AN ABSTRACT OF THE THESIS OF

Glenn A. Christensen for the degree of Master of Science in Forest Resources presented on January 9, 1997.

Title: Development of Douglas-fir Log Quality, Product Yield and Stand Value After Repeated Thinnings in Western Oregon.

Abstract approved: ______________________________

David D. Marshall

Forest managers are beginning to take an interest in management of young Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in Western Oregon and Washington. Studies have established the relationship between growth and levels-of-growing-stock but few have established a link to wood quality and value. This study used data collected from a long term stocking study and established how log quality, product yield, and stand value were affected by repeated early thinnings across a wide range of stand densities.

Methods developed by Briggs and Fight (1992) using the ORGANON and TREEVAL computer models to quantify Douglas-fir log quality, product yield and associated dollar value were used. Five thinning densities were considered on plots which are a part of the levels-of-growing-stock (LOGS) cooperative located west of Corvallis in Western Oregon.

At stand age 30 all thinning densities consisted of low quality and value log grades. By stand age 50 log quality improved considerably for all treatments. Projections made to stand age 100 show additional improvements in log quality and dollar value. All thinning treatments had a greater proportion of volume in higher quality logs than the unthinned control. Total standing volume was reduced as thinning intensity increased. Gross stand value was found to be highly related to standing board foot volume. By stand age 100 the lightest thinned treatments had the greatest total value and volume.

Product yield recovery was found to be fairly consistent between thinning treatments in the mix of lumber grades produced throughout the 80 year analysis period. This was attributed to little change in limb size between treatments and through time. Gross dollar value of lumber produced was found to be highly related to volume yield. The lightest thinned treatments had the greatest standing volume and value in lumber by stand age 100.

Development of Douglas-fir Log Quality, Product Yield, and Stand Value After Repeated Thinnings in Western Oregon

by

Glenn A. Christensen

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed January 9, 1997
Commencement June 1997

Master of Science thesis of Glenn A. Christensen presented on January 9, 1997.

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Glenn A. Christensen, Author

Acknowledgements

I am grateful to all of great people that have provided financial and technical support throughout this project. I thank the U.S. Forest Service, Pacific Northwest Research Station and Oregon State University for providing the main sources of funding. I also want to thank Dr. John F. Bell and the Dilworth Committee for providing additional support from the J. Richard Dilworth scholarship.

Technical expertise and guidance has come from numerous individuals. I am indebted to my major professor Dr. David D. Marshall for the support and encouragement that was always there when I needed it. I thank my committee members Drs. Steve Tesh and Jamie Barbour for their expertise. I have greatly learned and profited from working with the Levels-of-Growing-Stock Study cooperators, especially Dr. Robert O. Curtis who made most of this possible.

I thank my parents, Richard and Donna Christensen for encouraging me to push myself and always supporting my endeavors. I dedicate this thesis to my wife Diane and daughter Janie who were at my side every day and supported me in what sometimes seemed an overwhelming and endless task. I also dedicate this thesis to my grandfather, Walter Wampler who's love of learning and nature inspired me to pursue the rewards and challenges of an advanced degree.

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Development of Douglas-Fir Log Quality, Product Yield and Stand Value After Repeated Thinnings in Western Oregon

1.0 Introduction

The effects of silvicultural practices on wood quality and value of young Douglas-fir(*Pseudotsuga menziesii* (Mirb.) Franco)is poorly understood. In the past, most research has gone into the growth and yield of Douglas-fir for volume production. As the resource for Douglas-fir shifts from older forests which produce high quality timber to younger, quickly grown plantations, some wonder about the resulting change in wood quality (Marshall et al., 1992). Several methods have recently been developed that allow a closer look at how log quality, wood quality and associated stand value will be affected by different silvicultural regimes. This study used some of these new methods to specifically look at how thinning affected quality and value.

1.1 Problem Definition

Many young stands of Douglas-fir in the Coast Range of western Oregon and Washington have received early control of stocking density and competing vegetation. As stands grow, thinnings may be prescribed to allow crop trees the full utilization of available resources needed for rapid growth and wood production. Thinnings offer a potential tool for development of forest stand structure and wood fiber, but little is known about how these treatments will impact wood quality and values produced in intensively managed Douglas-fir stands.

Studies have speculated on how value will be affected by different management regimes (e.g. Marshall et al., 1992 and Curtis and Marshall, 1993) but few studies have quantified the relationship between a silvicultural treatment and its effect on quality and value. Other studies have provided some insight to this relationship using growth simulations (Maguire et al., 1991, Briggs and Fight, 1992) but methods developed by these studies have yet to be applied to actual field trials. This study uses data collected from a long-term levels-of-growing-stock study and establishes how log quality, product yield and stand value are affected by repeated early thinnings across a wide range of densities. Value is defined in terms of log quality and potential products based on field measurements and predictions.

1.2 Literature Review

1.2.1 Wood Quality Prediction

The relationship between product value and wood quality may be quite different in natural unmanaged stands and stands managed under different silvicultural regimes (Fight et al., 1986). Recently several studies have developed a variety of methods to quantify and establish a relationship between development of young Douglas-fir stands and wood quality to product yield and value.

To predict wood quality, Maguire et al. (1991) developed a model that can be used with an individual-tree, distance-independent growth model such as ORGANON (Oregon Growth Analysis and Projection) (Hann et al., 1994). The model uses predictions of branch whorl locations, mean of the largest four branches per log (BD_4) and diameter of crown (or juvenile) wood core as determinants of wood quality. Predictions of branch location and diameter are used to estimate knot frequency and size. The model is used with height growth predictions to determine branch whorl locations and position of major branches. Maximum branch diameter of a given whorl is estimated at the time of whorl mortality which is a function of depth into the crown, tree size, stand density, and site quality. Crown wood core volume predictions (defined as diameter inside bark at time of crown recession past each branch whorl or as wood contained in the first 20 growth rings from the pith) was estimated for each log. Data was collected in Southwest Oregon in stands of primarily Douglas-fir. Few stands were used that represented thinning treatments (Maguire et al., 1991).

Simulations were ran on 6 different silvicultural regimes to determine effects on wood quality. A range of initial densities and thinning treatments were used to simulate growth of a 9-year-old Douglas-fir plantation for 65 years. Findings indicate that a wider initial or post-thinning spacing produced larger knots and more crown wood which implies lower quality. The same treatments also predict a lower whorl frequency. Thinning from below vs. a proportional thinning increased average BD_4, decreased whorl frequency, and increased percent crown wood. The increase in volume per acre recovered from the butt logs in thinned stands was primarily crown wood which indicates lower quality but an unknown change in value (Maguire et al., 1991).

The study by Maguire et al. (1991) provides a method for prediction of branch diameter and juvenile wood that can be used in stands of Southwest Oregon Douglas-fir similar to those from which the data was collected. A limiting factor of the model is that predictions of branch diameters are based on diameter data from the lower third of the live crown in trees from southwest Oregon, any attempts to predict branch diameters higher in the crown are extrapolations (Maguire et al., 1991).

Johnston et al. (draft) developed a model which allows predictions of maximum branch diameter at any whorl within the live crown of young Douglas-fir in western Oregon and Washington. Stands selected were from a wide range of stocking levels at different stages of development and were managed even-aged stands of natural and planted origin. An analysis of model behavior was made by fitting two equations developed by Johnston et al. and the equation developed by Maguire et al. (1991) to the data collected in western Oregon and Washington. Johnston et al. found the equation developed for southwest Oregon was insufficiently flexible to predict branch diameter over depth into the live crown. The equations developed by Johnston et al. were found to predict branch diameters throughout the crown more realistically.

1.2.2 Wood Quality and Stand Value Studies

Fight et al. (1995) compared the soil expectation value (SEV) for pruned and unpruned stands of Douglas-fir across a wide range of stand densities. An objective of the study was to determine if silvicultural regimes that managed for timber quality were economically justified. Data collected from western Oregon stands varying in density from 100 to 500 trees per acre, with and without thinning entries, were used in a growth simulator to predict tree development. The branch diameter equation developed by Maguire et al. (1991) was used in the simulations (Fight et al., 1995). Equations from lumber recovery studies by Fahey et al. (1991) and Cahill et al. (1988) were used to determine product recovery and value.

Fight et al. (1995) found that when SEV is calculated at a 4% real interest rate, the SEV's tended to be higher for the pruned stands at all stocking densities. When regimes without pruning are assessed, stands at a lower stocking had higher SEV's. The stands of 500 trees per acre did have wood of higher quality (smaller limbs and about average juvenile wood percent) but they had trees of smaller average diameter which was a loss in harvest volume. These stands also had higher silvicultural costs which helped to off-set any value gains from quality. The study did reveal that because product volume recovery and average value of products generally increase with age, value growth rates are higher than volume growth rates. On the stands where two commercial thinnings were simulated, the final volumes and values were lower than for any stand that was not commercially thinned based on a 60 year rotation age. But on a 80 year rotation age, the thinned stands did tend to have higher SEV's than the unthinned stands (Fight et al., 1995).

Another approach to assess the effects of silvicultural regime on wood quality and stand value was developed by Briggs and Fight (1992). The approach used several models that simulate different parts of the analysis and links them together. The ORGANON growth and yield simulator was used to simulate growth and quality development of individual Douglas-fir trees and stands. TREEVAL (tree valuation model) (Briggs, 1989) used the predictions from ORGANON to estimate net product value and volume when processed into lumber, veneer, pulp, or chips. TREEVAL uses either of two bucking options combined with product recovery regression equations, product prices, and manufacturing cost estimates to estimate net product value and volume of the logs. TREEVAL2 (TREEVAL, version 2) added the ability to use branch diameter and juvenile wood predictions from a growth and yield simulator such as ORGANON to estimate product recovery and value. Finally, FIP (Forest Investment Program) (Ikaheimo, 1990) was used to combine the results from TREEVAL2 with management and logging costs to calculate SEV (Briggs and Fight, 1992).

To test application of this method, two stands of Douglas-fir that differed only in initial stocking were selected and grown using ORGANON. Stand A was initially stocked with 150 trees per acre and stand B was stocked with

800 trees per acre. The stands were grown and assessed in ten year increments from stand age 60 to 100 with no intermediate treatments. When the stands were assessed by ORGANON outputs of volume, knot size and juvenile wood, stand A had the highest SEV at all ages. But when the same stands were also assessed with TREEVAL2 and FIP which used the volume and quality estimates to predict potential product recovery after accounting for costs, stand B had the highest SEV after year 60 (Briggs and Fight, 1992).

These two studies give some indication of the relationship between silvicultural regime and wood quality but are based on predictions of growth models in stands of limited management. Many of today's young Douglas-fir stands were established through planting and/or have received early spacing treatments which are the stands where knowledge of how silvicultural treatments affect future wood quality and value are most needed by forest managers.

1.3 Objective

The relationship between growth and level-of-growing-stock of young Douglas-fir have been documented (Curtis and Marshall, 1986). But a study has not been done that establishes a relationship between Douglas-fir growth-growing stock levels and how log and wood quality develop through time and across a wide range of thinning densities.

Using the values associated with log and wood quality to develop a relationship between Douglas-fir growth-growing stock levels and stand value also remains to be accomplished.

Methods to quantify Douglas-fir log and wood quality have been developed and some analysis has been done using growth and yield simulators. A study has not been done that uses these developed techniques on data collected from long-term growth and thinning studies. This study used the methods developed to quantify Douglas-fir log and wood quality, associated product yields and stand value on data from a long-term growth study representing a wide range of thinning densities.

The main objective of this study was to quantify change in stand value based on two different measures; log grades and potential product yields, for a long-term thinning trial that represents a wide range of densities. Specific objectives were as follows:

1. Determine past, present and future stand value from log grades for Douglas-fir on long-term thinning trials that represent unthinned stands and stands thinned to a wide range of densities.
2. Determine past, present and future stand value from potential product yields for Douglas-fir on long-term

thinning trials that represent unthinned stands and stands thinned to a wide range of densities.

3. Compare changes and yields in value, based on log grades and potential product yields, with traditional volume measures for thinned and unthinned stands.

2.0 Methods

The general approach used in this study is similar to that used by Briggs and Fight (1992) to assess and quantify the effects of silvicultural practices on product quality and value. The important difference between this study and the one by Briggs and Fight is that actual measurement data was used for the first 50 years (an age similar to many industrial rotations). Using past and current measurement data collected from sample plots, a product model was used to determine past and current log grades, product yields and their associated value. Past and current stand values were determined by combining estimates of past and current log grade and product yield values. Prior to determining estimates of future log grades, product yields and stand values, stands were grown using a growth model. Once predictions of future tree characteristics were made, the same methods used to quantify past and current log grades, product yields and stand values were used. Each thinning density and unthinned control represented received the same analysis. Final analysis results are presented graphically with associated tables given in attached appendices.

2.1 The Hoskins Installation

The study area was located near Hoskins, about 22 miles west of Corvallis in Benton County, Oregon (section 27, Township 10 South, Range 7 West, Willamette Meridian), and is part of the regional levels-of-growing-stock (LOGS) cooperative. The main objective of the LOGS study was to gather data on the response of young, even-aged Douglas-fir to intensive, frequent thinnings. Descriptions of the LOGS Cooperative and the individual studies have been presented by Williamson and Staebler (1971) and analysis of early results are given by Curtis and Marshall (1986).

The Hoskins LOGS study was established in 1963 by Oregon State University in western Oregon on lands owned by Starker Forests of Corvallis, Oregon (Marshall et al., 1992). Intermediate results for this installation have been reported by Bell and Berg (1972) for the calibration (1963-66) and first treatment (1966-70) periods; Berg and Bell (1979) for the second (1970-73) and third (1973-75) treatment periods, Tappeiner et al. (1982) for the fourth treatment period (1975-79). At the end of the 1983 growing season the study completed the fifth and final treatment period of the experiment as originally designed. Results through this fifth treatment period have been reported by Marshall et al. (1992).

2.1.1 Description of Study Area

The Hoskins study was established in a 20-year-old stand of uniform, even-aged pure Douglas-fir, which had naturally regenerated after wildfire. Initial stocking on the three control plots ranged from 1,610 to 1,885 trees per acre, basal area ranged from 120 to 160 square feet per acre, and average quadratic mean diameter at breast height ranged from 3.6 to 4.2 inches (Marshall et al., 1992). Crown height was uniform at the time of study installation with a height-to-live-crown of approximately 8 feet and crown ratios averaging near 80 percent (Marshall, 1991). King's (1966) site index is 130 to 135 feet at 50 years (average of 133 feet) (Marshall et al., 1992). When established in 1963 the stand was 13-years-old at breast height and 20 years total.

2.1.2 Experimental Design

Eight regimes were tested by thinning to a wide range of growing stock densities. Each of the eight thinnings were replicated three times on 27 0.2-acre-square sample plots in a completely random design. The experiment was designed to last for five treatment periods after an initial calibration period.

Initial stand selection consisted of 4 criteria (Marshall, 1991):

1. A high degree of uniformity in stocking and site quality over an area sufficient to accommodate the approximately nine-acre installation.
2. Stand height between 20-40 feet and an average stand diameter less than 6 inches.
3. A vigorously growing stand with no apparent disease or damage and of such density that individual tree development had not been strongly influenced by competition, e.g. evidence of live crown extending over most of the bole.
4. At least 80 percent of the basal area in Douglas-fir.

The Hoskins installation meet all of these criteria. However, not all of the plots are contiguous. Because of space limitations, five plots had to be located on closely adjacent, but similar areas. A thinned buffer strip was maintained around the installation but, buffers were not established between plots (Marshall, 1991).

2.1.3 Stand Treatments

Calibration thinning. All of the 24 plots assigned to receive thinning treatments also received a calibration treatment of preparatory thinning. This initial thinning was intended to reduce variation in the original growing stock, resulting in uniform growth potential for all the treated plots (Marshall, 1991). The calibration thinning was applied in 1963 which reduced treated plots to 342 trees per acre.

Thinning treatments. Plots were thinned each time a set of crop trees (16 trees per acre selected at the beginning of the study based on strict spacing guidelines) grew an average of 10 feet in height. This resulted in thinnings that would be frequent when height growth and crown development were most rapid. Thinning treatments being made in 1966, 1970, 1973, 1975, and 1979 at total stand ages of 23, 27, 30, 32, and 36 years (Marshall et al., 1992).

Intensity of each thinning was determined by retaining a percentage of the gross basal area growth on the control plots. The gross growth on the control plots was used because it was assumed to approximate the full production of a given site at full stocking (Marshall, 1991).

All of the treatments accumulated growing stock throughout the experiment but at different rates. This study only considered the four fixed-percentage treatment regimes (1, 3, 5, and 7) which accumulate growing stock at constant percentages of the control plots' gross basal area growth. The four fixed levels are 10, 30, 50, and 70 percent which represented heavy to light thinnings, respectively.

The thinning guidelines for tree removal were (Marshall, 1991):

1. No crop trees were to be cut until all non-crop trees had been cut.
2. The average diameter of the trees removed at each thinning (d) was to equal the average diameter of the non-crop trees before thinning (D) (i.e., d/D=1.0 for the non-crop trees only). For all trees this resulted in a d/D ratio of less than 1, approximating a crown type thinning.
3. Trees removed in a thinning were to be distributed across the entire diameter range of the trees available for cutting without regard to merchantability.

After all non-crop trees had been removed, some additional crop trees were removed attempting to achieve a d/D of 1.0 and meet treatment basal area requirements (Marshall, 1991).

2.1.4 Data Collection

After initial plots were selected at the Hoskins study all trees with a diameter at breast height (DBH) of 1.6 inches or greater were numbered with paint. Numbered trees also have been marked at DBH with a ring of paint. During each measurement interval, DBH was measured to the nearest 0.1 inch and 12 to 15 trees on each plot were selected for total height (THT) measurement. A total of 9 measurements have been taken (1963, 1966, 1970, 1973, 1975, 1979, 1983, 1988 and 1993). Some crown ratio measurements were available initially and for the last three measurements. The site was last measured when it was 50-years-old, after the 1993 growing season. The heights of unmeasured trees were estimated using treatment level THT/DBH curves estimated for each measurement. Missing crown ratios were estimated by calibrating the curves of Zumrawi and Hann (1989) to measurements for each period available and smoothing to calibrate for other periods.

2.2 Log Quality Data Collection

The first study objective required determining past, present and future log grades and values. Log grades were included in this study because value is usually measured by the log grade when timber is sold and is assumed to be a good estimate of potential products. In addition to the above basic tree and stand data, additional information is needed to determine log grade. Variables important in determining log grades include (Bell and Dilworth, 1993):

1. Log length

2. Log scaling diameter (inside bark diameter of the small end)
3. Branch frequency, size and distribution
4. Surface defects (scars, rots, etc...)
5. Form (sweep, crook, forking, breakage, etc...)
6. Annual ring count

Determining log grades for trees currently occupying each treatment could easily have been done in the field using accepted log grading rules. However, knowing only what the grade of a particular log is now does not help determine what the grade of that log was in the past or what it will be in the future. In order to better determine current as well as past and future log grades it was concluded that information which would allow accurate description of a log's exterior quality characteristics was needed. Field measurements consisted of the height to each whorl, number of branches at each whorl, and average branch diameter at each whorl to 40 feet. Additional information collected in the field included surface defect and form of each tree.

To overcome the difficult logistics of accurately measuring quality characteristics such as branch diameter high-up on the tree, data was collected for the first 40 foot log only. It was assumed that the butt log would contain most (>50%) of the volume and value for each tree of two to three total logs. Other methods would be used to describe characteristics above the first log.

Branch measurement procedures consisted of measuring the mean diameter branch at each whorl. If a whorl contained a branch significantly larger (>0.5 inches) in diameter than the average branch, this diameter was also recorded. Diameter measurements were taken just beyond the collar where the branch joins the bole and recorded to the nearest 0.25 inch. A branch was counted if it was alive or dead, 0.5 inches and larger, or was a knot indicator 0.5 inches and larger. Branches smaller than 0.5 inches are not considered in determining log grades in accordance with official grading rules as published by the Northwest Log Rules Advisory Group (NLRAG) (1992).

Branch diameter measurements were taken using a fixed diameter caliper mounted on a height pole similar to that used by Grah (1961). The caliper consisted of a series of fixed diameters from 0.25 to 3.0 inches in 0.25 inch increments. Measurements were taken by sliding the caliper as far as it will go onto a branch. The diameter was read at the increment where the branch stops. Because the NLRAG log grading rules use branch diameter increment breaks of 0.5 inches it was assumed that recording diameters to within

0.25 inches would provide the needed accuracy. Height to each whorl was measured with a height pole to the nearest 0.1 foot.

Data was collected for each live tree on the plots receiving thinning treatments. Because of the uniformity of surface quality characteristics among trees of similar size within the unthinned control plots it was determined that a sample of trees could be measured. Sampling on the control plots consisted of selecting three trees from each 1.0 inch diameter class for trees up to 14.5 inches at DBH. Because larger trees are assumed to be more valuable, all trees larger than 14.5 inches at DBH were measured. Using the information collected from the sample, average surface quality characteristics were determined for each diameter class and applied to all unsampled trees within the corresponding diameter class for each control plot. Total number of measured trees by treatment were; 31 trees for treatment 1, 60 trees for treatment 3, 92 trees for treatment 5, 124 trees for treatment 7, and 122 of 226 trees were sampled on the control plots. All trees were visually checked for defect.

2.3 Log Grade Analysis

Grades were determined for each tree by bucking the tree into logs using specified bucking rules and evaluating each log based on surface characteristics (branch size, number of branches, distribution of branches, defect, and form) and size (length and scaling diameter). All logs were assigned both an export and domestic log grade using the grades and specifications presented in Tables 2-1 and 2-2. Table 2-3 defines how "clean" was applied to export grades. The terms "branch" and "knot" are used interchangeably in this report. The term "branch" is generally used when referring to tree and log characteristics and the term "knot" is used when referring to products such as lumber.

To facilitate the process of grading, a computer program was developed which evaluates each tree by bucking it into logs, assigning log grades, calculating volumes, and determining dollar values. Prices used for each log grade are presented in Tables 2-1 and 2-2. Analysis was performed at the treatment level by combining the three treatment plots into one response. Log grades were analyzed at each of the nine LOGS remeasurement periods, stand ages 20, 23, 27, 30, 32, 36, 40, 45, and 50 years. Grades were also projected and evaluated at stand ages 60, 70, 80, 90, and 100 years.

Table 2-1. Selected domestic log grade specifications, surface characteristics and prices (per thousand board feet, (Mbf) as of March 1996) for Douglas-fir. Adapted from NLRAG (1992) and Bell and Dilworth (1993). Log price information is from Log Lines log price reporting service (1996) and Pacific Rim Wood Market Report (1996).

Grade	Price ($/Mbf)	Minimum Length (ft.)	Scaling Diameter (in.)	Maximum Knot Size (in.)	Other Quality
Special Mill (SM)	818.00	17.0	16.0	1.5, also may include no more than 2 larger knots.	Knots averaging no more than 1 per foot of log length. At least 6 rings per inch.
No. 2 Sawmill (2 Saw)	718.00	12.0	12.0	2.5	None
No. 3 Special Mill (3 SM)	679.00	12.0	8.0	2.5	None
No. 3 Sawmill (3 Saw)	640.00	12.0	6.0	3.0	None
No. 4 Sawmill (4 Saw)	611.00	12.0	5.0	3.0+	Gross scale of at least 10 board feet

Table 2-2. Selected export log grade specifications, surface characteristics and prices (per thousand board feet, (Mbf) as of March 1996) for Douglas-fir. Compiled with information from Log Lines log price reporting service (1996), Pacific Rim Wood Market Report (1996), Twin Camas Company export sort card, Miller Shingle Company, Inc. sort specifications, Points West Trading, Inc. log specification sheet.[1]

Grade	Price ($/Mbf)	Minimum Length (ft.)	Scaling Diameter (in.)	Surface	Rings per Inch (RPI)
Japan 12" A sort	1,260.00	26.0	12.0+	No. 2 Saw+, clean	12
Japan 12" B sort	1,165.00	26.0	12.0+	No. 2 Saw+, clean	8
China 12"	892.00	26.0	12.0+	No. 3 Saw+ 3.0 in. maximum knot size.	No minimum RPI
Japan 8" A sort	931.00	30.0	8.0-11.0	No. 3 Special Mill+, clean	8
Japan 8" B sort	881.00	30.0	8.0-11.0	No. 3 Special Mill, clean	6
Korea	788.00	30.0	8.0-11.0	No. 3 Saw, 2.0 in. maximum knot size.	No minimum RPI

[1] Personal communication. 1995. Norm Marsh, consulting forester, Forest Resource Services, Salem OR.

Table 2-3 How "clean" is defined for export log grades.[2]

Log Grade	Branch Diameter (in.)	Allowed Branch Frequency and Distribution
Japan 12"	≤ 1.0	Unlimited number allowed.
	1.0 - 2.0	Approximately 2 per foot of log length.
	2.0 - 3.0	Approximately 1 per foot of log length.
	3.0 +	Not allowed.
Japan 8"	≤ 1.0	Unlimited number allowed.
	1.0 - 2.0	Approximately 1 per foot of log length.
	2.0 - 3.0	Very few allowed (3-5), must be well distributed.
	3.0 +	Not allowed.

2.3.1 Log Grading Program Description

The bucking, grading, calculating volumes and values, and summing results of each tree was accomplished with a computer program specifically designed for this study. The program used quality data collected in the field and LOGS

[2] Personal communication. 1995. Norm Marsh, consulting forester, Forest Resource Services, Salem OR.

cooperative remeasurement data entered into specifically formatted computer files.

Each tree was first reconstructed in the computer using data from two files for each tree, a tree file (Hoskins measurement data) and a quality file (field data) at each measurement period. Trees were then bucked using a preferred length of 40 feet plus 1 foot of trim from a stump height of 1 foot to a merchantable top diameter of 5 inches. Quality characteristics for each log were then determined. First the scaling diameter was calculated using the taper equation from Walters and Hann (1986) as used in the western Willamette Valley version of ORGANON. Branches were then evaluated for size, frequency, and distribution. ORGANON model and taper equation validation are presented in Appendices A and B, respectfully.

For all measurement periods a branch diameter was assumed to not change once height-to-live-crown has receded past the branch height until the branch self-prunes. Branches below the height-to-live-crown used the branch diameter as measured in the field. Other branch diameters (above 40 feet) were calculated using the model developed by Johnston et al. (draft) specifically for second-growth Douglas-fir in western Oregon and Washington:

$$\ln(BD) = C1 + C2*DINC + C3*\ln(DINC) + C4*\ln(DBH) + C5*THT$$

Where:

C1 = -0.178269

C2 = -0.036038

C3 = 0.790244

C4 = 0.725452

C5 = -0.012833

BD = Branch diameter (mm)

THT = Total tree height (m)

DINC = Depth into crown from tree top (m)

DBH = Diameter at breast height (cm)

To ensure validity of the model, it was tested against actual branch diameter measurements. Branch model testing results are presented in Appendix C. Once all branch diameters were determined the program found the maximum diameter and total number and distribution of branches for each log.

Other calculations made for each log included rings per inch (RPI), volume, and value. RPI was calculated at the top of each log using the taper equation from Walters and Hann (1986) and past diameter growth data. Both Scribner board foot and cubic foot volumes were calculated using the same methods as in ORGANON. Scribner board foot volumes used factors as presented in the NLRAG (1992) log scaling and grading rules. Cubic foot volumes used the Smalian rule (Bell and Dilworth, 1993):

$$\text{Volume}(\text{ft.}^3) = [(BS + BL)/2](L)$$

Where:

BS = Basal area inside bark of the small-end (ft.^{2})

BL = Basal area inside bark of the large-end (ft.^{2})

L = Length (ft.)

Section lengths of 4 feet were used.

Before value could be calculated a grade was assigned to each log. Using the grade specifications in tables 2-1 and 2-2, the program assigned a grade by beginning with the highest quality log grade specifications and compares them to the characteristics of a given log until the best grade which meets the characteristics of that log was found. The same procedure was followed for both export and domestic log grades. Once a log grade had been determined the total log value was calculated by using the associated grade value and log volume. Dollar value was only the current delivered log value per grade, no costs or interest rates were applied.

The program summarized all tree and log data per treatment per measurement period. Tree data summarized included number of trees evaluated, mean tree height, mean tree DBH, and mean height-to-live-crown. Log data summarized included mean; scaling diameter, number of branches, branch diameter, and RPI. Additionally, limiting factors for each log were evaluated and summarized. Factors considered which limit a log from obtaining the next highest grade included scaling diameter, length, branch diameter, number of branches, and RPI.

Final summary included the total merchantable Scribner board foot volume, merchantable cubic foot volume, and value based on domestic and export grades. Final volumes and values were calculated by summing data from all trees for each treatment per measurement period.

2.3.2 Current Log Grades

Current log grades were determined using collected log quality data, current tree measurement data and the log grading computer program. For the butt log, only actual field measurements were used for branch height and diameter. All other logs used the models to estimate surface characteristics. The taper equation from Walters and Hann (1986) was used to determine scaling diameter and length of all logs.

2.3.3 Past Log Grades and Thinnings

Past log grades and the estimated grade of logs removed in thinnings was determined at stand ages 20, 23, 27, 30, 32, 36, 40, and 45. The five thinning treatments occurred at stand ages 23, 27, 30, 32, and 36. Estimates of log grades from trees removed during each of the thinning treatments were also evaluated. As was done for current log grades, collected log quality data, past tree measurement data and the log grading computer program was used to perform the analysis. The number of trees evaluated per measurement period by treatment are given in Table 2-4. Table 2-5 presents the number of trees removed and evaluated during past thinning treatments.

Table 2-4. Number of trees evaluated for past log grades by treatment per measurement period.

Stand age (yrs.)	Treatment				
	1	3	5	7	Control
20	212	206	219	197	1,036
23	129	151	187	194	984
27	71	105	150	172	763
30	50	84	128	157	652
32	42	74	116	146	563
36	31	61	102	135	460
40	31	61	99	134	392
45	231	61	97	128	293

Table 2-5. Number of trees removed and evaluated for log grades by thinning per treatment.

Stand age (yrs.)	Treatment			
	1	3	5	7
23	82	54	31	3
27	58	46	37	22
30	21	21	21	15
32	8	10	11	10
36	11	13	14	8
Total:	180	144	114	58

Due to unavailability of data describing surface characteristics for trees that had been removed in thinnings or had been lost to mortality some assumptions and estimates were made. It was assumed that due to their small size these trees would produce only low quality logs (No. 4 and 3 Sawmill) and have little merchantable volume. It was further assumed that similar sized trees on the same treatment would have nearly the same surface characteristics allowing thinned or dead trees to be matched to a similar sized live tree.

Using the above assumptions the surface characteristics of trees in the past and trees removed in thinnings were estimated in one of two ways. The trees which are still alive used actual field data and the branch diameter model

(Johnston et al., draft) for branch data. Actual measurements were used if the height-to-live crown was above or equal to the branch height. Branches above the height-to-live-crown used the branch diameter model.

For trees which were removed in thinnings or had died a tree of average surface characteristics was created for each treatment. When a tree was encountered by the computer program which had no actual field data associated with it, the average tree of its size was used to estimate these parameters. Branch diameters were determined depending on where the height-to-live-crown was as discussed above.

Because trees in the past could not be visually checked for defects, grading of past logs used estimates of log size and branch size, distribution, and frequency as grading criteria. The same dollar value per grade as used for current log grades were used, unadjusted, for past and thinned log grades.

2.3.4 Future Log Grades

Future log grades were estimated from projected tree growth and mortality using current stand measurement data and the Western Willamette Valley version of ORGANON. All trees from each treatment were first grown in ORGANON in 10 year increments to a stand age of 100 years to project tree diameter, height, and crown ratio. Mortality was also projected and accounted for by use of an expansion factor applied to each tree. Once growth projections were made the tree data was entered into the log grading program. The same taper and branch diameter models used for past log grade predictions were used to project future log and branch diameters. As with grading past logs, the trees cannot be visually checked for defects. Grading of future logs used estimates of log size and branch size, frequency, and distribution as grading criteria. The same dollar value per grade as used with current log grades was applied, unadjusted, to future log grades.

To better account for changes in tree surface characteristics as a stand ages, rates of natural self-pruning had to be accounted for. After crown recession past a branch, the branch dies and will eventually fall off. To account for rates of natural self-pruning a factor of 60 years was used. Kachin (1940) found second-growth Douglas-fir to take about 60 years from the time of branch death to its complete occlusion. The log grading program accounted for self-pruning on each tree by removing all branches from a whorl once the height-to-live-crown had been greater than that whorl height for 60 years.

