). There is good evidence to show that low-vigor trees are more prone to beetle mortality (Larsson et al. 1983) and thinning improves tree vigor and resistance to beetle attacks (Mitchell et al. 1983).

This case study provides a local confirmation of how ponderosa pine responds to thinning at almost any age provided trees have sufficient crown to take advantage of the growing space (Cochran and Barrett 1998). Also, postthinning growth of tall, dominant trees was better at the wider spacing (Cochran and Barrett 1998).

From the small woodland owner's perspective, the gain in diameter growth is most important because it relates directly to how soon they may thin again. Average landowner age in the west is 62 years (Butler and Leatherberry 2004), and a thinning from below strategy that maximizes diameter growth and shortens return interval would allow older landowners more opportunities for thinning. Thinning to an intermediate SDI between the UMZ and LMZ level (e.g., SDI of 190) could provide more cubic and board foot volume growth, as long as thinning occurred in a timely manner as the stand approaches the UMZ and the risk of beetle mortality escalated. Absentee landowners, controlling 32% of western forestland (Butler and Leatherberry 2004), find it difficult to manage intensively because of distance-related problems. Thinning to the LMZ would establish long-term beetle protection and lower fire risk without a big sacrifice in volume, thus sustaining their forests' potentials and investment from afar.

Management of ponderosa pine forests on private land has come under increasing pressure to make up some of the reduction in timber availability as harvesting on federal forests has declined, wood consumption has grown, and increasing demands for urban and related land uses increase (Haynes et al. 1995; Alig et al. 2002). Our findings support managing ponderosa pine stands more intensively using research-based SDI stocking guidelines to meet a variety of management objectives. Thinning from below in the wide thinning treatment to the LMZ increased economic values (Lindburg 2004) most rapidly (Figures 1 and 2, Table 4), created esthetically pleasing stands, perhaps similar to historical conditions (Harrod et al. 1999), restored the stands' resistance to wildfire and insect pests (Mutch et al. 1993, Fitzgerald 2002, Graham et al. 2004) for 30–40 years, and could provide habitat for certain types of wildlife, such as development of large snags and dead wood faster (Bull et al. 1997, Harrod et al. 1998, Bull 2002). Most low-elevation forests (similar to our case study area) have shifted from low-severity to high-severity fire regimes, an estimated 10–12 million ac in Oregon and Washington, and are at severe risk for uncharacteristically intense wildfire (Agee 2002). Thinnings that reduce fuels and alter forest structure not only reduces risk of losing valuable timber resources from wildfire, but improves survival potential for certain sensitive native fish and wildlife populations (Mealey and Thomas 2002). Low thinning greatly reduces crown-fire initiation and torching (Peterson et al. 2005) and should be a high-priority treatment for landowners concerned with wildfire.

The free thinning alternative (SDI of 139) lowered beetle risk an estimated 30 years (FVS estimate), provided reasonable growth rates, and could be a good alternative for landowners who prefer more stand structure for aesthetic or wildlife reasons; however, some sacrifice of growth may occur (Table 4) and wildfire protection may be limited (Peterson et al. 2005). Although we show some preliminary benefits of the free thinning treatment, it takes more skill to apply correctly and to avoid high grading the stand. Free thinning may not work well in previously unmanaged stands that have already reached densities well above the UMZ, mainly because of poor vigor in intermediate and suppressed trees. More rigorous long-term studies are needed to define stand conditions where free thinning is applicable and evaluate thinning response. Both wide and free thinning treatments should yield reasonable forage production (Krueger 1981, Clary 1988) and may be a good economic option for ranchers considering combinations of timber and livestock (Clary et al. 1975).

We suggest woodland owners and their advisors learn to use the research-based density management tool SDI and related upper and lower management zones because (1) it is relatively independent of site quality and tree age; (2) site-specific guidelines have been developed; and (3) basal area, as an alternative, has limitations such as not reflecting available growing space as well (Cochran et al. 1994). When applying density management strategies in their decisionmaking process, landowners should consider key elements such as stand growth, tree vigor, individual tree growth, and mortality risk in concert with management objectives (Cochran and Barrett 1995).

