Comparing Timber and Lumber from plantation and Natural Stands of Ponderosa Pine

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ABSTRACT

Data derived from empirical studies, coupled with modeling and simulation techniques, were used to campare tree and product quality from two stands of small-diameter ponderosa pine trees growing in northern California: one plantation, the other natural. The plantation had no management following establishment, and the natural stand had no active management. Fifty trees of similar diameter classes were selected from each site, measured, bucked into logs, and sawn into boards, and the boards were scanned for defects. Trees from the plantation stond demonstrated less variability in tree height, crown length, and age structure. The plantation trees were on average 4 years younger than their natural cohorts, yet for all but the smallest diameter there were no significant differences between mean tree height or crown length. Predicted merchantable volumes differed significontly for the lorgest diameter class. Merchantable volume was estimated to be 5% greater for the plantation trees than for the natural stand trees. More logs were bucked from the plantation stands, resulting in greater lumber production and greater value overall. Built logs from the plantation stand had an average of 9 whorls per log, whereas natural butt logs averaged 10 whorls per log. The most numerous defects, outnumbering knots and wane, were needle traces. These occupied some 31% of natural board surface area, in comparison with 19% for plantation boards. Given the shorter time frame required to grow plantation trees, the greaaer merchantable volumes, and more consumer-acceptable defects, plantation stands, even with a minimal level of management, offer greater product potential than natural stands.

Keywords: ponderosa pine, plantation, AUTOSAW, lumber quality

Ponderosa pine *(Pinus ponderosa* Dougl. ex Laws.) is an important commercial timber species in the United States. In 2006, nearly half of the western region production of 1,459 million board feet (mbf) of ponderosa pine lumber originated in Oregon (24%) and California (22%) (Western Wood Products Association [WWPA] 2006). Ponderosa pine lumber production was exceeded by Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco) at 7,255 mbf, hemlock-fir *(Tsuga heterophylla* [Raf.] Sarg. and *Abies* spp.) at 5,134 mbf, and a combination of mixed softwoods (larch *[Larix occidentalis* Nutt.] and Douglas-fir) at 1,952 mbf. However, as ponderosa is predominantly used within the wood secondary market sector, it does not compete with these species. Regarded as a traditional species within the secondary industry, ponderosa pine, with an estimated usage of 6.8%, competes with traditional species such as yellow-poplar *(Liriodendron tulipifera)* at 8.5%, and alternative species such as radiata pine *(Pinus radiata)* at 4.7% (Smith et al. 2005).

At sites in California, ponderosa pine trees can exceed 6 ft in diameter (Van Hooser and Keegan 1988). Sites supporting trees of these dimensions are typical of old-growth stands and are valued for their production of high-value, clear lumber. Ponderosa pine also commonly grows on poorer soils (Powers 2004). Large areas in the western United States were planted to ponderosa pine in the mid-1900s to reforest burned or harvested sites. Other sites regenerated naturally. More than half of all acres planted on National Forests in California between 1982 and 1986 were to pine, predominately ponderosa. The average area planted annually was about 15,000 acres (McDonald and Fiddler 1989). On the Shasta-Trinity National Forest in northern California, more than 40,000 acres have been planted to ponderosa pine. In central and southwestern Oregon, very few stands are left to regenerate naturally. Most are planted to ponderosa pine, have received minimal levels of management activity, and as a result are densely stocked. Thinning to reduce stocking levels has not been well prescribed because of the economics of thinning prescriptions, perception of poor return on investment (Powers 2004), cost minimization within the forest industry, and the problem of slash disposal, after thinning, to prevent excessive fuel loading and fire risk. However, altering stand conditions to reduce fire hazard risk and improve forest health is currently a national priority for the US Forest Service, the US Department of Agriculture in general, and other land management agencies.

The ability to perform land management activities is partially based on product opportunities for the removed woody material. Tree characteristics and wood properties differ between plantation and natural, and young and mature trees. Manipulation of stands is conducted to encourage desired properties. To stimulate diameter and height growth, stands can be subjected to precommercial thinning practices (Oliver 1972). Thinning and other management practices that affect growth and volume recovery have a greater influence on productivity than differences because of stand age structures (O'Hara and Nagel 2006). Differences between stand age structures are observed in leaf area distributions, crown length, and tree height and are less variable within even-aged stands than multiaged stands (Nagel and O'Hara 2001).