2.4 Product Yield Analysis

The second study objective required determining potential product yields and values. Product yield is the estimated quantity and quality of wood products produced from logs. Log size and wood quality determine the type and value of products produced. Wood quality can be defined as a measure of the characteristics of wood that influence properties of products made from it (Haygreen and Bowyer, 1982). Factors affecting wood quality include density, uniformity of growth rings, knots (frequency, size and distribution), fiber lengths, percent of clear bole, straightness of grain, proportion of heartwood, presence of juvenile and reaction woods, and type of product produced (Haygreen and Bowyer, 1982).

The approach used to quantify potential product yields for this study was similar to that used by Briggs and Fight (1992). Each treatment was evaluated through collected or projected measurement and quality data. Treatment data was entered into the tree valuation product recovery model (TREEVAL). Projected product recovery from all trees per treatment was then summarized.

2.4.1 TREEVAL Program Description

TREEVAL uses empirical product recovery regression equations, product prices, and manufacturing cost estimates to estimate net product value of logs when used for lumber, veneer, or chips (Briggs and Fight, 1992). Inputs are prices, costs, and tree data. Tree data can be created from growth and yield models such as ORGANON. TREEVAL was designed for Douglas-fir stands in western Oregon and Washington.

Each tree in the stand data file is first bucked into mill length logs (either 16 or 20 feet). The end diameters inside bark are estimated from a taper curve, and cubic foot volume is calculated using either Bruce's butt log formula (Bruce, 1982) or the Smalian formula (Briggs and Fight, 1992). Wood quality characteristics are next estimated using an index of knot size and proportion of juvenile wood from data for each whorl in the tree (Briggs and Fight, 1992). For saw logs, the lumber recovery factor and grade yield are next estimated using equations from a recovery study by Fahey et al. (1991). Multiplying total lumber yield by a grade yield percent and price estimates the value of that grade in the log (Briggs and Fight, 1992). Total lumber revenue from a log is determined by summing for all grade yields (Briggs and Fight, 1992).

2.4.2 Projected Product Yields

Past, current and future potential product yields and associated value for all thinning treatments (1, 3, 5, 7, and the unthinned control) were evaluated using TREEVAL for Windows, version 1.0 (beta) (Fight and Coulter, 1996). As with the log grading analysis, past and current tree and quality data came from tree and field quality measurements. Tree data for future product yields came from ORGANON (Western Willamette Valley version) projections. Future quality projections were made by using the same methods as the log grade projections. The model from Johnston et al. (draft) was used for branch diameter projections. A branch self-pruning age of 60 years for limbs below the height-to-live-crown was used. Diameter of the juvenile wood core at each whorl as required by TREEVAL was projected at all stand ages (20-100 years) by ORGANON. TREEVAL uses the same format as ORGANON wood quality output files for stand data (tree and quality data combined) input files. All input data was reconfigured to the TREEVAL format.

The specific product considered for this study was lumber. Lumber grading rules used were those established by the Western Wood Products Association (1995). Only visual lumber grades were assessed. Specific lumber grades and prices used in this study are given in Table 2-6. Prices reported are f.o.b. mill price for Douglas-fir lumber, coast mills, from the publication "Production, Prices, Employment, and Trade in Northwest Forest Industries, First Quarter

1996," (Warren, 1996). As with the log grade analysis only gross values are reported. No adjustments were made for costs or time.

Table 2-6. Selected lumber grade specifications and prices (per thousand board feet, Mbf) as used and defined by TREEVAL. Lumber price information comes from "Production, Prices, Employment, and Trade in Northwest Forest Industries, First Quarter 1996," (Warren, 1996).

Lumber Grade	Price ($/Mbf)	Description
D selects and better	887.00	Includes: D and C selects, all shop grades, and export clears.
Select	446.00	Includes: all laminating stock; 2 in. select structural; 2 in. No. 1; 3 in. and thicker select structural; crossarms; scaffold planks; export commons.
No. 1	374.64	Includes: low grade selects and high grade No. 2.
No. 2	337.00	Includes: all studs; standard and better light framing; 2x6 and 2x8 No. 2 and better; 1x4 and 1x6 utility and better; 4x4 utility and better; 4x4 standard and better.
Utility	227.00	Includes: all utility and No. 3 grade lumber.
Economy	113.00	Includes all economy grade lumber.

3.0 Results

3.1 Hoskins

3.1.1 Results to Stand Age 50

Thirty-year result summaries from Hoskins (1963 - 1993) present the effect of differences in levels-of-growing-stock on stand development to a stand age of 50 years. These effects were most evident in basal area, quadratic mean diameter (QMD) (DBH of the tree of mean basal area), and standing volume development through time.

Figure 3-1 presents basal area accumulation by treatment before each thinning. The graph shows a wide range of basal area densities which have resulted from the four fixed-level thinning treatments considered in this study. Treatment 1, the heaviest thinning, which maintains only 10% of the gross basal area growth of the unthinned control has accumulated the least amount of basal area. Treatment 7, the lightest thinning, which maintains 70% of the gross basal area growth of the unthinned control has accumulated the most basal area. Treatment 7 is approaching the control in basal area as self-thinning induced mortality reduces the basal area growth on the control.

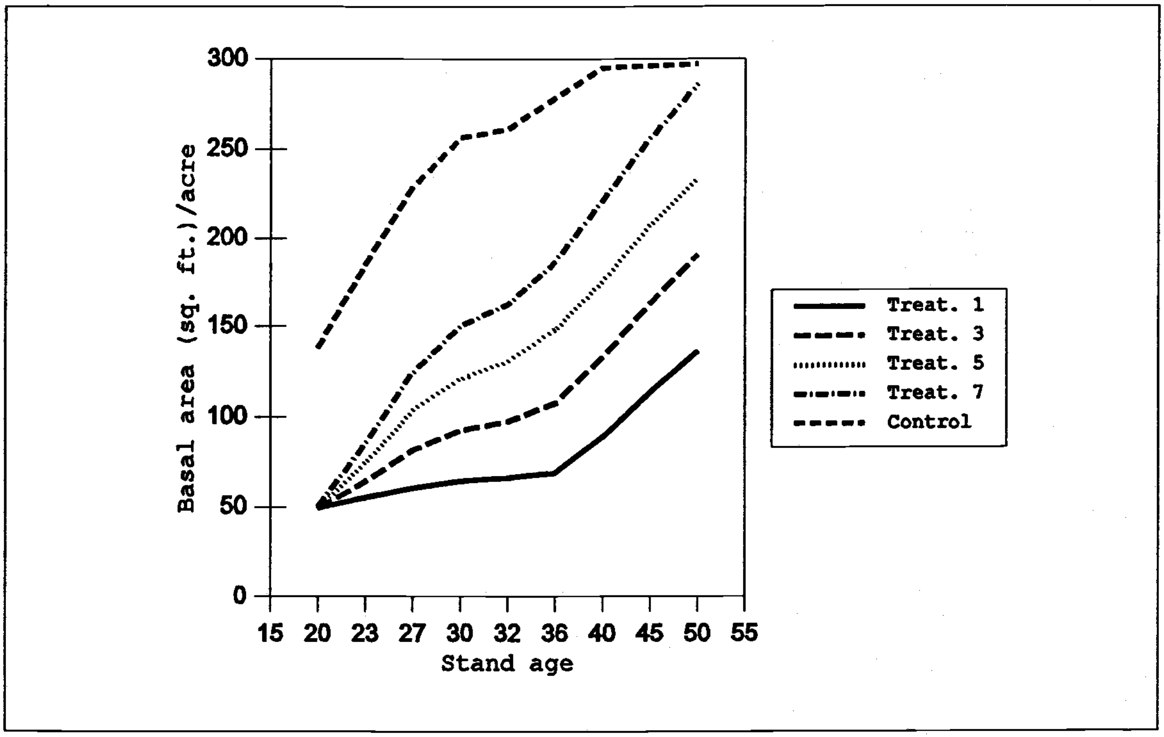


Figure 3-1. Hoskins cumulative basal area development before thinning for treatments 1, 3, 5, 7 and control (Marshall et al., 1992).

Figure 3-2 presents mean diameter (QMD) development before thinning for each treatment through time. The effect of thinning on diameter growth has been to increase growth with thinning intensity and to decrease growth with increasing growing stock (Marshall, 1991). By stand age 50, mean diameter on the control plots was 12.1 inches. On the lightest thinning (treatment 7) this had increased to 16.0 inches. For the heaviest thinning (treatment 1) the average diameter had increased to 22.0 inches, nearly twice that of the control.

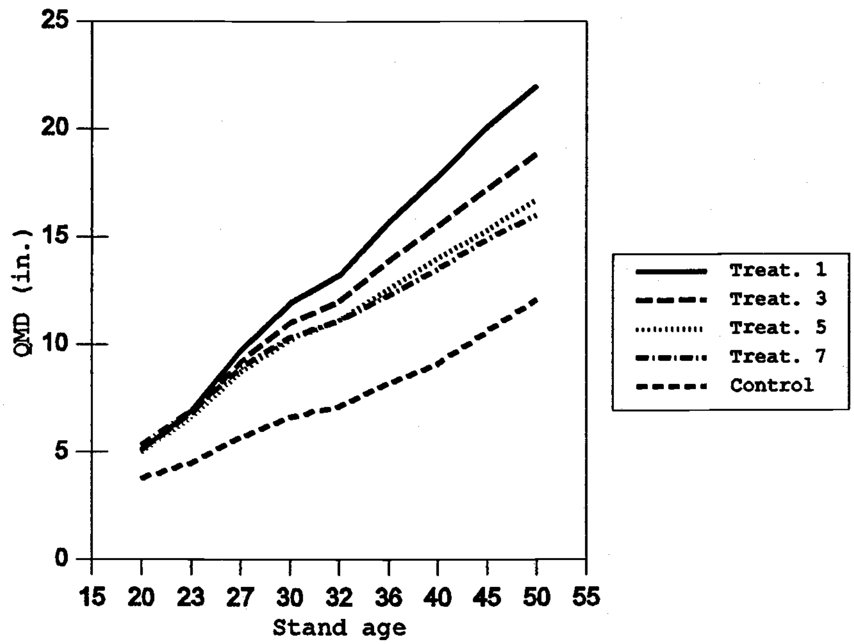


Figure 3-2. Hoskins attained quadratic mean diameter before thinning by stand age for treatments 1, 3, 5, 7, and control (Marshall et al., 1992).

Figure 3-3 presents the effect of thinning on standing total stem cubic foot volume yield per acre (gross volume, mortality and thinnings were not included). With an increase in thinning intensity the standing cubic foot volume yield was reduced. By stand age 50, the control had just been over-taken by treatment 7 as having the greatest standing total stem cubic foot volume, 13,385 cubic feet per acre on treatment 7 and 13,301 cubic feet per acre on the control. For the heaviest thinning (treatment 1) standing total stem cubic foot volume was less than half (43.9%) that of the control at only 5836 cubic feet per acre. Treatments 3 and 5 maintained intermediate response levels.

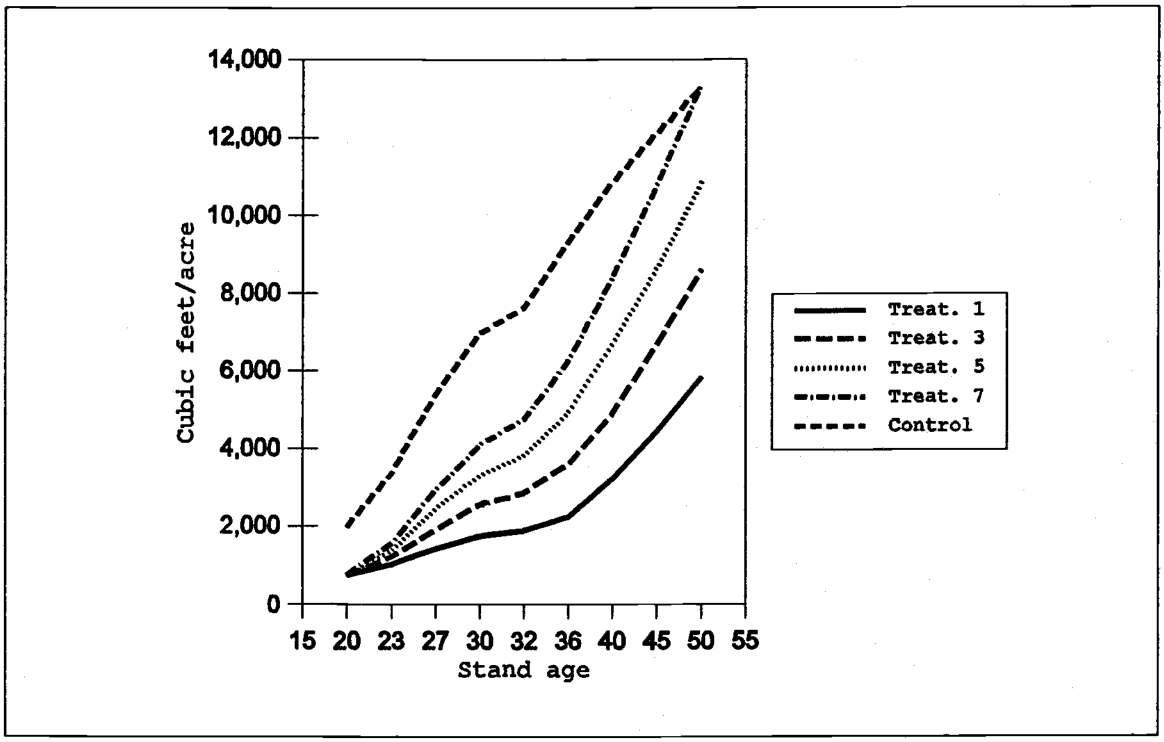


Figure 3-3. Hoskins cumulative standing total stem cubic foot volume yield before thinning in trees 1.6 inches DBH and larger by stand age for treatments 1, 3, 5, 7, and control (Marshall et al., 1992).

Tables 3-1 through 3-5 present Hoskins per acre stand summaries by treatment. These tables show thinning effects to date for each level of stocking. Height of the 40 largest trees per acre (HT40) steadily increased for all treatments and showed little difference between treatments. Curtis' (1982) relative density (RD) and Reineke's (1933) stand density index (SDI) are included to illustrate differences between and changes within treatments in stand density through time. Treatment 1 which maintains the least amount of stocking had the lowest RD and SDI levels through time as compared to the unthinned control (treatment 9). Treatment 7, which maintains the greatest stocking levels consistently had the greatest RD and SDI levels as compared to treatments 1, 3, and 5 but had lower levels than the control. The control had the highest RD and SDI levels as compared to all other treatments but both indexes were declining. RD and SDI peaked around stand age 30 on the control. Both cubic foot and Scribner board foot volumes per acre are presented as standing merchantable yields (thinnings and mortality were not included).

Table 3-1. Hoskins per acre stand summary for treatment 1 (Marshall et al., 1992).

	Treatment 1 Stand Age (years)								
	20	23	27	30	32	36	40	45	50
HT40[1]	40	50	62	71	75	87	98	108	122
TPA[2]	353	215	118	83	70	52	52	52	52
QMD[3]	5.1	6.9	9.7	11.9	13.2	15.7	17.8	20.1	22.0
BA[4]	49.4	55.1	60.4	64.4	66.1	69.0	89.1	114.0	136.4
RD[5]	21.9	21.0	19.4	18.7	18.2	17.4	21.1	25.4	29.1
SDI[6]	119	118.5	112.4	109.7	109.3	107.3	131.2	158.0	184.3
Cu.[7]	65	492	1121	1464	1625	2004	2980	4244	5698
Bd.[8]	333	2256	3864	4088	4482	6805	10664	15541	23761

[1]Height of the 40 largest trees per acre. (feet)
[2]Number of trees per acre.
[3]Quadratic mean diameter. (inches)
[4]Basal area per acre. (square feet)
[5]Relative density. (Curtis, 1982).
[6]Stand density index. (Reineke, 1933)
[7]Standing merchantable cubic foot volume per acre, 40 foot logs to a 5 inch inside bark top diameter. (cubic feet)
[8]Standing merchantable Scribner board foot volume per acre, 40 foot logs to a 5 inch inside bark top diameter. (Scribner board feet)

Table 3-2. Hoskins per acre stand summary for treatment 3 (Marshall et al., 1992).

	Treatment 3 Stand Age (years)								
	20	23	27	30	32	36	40	45	50
HT40[1]	39	49	61	73	77	89	99	111	124
TPA[2]	343	252	175	140	123	102	102	102	100
QMD[3]	5.1	6.8	9.2	11.0	12.0	13.9	15.5	17.2	18.8
BA[4]	49.0	64.2	81.6	92.4	97.6	107.5	132.9	163.0	190.6
RD[5]	21.7	24.6	26.9	27.9	28.2	28.8	33.8	39.3	44.0
SDI[6]	116.4	135.7	153.1	163.1	164.8	173.0	206.1	243.6	275.4
Cu.[7]	66	576	1462	2098	2443	3168	4501	6275	8295
Bd.[8]	300	2577	5280	6535	7509	11003	17320	24230	35323

[1]Height of the 40 largest trees per acre. (feet)
[2]Number of trees per acre.
[3]Quadratic mean diameter. (inches)
[4]Basal area per acre. (square feet)
[5]Relative density. (Curtis, 1982)
[6]Stand density index. (Reineke, 1933)
[7]Standing merchantable cubic foot volume per acre, 40 foot logs to a 5 inch inside bark top diameter. (cubic feet)
[8]Standing merchantable Scribner board foot volume per acre, 40 foot logs to a 5 inch inside bark top diameter. (Scribner board feet)

Table 3-3 Hoskins per acre stand summary for treatment 5 (Marshall et al., 1992).

	Treatment 5 Stand Age (years)								
	20	23	27	30	32	36	40	45	50
HT40[1]	40	50	62	72	77	89	105	115	127
TPA[2]	365	312	250	213	193	170	165	162	153
QMD[3]	5.0	6.6	8.7	10.2	11.1	12.6	14.0	15.3	16.7
BA[4]	49.2	74.9	103.6	121.1	130.4	147.9	175.4	207.4	233.6
RD[5]	22.0	29.2	35.1	37.9	39.1	41.7	46.9	53.0	57.2
SDI[6]	120.0	160.1	199.9	219.9	228.2	246.3	283.2	320.6	348.5
Cu.[7]	51	632	1788	2655	3229	4342	5995	8057	10407
Bd.[8]	259	3012	6876	8509	10648	16183	23831	32850	44942

[1]Height of the 40 largest trees per acre. (feet)
[2]Number of trees per acre.
[3]Quadratic mean diameter. (inches)
[4]Basal area per acre. (square feet)
[5]Relative density. (Curtis, 1982)
[6]Stand density index. (Reineke, 1933)
[7]Standing merchantable cubic foot volume per acre, 40 foot logs to a 5 inch inside bark top diameter. (cubic feet)
[8]Standing merchantable Scribner board foot volume per acre, 40 foot logs to a 5 inch inside bark top diameter. (Scribner board feet)

Table 3-4. Hoskins per acre stand summary for treatment 7 (Marshall et al., 1992).

	Treatment 7 Stand Age (years)								
	20	23	27	30	32	36	40	45	50
HT40[1]	39	49	62	73	78	89	102	114	125
TPA[2]	328	323	287	262	243	225	223	214	207
QMD[3]	5.3	6.9	8.9	10.3	11.1	12.3	13.5	14.9	16.0
BA[4]	50.1	84.9	124.5	150.0	162.3	186.2	221.1	256.0	286.2
RD[5]	21.8	32.3	41.7	46.7	48.7	53.1	60.2	66.3	71.6
SDI[6]	118.4	178.1	238.0	274.7	287.3	313.7	361.0	405.9	440.1
Cu.[7]	75	820	2198	3332	4046	5521	7628	10210	12857
Bd.[8]	364	3864	8419	10991	13856	21401	31820	42720	56461

[1]Height of the 40 largest trees per acre. (feet)
[2]Number of trees per acre.
[3]Quadratic mean diameter. (inches)
[4]Basal area per acre. (square feet)
[5]Relative density. (Curtis, 1982)
[6]Stand density index. (Reineke, 1933)
[7]Standing merchantable cubic foot volume per acre, 40 foot logs to a 5 inch inside bark top diameter. (cubic feet)
[8]Standing merchantable Scribner board foot volume per acre, 40 foot logs to a 5 inch inside bark top diameter. (Scribner board feet)

Table 3-5. Hoskins per acre stand summary for the unthinned control (treatment 9) (Marshall et al., 1992).

	Treatment 9 Stand Age (years)								
	20	23	27	30	32	36	40	45	50
HT40[1]	43	53	66	76	81	91	101	113	122
TPA[2]	1727	1640	1272	1087	938	767	653	488	377
QMD[3]	3.8	4.5	5.7	6.6	7.1	8.2	9.1	10.6	12.1
BA[4]	138.1	184.7	228.6	256.3	261.0	278.0	295.1	296.3	297.3
RD[5]	70.8	87.1	95.8	99.8	98.0	97.1	97.8	91.0	85.5
SDI[6]	365.5	455.2	516.0	558.0	541.3	557.8	561.3	535.8	511.9
Cu.[7]	178	901	2502	3962	4772	6654	8593	10539	12358
Bd.[8]	851	4663	12377	18685	21709	31588	41504	49594	57645

[1]Height of the 40 largest trees per acre. (feet)
[2]Number of trees per acre.
[3]Quadratic mean diameter. (inches)
[4]Basal area per acre. (square feet)
[5]Relative density. (Curtis, 1982)
[6]Stand density index. (Reineke, 1933)
[7]Standing merchantable cubic foot volume per acre, 40 foot logs to a 5 inch inside bark top diameter. (cubic feet)
[8]Standing merchantable Scribner board foot volume per acre, 40 foot logs to a 5 inch inside bark top diameter. (Scribner board feet)

Table 3-6 presents a summary of past thinnings by treatment. Treatment 1, which maintains the lowest stocking levels, had the greatest overall number of trees, basal area, and volume removed. While treatment 7, which maintains the greatest stocking levels as compared to the unthinned control, had the least overall number of trees, basal area, and volume removed. Treatments 3 and 5, which maintain intermediate stocking levels, had removal levels between those of treatments 1 and 7.

Table 3-6. Summary of all thinnings (excluding calibration) per treatment at Hoskins (Marshall et al., 1992). Five thinning treatments at stand ages 23, 27, 30, 32, and 36 years.

	Treatment			
	1	3	5	7
No. Trees	300	240	190	97
QMD (in.)	8.6	8.7	8.6	9.2
BA (sq. ft.)	121.5	99.5	76.6	44.5
Cu. ft.[1]	2181	1867	1475	880
Bd. ft.[2]	7935	6922	5954	3494

[1]Merchantable cubic foot volume per acre, 40 foot logs to a 5 inch inside bark top diameter. (cubic feet)
[2]Merchantable Scribner board foot volume per acre, 40 foot logs to a 5 inch inside bark top diameter. (Scribner board feet)

3.1.2 ORGANON Projected Stand Development

Tables 3-7 through 3-11 present projected Hoskins per acre stand summaries to a stand age of 100 years. The Western Willamette Valley version of ORGANON was used for all projections. LOGS remeasurement data collected at Hoskins following the 1993 growing season (stand age 50) was used as initial stand conditions for growth projections.

ORGANON projects mortality, crown recession, and diameter and height growth in 5-year increments.

Projected basal accumulation showed treatment 7 exceeding the control by stand age 60, treatment 5 exceeding the control by stand age 80, and treatment 3 exceeding the control by stand age 90. By stand age 100 the differences in basal area accumulation between treatments had narrowed. Differences between treatments 1 and 3 had only slightly narrowed from 54.2 sq. ft./acre at stand age 50 to 50.4 sq. ft./acre at stand age 100. Treatments 3 and 5 were projected to differ in basal area by 10.7 sq. ft./acre at stand age 100 as opposed to 43.0 sq. ft./acre at stand age 50. Treatments 5 and 7 showed differences similar to treatments 3 and 5, a difference of 10.3 sq. ft./acre at stand age 100 compared to 52.6 sq. ft./acre at stand age 50.

Projected diameter growth maintained the thinning effect found at stand age 50. Diameter growth increased with thinning intensity. By stand age 100 the mean diameter (QMD) on the control had increased to 20.5 inches, a diameter growth of 8.4 inches in 50 years. Mean diameter for treatment 7 (lightest thinning) was projected to grow 8.3 inches to a QMD of 24.3 inches by stand age 100. Treatment 1 (heaviest thinning), was projected to grow 11.8 inches to a QMD of 33.8 inches by stand age 100.

Projected standing cubic foot volume also maintained a similar thinning response as found at stand age 50. Standing gross cubic foot volume was reduced with increasing thinning intensity. Treatment 7 (lightest thinning) was projected to maintain the greatest standing cubic foot volume of all treatments through stand age 100. Projected standing cubic foot volume at stand age 100 for treatment 7 was 26,079 cu. ft./acre as compared to 24,834 cu. ft./acre for treatment 5, 23,777 cu. ft./acre for treatment 3, and 19,402 cu. ft./acre for treatment 1. Projected standing cubic foot volume for the control was 22,186 cu. ft./acre at stand age 100, exceeded by treatments 3, 5, and 7.

Height growth was projected to continue with small differences in HT40 between treatments. By stand age 100 all treatments were projected to have a mean height of close to 190 feet, a mean growth of approximately 66 feet in 50 years.

The control was projected to continue declining in density as measured by RD and SDI. By stand age 100, RD and SDI for the control decreased to an index of 71.0 and 446.3, respectfully. Treatment 7 was projected to reach a maximum stand density between ages 70 and 80 with RD and SDI values of 76.2 and 477.0, respectfully. All other treatments (1, 3, and 5) were projected to continue increasing in density.

Table 3-7. Hoskins per acre stand summary for treatment 1 as projected by ORGANON to a stand age of 100 years.

	Treatment 1	Stand Age (years)			
	60	70	80	90	100
HT40[1]	139	154	167	178	188
TPA[2]	51	50	49	48	47
QMD[3]	25.1	27.9	30.2	32.1	33.8
BA[4]	175.3	211.6	243.0	270.1	293.7
RD[5]	35.0	40.1	44.2	47.7	50.5
SDI[6]	223.8	259.0	287.6	312.0	333.3
Cu.[7]	8340	11245	14086	16837	19402
Bd.[8]	37695	54612	73193	90030	108077

[1]Height of the 40 largest trees per acre. (feet)
[2]Number of trees per acre.
[3]Quadratic mean diameter. (inches)
[4]Basal area per acre. (square feet)
[5]Relative density. (Curtis, 1982)
[6]Stand density index. (Reineke, 1933)
[7]Standing merchantable cubic foot volume per acre, 40 foot logs to a 5 inch inside bark top diameter. (cubic feet)
[8]Standing merchantable Scribner board foot volume per acre, 40 foot logs to a 5 inch inside bark top diameter. (Scribner board feet)

Table 3-8. Hoskins per acre stand summary for treatment 3 as projected by ORGANON to a stand age of 100 years.

	Treatment 3 Stand Age (years)				
	60	70	80	90	100
HT40[1]	141	156	168	180	189
TPA[2]	96	92	88	84	79
QMD[3]	21.2	23.3	25.1	26.7	28.2
BA[4]	235.3	273.1	302.7	325.8	344.1
RD[5]	51.1	56.6	60.4	63.1	64.8
SDI[6]	322.0	359.5	386.8	400.5	418.7
Cu.[7]	11766	15243	18414	21251	23777
Bd.[8]	54247	74567	95809	114368	131790

[1]Height of the 40 largest trees per acre. (feet)
[2]Number of trees per acre.
[3]Quadratic mean diameter. (inches)
[4]Basal area per acre. (square feet)
[5]Relative density. (Curtis, 1982)
[6]Stand density index. (Reineke, 1933)
[7]Standing merchantable cubic foot volume per acre, 40 foot logs to a 5 inch inside bark top diameter. (cubic feet)
[8]Standing merchantable Sçribner board foot volume per acre, 40 foot logs to a 5 inch inside bark top diameter. (Scribner board feet)

Table 3-9. Hoskins per acre stand summary for treatment 5 as projected by ORGANON to a stand age of 100 years.

	Treatment 5 Stand Age (years)				
	60	70	80	90	100
HT40[1]	143	157	170	181	190
TPA[2]	142	131	119	108	99
QMD[3]	18.8	20.7	22.4	24.1	25.6
BA[4]	274.9	305.2	327.0	342.9	354.8
RD[5]	63.4	67.1	69.1	69.8	70.1
SDI[6]	391.7	419.8	434.6	445.2	448.0
Cu.[7]	14083	17394	20246	22724	24834
Bd.[8]	65428	84798	104221	121296	136627

[1]Height of the 40 largest trees per acre. (feet)
[2]Number of trees per acre.
[3]Quadratic mean diameter. (inches)
[4]Basal area per acre. (square feet)
[5]Relative density. (Curtis, 1982)
[6]Stand density index. (Reineke, 1933)
[7]Standing merchantable cubic foot volume per acre, 40 foot logs to a 5 inch inside bark top diameter. (cubic feet)
[8]Standing merchantable Scribner board foot volume per acre, 40 foot logs to a 5 inch inside bark top diameter. (Scribner board feet)

Table 3-10. Hoskins per acre stand summary for treatment 7 as projected by ORGANON to a stand age of 100 years.

	Treatment 7 Stand Age (years)				
	60	70	80	90	100
HT40[1]	142	156	169	180	190
TPA[2]	184	162	143	127	113
QMD[3]	17.8	19.5	21.2	22.8	24.3
BA[4]	317.0	336.4	349.4	358.4	365.1
RD[5]	75.1	76.2	75.9	75.1	74.1
SDI[6]	463.5	472.9	477.0	476.0	471.9
Cu.[7]	16462	19503	22067	24196	26079
Bd.[8]	77168	94620	113475	128399	141640

[1]Height of the 40 largest trees per acre. (feet)
[2]Number of trees per acre.
[3]Quadratic mean diameter. (inches)
[4]Basal area per acre. (square feet)
[5]Relative density. (Curtis, 1982)
[6]Stand density index. (Reineke, 1933)
[7]Standing merchantable cubic foot volume per acre, 40 foot logs to a 5 inch inside bark top diameter. (cubic feet)
[8]Standing merchantable Scribner board foot volume per acre, 40 foot logs to a 5 inch inside bark top diameter. (Scribner board feet)

Table 3-11. Hoskins per acre stand summary for the unthinned control (treatment 9) as projected by ORGANON to a stand age of 100 years.