Managers of small private forests face a variety of problems in keeping their forest healthy and productive. There are several ways they can improve their ability to capture forest potential. First, determine stand density (SDI) to be sure it is below the UMZ for the site (Cochran et al. 1994), otherwise their stand may be at high risk for beetle attack. Second, if the stand is above the UMZ, choose a thinning approach: thin from below is safest, free thin is an option, but be cautious about high grading. Third, consider the pros and cons of going to the LMZ (very long return interval) or thin to some intermediate SDI (shorter to the next thinning, but less volume removed). Finally, have a plan; be ready to thin (stand marked, boundaries flagged) and wait for a good market. Mark the stand so thinning targets are actually attained and for best logging results. Waiting to thin is risky because beetles prefer large trees, they can spread, salvaged timber is worthless (blue stain), and market prices dip sharply during beetle epidemics. Our case study, with its attendant management strategies using SDI and FVS, could have application for family forest owners throughout the West where ponderosa pine grows, although the LMZ and UMZ would need adjustment for local plant communities.

We see the following research needs for further exploring thinning alternatives in managing ponderosa pine stands. The free or high thinning treatment, a nontraditional approach, has not been thoroughly tested and deserves further study. Further research is needed to understand its long-term implications regarding wildfire protection, insect and disease issues, growth and yield, wildlife, and stand structure. Further refinements of FVS outputs for a variety of local sites and stand conditions would provide more landowner confidence in using FVS (see Schwalm and Milner 2002). FVS outputs gave consistently lower total board foot volumes and higher basal area growth than our case study results; however, annual growth was similar (Table 4). Finally, we encourage further development in grouping individual plant associations into PAGs with accompanying SDI management guides because it is a simple way for landowners and their advisors to access and use SDI guidelines and FVS estimates.

Literature Cited

AGEE, J.K. 1993. Fire ecology of Pacific Northwest forests. Island Press, Covelo, CA. 493 p.

AGEE, J.K. 2002. The scope of the problem. P. 78–84 *in* Fire in Oregon's forests: Risks, effects, and treatment options, S.A. Fitzgerald (ed). Oregon For. Res. Institute.

ALIG, R., J. MILLS, AND B. BUTLER. 2002. Private timberlands: Growing demands, shrinking land base. J. For. 100(3):32–37.

AZUMA, D.L., P.A. DUNHAM, B.A. HISEREOTE, AND C.F. VENEKLASE. 2002. Timber resource statistics for eastern Oregon. USDA Resour. Bull. PNW-RB-238. 42 p.

BARRETT, J.W. 1978. Height growth and site index curves for managed even-aged stands of ponderosa pine in the Pacific Northwest. USDA For. Serv. PNW-RP-232. 14 p.

BARRETT, J.W. 1979. Silviculture of ponderosa pine in the Pacific Northwest: The state of our knowledge. USDA For. Serv. PNW-GTR-97. 106 p.

BULL, E.L., C.G. PARKS, AND T.R. TORGERSEN. 1997. Trees and logs important to wildlife in the interior Columbia River Basin. USDA For. Serv. Gen. Tech. Rep. PNW-GTR-391. 55 p.

BULL, E. 2002. The value of coarse woody debris to vertebrates in the Pacific Northwest. USDA For. Serv. Gen. Tech. Rep. PSW-GTR-181. 8 p.

BUTLER, B.J., AND E.C. LEATHERBERRY. 2004. America's family forest owners. J. For. 102(7):4–9.

CLARY, W.P., W.H. KRUSE, AND F.R. LARSON. 1975. Cattle grazing and wood production with different basal areas of ponderosa pine. J. Range Mange. 28(6):434–437.

CLARY, W.P. 1988. Silvicultural systems for forage production in ponderosa pine forests. P. 185–191 *in* Ponderosa pine—The species and its management, Baumgartner, D.M., and J.E. Lotan (eds.). Symp. Porc., Sept. 29-Oct. 1, 1987, Spokane, WA.

COCHRAN, P.H., J.M. GEIST, D.L. CLEMENS, R.R. CLAUSNITZER, AND D.C. POWELL. 1994. Suggested stocking levels for forest stands in northeastern Oregon and southeastern Washington. USDA For. Serv. Res. Note PNW-513. 21 p.

COCHRAN, P.H., AND J.W. BARRETT. 1995. Growth and mortality of ponderosa pine poles thinned to various densities in the Blue Mountains of Oregon. USDA For. Serv. Res. Pap. PNW-RP-483. 27 p.

COCHRAN, P.H., AND J.W. BARRETT. 1998. Thirty-five-year growth of thinned and unthinned ponderosa pine in the Methow Valley of northern Washington. USDA For. Serv. Res. Pap. PNW-RP-502. 24 p.

COCHRAN, P.H., AND J.W. BARRETT. 1999. Growth of ponderosa pine thinned to different stocking levels in Central Oregon: 30-year results. USDA For. Serv. Res. Pap. PNW-RP-508. 27 p.