Within even-aged ponderosa pine stands, individual tree diameter increment growth has recently been modeled as a linear mixed effects model that includes variables for tree competition and site productivity (Uzoh and Oliver 2008). Variables for site productivity included site index, latitude, slope, and aspect. Although elevation was considered when developing the model, it was subsequently excluded because of a high degree of colinearity with latitude and

Received June 6, 2008; accepted November 19, 2008.

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because latitude had a greater effect on diameter growth than elevation.

Models for ponderosa pine height growth and volume estimates have also been developed. The heights of ponderosa pine trees, when less than 30 in. dbh, can be estimated from diameter measurements using equations developed by Moore (1996). The equations are based on the Wykoff (Wykoff et al. 1982) and Lundqvist (Stage 1975, Zeide 1993) functions, respectively. Height, diameter, and measures of taper, such as the Girard form class (Girard 1933), form the basis for cubic volume estimates. The Girard form class is defined as the ratio of the dbh outside bark to the inside bark diameter at 17.3 ft aboveground and is expressed as a percentage. The more cylindrical a tree is, the larger is the form class. Conversely, larger taper yields a smaller form class. A smaller form class is associated with a reduction in merchantable volume (McTague and Stansfield 1988). Equations for estimating standing tree volumes by region, forest, and species are provided within the National Volume Estimator Library (NVEL) (US Forest Service 2008). Within NVEL, equations for Californian ponderosa pine are based on the Wensel and Olson Profile Model (Wensel and Olson 1993).

Lumber from ponderosa pine trees, both young- and old-growth, is valued for its appearance and workability. It can be graded according to either appearance or dimension grading criteria. However, for small-diameter ponderosa pine, economic returns from grade yields are greater when ponderosa logs are sawn into appearance, rather than dimension, lumber products (Lowell et al. 2000, Lowell and Green 2001, Gorman et al. 2007). As an appearance product, the lumber is commonly used as components for doors, windows, furniture, paneling, and shelving. The components are produced through remanufacturing processes at the rough mill that remove knots and other defects through combinations of ripping and crosscutting. In general, the higher the lumber grade, the higher the yield (Lamb 2002). Some defects are permitted, when not severe, on the backs of jamb and sill cuttings in the WWPA's (1998) factoty lumber No.3 Shop and Fingerjoint Shop Common grades. Although inclusion of other lesser defects are prohibited by grading standards, inclusion of some light character markings em both increase part yield (Buehlmann et al. 1998) and be acceptable to consumers (West 2000, Donovan and Nicholls 2003).

Consumer preference research on hardwood lumber in furniture products has indicated that light character markings in maple and oak are acceptable (Jahn et al. 2001). Greater acceptance of small or subtle character marks, such as knots with a diameter of less than 0.5 in., were found by Bumgardner et al. (2001). Furthermore, Donovan and Nicholls (2003) found that the majority of consumers preferred some character markings in birch kitchen cabinet doors.

Character markings such as needle flecks appear frequently in pines and result from live stem needles, which can be the source of adventitious shoots. Needle flecks have been documented in radiara pine (*Pinus radiata* D. Don) which competes with ponderosa pine in the US millwork industry. Kininmonth and Whiteside (1991) report that needle flecks usually occur on the inner two to four growth rings. Removal of stem needles has been recommended by Inglis (1985) and the Forest Research Institute (1976) when pruning plantation radi~ta pine. In examining pruned and unpruned radiata pine for clonal variation in quality of random width boards, Beauregard et al. (1999) found needle flecks on some outer boards and attributed it to growth rate and saw pattern.

There has been little research on the quality and yield attributes of ponderosa trees, logs, and lumber derived from two different stand types, plantation and natural, within a close geographic region. In this study, we compare ponderosa pine tree growth, branching patterns, product recoveries, lumber grades, and surface defects derived from the two stand types within the Californian region. We use a combined approach that includes empirical studies, regression equations (selected from the literature and introduced above), and simulation techniques. Our goal is to determine what benefits, if any, result from stands of ponderosa pine when silvicultural management practices have been constrained to minimal levels of activity.