	Treatment 9	Stand Age (years)			
	60	70	80	90	100
HT40[1]	141	155	168	179	189
TPA[2]	295	236	195	164	141
QMD[3]	13.7	15.5	17.2	18.8	20.5
BA[4]	303.4	308.3	312.8	317.2	321.6
RD[5]	82.0	78.3	75.4	73.2	71.0
SDI[6]	488.3	477.7	464.9	451.7	446.3
Cu.[7]	14808	16946	18848	20571	22186
Bd.[8]	69634	81566	93934	106423	118645

[1]Height of the 40 largest trees per acre. (feet)
[2]Number of trees per acre.
[3]Quadratic mean diameter. (inches)
[4]Basal area per acre. (square feet)
[5]Relative density. (Curtis, 1982)
[6]Stand density index. (Reineke, 1933)
[7]Standing merchantable cubic foot volume per acre, 40 foot logs to a 5 inch inside bark top diameter. (cubic feet)
[8]Standing merchantable Scribner board foot volume per acre, 40 foot logs to a 5 inch inside bark top diameter. (Scribner board feet)

3.2 Log Grade Analysis

3.2.1 Log Grades From Thinning Treatments

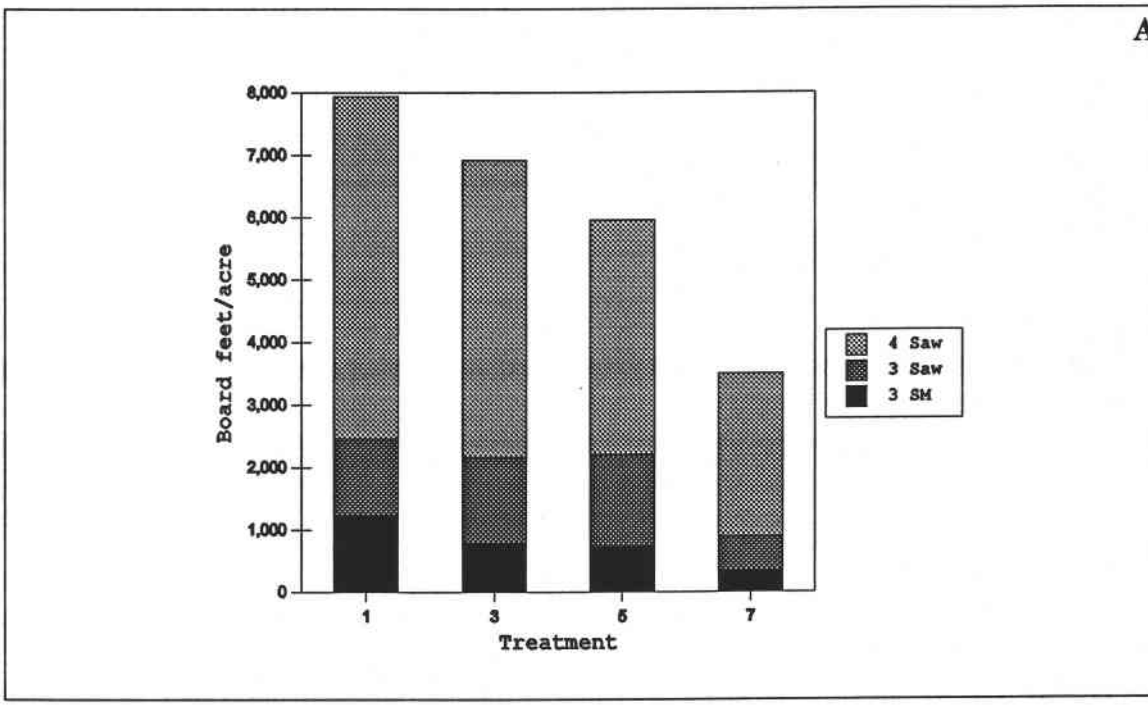
Figures 3-4 and 3-5 present total gross volume and gross dollar value per acre in domestic and export log grades potentially removed from all five thinnings by treatment (treatments 1, 3, 5, and 7). Losses in volume and value due to defect and breakage are assumed to be very minor (+/- 2.0%) were are not included in the results. In general, little merchantable volume was removed in thinnings. The volume which was removed is in low quality logs, mostly No. 4 Sawmill logs. Because these logs are low in quality they are of low value and as a result little dollar value was removed in thinnings.

Figure 3-4(A) gives total gross board foot volumes per acre removed for all thinnings in domestic log grades. Treatment 1 (heaviest thinning) had the greatest volume removed, with No. 4 Sawmill logs representing 68.9% of the total volume. Treatment 3 had 68.7% in No. 4 Sawmill logs. Treatment 5 had, 62.8% in No. 4 Sawmill logs. Treatment 7 (lightest thinning) had the least amount of volume removed, and the greatest percent in No. 4 Sawmill logs, 74.4%. For all treatments the remaining volume was divided between No. 3 Sawmill and No. 3 Special Mill logs.

Figure 3-5(A) gives total gross board foot volumes per acre removed for all thinnings in export log grades. Volumes removed in all treatments are the same as domestic log grades for No. 4 and No. 3 Sawmill log grades. The only export grade any log removed in all thinnings qualified for was Korean. Because only a small number of logs met export grade specifications, remaining volume and value was allocated to low quality domestic grades (No. 3 and 4 Sawmill). Treatment 1 had the greatest volume in Korean grade logs, 1228.00 bf./acre (15.5% of the total volume). While treatment 7 had the least, 340.00 bf./acre (9.7% of the total volume).

Figure 3-4(B) presents total gross dollar value per acre removed for all thinnings in domestic log grades. Thinning costs and revenues are not accounted for in the results. Trends in value of logs removed in thinnings are the same as with volume. Treatment 1 had the greatest potential value from thinnings, $4969.00/acre, 67.2% of total value from No. 4 Sawmill logs. Treatment 3 had a potential value of $4322.00/acre, 67.2% of total value from No. 4 Sawmill logs. Treatment 5 potential value was $3731.00/acre, with 61.2% of total value from No. 4 Sawmill logs. As with volume, treatment 7 had the least potential value from thinnings ($2175.00/acre) and the greatest proportion of volume allocated to No. 4 Sawmill logs (73.1%).

Figure 3-5(B) presents total gross dollar value per acre removed for all thinnings in export log grades. As with export log volumes, values removed in all treatments were the same as domestic log grades for No. 4 and 3 Sawmill log grades. Total export log values were greater than domestic log values due to Korean grade logs having a greater value than No. 3 Special Mill logs. Treatment 1 had the greatest value in Korean grade logs, $967.00/acre (18.9% of the total value). Treatment 3 had $620.00/acre in Korean grade logs (14.1% of total value). Treatment 5 had $578.00/acre in Korean grade logs (15.2% of total value). Treatment 7 had the least value in Korean grade logs, $268.00/acre (12.1% of total value).



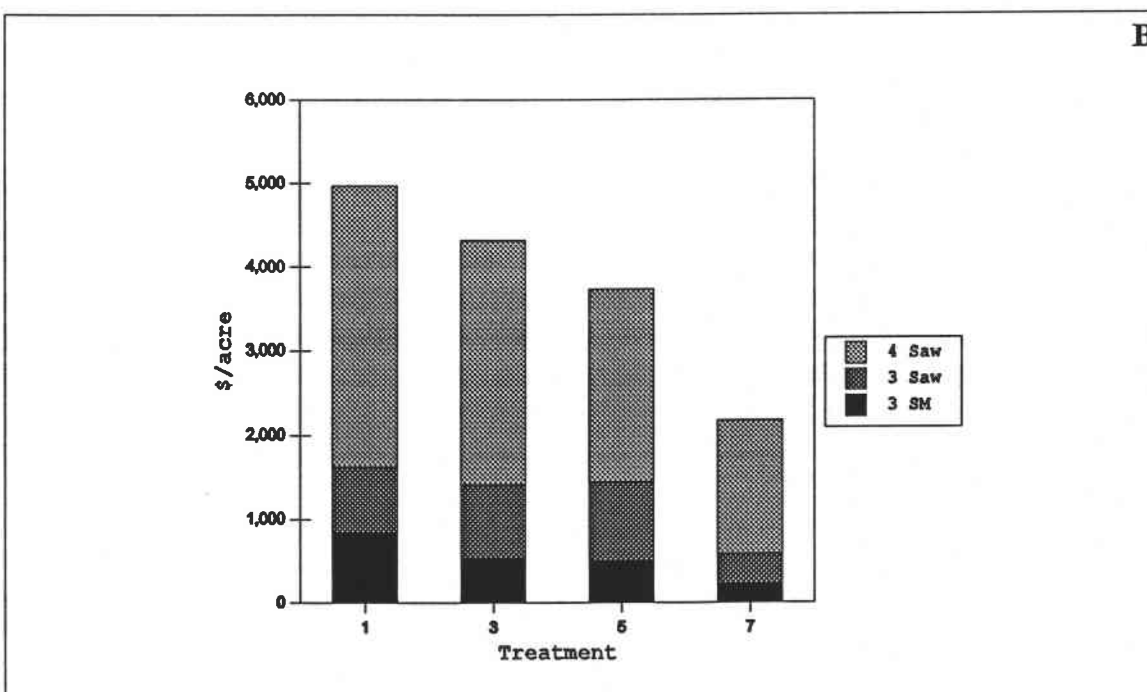


Figure 3-4. Board foot volume (A) and dollar value (B) per acre removed for all thinnings by treatment in domestic log grades.

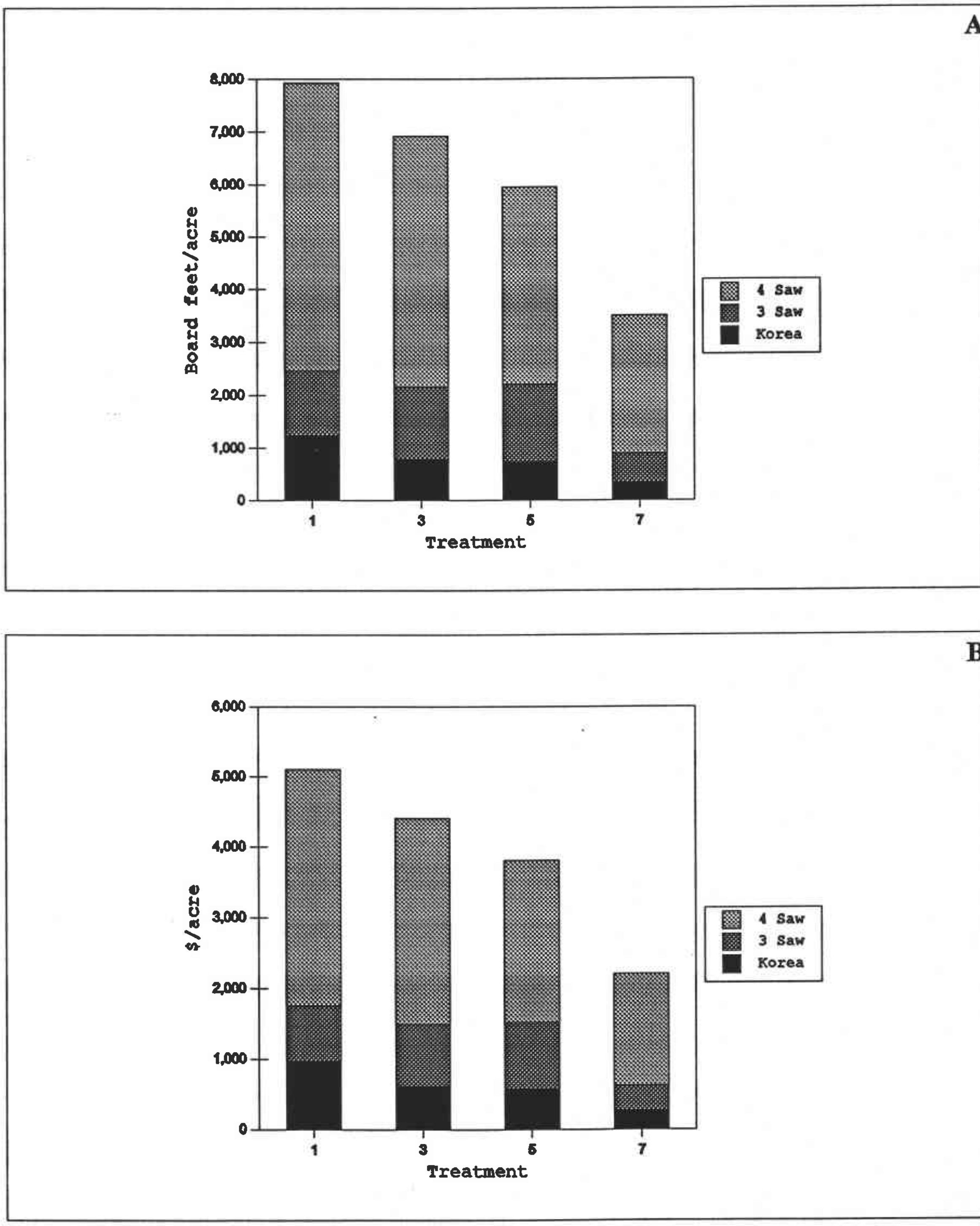


Figure 3-5. Board foot volume (A) and dollar value (B) per acre removed for all thinnings by treatment in export log grades.

3.2.2 Past Log Grades

Figures 3-6 and 3-7 present total standing volume and dollar value per acre in domestic and export log grades at stand age 30 for all treatments. Results are presented as standing volume and value, no adjustments are made for thinnings or mortality. Findings at stand age 30 are similar to the thinnings, most treatments had little merchantable volume which was mostly in low quality log grades. The majority of volume and value for each treatment was in No. 4 Sawmill logs.

Figure 3-6(A) gives standing merchantable board foot volumes per acre for all treatments in domestic log grades at stand age 30. Treatment 1 had the least total merchantable volume of all treatments, 4088.00 bf./acre, but also had the least amount of volume in No. 4 Sawmill logs, 55.4%. Treatment 3 had 6535.00 bf./acre, 57.4% in No. 4 Sawmill logs. Treatment 5 had 8510.00 bf./acre with 77.5% in No. 4 Sawmill logs. Treatment 7 had the greatest volume of all the thinning treatments, 10,991.00 bf./acre, with 69.2% in No. 4 Sawmill logs. The unthinned control had the greatest overall standing volume, 18,685.00 bf./acre, over 4.5 times greater than treatment 1 and 1.7 times greater than treatment 7. The unthinned control also had the greatest proportion of volume in No. 4 Sawmill logs (83.7%)

and the only treatment to have volume in higher quality No. 3 Special Mill logs (340.00 bf./acre, 1.8% of total volume).

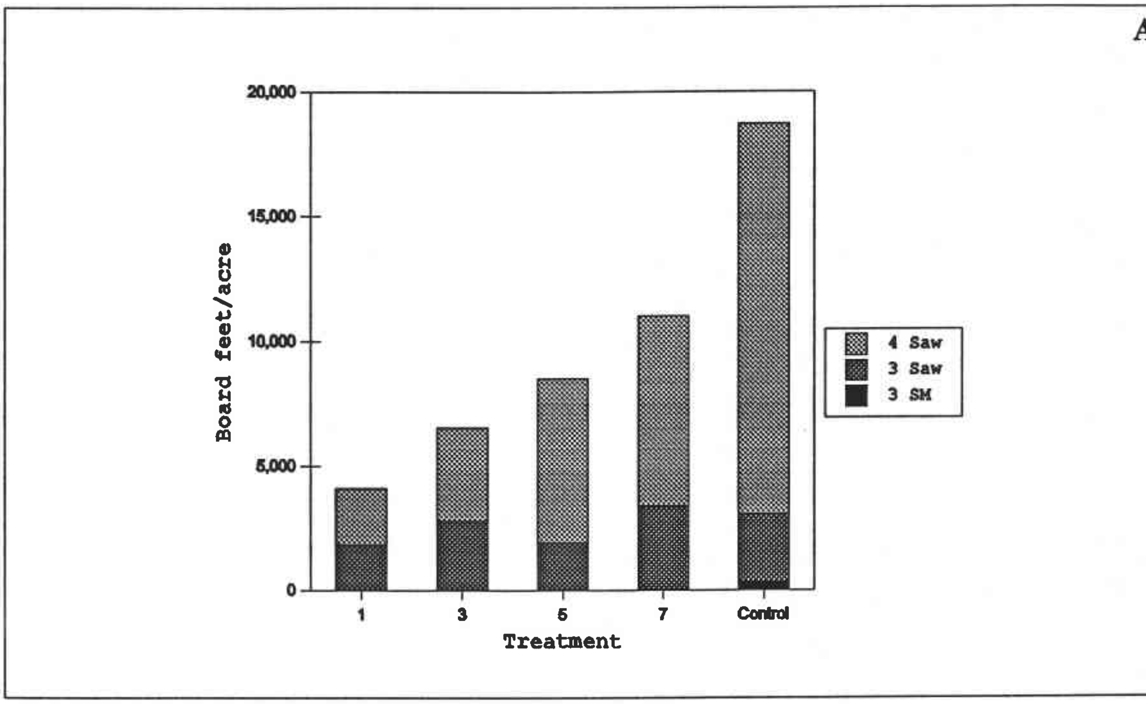
Figure 3-7(A) gives standing merchantable board foot volumes per acre for all treatments in export log grades at stand age 30. Total volume and allocation to No. 4 and No. 3 Sawmill log grades in all treatments was identical to domestic log grade volumes. The only difference was in the unthinned control, the volume allocated to No. 3 Special Mill (340.00 bf./acre) domestic logs is now allocated to the Korean export grade.

Figure 3-6(B) presents total gross dollar value per acre for all treatments in domestic log grades at stand age 30. Values are gross, costs were not included in the analysis. As with the thinnings, value was highly related to volume, trends found within and between treatments for volumes were the same for value. Value was allocated between No. 4 and 3 Sawmill logs for all treatments with No. 4 Sawmill logs getting the majority of value. The unthinned control had a small percent of value in No. 3 Special Mill logs ($231.00/acre, 2.0% of total), while the remaining value was in No. 4 and 3 Sawmill logs.

Treatment 1 had the least potential total value at stand age 30, $2551.00/acre. Treatments 3 and 5 had an intermediate potential value of $4074.00/acre and

$5254.00/acre, respectfully. Treatment 7 had the greatest potential value of the thinning treatments, $6813.00/acre. The unthinned control had the greatest overall potential value, $11,519.00/acre.

Figure 3-7(B) gives total gross dollar value per acre for all treatments in export log grades at stand age 30. Total value and allocation to No. 4 and 3 Sawmill log grades in all thinning treatments was identical to domestic log grade values. The only difference was in the unthinned control, the value of volume in Korean export grade was $268.00/acre resulting in a total value of $11,556.00/acre. $37.00/acre greater than the unthinned control with domestic log grades only.



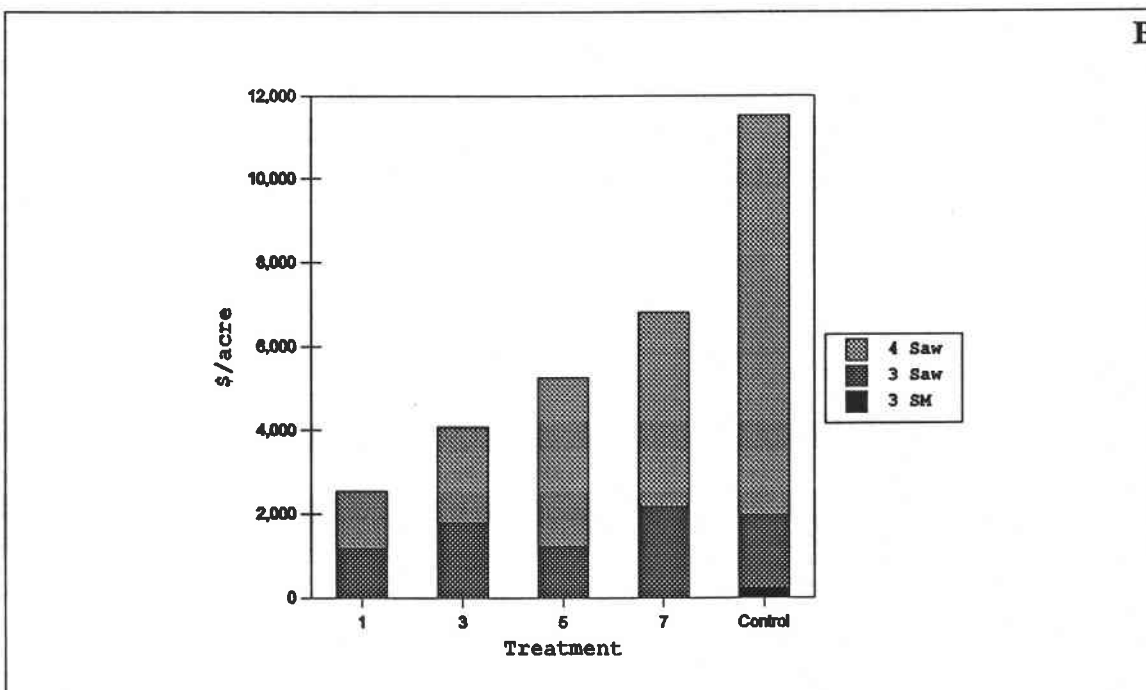


Figure 3-6. Board foot volume (A) and dollar value (B) per acre by treatment in domestic log grades at stand age 30.

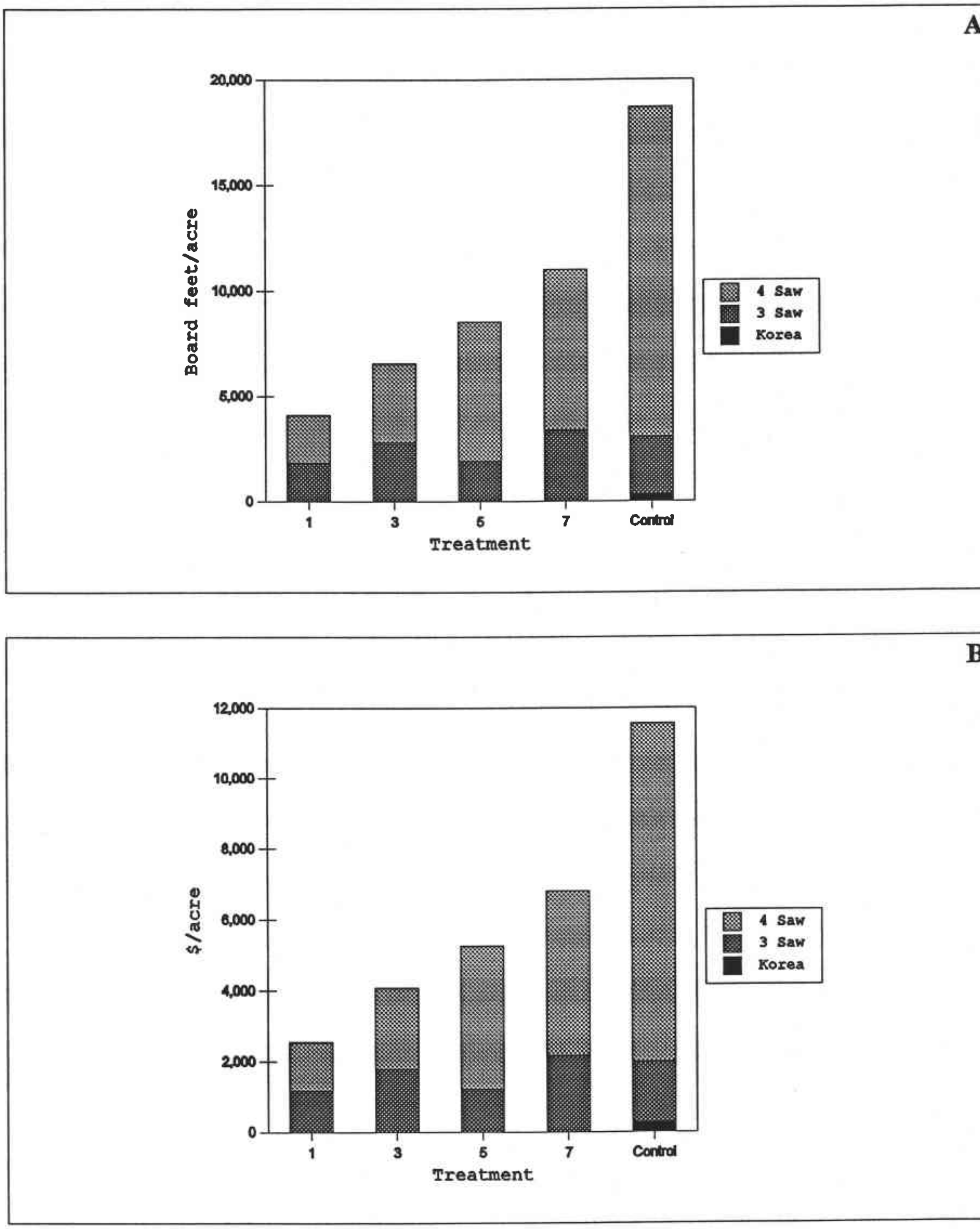


Figure 3-7. Board foot volume (A) and dollar value (B) per acre by treatment in export log grades at stand age 30.

3.2.3 Current log Grades

Figures 3-8 and 3-9 present standing volume and dollar value per acre in domestic and export log grades at stand age 50 for all treatments. Findings at stand age 50 indicated improving log quality as the majority of merchantable volume moved to No. 2 Sawmill and China grade logs for the thinning treatments. Increases in standing volume and improved log quality resulted in increased total dollar values for all treatments.

Figure 3-8(A) gives results in standing merchantable board foot volume per acre by treatment at stand age 50 in domestic log grades. Previously established trends in total volume differences between treatments remained intact at this time. Treatment 1 continued to carry the least total standing volume of all treatments (23,761.00 bf./acre) but had the greatest proportion of volume in higher quality No. 2 Sawmill logs (71.0%). Treatment 3 had 35,324.00 bf./acre, 61.2% in No. 2 Sawmill logs. Treatment 5 had 44,942.00 bf./acre, 48.9% in No. 2 Sawmill logs. Treatment 7 continued to carry the greatest total standing volume (56,461.00 bf./acre), and the least amount of volume in No. 2 Sawmill logs (43.8%) of all thinning treatments. The unthinned control had the greatest overall total standing volume (57,646.00 bf./acre) and the least amount of volume allocated to No. 2 Sawmill logs (15.8%).

Figure 3-9(A) presents standing merchantable board foot volume per acre by treatment at stand age 50 in export log grades. To clarify presentation, several export grades were grouped into one grade. The Japan 12" A sort and Japan 12" B sort were combined and presented as Japan 12". Japan 8" A sort and Japan 8" B sort were combined into Japan 8". Low quality logs which did not meet export log grade criteria were graded as domestic No. 3 or No. 4 Sawmill logs which are then grouped together and presented as Domestic grade logs.

Similar trends found in domestic log grades were also found in export log grades. The No. 2 Sawmill logs were essentially replaced by China grade export logs. Treatment 1 had 73.8% of total volume in China grade logs. The other thinning treatments had 62.9% (treatment 3), 48.9% (treatment 5), and 44.3% (treatment 7) of their total volume in China grade logs. The unthinned control had only 15.2% of its volume in China grade logs.

Some high quality Japan grade export logs were beginning to appear in treatments 3, 5, 7, and the unthinned control. Treatment 3 had 193.00 bf./acre (0.5%), treatment 5 had 3415.00 bf./acre (7.6%), and treatment 7 had 4862.00

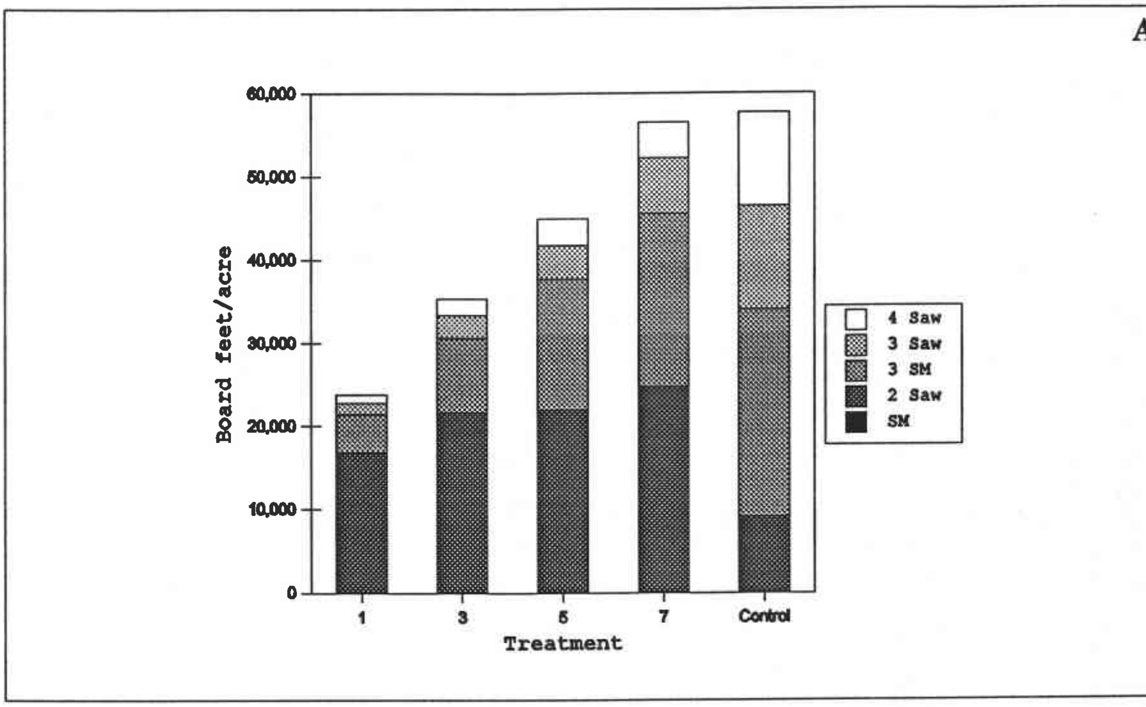
bf./acre (8.6%) in Japan 8" grade. The unthinned control had the greatest overall volume in Japan grade logs, 11,412.00 bf./acre (19.8%) in Japan 8" and 327.00 bf./acre (0.6%) in Japan 12".

Figure 3-8(B) presents results in gross dollar value per acre by treatment at stand age 50 in domestic log grades. Allocation of dollar value into to the various log grades within and between treatments was closely related to standing volume.

At stand age 50 treatment 1 had the least gross dollar value at $16,672.00/acre, 72.7% in No. 2 Sawmill logs. Treatment 3 had a total value of $24,587.00/acre, 63.1% in No. 2 Sawmill logs. Treatment 5 had a total value of $30,998.00/acre, 50.9% in No. 2 Sawmill logs. Treatment 7 now had the greatest overall total value in domestic log grades, $38,749.00/acre, 45.8% in No. 2 Sawmill logs. The unthinned control was close behind treatment 7 in value at $38,251.00/acre, 17.1% in No. 2 Sawmill logs.

Figure 3-9(B) presents results in gross dollar value per acre by treatment at stand age 50 in export log grades. Differences in total value between domestic and export log grades became evident now. When export log grades were used, total value was greater than domestic values for all treatments. Treatment 1 had the least total value at

$20,077.00/acre. Treatment 3 had a total value of $29,458.00/acre and treatment 5 had a total value of $36,924.00/acre. Treatment 7 had the greatest total value of all treatments, $45,946.00/acre. The unthinned control had a total value of $44,118.00/acre.



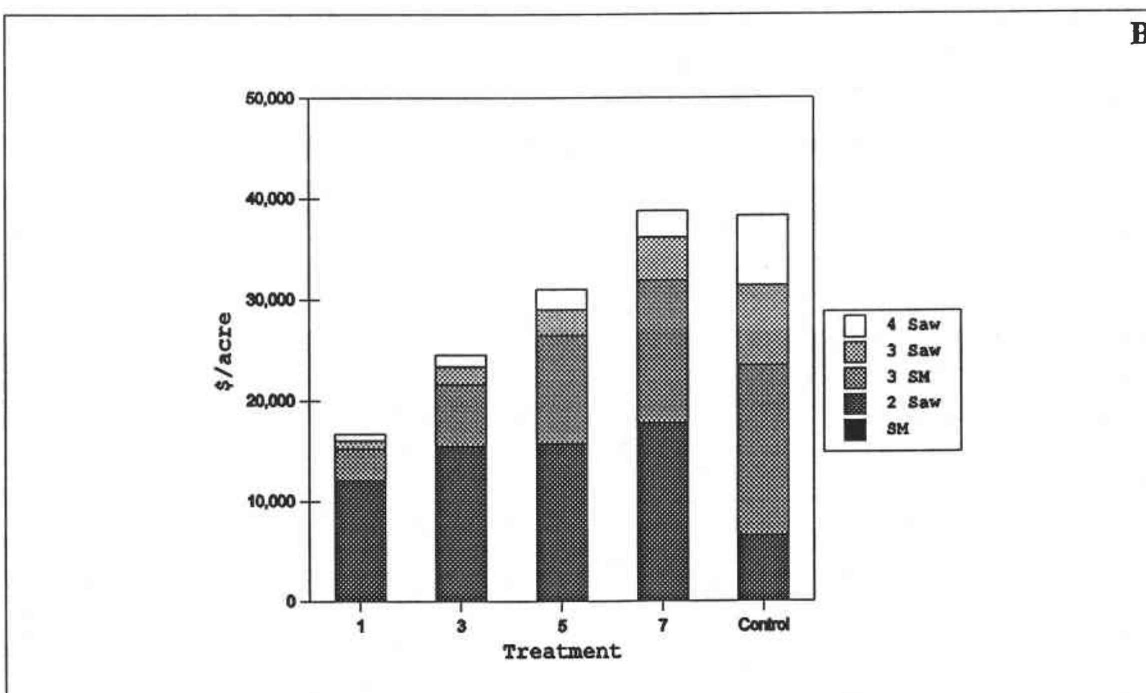
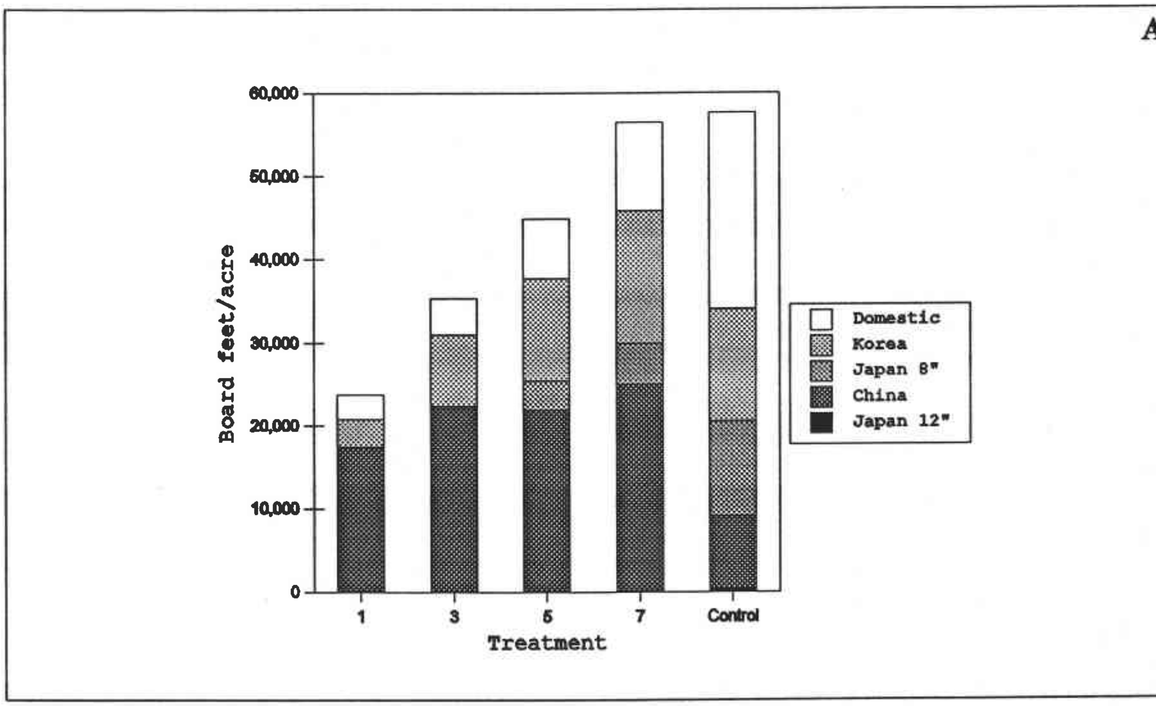


Figure 3-8. Board foot volume (A) and dollar value (B) per acre by treatment in domestic log grades at stand age 50.