COVINGTON, W.W., P.Z. FULE, M.M. MOORE, S.C. HART, T. E. KOLB, J.N. MAST, S.S. SACKETT, AND M.R. WAGNER. 1997. Restoring ecosystem health in ponderosa pine forests of the southwest. J. For. 95(4):23–29.

DANIEL, T.W., J.A. HELMS, AND F.S. BAKER. 1979. Principles of silviculture, 2nd ed. McGraw-Hill, New York. 500 p.

DYKSTENHUIS, E.L., AND C.T. HIGH. 1985. Soil survey of Union County area, Oregon. USDA Soil Conservation Service, Washington, DC. 194 p.

EVERETT, R., P. HESSBURG, J. LEHMKUHL, M. JENSEN, AND P. BOURGERON. 1994. Old forests in dynamic landscapes. J. For. 92(1):22–25.

FILIP, G.M., S.A. FITZGERALD, AND L.M. GANIO. 1999. Precommercial thinning in a ponderosa pine stand affected by Armillaria root disease in central Oregon: 30 years of growth and mortality. West. J. Appl. For. 14(3):144–148.

FITZGERALD, S.A. (ed.). 2002. Fire in Oregon's forests: Risks, effects and treatment options. Oregon For. Res. Institute. 161 p.

GRAHAM, R.T., S. MCCAFFREY, AND T.B. JAIN (TECH. EDS.). 2004. Science basis for changing forest structure to modify wildfire behavior and severity. USDA Gen. Tech. Rep. RMRS-GTR-120. 43 p.

HARROD, R.J., W.L. GAINES, W.E. HARTL, AND A. CAMP. 1998. Estimating historical snag density in dry forests east of the Cascade Range. USDA Gen. Tech. Rep. PNW-GTR-428. 16 p.

HARROD, R.J., B.H. MCRAE, AND W.E. HARTL. 1999. Historical stand reconstruction in ponderosa pine forests to guide silvicultural prescriptions. For. Ecol. Manage. 114:433–446.

HESSBURG, P.F., B.G. SMITH, R.B. SALTER, R.D. OTTMAR, AND E. ALVARADO. 2000. Recent changes (1930s–1990s) in spatial patterns of interior northwest forests, USA. For. Ecol. Manage. 136:53–83.

HAYNES, R.W., D.M. ADAMS, AND J.R. MILLS. 1995. The 1993 RPA timber assessment update. USDA For. Serv., Gen. Tech. Rep. RM-GTR-259. 66 p.

Johnson, C.G. Jr., and S.A. Simon. 1987. Plant associations of the Wallowa-Snake Province. USDA For. Serv. R6-ECOL-TP-225B-06-98. 400 p.

Johnson, C.G., and R.R. Clausnitzer. 1992. Plant associations of the Blue and Ochoco Mountains. USDA For. Serv. Tech. Pub. R6-ERW-TP-036-92. 164 p.

Krueger, W.C. 1981. How a forest affects a forage crop. Rangelands 3(2). 2p.

Lankford, L. 1994. Ecosystem forestry from the ground up. J. For. 92(7):26–29.

Larsson, S., R. Oren, R.H. Waring, and J.W. Barrett. 1983. Attacks of mountain pine beetle as related to tree vigor of ponderosa pine. For. Sci. 29:395–402.

Lindberg, J. 2004. Oregon log market report. Vancouver, WA. 60 p.

Long, J.N. 1996. A technique for the control of stocking in two-storied stands. West. J. Appl. For. 11(2):59–61.

McCarter, J.B., and J.N. Long. 1986. A lodgepole pine density management diagram. West. J. Appl. For. 1:6–11.

McConnell, B.R., and J.G. Smith. 1970. Response of understory vegetation to ponderosa pine thinning in eastern Washington. J. Range Manage. 23(3):208–212.

McIver, J.D., P.W. Adams, J.A. Doyal, E.S. Drews, B.R. Hartsough, L.D. Kellogg, C.G. Niwa, R. Ottmar, R. Peck, M. Taratoot, T. Torgersen, and A. Youngblood. 2003. Environmental effects and economics of mechanized logging for fuel reduction in northeast Oregon mixed-conifer stands. West. J. Appl. For. 18(4):238–249.

Mealey, S.P., and J.W. Thomas. 2002. Uncharacteristic wildfire risk and fish conservation in Oregon. P. 85–95 *in* Fire in Oregon's forests: risks, effects, and treatment options, S.A. Fitzgerald (ed). Oregon For. Res. Institute.