Materials and Methods

Stand Selection

A plantation and a natural stand located southwest of Redding, California, and scheduled for thinning were identified. The plantation stand (Jones Burn, Yolla Bolla Ranger District, Shasta-Trinity National Forest) burned in 1959. Over half the burned acres were replanted to ponderosa pine between 1960 and 1965 with an initial spacing of 10 × 10 ft. In 2000,60 ac were identified to be thinned to about 17 × 17 ft spacing to develop and manage a healthy ponderosa pine plantation through stocking control and to reduce the risk of wildfire. The elevation of the stand was 4,590 ft. The natural stand was located in the Hayfork Valley, at an elevation of 2,350 ft, and grew on land that had been mined in the mid-1930s. After the cessation of mining activity, the stand naturally regenerated over a period from the 19505. The natural stand is about one site class lower than the plantation (J. Paulo, Silviculturist, US Forest Service, Region 5, Yolla Bolla Ranger District, Shasta-Trinity National Forest, CA, April 2008). No additional management activities were performed on either stand following establishment.

Tree Measurements

Fifty trees were selected from each stand on the basis of dbh. The trees were selected in l-in, diameter classes ranging from 5 to 9 in. Ten trees were selected at random from each class in each stand. After selection, the trees were felled, and measurements of tree height, height to live crown, over-bark diameter, and bark thickness were made. Height, diameter, and bark thickness measurements were subsequently used to determine the Girard form class of each tree. Tree age was determined by counting growth rings on the stump.

Tree lengrh stems were hauled to the logyard. Stems were scaled long log (cubic and Scribner) for defect and then bucked into 8-ft logs. Short logs were then scaled cubic and Scribner. Logs were further classified according co vertical position within the stem (height class). Manufacturing limitations on log large-end diameter (12 in. outside bark) required a small stem section to be removed from the base of two butt logs (one from each rype of stand). Three plantation and four natural butt logs either were too small or had excessive defects and were not processed. Tree length harvesting allowed for maximizing 8-ft short log production. Short segments were removed from the butt log to buck out sweep. This occurred in 16 instances (9 plantation, 7 natural). When section removal was less man 4 ft from the stump, the next section was recorded as being of height class 1; when it was more than 4 ft from the stump, the log was assigned to height class 2.

Logs were debarked and all knots were diagrammed using techniques developed by Barbour et al. (1999). The techniques captured detailed measurements of all external knots-their locations (both longitudinal and circumferential), sizes (both lengthwise and perpendicular diameters across knots), and type (either red or black)-and further enabled the reconstruction of digital "glass"log models for subsequent simulated sawing.

Log Processing

Logs were processed into lumber using an Economizer portable sawmill. The Economizer is a single-pass mill with a chipping headrig followed by three horizontal saws on the out feed, allowing for production of cants and/or lumber in a single pass. The mill is designed to handle log diameters from 3 to 12 in. Prior to processing, logs were sorted by small-end diameter (SED). Sawing pattern was based on log SED, and random-width 5/4 Shop lumber was manufactured. Widths ranged from 3 to 6 in. The lumber was kiln-dried and graded by a certified lumber grader according to WWPA grading rules (1998). All lumberwas shipped to the Northeast Research Station (now the Northern Research Station), Forestry Sciences Laboratory in Princeton, West Virginia. There, the lumber was manually digitized, recording the size and shape of the lumber as well as the location, size, and type of all defects on both faces (Anderson et al. 1993). In addition, the surface area occupied by each defect type was calculated as a percentage of the board surface area.

Digital models of the 8-ft logs were created from collected knot data and were processed using the AUTOSAW sawing simulator (Todoroki 1990). The log models were processed into 5/4 random-width lumber and graded, while green, using automated routines. The routines invoked algorithms for implementing factory lumber criteria (WWPA 1998, chapter 11) in the presence of simulated lumber with knots (red/live or black/dead), wane, and/or pith defects. In caseswhere lumber grade did not meet criteria for any of the Shop or Fingerjoint Shop grades, the lower Shop Out grade was assigned.

Statistical Analysis

Confidence intervals (CI) were calculated for the difference between means of variables of interest using a 95% level of confidence. When the sample size for a variable was greater than 30, the normal distribution was assumed. When less than 30, the more appropriate z-distribution was assumed (Wilcox 2001). The confidence intervals are presented as [L,U], where L represents the lower limit and U the upper limit at the 95% confidence level. When zero is contained within that interval, a significant difference has not been demonstrated.