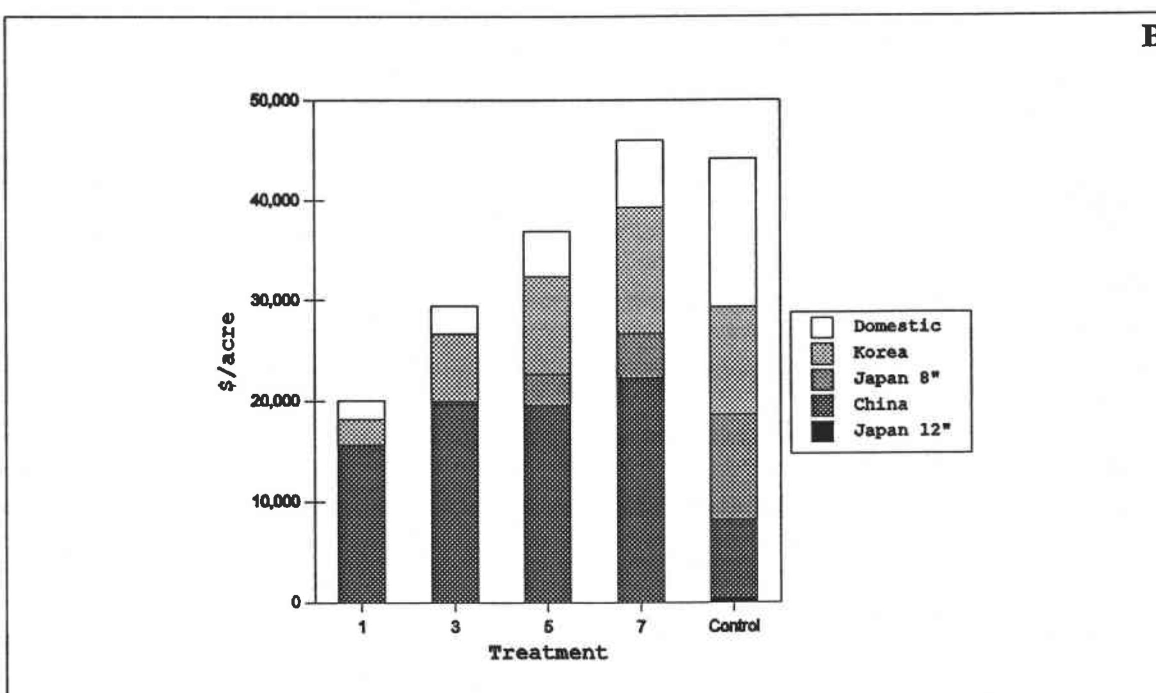


Figure 3-9. Board foot volume (A) and dollar value (B) per acre by treatment in export log grades at stand age 50.

3.2.4 Future Log Grades

Figures 3-10 and 3-11 present standing volume and dollar value per acre in domestic and export log grades at stand age 100 for all treatments. Findings at stand age 100 suggested that log quality greatly improves with 50 additional years of stand growth. The majority of merchantable volume had moved to No. 2 Sawmill and Special Mill for domestic log grades and Japan 12" for export grades.

Figure 3-10(A) presents results in standing merchantable board foot volume per acre by treatment at stand age 100 in domestic log grades. Trends found at stand age 50 in total volume differences between thinning treatments were projected to continue, however the magnitude of difference was diminished. Treatment 1 continued to carry the least total standing volume of all treatments (108,078.00 bf./acre) with 97.2% of total volume in high quality No. 2 Sawmill and Special Mill log grades. However, treatment 1 had the least amount of volume allocated to Special Mill logs (24.1%). Treatment 3 had 131,790.00 bf./acre, 94.6% of which is in No. 2 Sawmill and Special Mill logs. Treatment 5 had 136,627.00 bf./acre, 91.6% in No. 2 Sawmill and Special Mill logs. Treatment 7 now had the greatest total standing volume of all treatments

(141,639.00 bf./acre), and had the greatest volume in Special Mill logs (46.8%). The unthinned control now ranked behind treatments 3, 5, and 7 in total standing volume (118,645.00 bf./acre) and had the least amount of volume allocated to No. 2 Sawmill and Special Mill logs (80.7%).

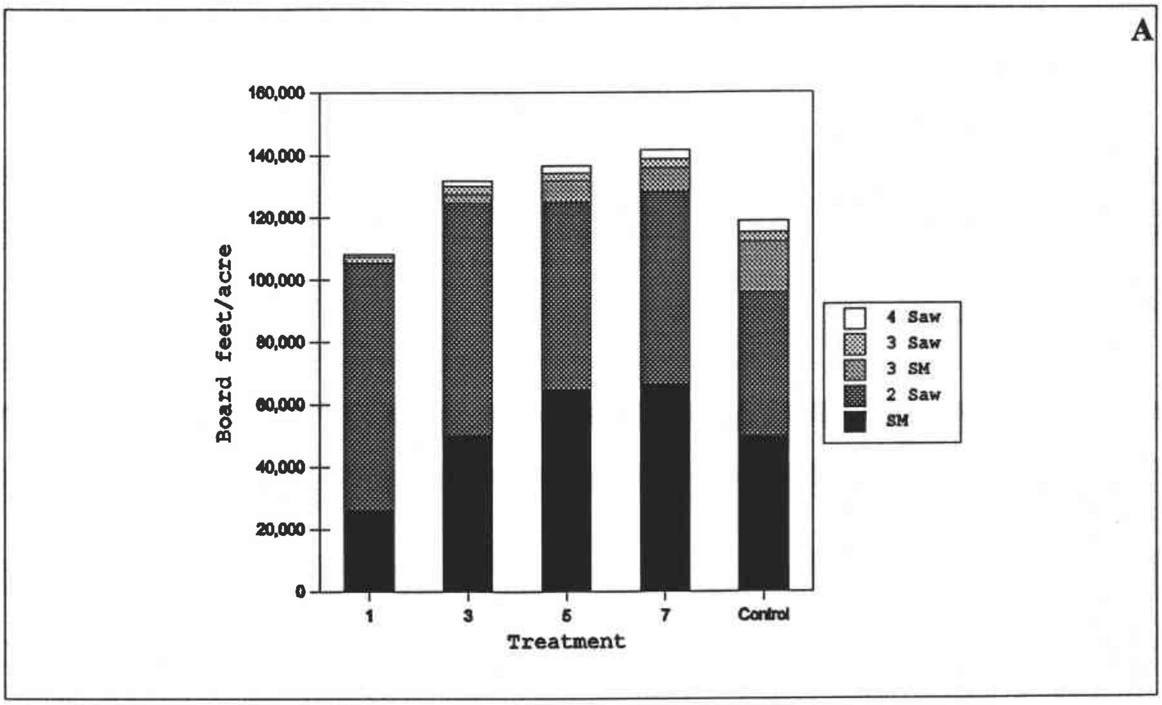
Figure 3-11(A) presents standing merchantable board foot volume per acre by treatment at stand age 100 in export log grades. As with export log grades at stand age 50, the combined grades of Domestic, Japan 8", and Japan 12" were used. Projected export log grades at stand age 100 showed improvements in log quality similar to domestic grades. The No. 2 Sawmill and Special Mill logs were almost entirely replaced by Japan 12" export grade logs with the remainder in China grade. Treatment 1 had 32.2% of total volume in Japan 12". The other thinning treatments had 85.4% (treatment 3), 88.9% (treatment 5), and 88.9% (treatment 7) of their total volume in Japan 12" logs. The unthinned control had 80.2% of its total volume in Japan 12" grade logs.

Figure 3-10(B) presents results in total gross dollar value per acre by treatment at stand age 100 in domestic log grades. Allocation of dollar value into the various log grades within and between treatments continued to be closely related to volume. Of the thinning treatments, those which had the greatest standing volume continued to have the greatest value.

At stand age 100 treatment 1 had a gross dollar value of $79,957.00/acre, 97.6% in No. 2 Sawmill and Special Mill logs. Treatment 3 had a value of $99,179.00/acre, 95.4% in No. 2 Sawmill and Special Mill logs. Treatment 5 had a value of $103,851.00/acre, 92.7% in No. 2 Sawmill and Special Mill logs. Treatment 7 continued to have the greatest overall total value in domestic log grades, $107,492.00/acre, 91.8% in No. 2 Sawmill and Special Mill logs. As with volume, the unthinned control ranked behind treatments 3, 5, and 7 in value at $88,913.00/acre, 82.9% in No. 2 Sawmill and Special Mill logs.

Figure 3-11(B) gives results in total gross dollar value per acre by treatment at stand age 100 in export log grades. Differences in total dollar value between domestic and export log grades increased from stand age 50. Treatment 1 had the least total value at $116,635.00/acre, 71.2% in Japan 12" logs. Treatment 3 had a total value of $153,252.00/acre, 89.7% in Japan 12" logs. Treatment 5 had a total value of $160,388.00/acre, 92.7% in Japan 12" logs. As with domestic value, treatment 7 had the greatest total value of all treatments, $167,637.00/acre, 92.8% in Japan

12" logs. The unthinned control had a total value of $136,673.00/acre, 86.4% in Japan 12" logs.



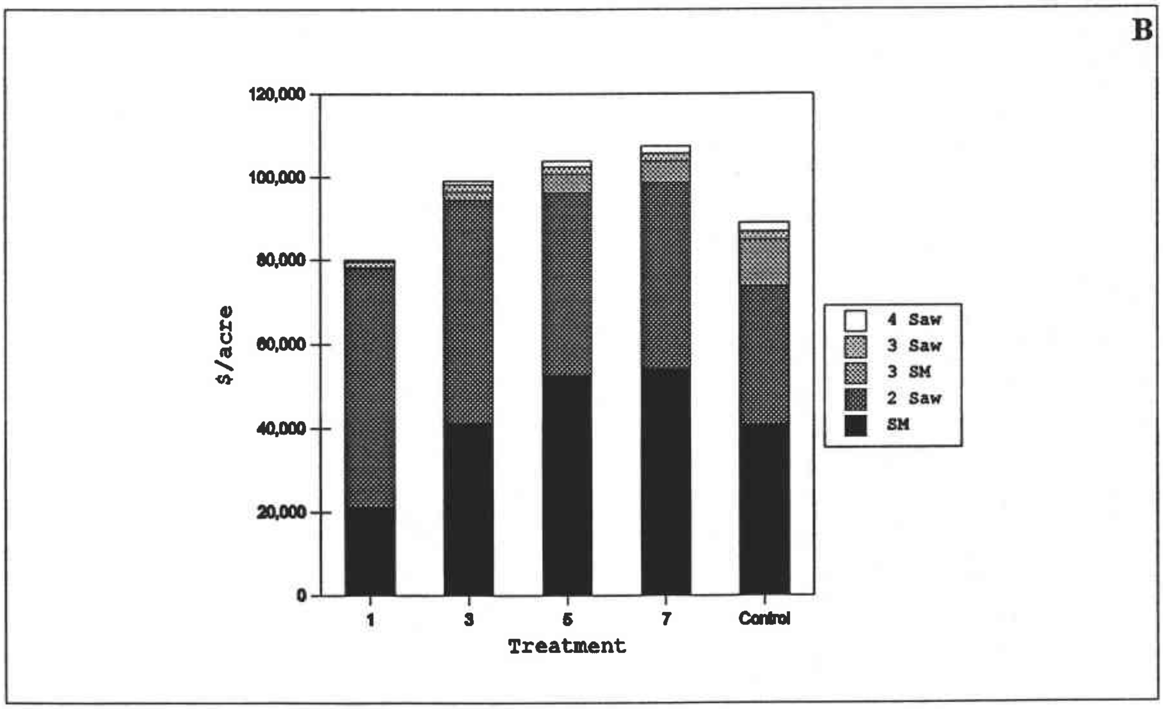
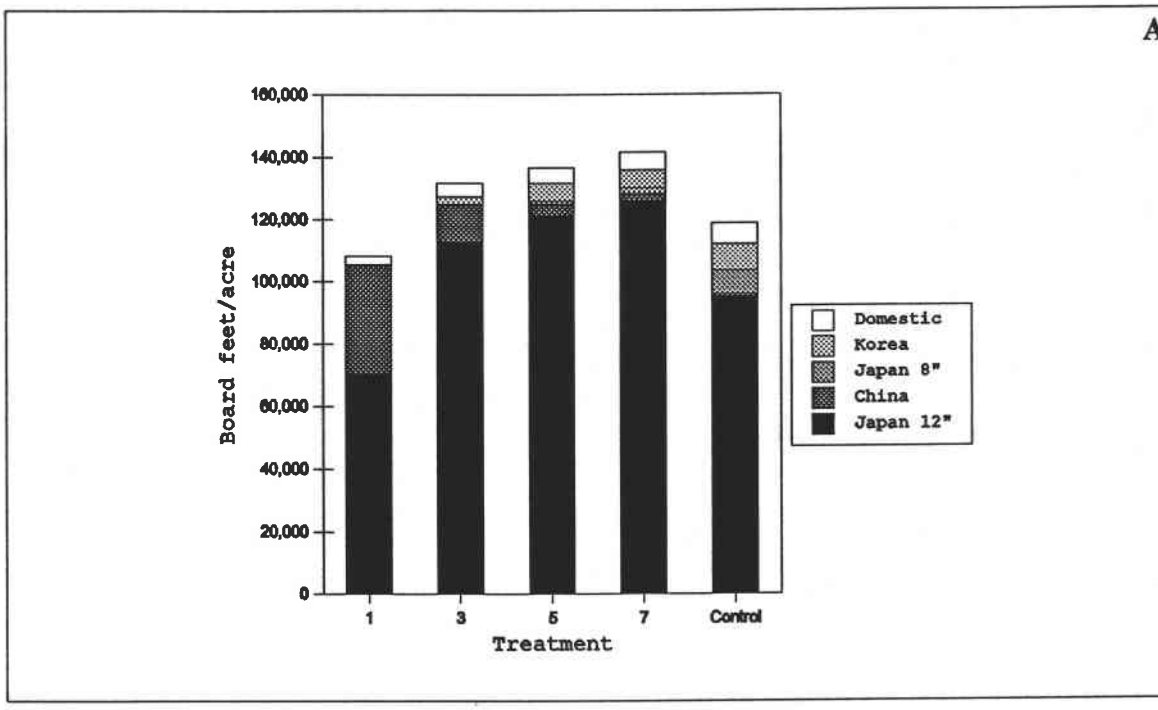


Figure 3-10. Board foot volume (A) and dollar value (B) per acre by treatment in domestic log grades at stand age 100.



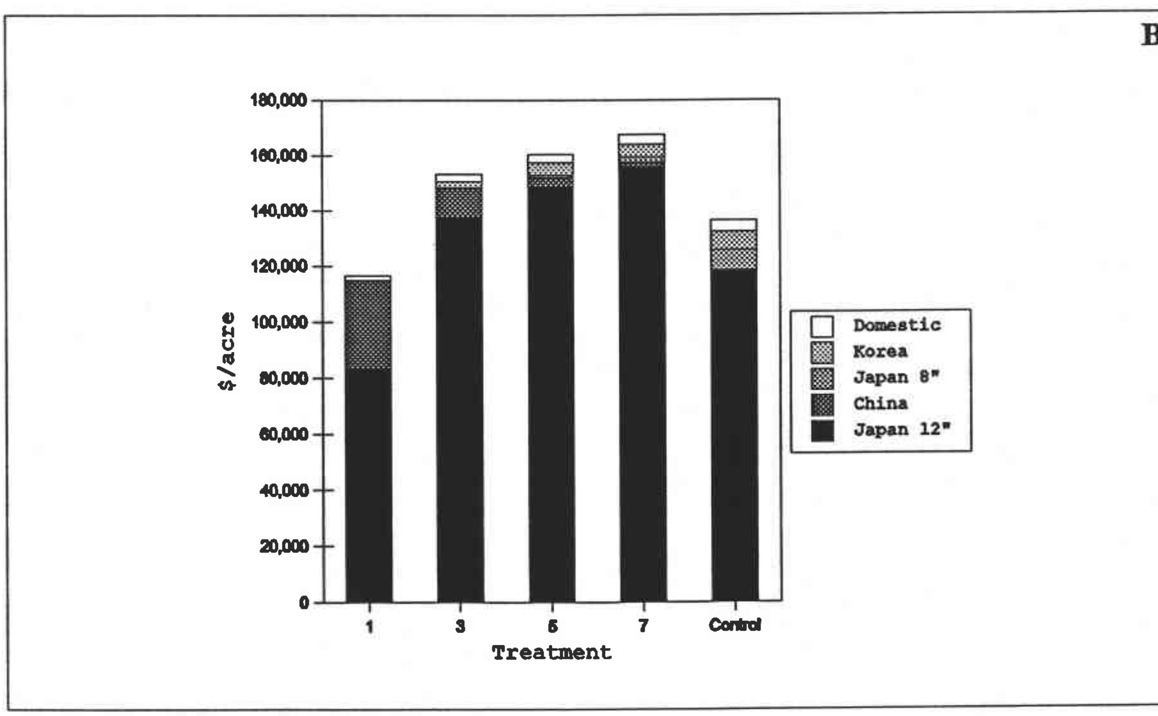


Figure 3-11. Board foot volume (A) and dollar value (B) per acre by treatment in export log grades at stand age 100.

3.2.5 Log Grades Through All Time Periods

Figure 3-12 presents standing merchantable board foot volume per acre by treatment from stand age 20 to 100 years. This figure shows how standing volume accumulated for each treatment. Actual volumes were used up to stand age 50, ORGANON projections were used from age 50 to 100 years. The unthinned control maintained the greatest standing volume until approximately stand age 52 at which time volume on treatment 7 (the lightest thinning) exceeded the control. From this point on, treatment 7 maintained the greatest standing volume to stand age 100. Treatment 1 (the heaviest thinning) maintained the least standing volume throughout the entire analysis period.

Figure 3-13 shows the mean annual increment (MAI) in merchantable board feet per acre for stand age 20 through 100 years. Annual increment on the unthinned control was the first of all treatments to slow down and had essentially flattened-out by about stand age 50. Treatment 7 was shown to have the greatest MAI of all the thinning treatments at stand age 100 but also had flattened-out by about stand age 80. Treatments 1, 3, and 5 continued to gain in MAI at stand age 100 but at a diminished rate.

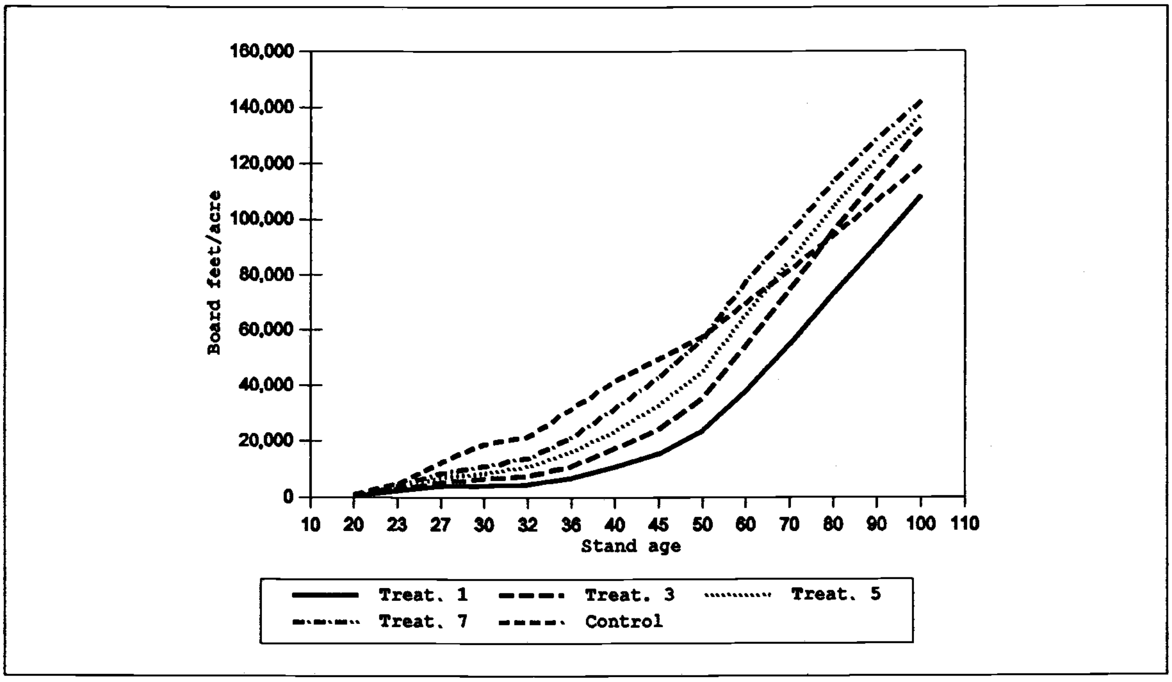


Figure 3-12. Total standing merchantable board foot volume per acre through time.

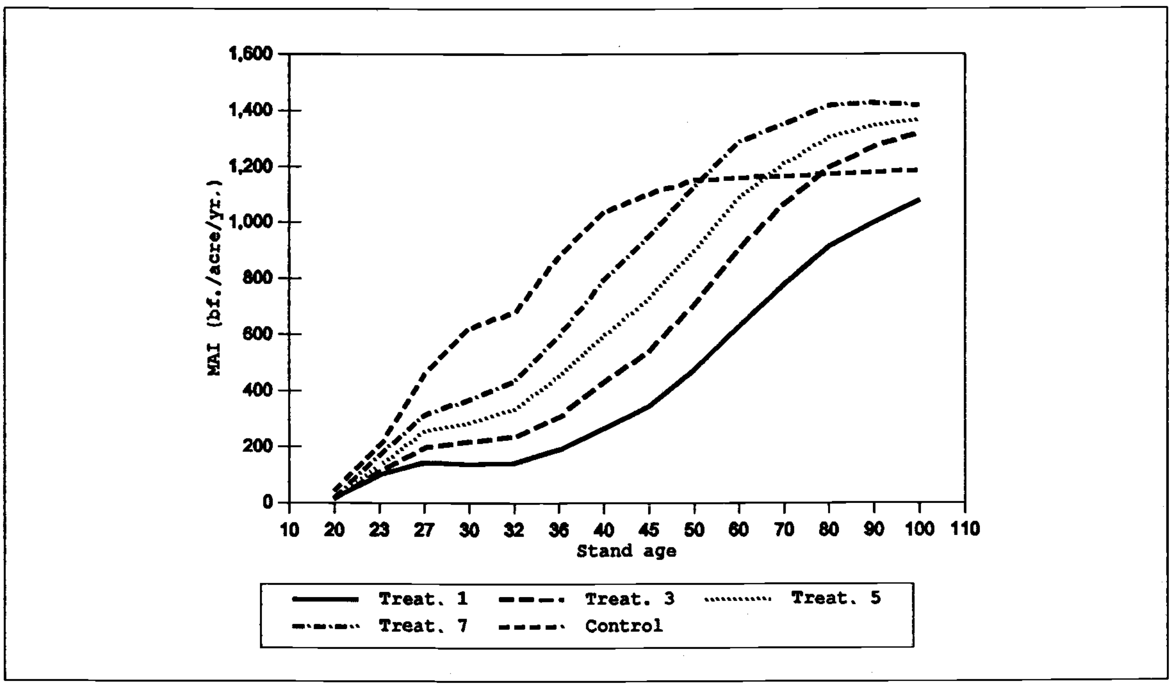


Figure 3-13. Standing merchantable volume MAI (board feet/acre/year) through time.

Total gross dollar value per acre through time for domestic log grades by treatment is presented in Figure 3-14. The same trends found in cumulative volume production were found in value. The unthinned control dropped behind treatment 7 at stand age 50. The thinning treatments continued to gain in value and by stand age 80, treatments 3 and 5 had also exceeded the control in total value. Treatment 1 maintained the least total value though-out the entire 80 year analysis period.

Figure 3-15 presents dollar value MAI for domestic log grades by treatment through time. The relationship between treatments was similar as found with volume MAI in Figure 3-13. The unthinned control had fallen behind treatments 3, 5, and 7 in value increment by stand age 50. By stand age 100 value increment had not flattened-out for any of the treatments as with volume increment. All treatments were increasing in value at a faster rate than volume.

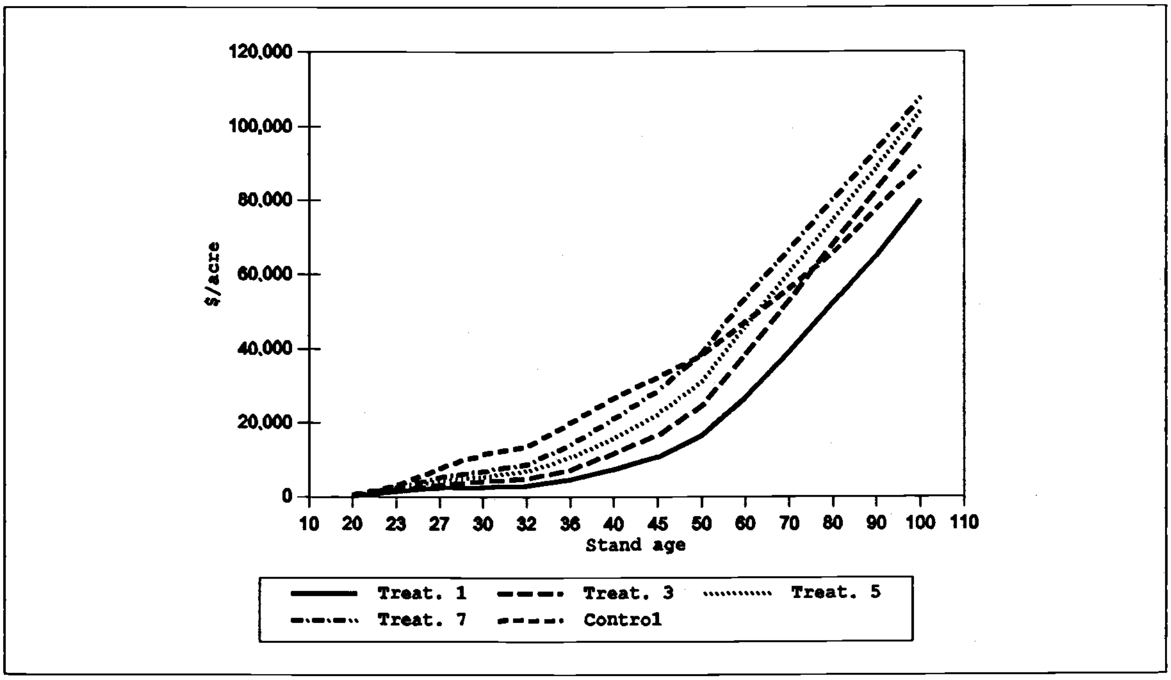


Figure 3-14. Gross dollar value per acre for domestic log grades through time by treatment.

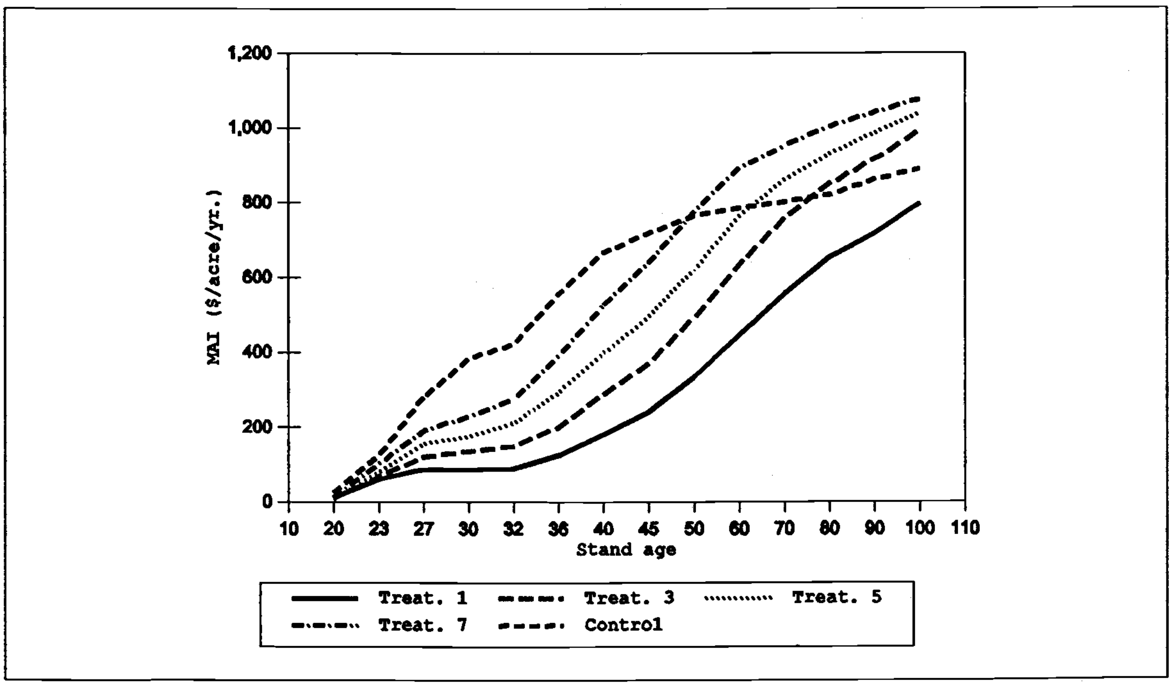


Figure 3-15. Value MAI ($/acre/year) by treatment for domestic log grades through time.

Total gross dollar value per acre through time for export log grades by treatment is presented in Figure 3-16. As with value in domestic log grades, the unthinned control dropped behind treatment 7 in total value at stand age 50 and treatments 3 and 5 by stand age 80. Treatment 1 maintained the least total value though-out the entire analysis. After stand age 50 export values were consistently greater than domestic values for the same treatment.