Metlen, K.L., C.E. Fiedler, and A. Youngblood. 2004. Understory response to fuel reduction treatments in the Blue Mountains of northeast Oregon. Northwest Sci. 78:175–185.

Meyer, W.H. 1961. Yield of even-aged stands of ponderosa pine. USDA For. Serv. Tech. Bull. No. 630. 59 p.

Mitchell, R.G., R.H. Waring, and G.B. Pitman. 1983. Thinning lodgepole pine increases tree vigor and resistance to mountain pine beetle. For. Sci. 29(1):204–2111.

Morgan, P. 1987. Managing ponderosa pine forests for multiple objectives. P. 161–164 *in* Proc. of ponderosa pine: The species and its management. Washington State University, Pullman, WA.

Munger, T.T. 1917. Western yellow pine in Oregon. USDA For. Serv. Bull. 418. 48 p.

Mutch, R.W., S.F. Arno, J.K. Brown, C.E. Carlson, R.D. Ottmar, and J.L. Peterson. 1993. Forest health in the Blue Mountains: A management strategy for fire-adapted ecosystems. USDA For. Serv. Gen. Tech. Rep. PNW-GTR-310. 14 p.

Oliver, W. The west-wide ponderosa pine levels-of-growing-stock study at age 40. *In* Ponderosa pine: Issues, trends, and management options. Ritchie, M.W., A. Youngblood, and D. Maguire (eds.). USDA Forest Service Gen. Tech. Rep. PSW-GTR-xxx, in press.

Oliver, W.W., and R. Ryker. 1990. *Pinus ponderosa* Dougl. Ex Laws. Ponderosa pine. *In* Silvics of North America. Vol. 1, Conifers, Burns, R.M., and B.H. Honkala (tech. coor.). USDA Agric. Handb. 654:413–424.

Oliver, C.D., and B.C. Larson. 1996. Forest stand dynamics. John Wiley & Sons, Inc., New York. 520 p.

Peterson, D.L., M.C. Johnson, J.K. Agee, T.B. Jain, D. McKenzie, and E.D. Reinhardt. 2005. Forest structure and fire hazard in dry forests of the Western United States. USDA Gen. Tech. Rep. PNW-GTR-628. 30 p.

Powell, D.C. 1999. Suggested stocking levels for forest stands in northeast Oregon and southeastern Washington: An implementation guide for the Umatilla National Forest. USDA Tech. Pub. F14-SO-TP-03-99. 300 p.

Powell, D.C., C.G. Johnson Jr., E.A. Crowe, and D.K. Swanson. In review. Potential vegetation hierarchy for the Blue Mountains section of northeastern Oregon, southeastern Washington, and west-central Idaho. USDA For. Serv. PNW GTR.

Quigley, T.M., J.L. Hayes, and L. Starr. 2001. Improving forest health and productivity in eastern Oregon and Washington. Northwest Sci. 75:234–250.

Reineke, L.H. 1933. Perfecting a stand-density index for even-aged forests. J. Agric. Res. 46(7):627–638.

Sartwell, C., and R.E. Larson. 1975. Mountain pine beetle in ponderosa pine: prospects for silviculture control. J. For. 73 (3). 5 p.

Schwalm, C.R., and K.S. Milner. 2002. Stand response following partial cutting in western Montana. West. J. Appl. For. 17(1):37–45.

Smith, H.Y., and S.F. Arno (eds.). 1999. Eighty-years of change in a managed ponderosa pine forest. USDA For. Serv. Gen. Tech. Rep. RMRS-23. 55 p.

South, D.B. 1995. Relative growth rates: A critique. South African For. J. 173:43–48.

Snedecor, G.W., and W.G. Cochran. 1967. Statistical methods. The Iowa University Press, Ames, IA. 593 p.

Turnbull, K.J., G.R. Little, and G.E. Hoyer. 1970 (revised). Comprehensive tree-volume tariff tables. State of Wash., Dept. of Nat. Res., Olympia, WA. 23 p.

USDA Forest Service. 2005. Forest vegetation simulator. Available online at www.fs.fed.us/fmsc/fvs/software/setup.php.

Waltz, A.E.M., P.Z. Fule, W. W. Covington, and M.M. Moore. 2003. Diversity in ponderosa pine forest structure following ecological restoration treatments. For. Sci. 49:885–900.

Western Wood Products Association. 2004. Ponderosa pine. Available online at www.wwpa.org/ppine.htm.

Wykoff, W.R., N.L. Crookston, and A.R. Stage. 1982. User's guide to the stand prognosis model. USDA For. Serv. Gen. Tech. Rep. INT-133. 112 p.