Results and Discussion

Plantation and Natural Stand Comparison

Tree and log sample data are shown in Table 1. Tree ages were approximately normally distributed for both samples, but the plantation sample was slightly younger and less variable in age than the natural sample. Mean age of the plantation sample was 34 years, with an SD of 4 years, whereas mean age for the natural sample was 38 years, with an SD of 7 years. At a 95% confidence level, the difference between mean ages was significant (95% CI, -6 to -2 years). Within diameter classes, only the 9-in. dbh trees demonstrated significant differences: at 34 years the plantation sample was an average of 11 years younger than the natural sample (Table 1).

The plantation trees demonstrated a greater tendency of increasing height and increasing Girard form class (decreasing taper) with increasing diameter class (Table 2). These trends were not as evident within the natural stand. The plantation stand generally had less variation in height (Table 2) and in crown length (Table 3) within diameter classes than the natural stand.

Table 1. Tree sample and age statistics (mean ± standard deviation) of the 100 trees selected from two stand types across five diameter classes. Confidence intervals containing zero do not demonstrate a significant difference.

dbh (in.)	Sample size: Plantation	Sample size: Natural	Tree age: Plantation	Tree age: Natural	95% CI
			...............(yr)...............		
5	10	10	31 ± 3	33 ± 5	[−7, 2]
6	10	10	34 ± 4	36 ± 8	[−9, 4]
7	10	10	35 ± 3	38 ± 5	[−7, 2]
8	10	10	37 ± 3	40 ± 6	[−8, 1]
9	10	10	34 ± 3	45 ± 3	[−14, −7]
All	50	50	34 ± 4	38 ± 7	[−6, −2]

Table 2. Tree height and Girard form class statistics (mean ± standard deviation).

dbh (in.)	Tree height: Plantation	Tree height: Natural	95% CI	Girard form class: Plantation	Girard form class: Natural	95% CI
	............(ft)............					
5	26 ± 4	35 ± 9	[−16, −1]	42 ± 13	57 ± 11	[−27, −2]
6	38 ± 7	32 ± 9	[−2, 14]	62 ± 8	47 ± 14	[3, 27]
7	47 ± 6	39 ± 14	[−3, 19]	71 ± 6	55 ± 13	[6, 26]
8	47 ± 9	46 ± 6	[−7, 10]	73 ± 7	67 ± 6	[−1, 12]
9	56 ± 6	51 ± 7	[−2, 11]	76 ± 4	68 ± 5	[3, 13]

Table 3. Crown length and height to first live branch statistics (mean ± standard deviation).

dbh (in.)	Crown length: Plantation	Crown length: Natural	95% CI	Height to 1st live branch: Plantation	Height to 1st live branch: Natural	95% CI
	........................(ft)........................			............(ft)............		
5	7 ± 4	14 ± 6	[−12, −1]	3 ± 2	4 ± 2	[−3, 1]
6	14 ± 5	12 ± 10	[−7, 10]	5 ± 1	3 ± 2	[0, 4]
7	20 ± 6	17 ± 14	[−8, 14]	4 ± 2	5 ± 3	[−4, 2]
8	17 ± 5	16 ± 5	[−4, 6]	4 ± 3	5 ± 3	[−3, 2]
9	20 ± 5	17 ± 8	[−4, 10]	4 ± 3	5 ± 3	[−4, 2]

Within the 5-in. dbh class, plantation trees were on average shorter (at 26 ft) than the natural cohorts (at 35 ft) and had greater taper (i.e., a smaller Girard form class) and shorter crown lengths (7 and 14 ft, respectively). For this 5-in. diameter class, differences between mean tree height, mean Girard form class, and mean crown length were all significant (Tables 2 and 3). For all other diameter classes, there was a tendency for mean tree height of the plantation sample to exceed that of the natural sample. However, the height differences were not significant for these larger diameter classes. The 6-, 7-, and 9-in. classes did demonstrate significantly greater Girard form class (in other words, significantly less taper) than the natural cohorts,