Figure 3-17 presents dollar value MAI for export log grades by treatment through time. The relationship between treatments was similar as found with volume MAI in Figure 3-13 and domestic value MAI in Figure 3-15. After about stand age 47 the unthinned control had fallen behind treatment 7 in value increment and behind treatments 3 and 5 by approximately stand age 77. As with value MAI for domestic log grades, value increment had not flattened-out for any of the treatments like volume increment and continues increasing. All treatments were increasing in value at a greater rate then value in domestic log grades.

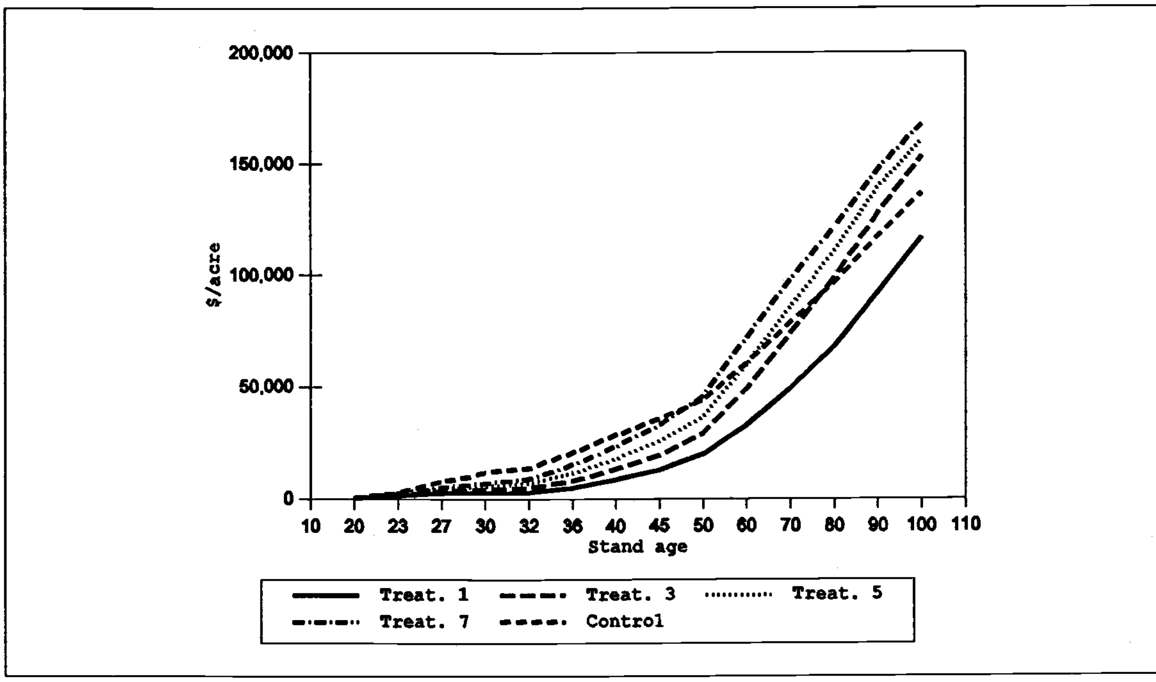


Figure 3-16. Total gross dollar value per acre for export log grades by treatment through time.

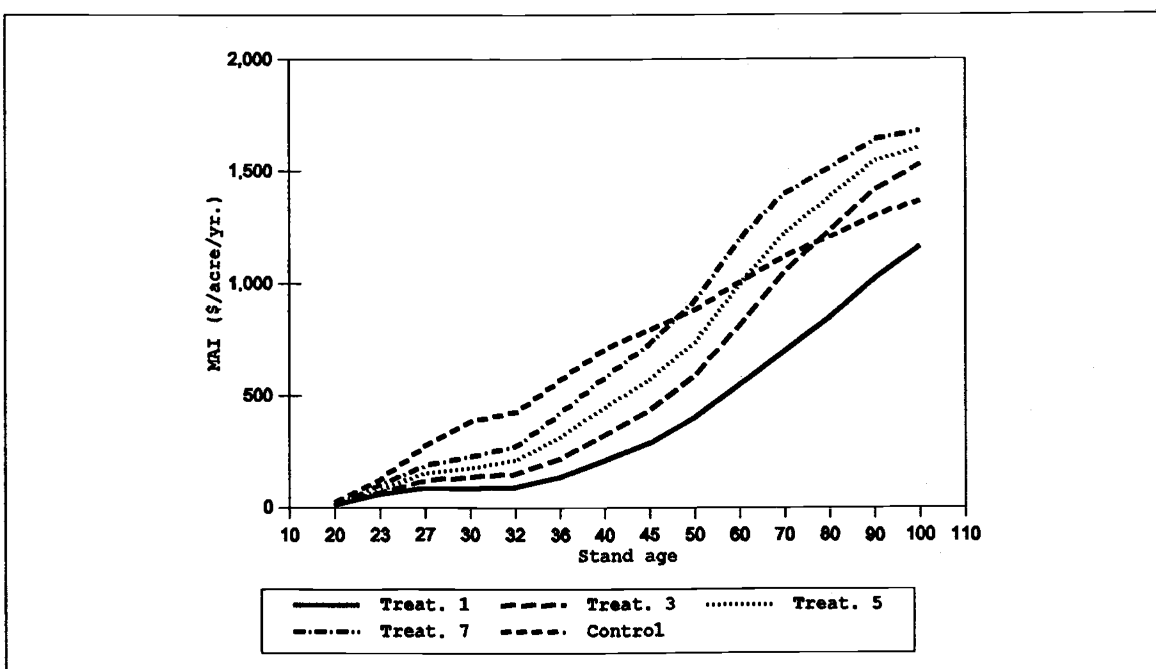


Figure 3-17. Value MAI ($/acre/year) for export log grades by treatment through time.

Figures 3-18 through 3-23 present results in percent standing volume yield through time in domestic and export log grades for treatments 1, 7, and the unthinned control. These graphs illustrate development of specific log grades through time relative to each other within and between treatments. Figures 3-18, 3-20, and 3-22 are in domestic log grades and Figures 3-19, 3-21, and 3-23 are in export log grades.

In figure 3-18, from stand age 20 to 27 essentially 100% of the total standing volume was in No. 4 Sawmill logs for treatment 1. No. 3 Sawmill logs rapidly replaced No. 4 Sawmill logs, closely followed by No. 3 Special Mill until about stand age 45 when No. 2 Sawmill logs dominated. No. 2 Sawmill logs consumed the majority of the volume until stand age 100 when Special Mill logs began to appear. Treatments 7 (Figure 3-20) and the control (Figure 3-22) followed similar paths as treatment 1 but at different rates and quantities. Treatment 1 was characterized by rapid grade changes as compared to the other treatments. The low quality grades occupied a larger percent of the total volume longer for treatments 7 and the control. But the Special Mill grade was increasing faster and in larger quantities for treatments 7 and the control as the stands approached 100-years-old.

Figures 3-19, 3-21, and 3-23 present percent volume yield in export log grades for treatments 1, 7, and the control. Treatment 1 (Figure 3-19) displayed very similar characteristics as the same treatment with domestic log grades (Figure 3-18), early occupance by low quality grades and rapid transition to higher quality logs. By stand age 45 China grade logs occupied most of the volume and by stand age 80 the high quality Japan 12" grade logs increased rapidly. As with domestic grades, treatments 7 (Figure 3-21) and the control (Figure 3-23) developed similar to treatment 1 but at different rates and quantities. The transition from China to Japan 12" grade logs happened much faster for treatments 7 and the control. The control had a fairly wide band of the high quality Japan 8" logs which was minimal on treatments 1 and 7.

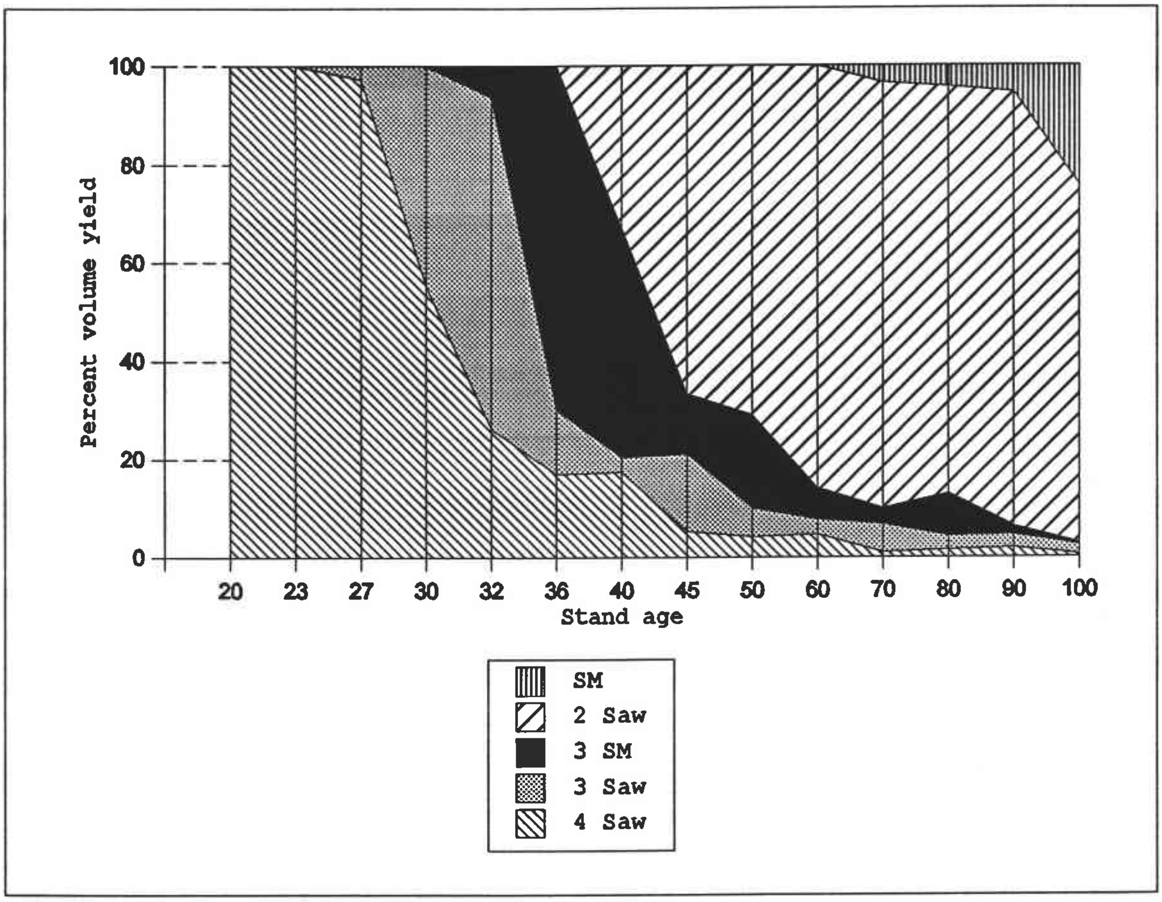


Figure 3-18. Percent volume yield through time in domestic log grades, treatment 1.

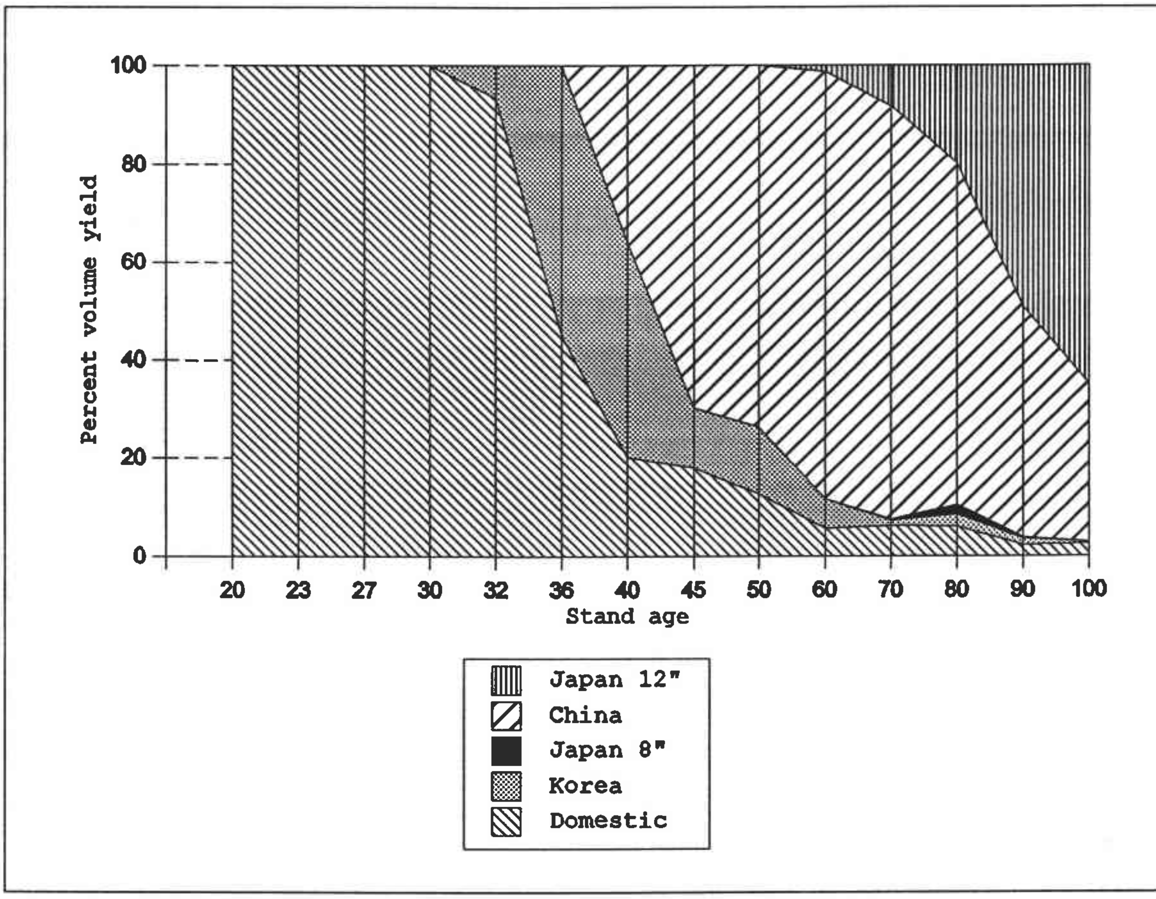


Figure 3-19. Percent volume yield through time in export log grades, treatment 1.

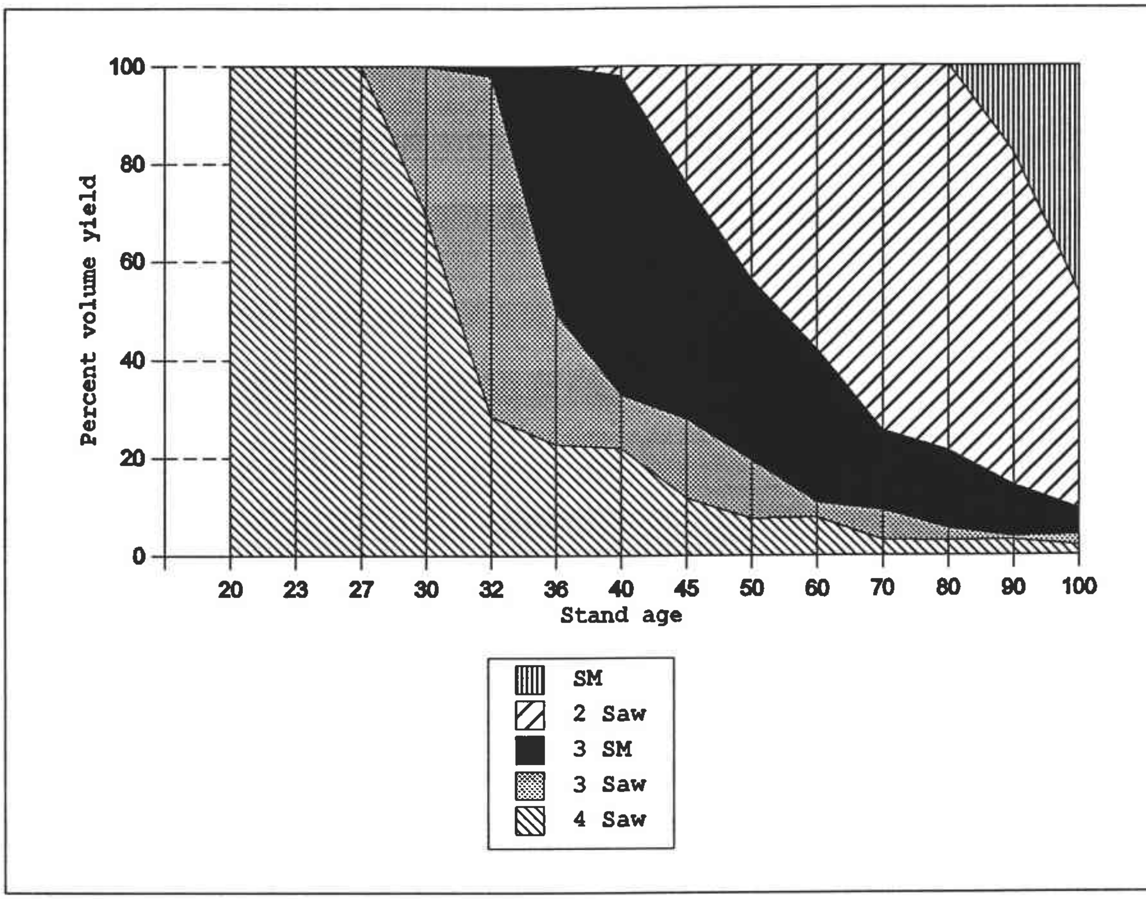


Figure 3-20. Percent volume yield through time in domestic log grades, treatment 7.

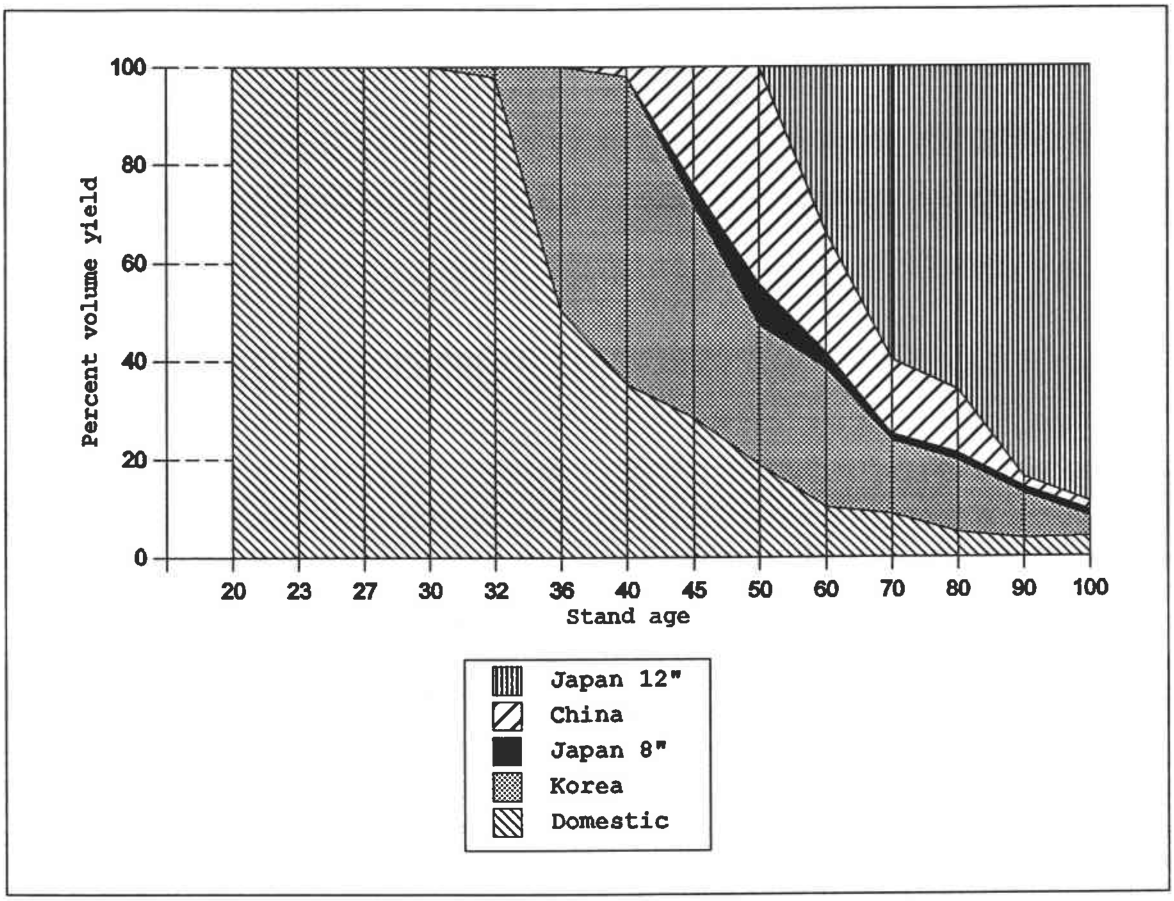


Figure 3-21. Percent volume yield through time in export log grades, treatment 7.

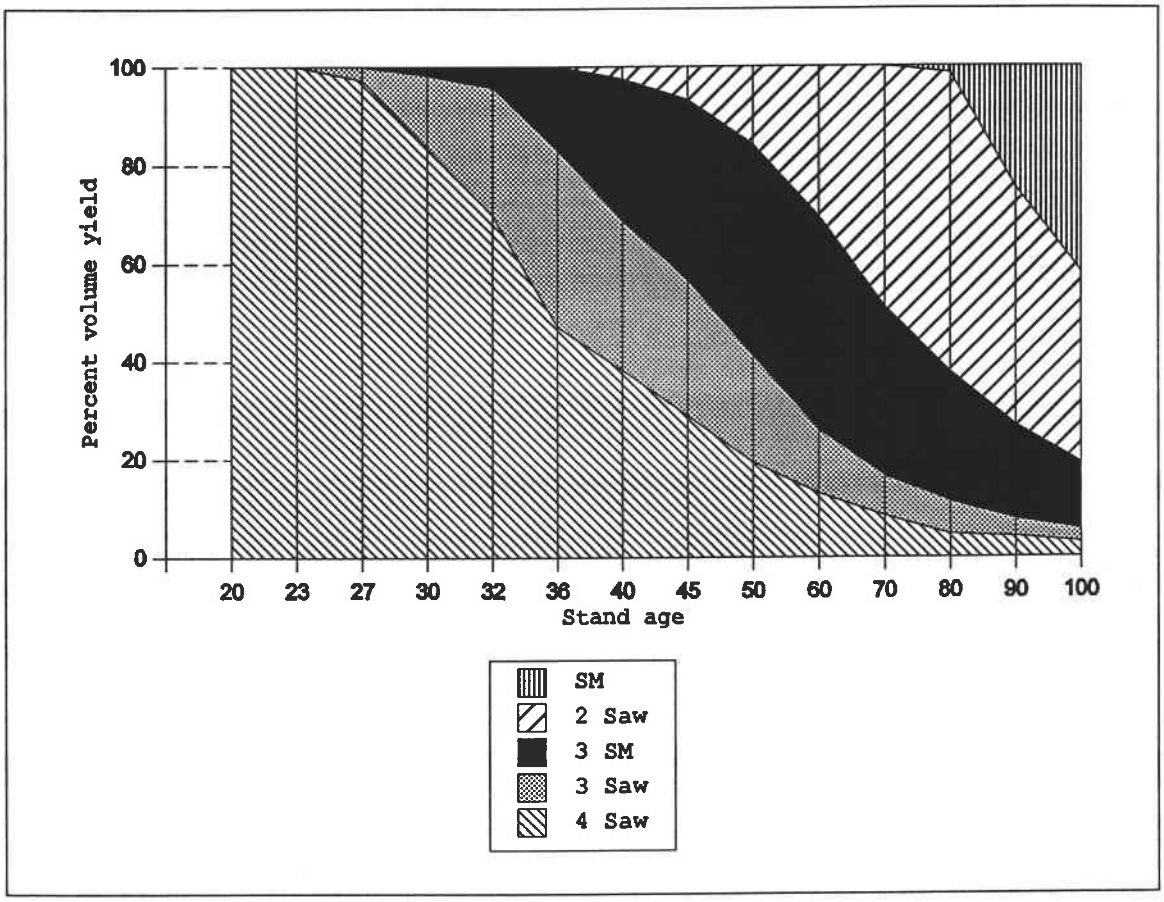


Figure 3-22. Percent volume yield through time in domestic log grades, control (treatment 9).

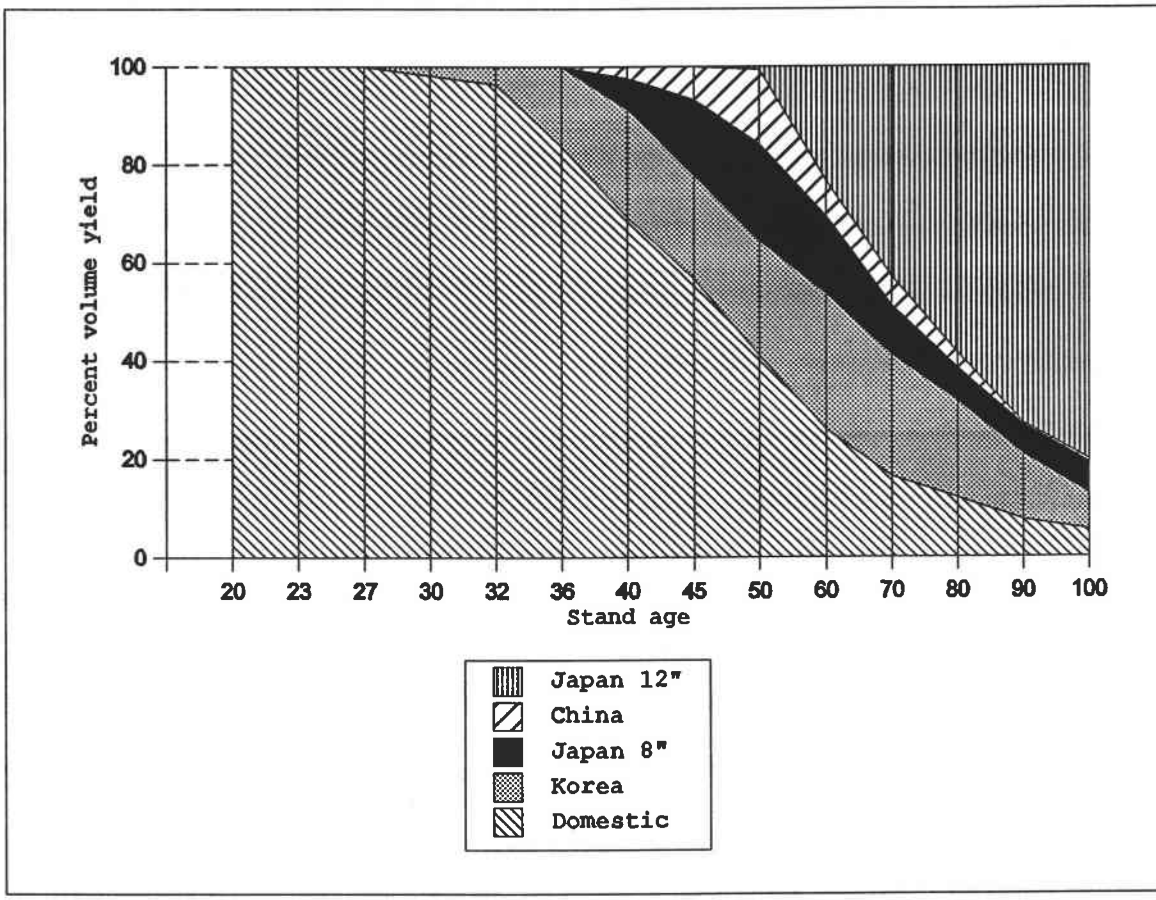


Figure 3-23. Percent volume yield through time in export log grades, control (treatment 9).

3.3 Product Yield Analysis

3.3.1 Product Yields From Thinnings

Figure 3-24 presents results in total gross volume and dollar value per acre in product yields potentially removed from all five thinnings by treatment. Losses in volume and value due to defect and breakage are assumed to be minor (+/- 2%) and were not included in the analysis. Results are presented as gross value, no adjustment was made for costs or revenue. Potential products considered included visually graded lumber.

Figure 3-24(A) presents total board foot volume removed per acre in all thinnings by treatment in visual lumber grades. In general, proportion of volume allocated into the different lumber grades was fairly constant for all treatments. Trends in relative differences of total volume removed by lumber grade between treatments remained the same as with total volume removed by log grade. The heaviest thinned treatments had the greatest potential yield in lumber, 9,318.10 bf./acre from treatment 1, 8,116.20 bf./acre from treatment 3, 6,521.40 bf./acre from treatment 5, and 4,252.00 bf./acre from treatment 7. The largest proportion of volume was allocated to No. 2 grade lumber for all treatments, 47.30% in treatment 1, 45.57% for treatment 3, 46.16% for treatment 5, and 46.44% in the unthinned control.

Results of total dollar value per acre potentially removed from all thinnings by treatment is given in Figure 3-24(B). Total value removed was highly related to volume removed. The heaviest thinned treatments had the greatest potential value, $3,139.33 per acre from treatment 1, and $2,792.44 per acre from treatment 3. While the lightest thinned treatments had the least potential value, $2,241.80

per acre from treatment 5, and $1,459.47 per acre from treatment 7. As found with volume, the lumber grade with the greatest proportion of value in each treatment was No. 2, 47.31% in treatment 1, 44.63% in treatment 3, 45.25% in treatment 5, and 45.60% in treatment 7.

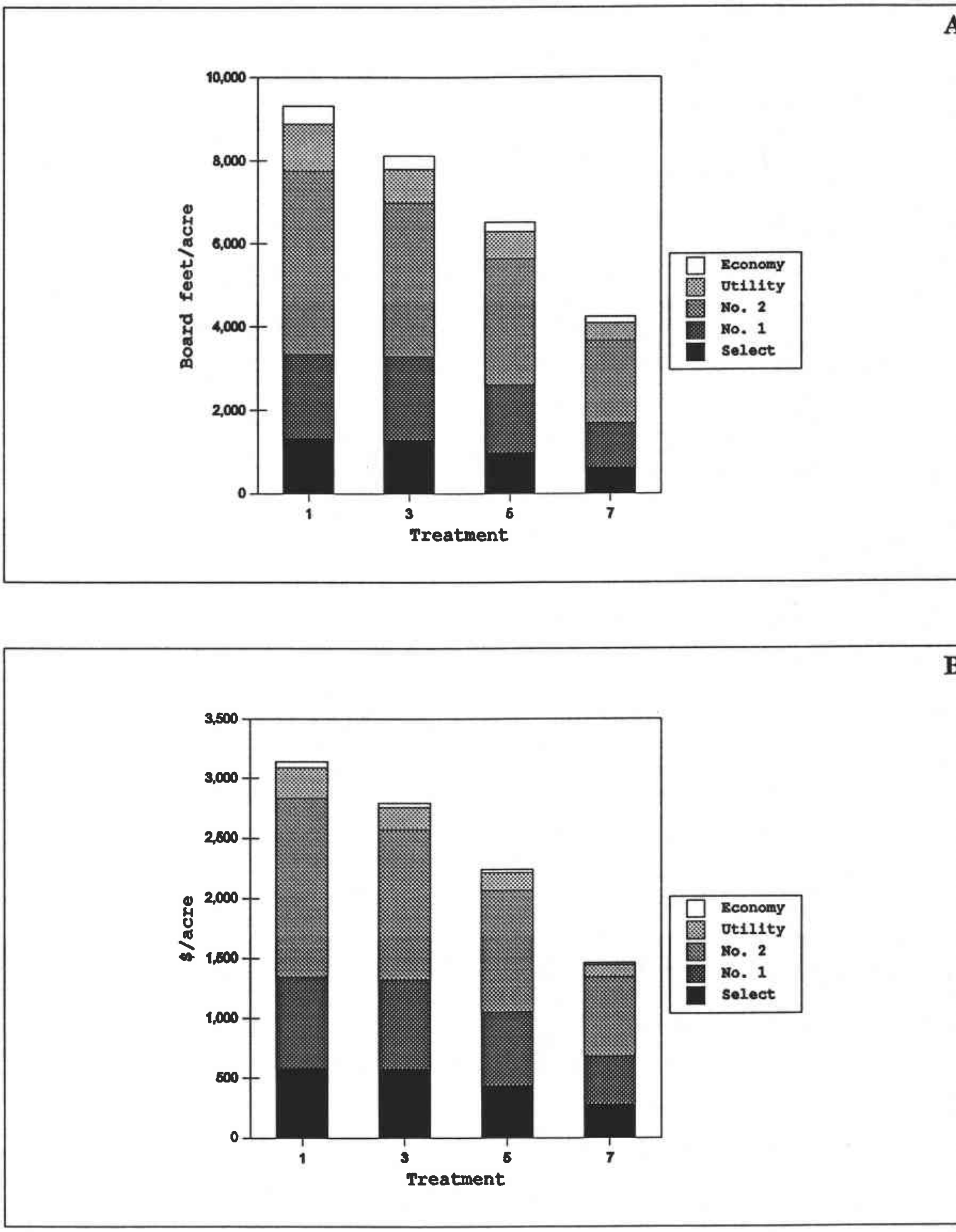


Figure 3-24. Total board foot volume (A) and dollar value (B) per acre removed in all thinnings by treatment in lumber grades.