The first live branch was at a height aboveground of about 10% of the tree height for both plantation and natural samples (Table 3). Differences between means were not significant at the 95% level. Tree height predictions from breast height diameter measurements for the plantation stand were within 5 ft of the average height when predictions were based on Wykoffs equation (Figure 1). For the natural stand, predictions with Wykoffs equation were within 5 ft

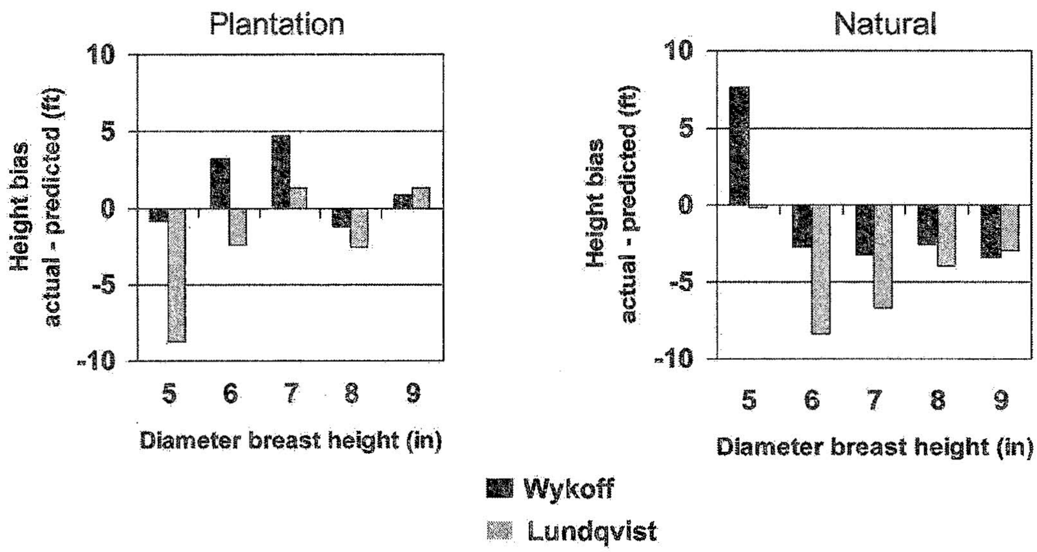

Figure 1. Bias in total height predictions using Wykoff and Lundqvist functions for plantation and natural ponderosa pine trees.

Table 4. Tree and merchantable volume predicted using equations for California ponderosa from the National Volume Estimator Library.

dbh (in.)	Tree volume			Merchantable volume		
	Plantation	Natural	95% CI	Plantation	Natural	95% CI
	......(ft^3)......			......(ft^3)......		
5	1.4 ± 0.2	1.9 ± 0.6	[−0.8, −0.1]	0.0 ± 0.0	0.5 ± 0.5	[−0.8, −0.1]
6	2.6 ± 0.6	2.4 ± 0.7	[−0.4, 0.8]	1.4 ± 0.5	1.0 ± 0.8	[−0.2, 0.9]
7	4.5 ± 0.6	3.8 ± 1.5	[−0.3, 1.7]	3.0 ± 0.4	2.5 ± 1.3	[−0.3, 1.3]
8	6.0 ± 1.4	5.9 ± 0.5	[−0.9, 1.0]	4.6 ± 1.3	4.4 ± 0.5	[−0.8, 1.0]
9	8.6 ± 1.0	8.3 ± 0.8	[−0.5, 1.1]	6.7 ± 1.2	6.5 ± 1.0	[−0.8, 1.2]

of the average, and in excess of the average, for all but the 5-in. dbh class. Biases were slightly greater when predicting height from Lundqvist's equation for both plantation and natural stand data. Within the natural stand, predictions using the Lundqvist equation exceeded actual measures across all diameter classes, causing the negative bias demonstrated in Figure 1.

Tree volume and merchantable volume estimates increased with increasing diameter class for both plantation and natural samples (Table 4). The increase in volumes was more pronounced for the plantation than the natural samples. With the exception of the smallest diameter trees, plantation tree volumes were, on average, greater than natural tree volumes. However, differences (again with the exception of the smallest diameter trees) were nor significant. In contrast, the smallest diameter trees recorded greater volumes within the natural stands. A similar result was found when estimating merchantable tree volumes. Total merchantable volume from 50 trees representing the plantation stand was estimated at 156 ft^3, whereas that for the 50 natural stand trees was estimated to be 5% lower, 149 ft^3. The lack of merchantable volume from the 5-in. plantation trees (two trees produced merchantable volumes of 0.08 and 0.11 ft^3 respectively) was due to tree taper.