3.3.2 Past Product Yields

Figure 3-25 presents standing volume and dollar value per acre in product yields potentially found in all treatments at a stand age of 30 years. Results are presented as standing volume and value, no adjustment was made for thinnings, mortality, costs, or revenue.

Board foot volume per acre by visual lumber grade for all treatments at stand age 30 is presented in Figure 3-25(A). Total volume recovered by treatment was 6,219.50 bf./acre from treatment 1, 8,959.70 bf./acre from treatment 3, 11,348.90 bf./acre from treatment 5, and 14,306.70 bf./acre from treatment 7. The unthinned control had the greatest volume recovered of all treatments, 18,946.50 bf./acre.

As found with volume yield from all thinnings, the greatest proportion of volume in each treatment was allocated to No. 2 grade lumber. Treatment 1 had the greatest percent of volume in No. 2 grade lumber, 50.25%, followed by treatments 3, 5 and 7 with 48.79%, 48.55%, and 48.79%, respectfully. The control had the least with 45.40% in No. 2 grade lumber.

However, the control had the greatest proportion of volume in Select grade lumber and treatment 1 had the least. Distribution of Select lumber among the treatments was as follows (from greatest to least); 16.34% in the control, 12.76% in treatment 5, 12.32% in treatment 7, 12.23% in treatment 3, and 10.54% in treatment 1.

Treatment 1 had the greatest proportion of total volume in Utility grade lumber and the control had the least. Utility lumber was distributed among all treatments as follows (from greatest to least); 14.46% in treatment 1, 12.36% in treatment 3, 12.02% in treatment 5, 11.99% in treatment 7, and 9.78% in the control. Allocation to Economy grade lumber was minor, about 5% for thinned treatments and 4% for the control.

Figure 3-25(B) gives results in gross dollar value per acre by lumber grade for all treatments at stand age 30. At this point of stand development the unthinned control had the greatest total value ($6,539.00 per acre) and treatment 1 had the least ($2,37.52 per acre). Total value of the other treatments was as follows (from greatest to least); $4,802.75 per acre for treatment 7, $3,813.68 per acre for treatment 5, and $2,998.72 per acre for treatment 3.

Distribution of dollar value into specific lumber grades was highly related to volume. Close to half of the total value was in No. 2 grade lumber for all treatments. Specific allocation of No. 2 lumber by treatment was 51.69%

in treatment 1, 49.13% in treatment 3, 48.69% in treatment 5, 48.98% in treatment 7, and 44.33% in the control.

The control had the greatest dollar value in Select grade lumber (21.11%) and treatment 1 had the least (14.36%). Treatments 3, 5, and 7 all had an average of about 16.5% of total value in Select grade lumber (16.30% in treatment 3, 16.94% in treatment 5, and 16.37% in treatment 7).

Utility grade lumber had the greatest proportion of dollar value in treatment 1 (10.02%) and the least in the control (6.43%). Treatments 3, 5, and 7 had an average of about 8.2% Utility grade (8.38% in treatment 3, 8.12% in treatment 5, and 8.11% in treatment 7).

Due to the low dollar value of Economy grade lumber it contributed less to the total value per treatment then with total volume. Less then 2.0% of total value for all treatments was from Economy grade lumber (1.88% in treatment 1, 1.56% in treatment 3, 1.50% in treatment 5, 1.50% in treatment 7, and 1.20% in the control).

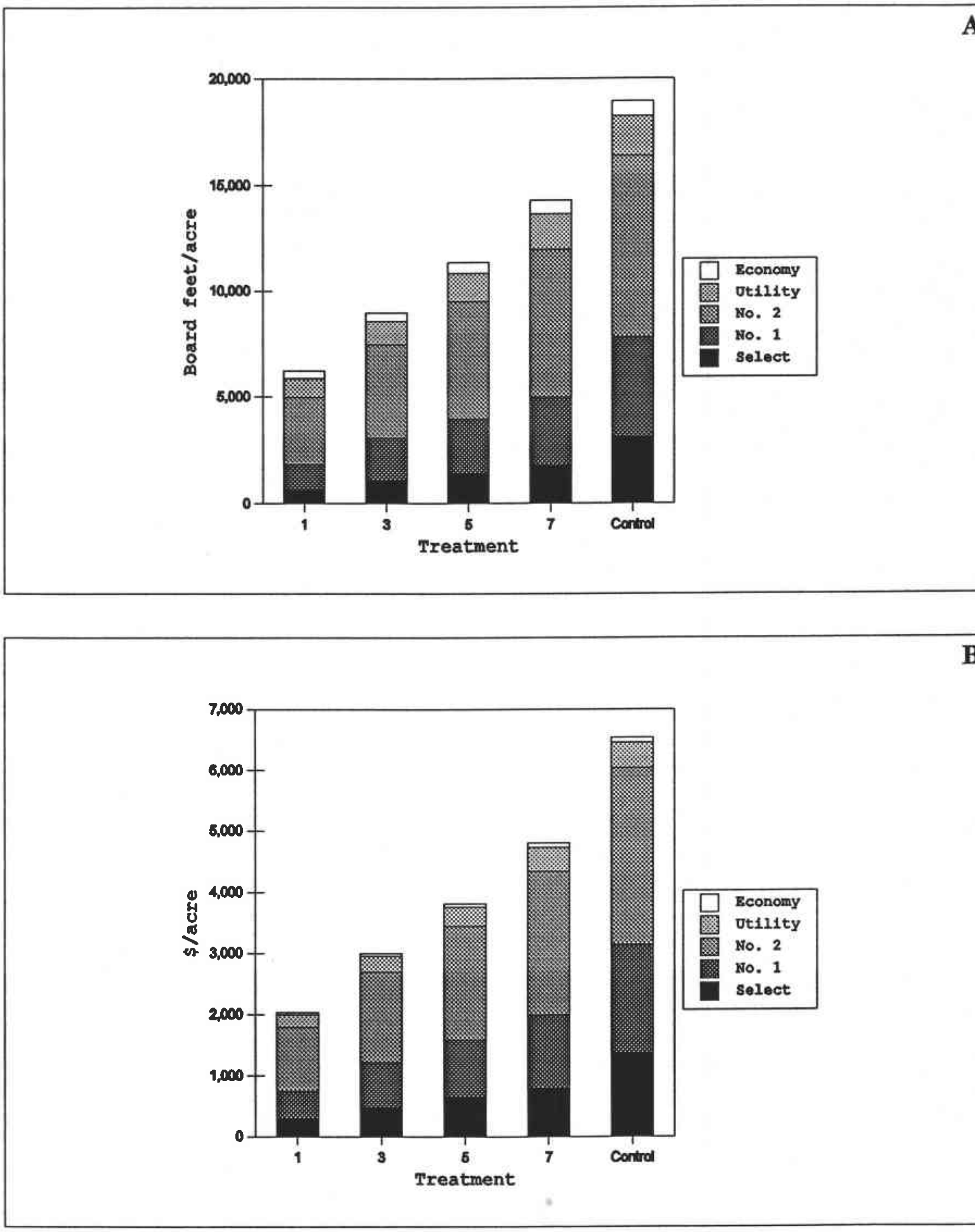


Figure 3-25. Board foot volume (A) and dollar value (B) per acre by treatment in lumber grades at stand age 30.

3.3.3 Current Product Yields

Figure 3-26 presents standing volume and dollar value per acre in product yields found for all treatments at the current stand age of 50 years. Figure 3-26(A) gives results in standing board foot volume per acre by lumber grade for all treatments at stand age 50. Trends in relative differences between treatments and allocation into specific lumber grades found at stand age 30 tended to continue to stand age 50. The main difference between the two ages was that the control treatment had fallen behind treatment 7 in standing volume and value yield. Treatment 7 had a total volume of 22,348.08 bf./acre and the control had 20,742.93 bf./acre. Total volume yield from treatments 1, 3, and 5 was 10,037.90 bf./acre, 14,661.25 bf./acre, and 18,218.03 bf./acre, respectfully.

Distribution of volume into each lumber grade was similar for each treatment by stand age 50. The greatest allocation of volume in each treatment continued to be in No. 2 grade lumber. All treatments had close to half of the total volume the No. 2 grade, 49.38% in treatment 1, 48.63% in treatment 3, 48.93% in treatment 5, 49.35% in treatment 7, and 48.78% in the control. Select grade lumber was also fairly evenly distributed among all treatments with an average allocation of 12.7%, specifically, 12.13% for treatment 1, 13.41% for treatment 3, 12.98% for treatment 5, 12.34% for treatment 7, and 12.65% for the control. Distribution of Utility grade lumber was 14.29% in treatment 1, 13.28% in treatment 3, 12.97% in treatment 5, 13.03% in treatment 7, and 12.10% in the unthinned control.

Figure 3-26(B) gives stand age 50 results in dollar value per acre by lumber grade for all treatments. Treatment 7 exceeded the control in total value by $1,605.15 per acre. Total value per treatment was as follows; $10,037.90 per acre for treatment 1, $14,661.25 per acre for treatment 3, $18,218.03 per acre for treatment 5, $22,348.08 per acre for treatment 7, and $20,742.93 for the control.

As found with volume distribution by grade, No. 2 grade lumber accounted for approximately half of the total value in all treatments. Specific percent allocation by treatment of No. 2 lumber was 50.52% in treatment 1, 49.18% in treatment 3, 49.43% in treatment 5, 49.95% in treatment 7, and 48.96% in the control.

Mean percent distribution of value for Select grade lumber was 17.0% for all treatments. By treatment, percent of total value in Select lumber was 16.43% in treatment 1, 17.95% in treatment 3, 17.35% in treatment 5, 16.53% in treatment 7, and 16.80% in the control.

Utility grade lumber had a similar even distribution of value among all treatments. Mean percent allocation of value to Utility lumber was 8.96% for all treatments. By treatment, percent allocation to Utility lumber was 9.85% in treatment 1, 9.05% in treatment 3, 8.83% in treatment 5, 8.89% in treatment 7, and 8.18% in the control.

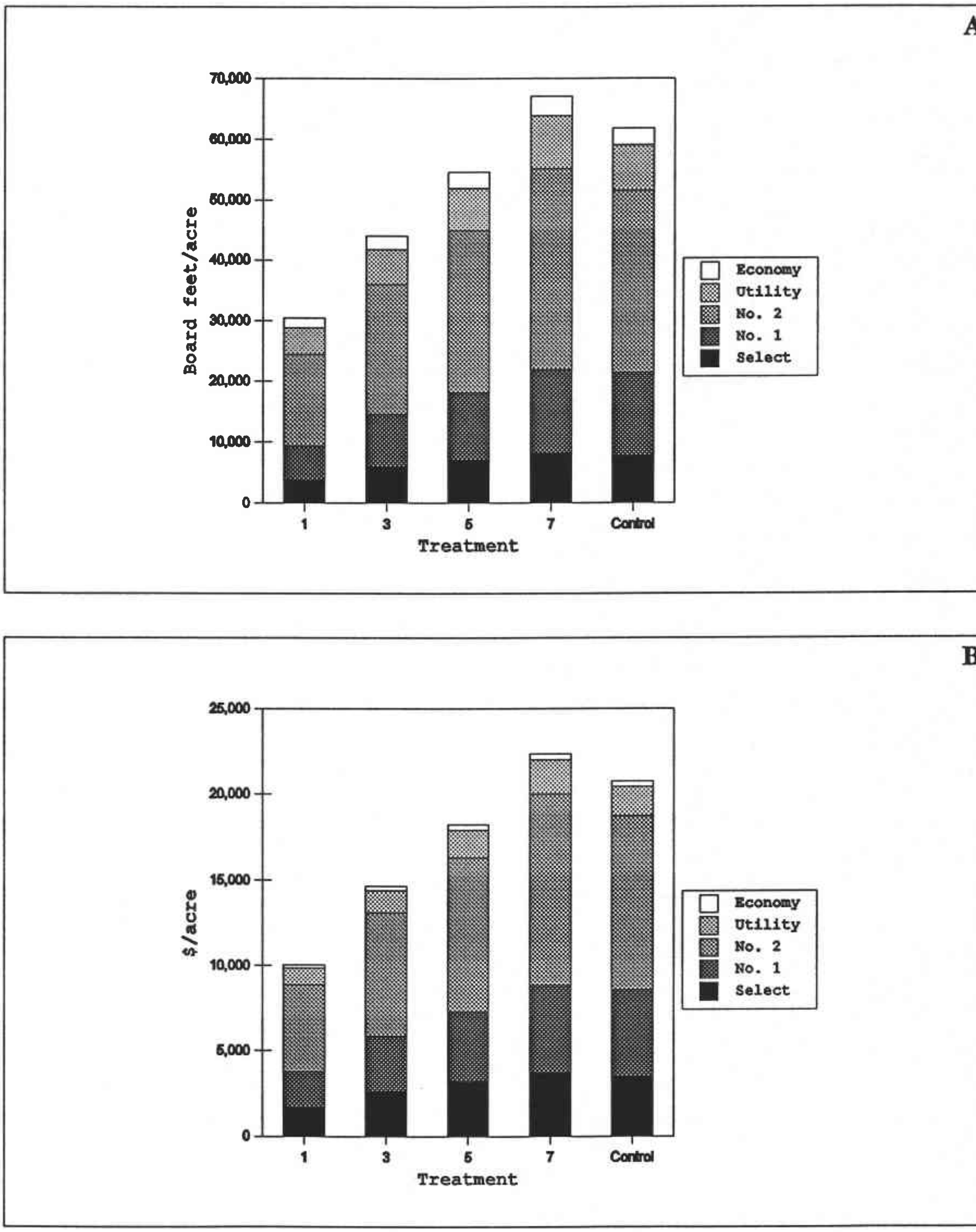


Figure 3-26. Board foot volume (A) and dollar value (B) per acre by treatment in lumber grades at stand age 50.

3.3.4 Future Product Yields

Figure 3-27 presents results in standing volume and dollar value per acre by visual lumber grade for all treatments at stand age 100. Trends found at stand age 50 were projected to continue into the future. Total volume and value maintained similar distribution among the treatments, treatment 1 had the least standing volume and value and treatment 7 had the greatest. However the differences between treatments was beginning to narrow.

Results given in Figure 3-27(A) are in board feet per acre by lumber grade for all treatments at stand age 100. Treatment 1 had a standing volume of 121,919.00 bf./acre, treatment 3 had 157,793.00 bf./acre, treatment 5 had 177,440/00 bf./acre, treatment 7 had 200,530 bf./acre, and the control had 179,465.10 bf./acre.

Distribution of volume within treatments into each lumber grade became more mixed by stand age 100 but remained similar between treatments. The greatest allocation of volume remained to be in No. 2 grade lumber for all treatments but had fallen to less than half of total volume. Mean percent distribution of No. 2 lumber was now 45.9% for all treatments (46.97% in treatment 1, 45.62% in treatment 3, 45.39% in treatment 5, 45.26% in treatment 7, and 46.34% in the control). Mean percent distribution of Select grade lumber had risen to 16.13% for all treatments (15.01% in treatment 1, 16.60% in treatment 3, 16.79% in treatment 5, 16.90% in treatment 7, and 15.34% in the control). Utility grade had fallen to a mean percent distribution of 10.38% for all treatments (11.49% in treatment 1, 10.35% in treatment 3, 10.04% in treatment 5, 9.84% in treatment 7, and 10.20% in the control).

Figure 3-27(B) gives results in gross dollar value per acre by grade for all treatments at stand age 100. Treatment 7 continued to have the greatest total value at $69,277.82 per acre and treatment 1 had the least, $41,380.00 per acre. Treatments 3, 5, and the control had a value of $54,257.94 per acre, $61,191.11 per acre, and $61,585.37 per acre, respectfully.

Value distribution of No. 2 grade lumber among all treatments responded similar to volume distribution. Mean percent distribution of No. 2 lumber dropped from approximately 50% to approximately 45% for all treatments. Specific allocation of total dollar value into No. 2 lumber for each treatment was as follows; 46.64% in treatment 1, 44.71% in treatment 3, 44.36% in treatment 5, 44.15% in treatment 7, and 45.50% in the control.

Proportion of value in Select grade lumber increased for all treatments while allocation to Utility grade has declined. Overall mean allocation of value in Select lumber was 20.95% for all treatments (19.73% in treatment 1, 21.53% in treatment 3, 21.72% in treatment 5, 21.82% in treatment 7, and 19.93% in the control). Overall mean allocation of value in Utility lumber was 6.87% for all treatments (7.68% in treatment 1, 6.83% in treatment 3, 6.61% in treatment 5, 6.47% in treatment 7, and 6.75% in the control).

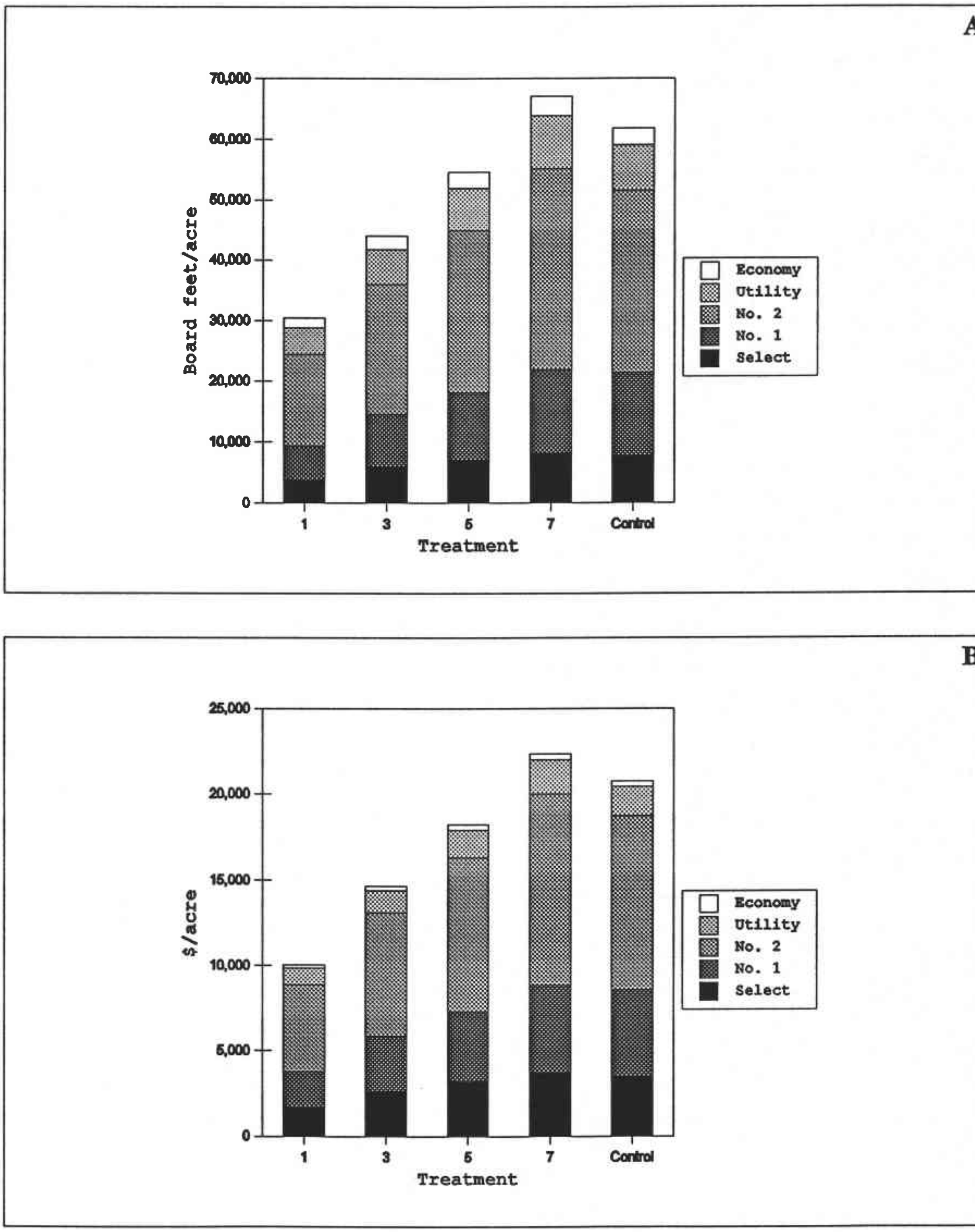


Figure 3-26. Board foot volume (A) and dollar value (B) per acre by treatment in lumber grades at stand age 50.

Table 3-12 presents residue volume in cubic feet per acre by product at stand ages 30, 50, 100 and from all thinnings per treatment. Residue products considered include chip logs, residue chips and residue sawdust. Treatment 1 yielded the greatest total volume of residue for all treatments in thinnings while treatment 7 had the least. At stand age 30 the unthinned control had the greatest residue yield for all products while treatment 1 had the least. Treatment 7 had the greatest residue yield of all thinned treatments at age 30. Similar trends as found at age 30 were found at stand age 50. By stand age 100 treatment 7 had the greatest overall residue yield (9,039.80 cu. ft./acre) closely followed by the control (8,965.20 cu. ft./acre). Treatment 1 continued to have the least residue yield of all treatments (4,865.10 cu. ft./acre).

Table 3-12. Lumber residue volume in cubic feet per acre by treatment at stand ages 30, 50, 100, and all thinnings.

	Treatment				
Product	1	3	5	7	Control
Total thinnings					
Chip logs	112.90	87.60	62.00	28.60	0.00
Residue chips	703.10	608.90	502.70	318.10	0.00
Residue sawdust	85.30	74.30	60.10	39.10	0.00
Stand age 30					
Chip logs	18.80	33.80	55.60	70.10	538.40
Residue chips	419.70	625.40	828.90	1038.30	1649.10
Residue sawdust	56.30	81.40	103.70	130.70	177.20
Stand age 50					
Chip logs	9.90	19.80	33.70	46.70	100.80
Residue chips	1221.60	1875.50	2446.70	3089.60	3371.30
Residue sawdust	264.90	384.70	479.50	590.80	551.60
Stand age 100					
Chip logs	8.80	20.10	33.80	47.80	93.00
Residue chips	3809.90	5220.60	6178.60	7252.20	7303.30
Residue sawdust	1046.40	1360.60	1535.40	1739.80	1568.90

3.3.5 Percent Volume Product Yield Through Time

Figures 3-28, 3-29, and 3-30 give results in percent standing volume yield through time by visual lumber grade for treatments 1, 7, and the control. These treatments represented the entire range of thinning intensities. Compared to log grades, lumber grades changed very little through time from stand age 20 to 100 years.

Figure 3-28 presents results for treatment 1. Throughout the entire analysis period No. 2 grade lumber predominated with a mean yield of 49.06% of total volume and a range of 46.97% to 50.25%. No. 1 grade lumber had the second greatest mean yield though time, 20.47% (17.57% - 25.39%). Utility grade was the next highest with a mean yield of 13.23% (10.20% - 15.35%). Followed by Select grade which had a mean yield of 12.25% (10.54% - 15.01%). The grade which contributed the least volume though time was Economy with a mean yield of 5.00% (3.77% - 5.90%). The D Select and better grade was never found throughout the entire analysis period.

Figure 3-29 presents results for treatment 7. Treatment 7 followed a pattern very similar to treatment 1. No. 2 grade lumber predominated with a mean yield of 47.90% (45.26% - 49.53%) of total volume. No. 1 grade lumber had the second greatest mean yield of 22.63% (20.43% - 25.49%).

Unlike treatment 1, the third greatest mean yield for treatment 7 was in Select lumber, 13.65% (11.77% - 16.90%). Followed by Utility with a mean yield of 11.53% (9.80% - 13.11%) and Economy at 4.29% (3.64% - 4.89%).

Figure 3-30 presents results for the unthinned control. Percent volume yield for the control followed treatment 7 very closely. No. 2 grade lumber had the greatest mean yield though time, 47.45% (44.02% - 49.47%). Followed by No. 1 grade, 23.43% (21.93% - 24.99%) and Select grade 13.98% (11.50% - 17.84%). Utility and Economy grade lumber had the least mean yield through time. Utility grade had a mean yield of 11.04% (9.50% - 12.19%). Economy grade had a mean yield of 4.10% (3.64% - 4.49%).

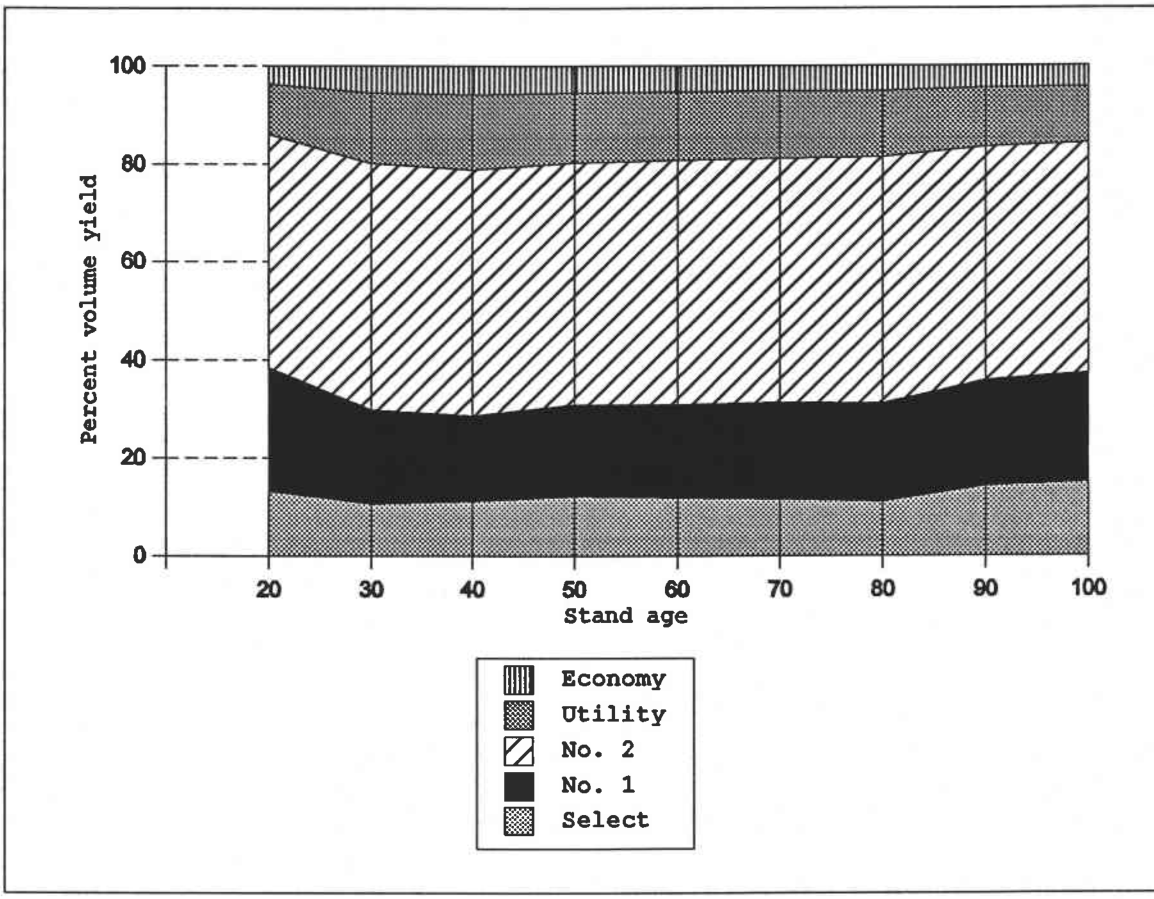


Figure 3-28. Percent volume yield through time by lumber grade, treatment 1.

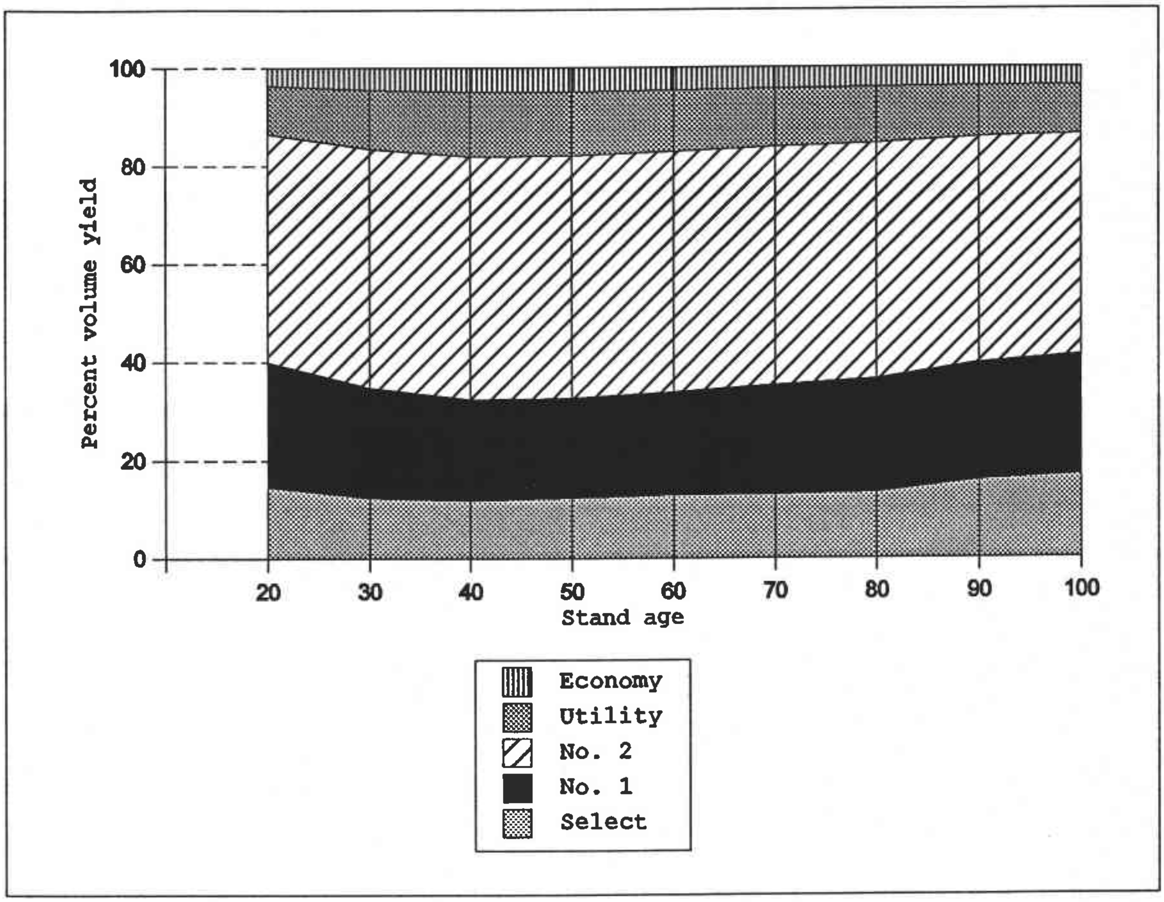


Figure 3-29. Percent volume yield through time by lumber grade, treatment 7.