Log Level Comparison

The number of logs obtained from the plantation trees exceeded those from the natural sample (Table 5). The plantation produced about 19% more 8-ft logs. Overall 130 logs of 8-ft lengths were bucked and sawn from the plantation trees compared with 109 from the natural trees.

Table 5. Number of sample logs by stand type and height class.

Log height class	Plantation	Natural
1	46	45
2	34	29
3	26	20
4	19	11
5	5	4
Total	130	109

Butt logs cut from the plantation trees had 24 branches on average, with an SD of 5. The variability in the number of branches tended to decrease with increasing diameter class, from an SD of 8 for the smallest diameter class (with an average of 22 branches per log) down to 3 for the largest class (with an average of 25 branches per log). Butt logs cut from the natural trees had 21 branches on average and an SD of 9. Unlike the plantation logs, variability did not decrease with increasing diameter class.

The percentage of dead branches in each butt log tended to increase with increasing diameter class and, as expected, declined with increasing log height class, for both plantation and natural samples. The majority of dead branches were contained within the first two logs aboveground. Of the upper plantation logs only 9 of the 50 contained at least one dead branch; for the natural counterparts, there were 8 of 35 such logs.

Branch size distributions were similar for the two butt log samples. The largest branch perlog was on average 1.1 in., with standard deviations of 0.3 and 0.4 in. for the plantation and natural samples,

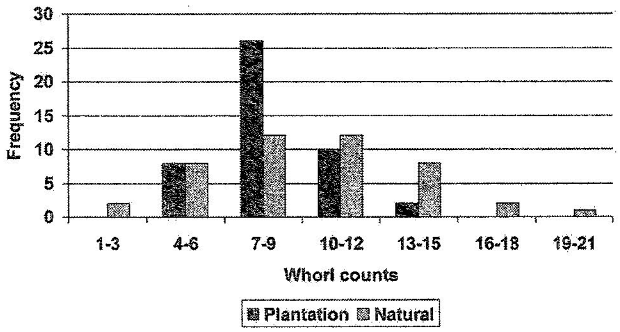

Figure 2. Whorl distributions within 8-ft ponderosa pine butt logs from plantation and natural stands.

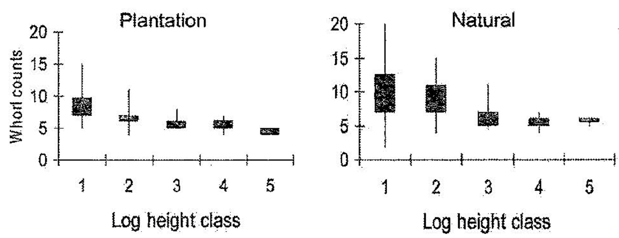

Figure 3. Number of whorls by log height class for plantation and natural ponderosa pine logs. The upper and lower edges of the boxes represent upper and lower quartiles, respectively, and the tails extend from maxima to minimum.

respectively. Branch size distributions were similar for the upper logs.

Whorl distributions within the butt logs were noticeably different (Figure 2). The majority of the plantation logs had an average of 8.7 whorls, with an SD of 2.4 whorls. The natural stand had a greater average whorl count and greater variability (average 9.8, SD 4.0). The number of whorls within the upper logs tended to decrease with increasing height class. The variability also decreased with increasing height class (Figure 3), particularly for the natural stand data.

Lumber Volume, Quality, and Value Comparison

Empirical Study

The empirical product recovery study produced 17% more board feet (bd ft) of lumber from the 8-ft logs in the plantation sample. This is a result of the plantation sample having more useable logs (Table 5). Because saw pattern was based on log small-end diameter, lumber recovety percentages were about the same for plantation and natural samples. Only one piece of lumber from the study was graded No.1 Shop; the remaining lumber was graded Shop Out. Average board width was about the same from the natural (4.2 in.) as from the plantation stand (4.3 in.).

AUTOSAW Simulation

Through application of the sawing simulator to the 8-ft log models, lumber tallies were generated for each sample. As expected, the plantation sample yielded more lumber than the natural sample (Figure 4). The difference between lumber volumes from the two stands totaled more than 150 bd ft (837 and 683 bd ft for the plantation and natural stands, respectively). Approximately 50% of lumber production was obtained from the 9-in. diameter class. Lumber from the first three height classes of plantation trees exceeded the total lumber volume, across all height classes, from the natural stand.

Grade distributions for both samples, across all height classes, were poor, with the majority of lumber grades falling in the lowest two categories: Fingerjoint Shop and Shop Out (Figure 4). For the plantation stand there was about a *50/50* split between Fingerjoint Shop and Shop Out, whereas for the natural stand the split was *40/60*. There was, however, a small amount (less than 1%) of boards that were graded to No.2 Shop within the natural sample.

AUTOSAW produced more lumber than the empirical product recovery study. Most logs with a small-end diameter greater than 6 in. produced four boards with AUTOSAW. The empirical study never recovered more than three boards per log. The saw pattern on the Economizer was set so that all logs greater than 6.5 in. produced three boards.

With the association of prices to the grade categories ($913.61/fmbf for No.2 shop, *$522.32/mbf* for No.3 Shop, $316.80/mbf for Fingerjoint Shop Common, and $216.87/mbf for Shop Out (WWPA2008), the value of the natural lumber in comparison with plantation lumber was 12% less, despite the 18% lumber tally difference.

Board Defects

The most numerous defects identified in the lumber were, in order of increasing severity: needle flecks, wane, red knots, pith, and dead knots (Figure 5). Needle flecks were particularly abundant on boards from natural stands, occupying about 31% of the boards' surface area, in contrast to the 19% area occupied by needle traces on plantation boards. The plantation boards (215 scanned) had an average defect area of 270 in^2 per board (representing defect on both flat sides of each board) leaving 67% of the surface area clear wood. The natural stand (174 boards scanned) averaged 377 in^2 of defect per board, or only 54% as clear wood. If needle flecks are accepted, the clear area increases to 86% for the plantation pine and 85% for the natural stand.

Conclusions

Plantation trees, selected on the basis of diameter class, were on average 4 years younger than their naturally grown counterparts (averaging 34 and 38 years for the plantation and natural trees, respectively). Within the 9-in. diameter class, the plantation trees were some 11 years younger (34 and 45 years, respectively). In addition to a less variable age structure, the plantation sample demonstrated less variation in height and crown length, confirming the result of Nagel and O'Hara (2001) in their comparison of even-aged and multiaged stands. We also found less variation in some branching patterns, with the plantation butt logs demonstrating less variability than the natural cohorts in whorl and branch counts.

With limited silvicultural management, the plantation stand produced about 19% more useable logs (130 compared with 109), about 5% more merchantable volume, and about 17% more lumber. Furthermore, the quality of lumber from the plantation stand, in terms of consumers' least preferred defects-needle traces and wane-was better given the lower rate of incidence on boards.

The predictive tree height equations of Wykoff and Lundqvist also demonstrated some differences. Overall there was less bias when using the Wykoff equation for both stand types. However, with the exception of the 5-in. diameter class, both equations over-predicted