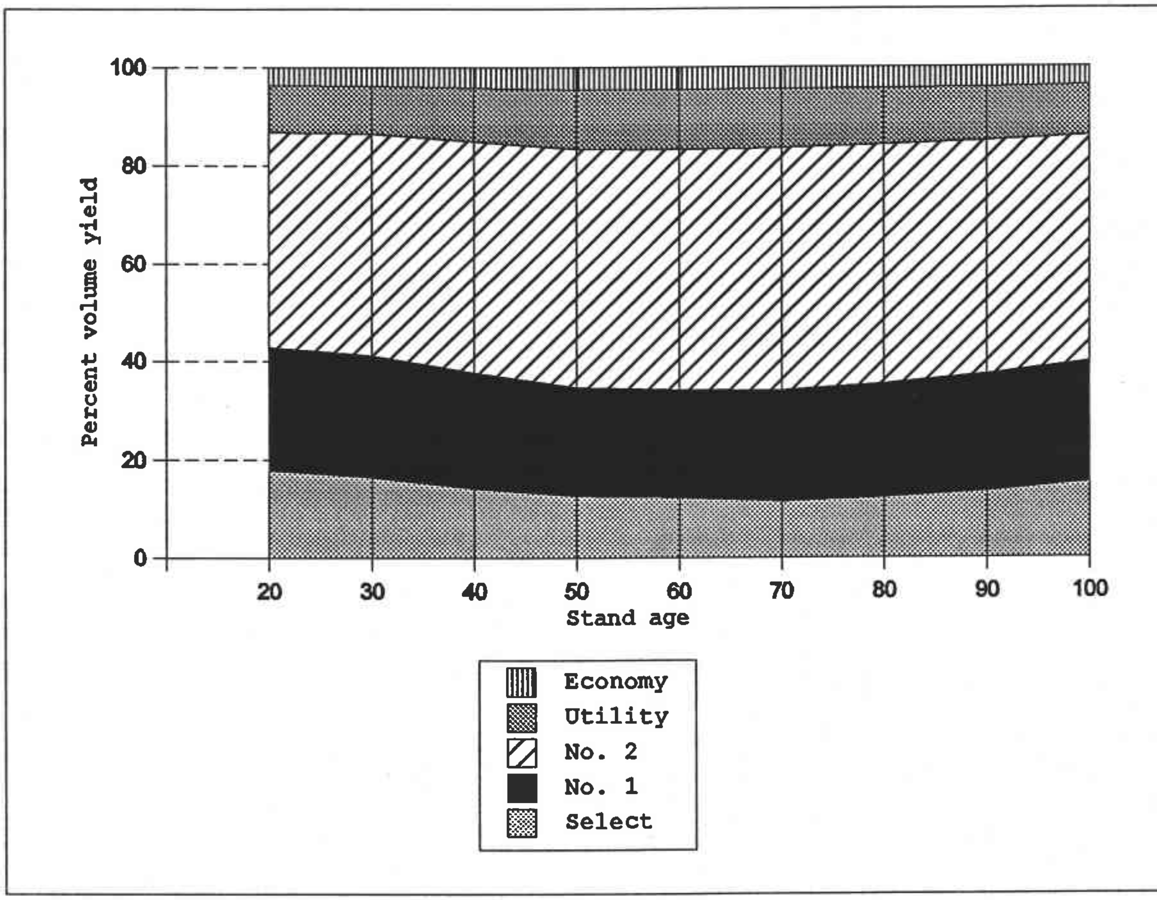


Figure 3-30. Percent volume yield through time by lumber grade, control (treatment 9).

4.0 Discussion

Use of actual tree measurements taken from long-term spacing studies combined with the ORGANON and TREEVAL models has allowed a detailed look at the impacts of early repeated thinnings in young stands of Douglas-fir. Using data which has been collected as part of the LOGS study allow assessment of past and current stand conditions with associated impacts on individual tree development. The models provide tools needed to look at potential future implications of the thinning treatments on stand structure, tree development, product yield, and dollar value.

4.1 Log Grade Analysis

Projections to 100 years of stand development indicate that repeated early thinning has the greatest impact on total standing merchantable volume yield and dollar value. Those treatments which received the heaviest thinnings (treatments 1 and 3) have lower volumes and values than were found on the treatments which received lighter thinnings (treatments 5 and 7) after 100 years. The heaviest thinnings develop larger trees which eventually bring premium log grades and values. But these bigger trees are simply too sparsely spaced across an acre to acquire total volumes and values needed to meet those found on the denser, lightly thinned treatments. The unthinned control treatment maintained the greatest total standing volume and value up to stand age 50 through heavy stocking. But heavy stocking on the control eventually led to reduced rates of volume growth and increased natural mortality. Treatment 7 overtook the control in standing volume and gross dollar value accumulation just after stand age 50 through greater growth rates and less mortality. Treatment 7 continued to have the greatest standing volume and value of all treatments throughout the remaining 50 years of projected stand growth. By stand age 100 treatment 5 is approaching treatment 7 in total standing volume and value as growth rates on treatment 7 begin to decline.

Throughout the entire 80 year analysis period value is closely related to volume. Those treatments which maintain the greatest standing volume always maintained the greatest dollar value. This indicates that the premium associated with larger logs from heavier thinnings may not be as great as some suggest. However as compared to the unthinned control, thinning does provide prolonged rates of volume growth eventually leading to improved log quality and greater stand values.

By stand age 100 value growth per acre per year (MAI) was still increasing while volume growth had slowed. The greatest difference was between the lightest thinned treatments. Volume growth per acre per year for the lightest thinned treatments had greatly declined by stand age 100. But value growth for the same treatments was still increasing at 100 years. The continued increase in value growth at 100 years strongly suggests that using a typical rotation age of 80 years would be premature for these treatments. A rotation age of 80 years on this site would involve reductions in potential volume and value.

4.1.1 Findings of Other Studies

Analysis of thinning treatments and associated dollar values have been done on other LOGS installations (Hoyer et al., 1996, King, In preparation). General trends found at Hoskins match those found by Hoyer et al. (1996) and King (In preparation). The analysis by King on the Skykomish LOGS installation used dollar values taken from comparable sales in the local area. His findings ranked treatments by total volume and value as if final harvest occurred at stand age 56. As found at Hoskins, if final harvest occurred at stand age 56 the unthinned control and treatment 7 would have about the same volume and the greatest total volume of all treatments. The ranking of the other treatments was 5, 3, and 1, respective. The same trends were found with total dollar value of the final cut.

The study by Hoyer et al. (1996) on the Francis LOGS installation used volume and taper equations to divide each tree into logs. Each log was then graded and assigned a dollar value based on average local selling prices. Costs are accounted for to arrive at a net dollar value for each treatment at stand age 42. Total volume and value was presented by treatment. General trends in the findings from Francis match those found at Hoskins. Treatment 7 had the greatest accumulated volume and value of all treatments followed by treatments 5, 3, and 1. The unthinned control fell between treatments 7 and 5 in total volume. In total value, unlike Hoskins the unthinned control fell between treatments 5 and 3.

4.1.2 Development of Special Mill Grade Logs

Figure 4-1 presents the accumulation of volume yield in Special Mill grade logs through time by treatment. Until stand age 50 no treatments produced high quality Special Mill logs. After stand age 50 all treatments began to gradually accumulate volume in the Special Mill grade until age 80. After age 80 the effects of branch self-pruning on the first log began to appear with a jump in volume allocation to Special Mill for all treatments except treatment 1. By stand age 100 treatments 5 and 7 had the greatest allocation of volume to Special Mill grade logs, 47.3% and 46.8%, respectfully. Followed by the control (42.0%), treatment 3 (38.2%), and treatment 1 (24.1%).

Heavy thinning at young stand ages (treatment 1) did not produce greater volume in high quality logs earlier. The lack of Special Mill logs on the heaviest thinned treatments is due to the rapid diameter growth rates resulting in annual ring counts too low to meet grading specifications. Large, live limbs lower on the bole slowing self-pruning rates also contributed to the lack of Special Mill logs on the heaviest thinned treatments. However, heavy early thinning did produce the largest diameter logs. In contrast, not thinning (control) also failed to produce greater volumes in high quality logs. The lack of volume in Special Mill logs on the control is due to suppressed diameter growth resulting in logs too small in diameter to meet Special Mill grading specifications. Early thinnings which are relatively light (treatments 5 and 7) produced the greatest volume in high quality Special Mill logs by stand age 100.

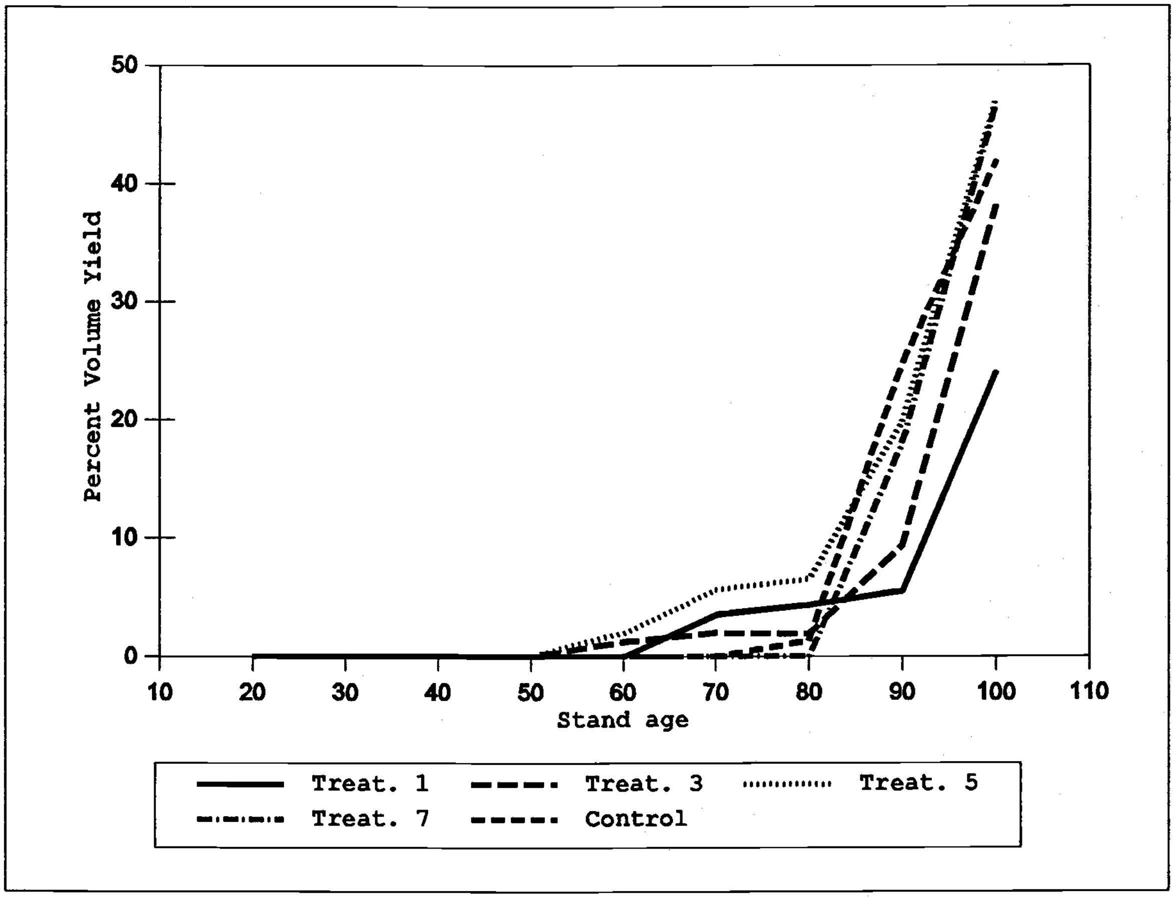


Figure 4-1. Percent of total volume production in Special Mill grade logs by treatment through time.

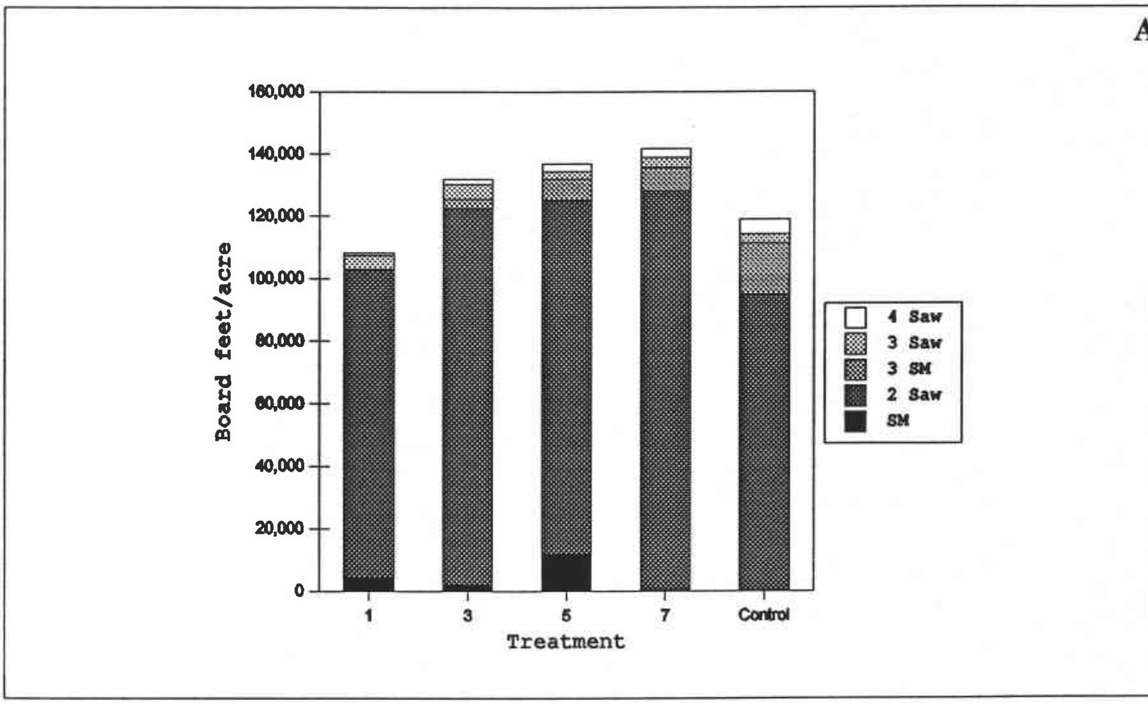
4.1.3 Branch Self-Pruning

As Figures 3-18, 3-20, 3-22, and 4-1 indicate, using a branch self-pruning age of 60 years resulted in large jumps in volume allocated to Special Mill production after stand age 80. In reality, these increases may be more smooth and gradual. Some limbs will occlude much earlier than 60 years and some will persist for several more decades. Without a more accurate self-pruning model available, using an average occlusion age provides a good indicator of how log grades change through time as self-pruning begins to occur.

To illustrate the effect of not accounting for natural branch self-pruning, results at stand age 100 were analyzed for all treatments without including branch self-pruning. Figures 4-2 and 4-3 present standing board foot volume and gross dollar value per acre by treatment in export and domestic log grades at stand age 100 without self-pruning. All results were generated exactly as presented in Figures 3-10 and 3-11.

Comparing Figures 3-10(A) and 4-2(A) which present results in standing board foot volume per acre by treatment for domestic log grades shows the effect of including self-pruning in the analysis. The effect is greatest in the Special Mill grade. When self-pruning is not accounted for (Figure 4-2(A)), very few Special Mill logs were produced by stand age 100 compared to Figure 3-10(A) where volume production in Special Mill logs was more realistic. Similar effects were found with dollar value in domestic log grades at stand age 100.

Export log grades showed less dramatic yet similar effects when self-pruning was not accounted for. As with domestic log grades the primary difference was in allocation to the highest quality logs (Japan 12"). Less volume and dollar value was produced in Japan 12" logs when self-pruning is not included in the analysis. Allocation of volume and value to Japan 12" grade logs was less relatively limited by the presence of limbs then were Special Mill grade logs.



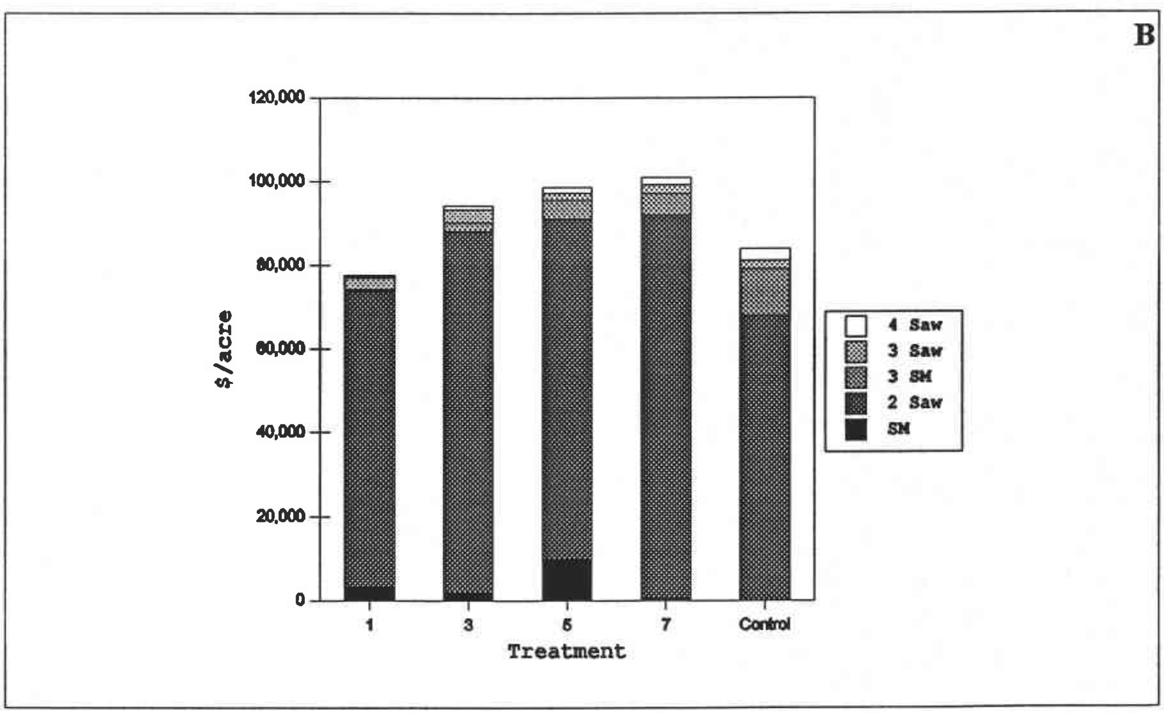


Figure 4-2. Board foot volume (A) and dollar value (B) per acre by treatment in domestic log grades at stand age 100 without branch self-pruning.

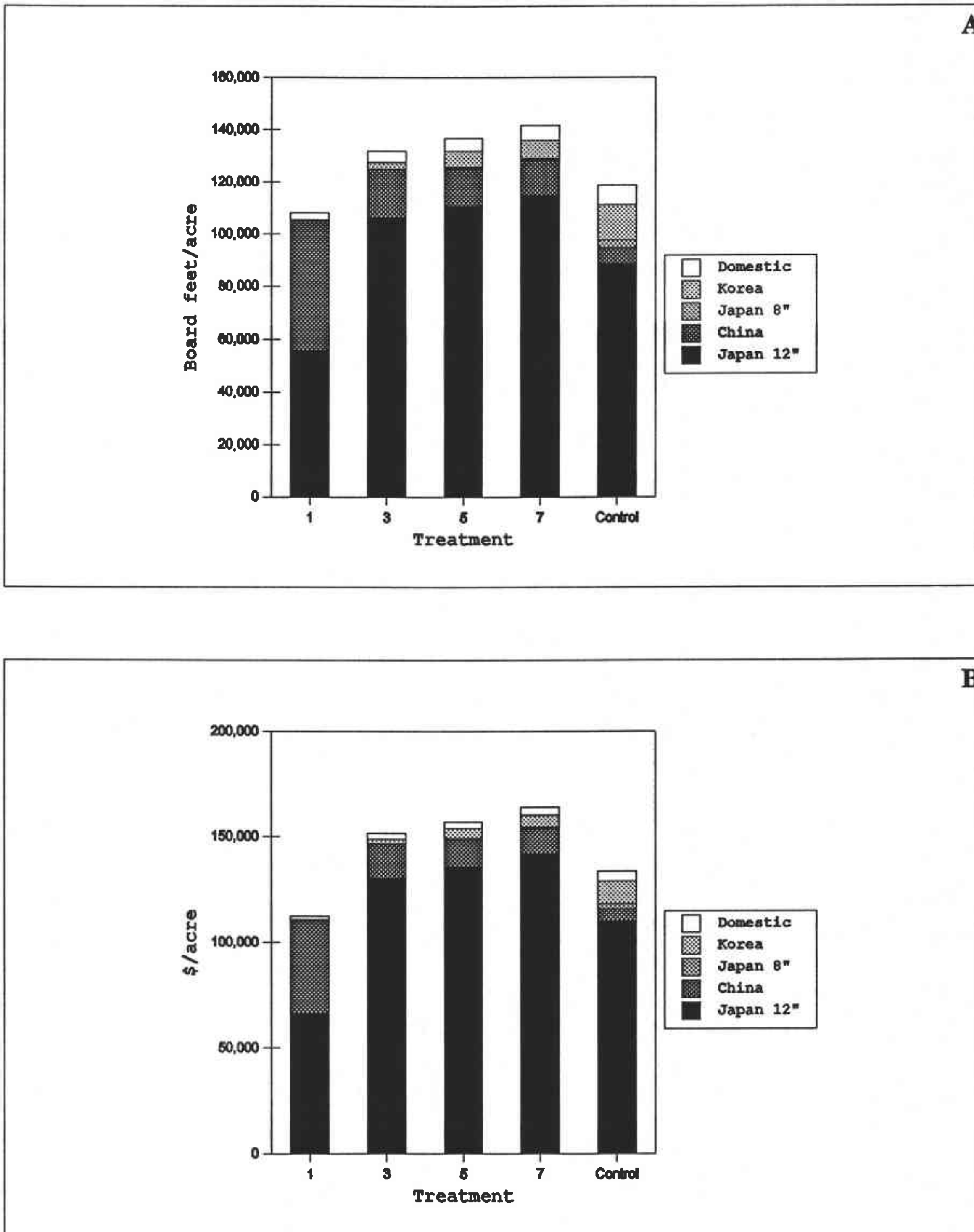


Figure 4-3. Board foot volume (A) and dollar value (B) per acre by treatment in export log grades at stand age 100 without branch self-pruning.

4.1.4 Log Grade Limiting Factors

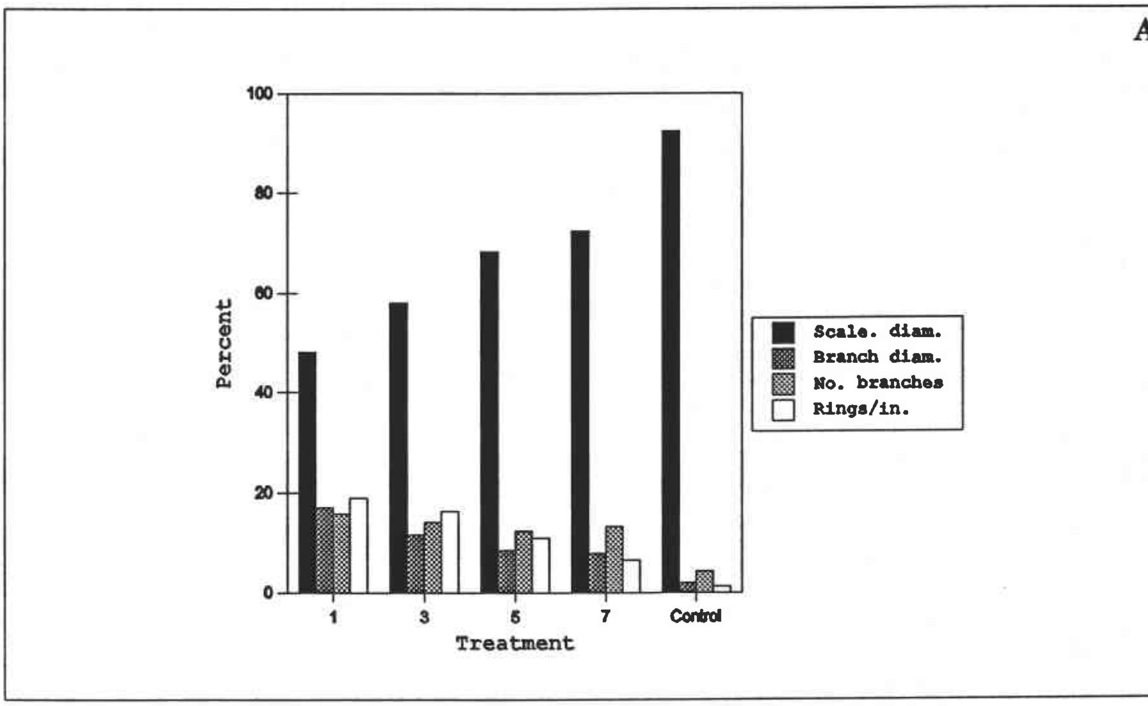
Part of the log grade analysis included determining for each log graded, what quality factors prevented that log from achieving the next highest grade. Quality limiting factors considered for each log included scaling diameter, mean maximum branch diameter, number of branches, and the number of rings per inch at the scaling end of the log. Figures 4-4 and 4-5 present limiting factor findings in percent by treatment at stand ages 50 and 100 years for domestic and export log grades.

Figure 4-4 gives percent limiting factors by treatment at stand age 50 for domestic (A) and export (B) logs. Figure 4-4(A) shows that at stand age 50 the scaling diameter of the log was by far the greatest limiting factor on all treatments for domestic logs. The importance of scaling diameter in limiting a log from achieving the next highest log grade decreased as thinning intensity increased. As the importance of scaling diameter decreased the relative importance of all other limiting factors (mean maximum branch diameter, total number of branches on a log (except treatment 7), and growth rings per inch) increased. This was because with increased thinning intensity stem and branch diameter growth rates were increased.

Figure 4-4(B) gives the same results at stand age 50 for export logs. Some of the same trends as observed with domestic logs were found with export logs. Diameter tends to be the greatest overall limiting factor for all treatments (except treatment 1). Rings per inch were much more important when grading export logs as indicated by its high relative importance to other factors. For treatment 1, making the needed number of rings per inch was the most import factor limiting logs. This was due to heavy thinning causing rapid diameter growth. Rapid diameter growth rates helped treatment 1 get large scaling diameters but too quickly to make rings per inch requirements. Interestingly, the mean maximum branch diameter was almost of no importance for export logs. This was only due the much greater relative importance of scaling diameter and rings per inch. The total number of branches were least important at the extremes (treatments 1, and the control) and more important for intermediate treatments (treatments 3,5, and 7). This was due to the much greater relative importance of scaling diameter and rings per inch for the unthinned control and treatment 1, respectfully.

Figure 4-5 gives percent limiting factors by treatment at stand age 100 for domestic (A) and export (B) logs. At 100 years scaling diameter was still primarily the greatest limiting factor in domestic logs for all treatments (except treatment 1). The same trends in limiting factors found with domestic logs at stand age 50 still held true. With increased thinning intensity diameter lost relative importance and all other factors gained in importance. The mean maximum branch diameter replaced scaling diameter as the most important factor for treatment 1. Due to decreased diameter growth rates, rings per inch dropped-out as a limiting factor for domestic log grades.

Limiting factors for export logs by treatment at stand age 100 (Figure 4-5(B)) showed a dramatic increase in the importance of scaling diameter in limiting log grades. Scaling diameter was by far the greatest limiting factor in export logs for all treatments. As with domestic logs its relative importance decreased with increasing thinning intensity. The jump in scaling diameter importance was primarily due to slower growth rates and branch self-pruning which allowed most other grading criteria to be met. The mean maximum branch diameter dropped-out completely as a limiting factor and rings per inch was reduced. The importance of total number of branches as a limiting factor appeared to have no clear trend between treatments but maintained an importance in all treatments.



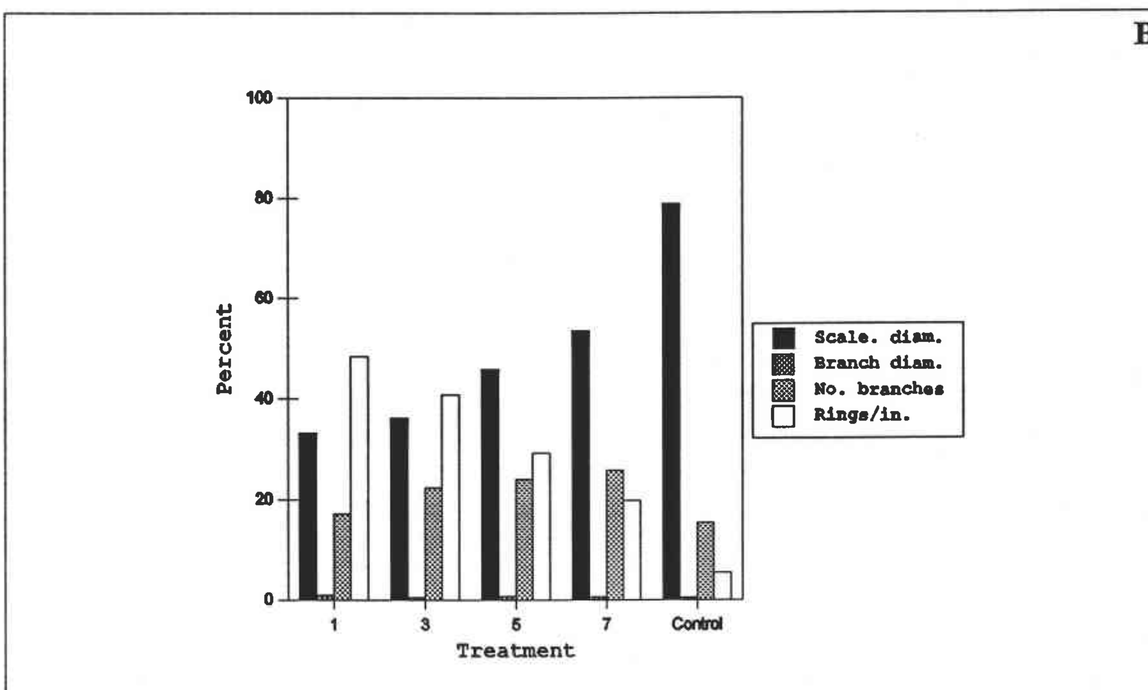


Figure 4-4. Domestic (A) and export (B) log grade limiting factors in percent by treatment at stand age 50.

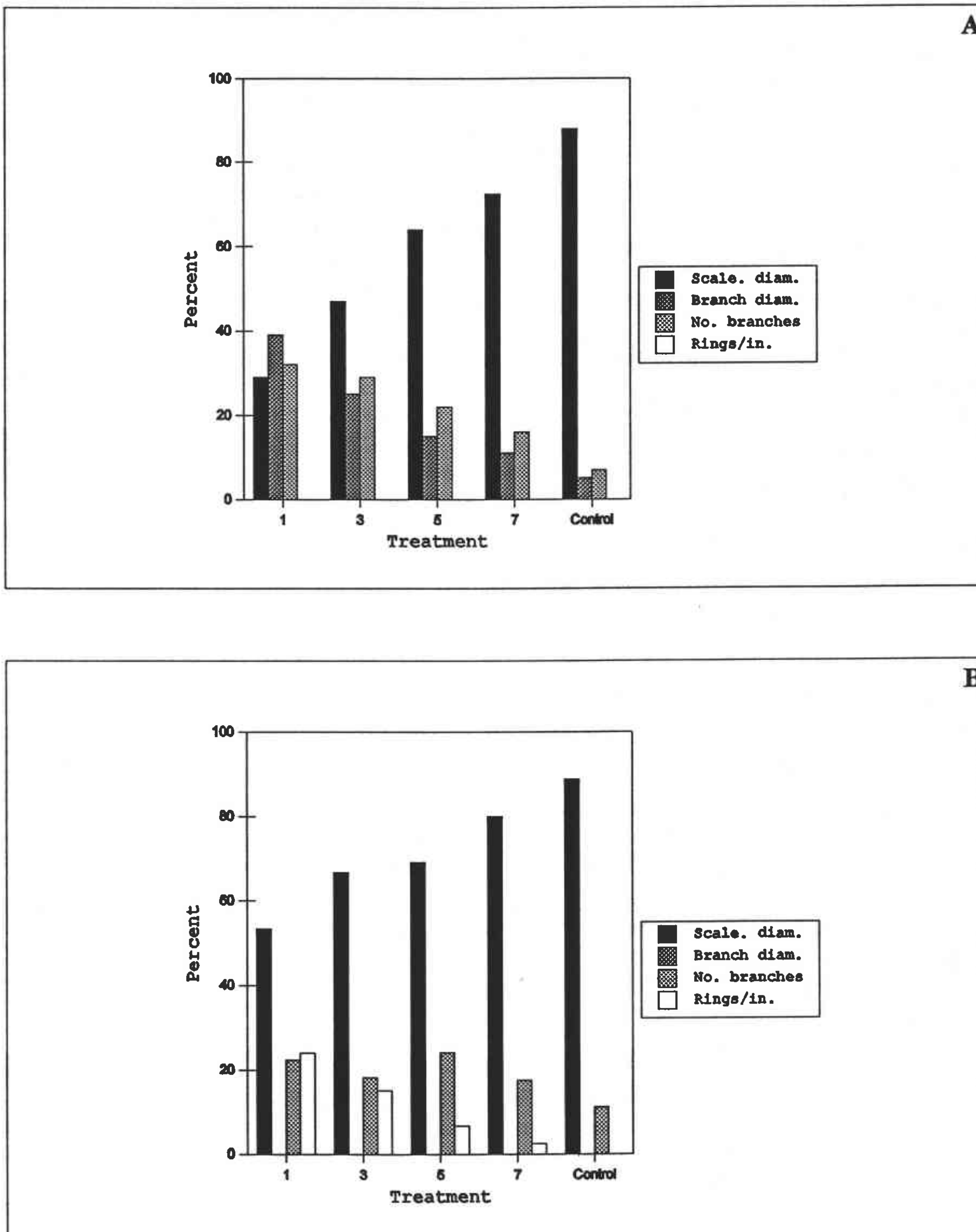


Figure 4-5. Domestic (A) and export (B) log grade limiting factors in percent by treatment at stand age 100.