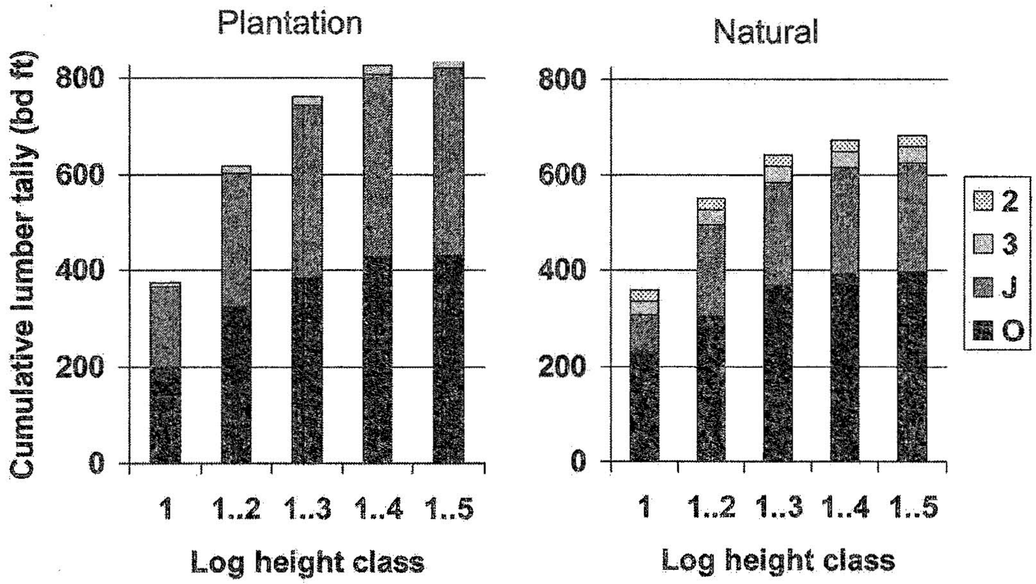

Figure 4. AUTOSAW simulated cumulative lumber grade distributions for 8-ft logs from plantation and natural stands. 2, No. 2 Shop; 3, No. 3 Shop; J, Fingerjoint Shop; O, Shop Out.

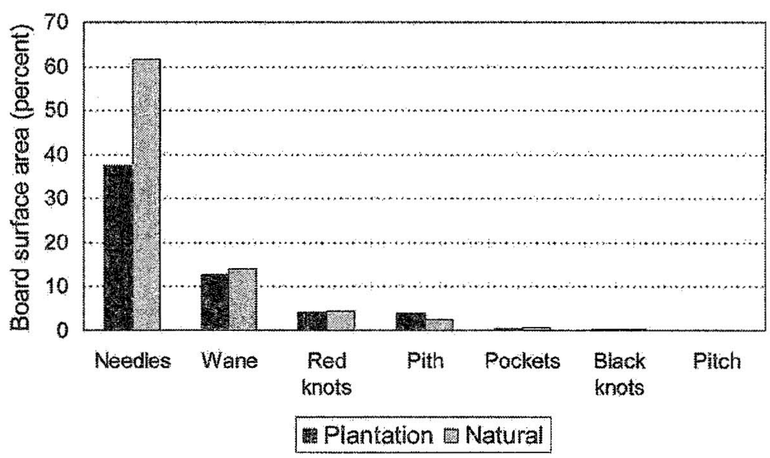

Figure 5. Primary defects, as a percentage of surface area, found in boards sawn from plantation and natural stands.

heights for trees from the natural stand. This will have implications when determining tree and merchantable volumes.

With our choice of sawmill, the combination of saw settings and product thicknesses restricted yield to a maximum of three boards per log. This is in contrast to the maximum of four boards per log that was obtained in the sawing simulations. The empirical results reflect yields that would likely be realized by other small log headrigs that process small logs with rapid throughput, whereas the simulated yields indicate that opportunities exist to improve volume recovery from small-diameter trees (up to 9-in. dbh).

Differences between empirical and simulated lumber grades had been anticipated. This was primarily because with the empirical study, the lumber was dried prior to grading, whereas with the simulator the "lumber" was processed and graded in the green state. Second, our knot diagramming procedures capture externally visible knots. Thus, if self-pruning had occurred and the knots become completely entombed within the tree trunk, they would not have been seen or recorded. Nonetheless, both the manual grading and simulated grading procedures were consistently applied to all lumber.

One of the major obstacles in performing this comparison was finding stands with equivalent site conditions. In this study, the sites were of similar latitude but differed in elevation. The plantation stand was more than 2000 ft higher than the natural stand. Although elevation has been demonstrated to have a lesser effect on growth than latitude (Uzoh and Oliver 2008), other site factors, such as soil fertility and disturbance, particularly after mining activity, may have affected growth rates. In addition to finding equivalent site conditions, opportunities to harvest natural stands in the same locale as plantation stands were limited. Thus, our choice of stands represented the best available option.

The objective of our study was to compare log and lumber quality from the two stand types. A financial analysis of management (including site preparation and planting) and market scenarios would be required to determine the financial feasibility of thinning densely stocked stands of ponderosa pine. This could aid decision-makers in determining whether or not to select plantations over naturally regenerated stands.

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