4.1.5 Log Visual Appearance

A weakness of this study is the lack of ability to fully quantify the visual appearance of the log surface at any stand age. This is less important when the trees are young but as they approach 80 and 100 years-old log surface appearance becomes very important. Fortunately domestic log grades do not rely very heavily on appearance but for export grade logs, surface appearance alone may determine the grade.

Determining log surface appearance and how it affects export log grades requires considerable experience and judgement by the log grader. Log surface appearance terms include but are not limited to "smooth appearing", "Cascade appearance", and "semi-Cascade appearance." "Smooth appearing," describes a log which has flush-cut limbs, clean and smooth bark, and no "rough" areas on the log from limbs and natural or mechanical damage. "Cascade appearance," describes a log which may not be from an old-growth stand but has an old-growth look such as deeply furrowed bark, thick moss, and tight growth rings. This log is not from young, rapidly grown second growth stands. "Semi-Cascade appearance," describes a log between "Cascade appearance" and faster grown second growth. If was possible to quantify log visual appearance practical application would still be difficult due to the lack of a standard interpretation and application by log buyers and sellers.

With the models and methods available there is not a way to accurately determine how the log surface will "look" in the future. The best that can be done is to measure all quantifiable log attributes which may be used as an indicator of log quality, the approach used in this study. Because log surface appearance is not directly accounted for in this analysis future projections of export grade volumes and dollar values may be overly optimistic for some grades. This may result in some treatments having a greater total dollar value than would be realized in reality.

4.1.6 Log Lengths

Trees are bucked into logs using one of several different methods. Each method used may result in different length logs. One method which yields the greatest dollar value possible for a tree is optimal bucking. Using a predetermined set of log bucking rules which include minimum log sizes and dollar values per grade, log lengths are selected which yield the greatest monetary value. This may require bucking a tree into a short butt log, several long logs from the middle, and a short top log. The result is that there may be great variation in the lengths of logs for each tree and set of bucking rules used.

Log lengths were not optimally bucked to yield the greatest dollar value in this study because it was desired to compare the same log using domestic and export grading standards. Optimizing log lengths would result in some trees being bucked into different log lengths depending on which grading standard was used. By comparing the exact same log using both grading standards, differences in quality and value can be more closely tracked and compared. However, it would be of great interest to evaluate results using optimal bucking.

4.2 Product Yield Analysis

Results from the product yield analysis using TREEVAL show that like the log grade analysis, repeated early thinning has the greatest impact on total volume yield and dollar value, not on how volume and value differ in distribution among lumber grades between treatments. The heaviest thinned treatments (treatments 1 and 3) did not meet or exceed volumes and values found on the lighter thinned treatments (treatments 5 and 7) after a stand age of 100 years. Prior to stand age 50, the unthinned control treatment maintained the greatest total standing volume and dollar value. After stand age 50 treatment 7 maintained the greatest total volume and value throughout the analysis period. However, the unthinned control treatment did maintain the second greatest total standing volume and value. By stand age 100 treatment 5 had nearly reached the control in total volume and value. It is assumed that treatment 5 would surpass the control soon after stand age 100.

The results indicate that product yield grade mix among treatments varies little throughout the entire analysis period when visually graded lumber is evaluated. Figures 3-28 through 3-30 illustrate how little product mix changes through time for treatments 1, 7, and the control. Economy grade lumber had a mean yield of 5.00%, 4.48%, 4.28%, 4.29%, and 4.10 for treatments 1, 3, 5, 7, and the control, respectfully. Utility grade lumber had a mean yield of 13.23%, 11.96%, 11.46%, 11.53%, 11.04% for treatments 1, 3, 5, 7, and the control, respectfully. No. 2 grade lumber had the greatest yield in all treatments with a mean yield of 49.06%, 47.95%, 47.46%, 47.90%, and 47.45% for treatments 1, 3, 5, 7, and the control, respectfully. No. 1 grade lumber had a mean yield of 20.47%, 21.86%, 22.44%, 22.63%, and 23.43% for treatments 1, 3, 5, 7, and the control, respectfully. Select grade lumber had a mean yield of 12.25%, 13.75%, 14.36%, 13.65%, and 13.98% for treatment 1, 3, 5, 7, and the control, respectfully. These findings suggest that the range of thinning treatments evaluated had little affect on the mix of lumber grades produced among treatments. As was found with the log grade analysis, dollar value was closely related to volume throughout the entire 80 year analysis period.

4.2.1 Development of Select Grade Lumber

A method to measure quality differences among treatments is to chart accumulation of high quality products produced. The best visual lumber grade produced by any treatment in this analysis was Select. Figure 4-6 charts the accumulation of Select grade lumber by treatment in percent total volume yield. As the graph indicates, all treatments tended to closely follow each other though time between approximately 10% to 18% total yield. Thinning treatments began with relatively high levels of Select production at stand age 20, then declined by age 30, stayed fairly level until age 80, and then increased through age 100. The unthinned control treatment charted a slightly different course. The control began with the highest rates of production and then gradually declined to treatment 1 production levels by stand age 70. After age 70 the control began increasing in Select production through age 100. At stand age 100 there was a grouping of treatments with 3, 5, and 7 all having the greatest yield of Select grade (approximately 17%) and treatment 1 and the control having the least (approximately 15%). All treatments were so close in percent yield through time that it is doubtful the differences are statistically real.

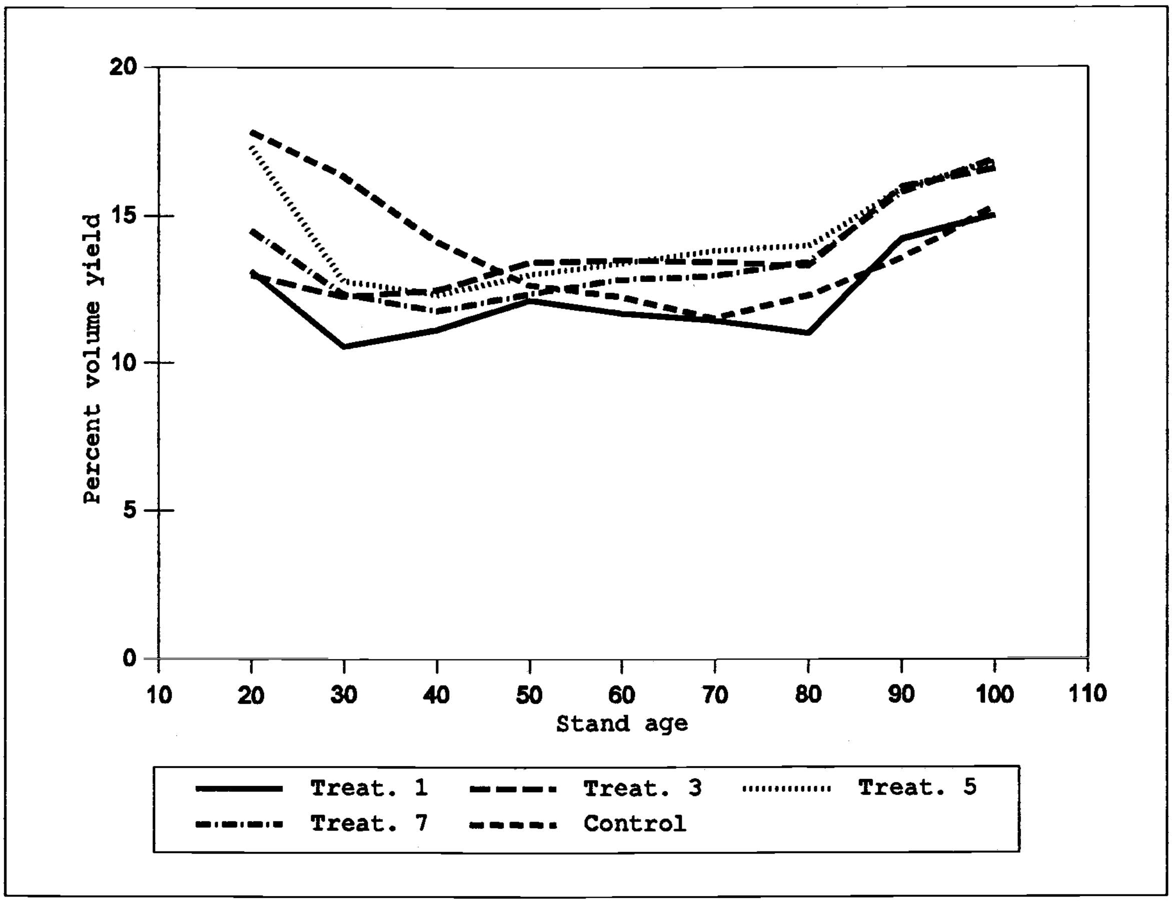


Figure 4-6. Percent total volume production in Select grade lumber by treatment through time.

4.2.2 The TREEVAL Model

A limit to interpreting TREEVAL results is that the model depends on lumber recovery equations developed by Fahey et al. (1991). These equations were developed from mill recovery studies which assessed only 2 by 4 and 2 by 6 dimensional lumber. Some mills may actually cut only these two lumber sizes but many would not if larger dimension lumber could be cut from large diameter logs (Briggs and Fight, 1992). Larger dimension lumber can accept larger knot sizes which may affect comparisons between treatments.

Another potential limit of TREEVAL is the failure to produce any volume in the D Select and Better lumber grade in all treatments. This may actually be the case for these treatments given that significant branch self-pruning is predicted to not begin until stand age 80. Combined with decreased diameter growth rates by stand age 100, enough clear wood may not have been produced by the end of the analysis period to yield any high grade clear lumber. The lack of D Select and Better grade may also be due to a limit of TREEVAL. The Fahey et al. (1991) recovery study did not evaluate lumber grades higher than Select because D Select and Better grade is not normally produced in second-growth Douglas-fir by the end of a typical 80 year harvest rotation.

Using TREEVAL to predict product recovery from very young and old stands (<40 years and >80 years) may be pushing the model beyond its statistically valid limit. The data set used by Fahey et al. (1991) was collected from fifteen stands of intensively managed second-growth Douglas-fir with most stand ages being between 40 and 65 years. Only four stands are less than 40-years-old (39, 36, 29, and 25 years) and only one stand is older than 80 years (85 years). Additionally, all trees greater than 30 inches DBH were not included in the recovery analysis. Figure 4-6 suggests that high volume yields of Select grade lumber would be produced at very young stand ages. These yields may be inflated due to the predictive limits of the recovery model. Results presented in this study for treatments younger than 40 years and greater than 80 years are at or just beyond the limit of the equations used to predict recovery and are extrapolations which should be interpreted with caution.

4.3 Relationship Between Log Grades and Lumber Recovery

Results from this study show that lumber recovery grade mix stays relatively constant across all treatments though time despite great changes in the mix of log grades during the same time period. This suggests that the quality factors which determine log grades are changing through time and between treatments while those which determine lumber grades do not. Figures 4-3 and 4-5 illustrate that for log grades, scaling diameter had the greatest overall influence in determining grade. Fahey et al. (1991) found that the inclusion of log diameter and limb frequency did not significantly increase the precision of lumber recovery prediction equations. They found that the log quality attribute which had the greatest correlation to lumber recovery was limb diameter (knot size).

Throughout the 80 year analysis period log diameter changed considerably between treatments and with stand age. However, branch size did not change as quickly during the same time period. Figure 4-7 charts the change in log scaling diameter and mean maximum branch diameter of the first log for treatments 1, 7, and the control through time. Scaling diameter of the first log changed the greatest on treatment 1 (by a factor of 4.98) and the least on the control (by a factor of 2.98). However, mean maximum branch diameter on the same treatments changed much slower. Treatment 1 mean maximum branch diameter changed by a factor of 2, nearly 3 times less than does scaling diameter. Branch diameter on the control treatment changed by a factor of 1.30, or 1.7 times less than scaling diameter. Since lumber grade is mostly dependent on knot size and it changed little for the first log during 80 years of stand growth, little change in the relative mix of lumber grades recovered is the result.

This study confirmed what others have already found, there is a strong relationship between log volume and volume of lumber recovered. Fahey and Martin (1974) presented results which charted the recovery ratio of log volume and product yield by log diameter for both open and dense stands of second-growth Douglas-fir. The recovery ratios found at Hoskins closely matched those found by Fahey and Martin. The open stands had greater recovery ratios than the dense stands. Regardless of treatment, recovery ratios were greatest for young small diameter logs and declined with age as log diameter increased.

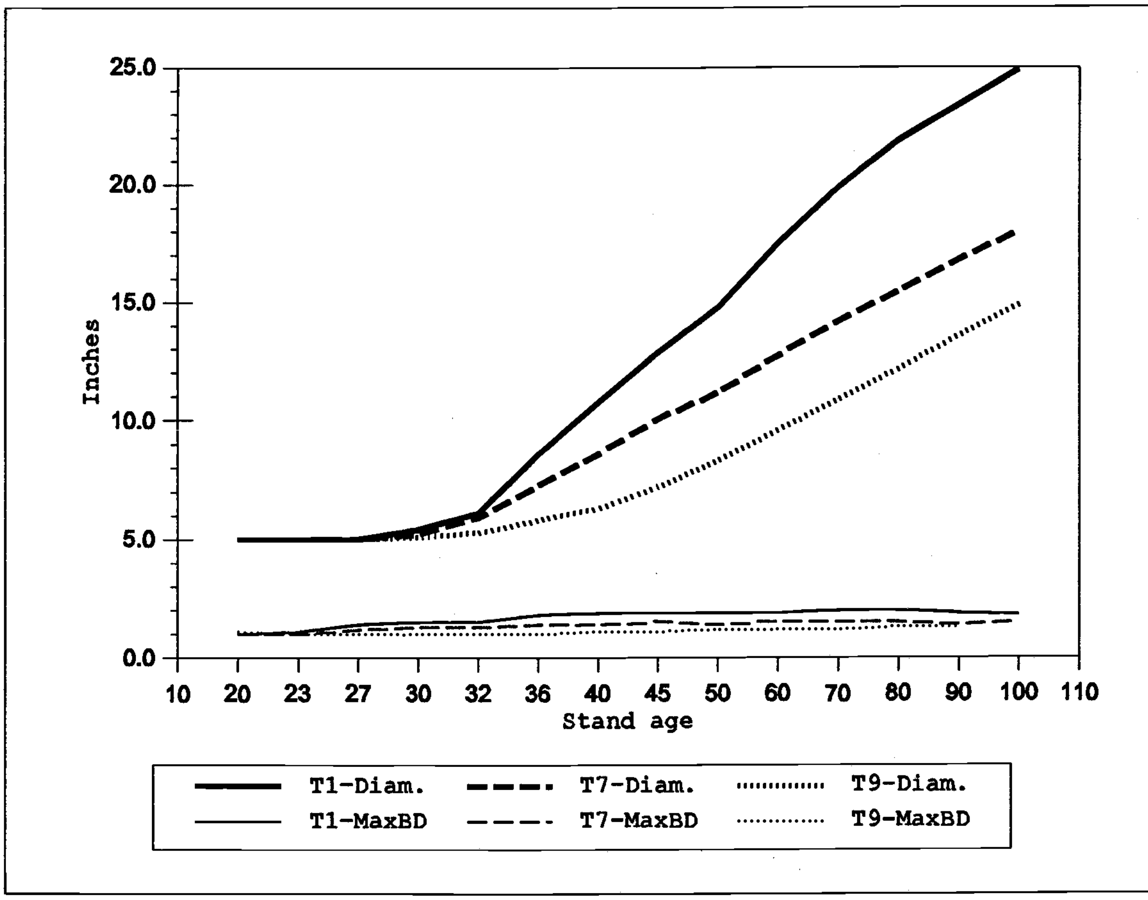


Figure 4-7. Mean scaling diameter (Diam.) and mean maximum branch diameter (MaxBD) of the first log for treatments 1 (T1), 7 (T7), and the control (T9) through time.

4.4 Value and Associated Costs

The main objective of this study was to determine stand value through time by treatment using log grades and potential product yields. These values were then to be assessed and compared to the other thinning treatments and the unthinned control. Because only the relative differences between treatment values were of interest, costs were not taken into consideration. It assumed that had costs been included in the analysis relative differences between treatments would remain the same but at reduced levels of value per acre. There are cost differences which arise from handling different sized logs but these are assumed to be negligible. All other costs would be equal. At stand age 100, had costs been included, treatment 7 would still exceed treatment 1 in total value but at less value per acre. There would also be a decreased difference between the two treatments due to treatment 7 having increased handling costs from a greater number of trees producing smaller logs.

Additional reasons for not including costs came from the general problems associated with stumpage appraisals. These problems included great variability and difficulty in determining the seller's interest in the buyer, conditions of the sale, estimating product selling value, production costs, problems of measurement, and the time element (Davis and Johnson, 1987). In general, accounting for costs is widely variable from one buyer to the next which makes it very difficult to give useful and accurate results. This study gives results in gross standing dollar value per acre with the assumption that for those interested in determining net value at any particular point in time their own costs and log/lumber values may be applied.

If costs were to be included in the analysis there are several different methods which arrive at net dollar value. One approach is to determine net value based on log grades. Using log grades to determine value can be done by determining gross value and accounting for all costs as was done by Hoyer et al. (1996) on the Francis LOGS installation or by using the "comparable sales" approach as was done by King (In preparation) on the Skykomish LOGS installation. Hoyer et al. determined value by using average log selling prices in the local area and subtracting all costs included in planting, thinning, and hauling. The assigned costs were part of a routine thinning cost assessment procedure used for timber sales preparation (Chambers and Smego, 1983). King arrived at net dollar value by applying values obtained from recent timber sales in the local area to the net volume yield per treatment.

Another approach to determine net dollar value is to find the net value of the products produced from each treatment. The product recovery approach is that which is used by TREEVAL for economic analysis. This method of valuation requires specific information on product prices and costs. Price information includes the individual product prices along with the percent real price change per year. Cost information includes management and sales costs per acre, treatment costs per acre (stand establishment, fertilization, pruning, and thinning), harvesting and hauling costs by log diameter class, manufacturing costs per log diameter class, and the percent real cost change in each category per year. Once all values and costs are accounted for TREEVAL calculates net present value and the soil expectation value per acre.

5.0 Conclusion

Early repeated thinning has an effect on quality and value of young coastal Douglas-fir. Total standing volume was reduced as thinning intensity increased. Value was highly related to volume which caused value to also be reduced as thinning intensity increased. The thinning treatments which optimize standing volume production also had the greatest gross dollar value. At stand ages 50 and 100 years, the lightest thinned treatments had the greatest standing volume and value. These treatments also produced higher quality logs. They had the greatest proportion of volume allocated to Special Mill domestic grade logs and Japan 12" export grade logs. Scaling diameter was the most important factor in determining log grade in the lightest thinned treatments and at young ages. At stand age 100 volume growth per acre per year (MAI) was projected to decline for the lightest thinned treatments. However, value growth per acre per year for the same treatments was projected to continue increasing. Continued increasing value growth rates suggests that using typical rotation ages of 80 years may be premature for these treatments on this site.

Product yield analysis revealed that there was little difference between treatments in the mix of products produced. This was attributed to little change in limb size between treatments and through time. Like log grades, product yield dollar value was highly related to volume. Those treatments which had the greatest recovery yield had the greatest total gross value.

The combined effect of the five early thinnings on each treatment closely resemble a thinning which would be applied to commercial stands of young timber. Because the Hoskins LOGS installation was naturally regenerated and heavily stocked, care should be taken when interpreting results for planted stands. The relative differences between treatments should remain the same but may differ in magnitude. Additionally, because this analysis used data collected at only one site, results are valid for the Hoskins installation only.

Initial planting density may have significant effects on log and product quality. The main quality factors which would be affected by a wider initial spacing are growth rate, stem diameter, and branch diameter. Young trees growing on an intensively managed plantation of equal site productivity to Hoskins would follow a similar pattern of stand development but at a different rate. Planted stands would likely produce merchantable volume earlier due to increased growth rates before stand age 20. The unthinned control at Hoskins was heavily stocked (1727 trees per acre) suggesting that early stand development may have been very slow due to limited resources. Planted stands would initially have rapid growth rates producing larger diameter trees earlier than at Hoskins. Rapid stem growth will also stimulate faster branch growth but if stand density is controlled, branch diameter growth could be minimized. Standing volume would likely be greater than any of the Hoskins treatments of the same stand age. However, wider spaced trees produce wider growth rings, more and larger limbs, and greater volumes of juvenile wood. Total standing volume may be greater for planted stands of the same age but total value may be less due to reduced wood quality. Before stand value and volume production on planted stands can be quantified further study is needed using the methods developed in this study.

A limitation of the Hoskins study is the lack of an unthinned control treatment which was calibrated to the same initial stand density as the thinned treatments. How the thinning treatments would have compared to a calibrated control remains unknown but is speculated to have given results similar to the lightest thinned treatments. It would have produced more standing volume and value by stand age 100 than the uncalibrated control but by how much is unknown.

Study results indicate that modest thinning has the potential to increase standing volume yield, dollar value, and log quality. From this study it appears that thinning has little affect on visual lumber quality given the range of treatments considered. It is assumed that after 80 years of stand growth significant differences in lumber grade distribution would begin to appear as clear wood production increased. It is speculated that the lightly thinned treatments would have the greatest lumber quality after stand age 100 through a balance of small limb size and improved diameter growth. Due to limitations of the recovery equations used by TREEVAL, lumber yield projections made for very young stands (<40 years) and old stands (>80 years) are extrapolations and should be interpreted with caution.

Heavy thinning produced large logs but of lesser quality. These logs had larger limbs (>1.5 inches) and lower growth ring counts (<15 per inch) at 100 years which prevented production of high quality logs until after stand age 80. Not thinning produced high quality Special Mill logs but too few to meet the volumes produced by the lighter thinned treatments. These results suggest that by carefully planning thinning treatments large, high quality logs can be produced faster than by not thinning. To more fully understand how product yield responds to early thinning additional research is needed across a wider range of treatments.

Heavy early thinning as in treatment 1 can be used to accelerate certain stand structural elements found in late-seral stage forests such as large diameter trees with large limbs. These heavily thinned stands may provide improved plant and wildlife habitat for certain species which may not prefer denser stands. Carey et al. (1996) found that plant and small mammal biodiversity appear to be more likely preserved if understory vegetation enhancement and avoidance of stem-exclusion conditions are explicit goals in managed forests. This indicates that habitat can be improved for some plant and animal species by providing larger crowns and increased understory development as found with the early heavily thinned treatments. Results suggest that it may be possible to find a balance between providing some of the structural elements important for improved plant and wildlife habitat and increasing stand value through improved wood quality. The ORGANON and TREEVAL models provide the tools needed to help find this balance and assess a wide range of silvicultural treatments to determine trade-offs between objectives.

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APPENDICES

Appendix A ORGANON Model Validation

The Western Willamette Valley version of ORGANON was evaluated for validity by testing model output against actual stand data and projections from the Douglas-fir Simulator (DFSIM) (Curtis et al., 1981) growth model. Basal area, trees per acre, and total stem cubic foot volume were selected for evaluation. Projections were started from stand ages 40 and 50 for the thinning treatments and stand ages 20, 40, and 50 for the control. Model projections were compared to actual stand data and evaluated. ORGANON was found to project actual stand development closer than DFSIM when starting from stand ages 20 and 40.

When projections were made from stand age 20 to age 50 differences (actual - projected) for DFSIM were; -74.0 in trees per acre, 19.9 sq. ft./acre in basal area, and 267.0 cu. ft./acre in volume. ORGANON differences for the same projections were; -75.3 in trees per acre, 13.0 sq. ft./acre in basal area, and 115.0 cu. ft./acre in volume. When projections were made from stand age 40 to age 50 differences for DFSIM were; -86.0 in trees per acre, -18.2 sq. ft./acre in basal area, and -1,498.0 cu. ft./acre in volume. ORGANON differences for the same projections were; -65.0 in trees per acre, -3.2 sq. ft./acre in basal area, and -1,038.0 cu. ft./acre in volume.

Stand growth projections used in the study were made with ORGANON starting from stand age 50. Figures A-1 through A-3 give actual and ORGANON projected stand development in basal area (sq. ft./ac.), trees per acre, and total stem cubic foot volume for treatments 1, 7, and the control.

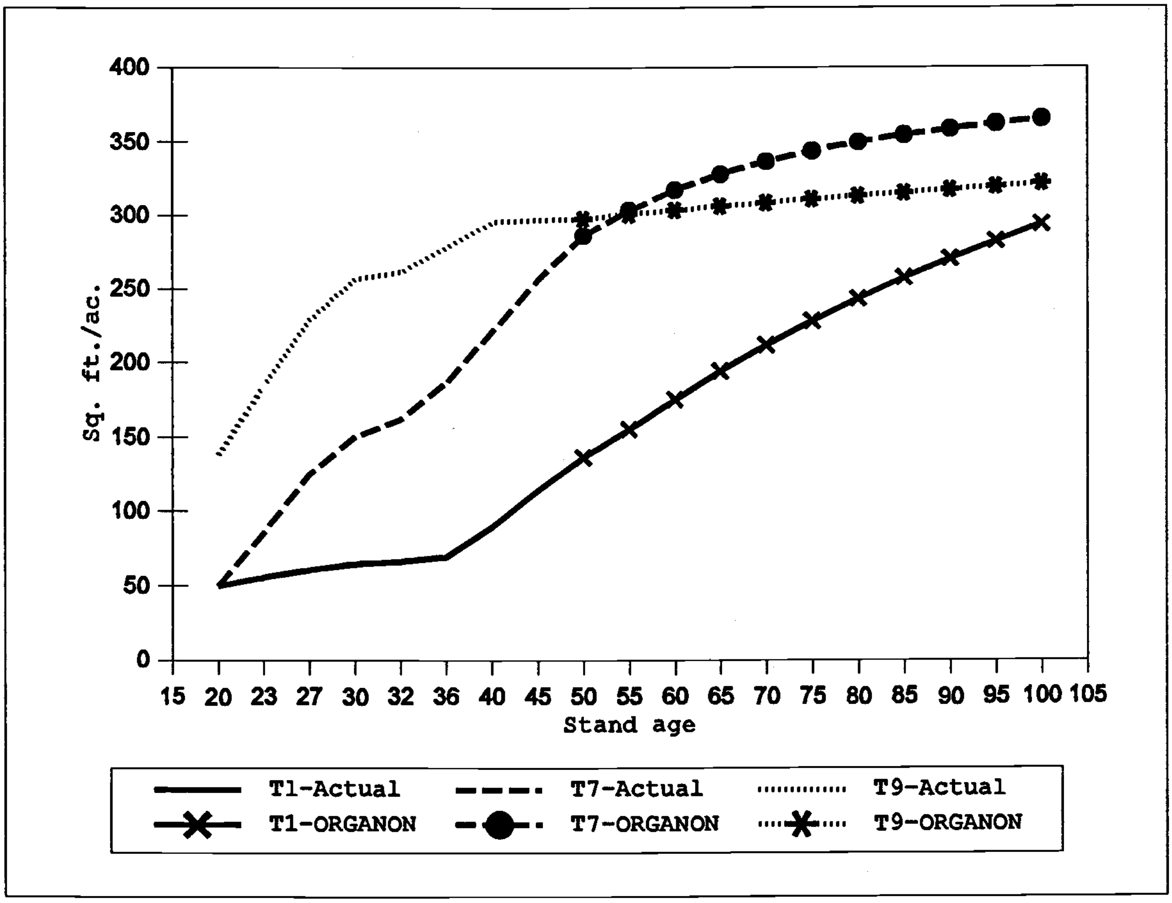

Figure A-1. Actual and ORGANON projected basal area per acre development for treatments 1 (T1), 7 (T7), and the control (T9).

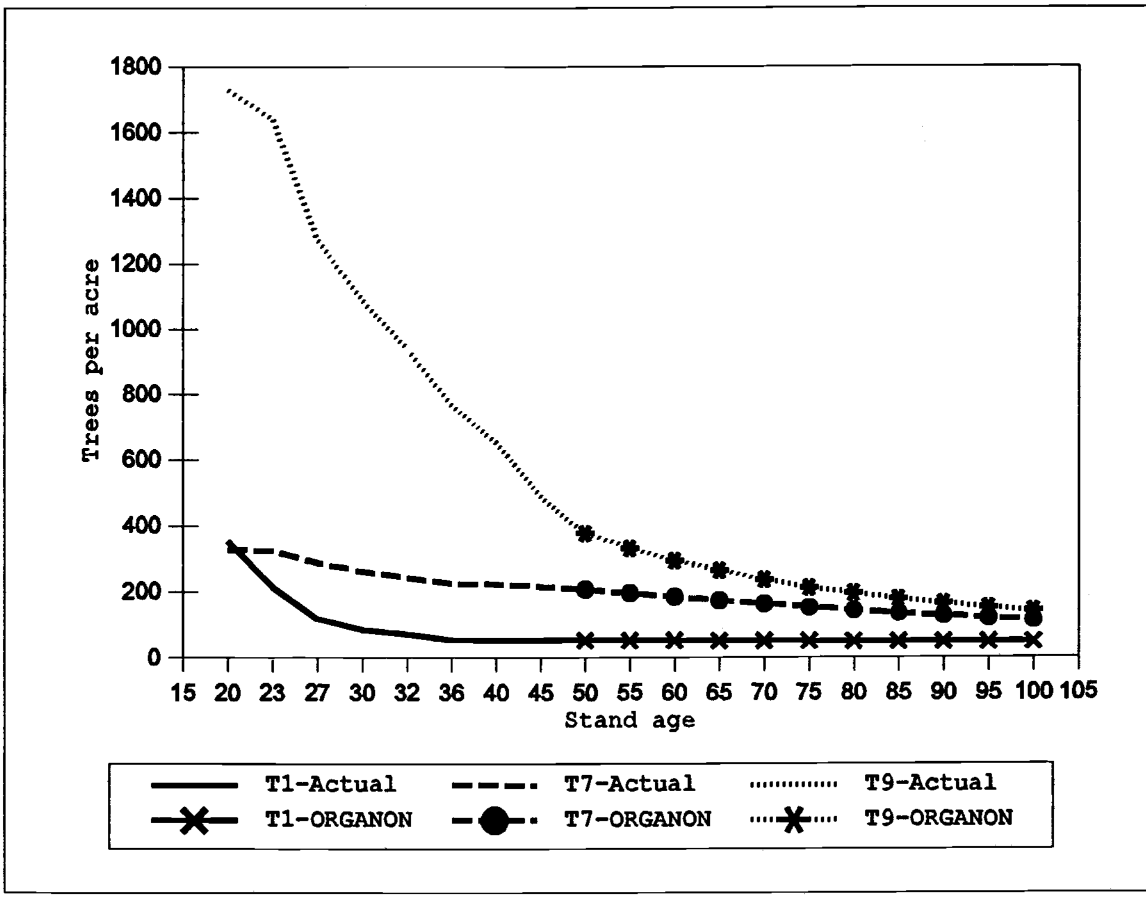

Figure A-2. Actual and ORGANON projected trees per acre development for treatments 1 (T1), 7 (T7), and the control (T9).

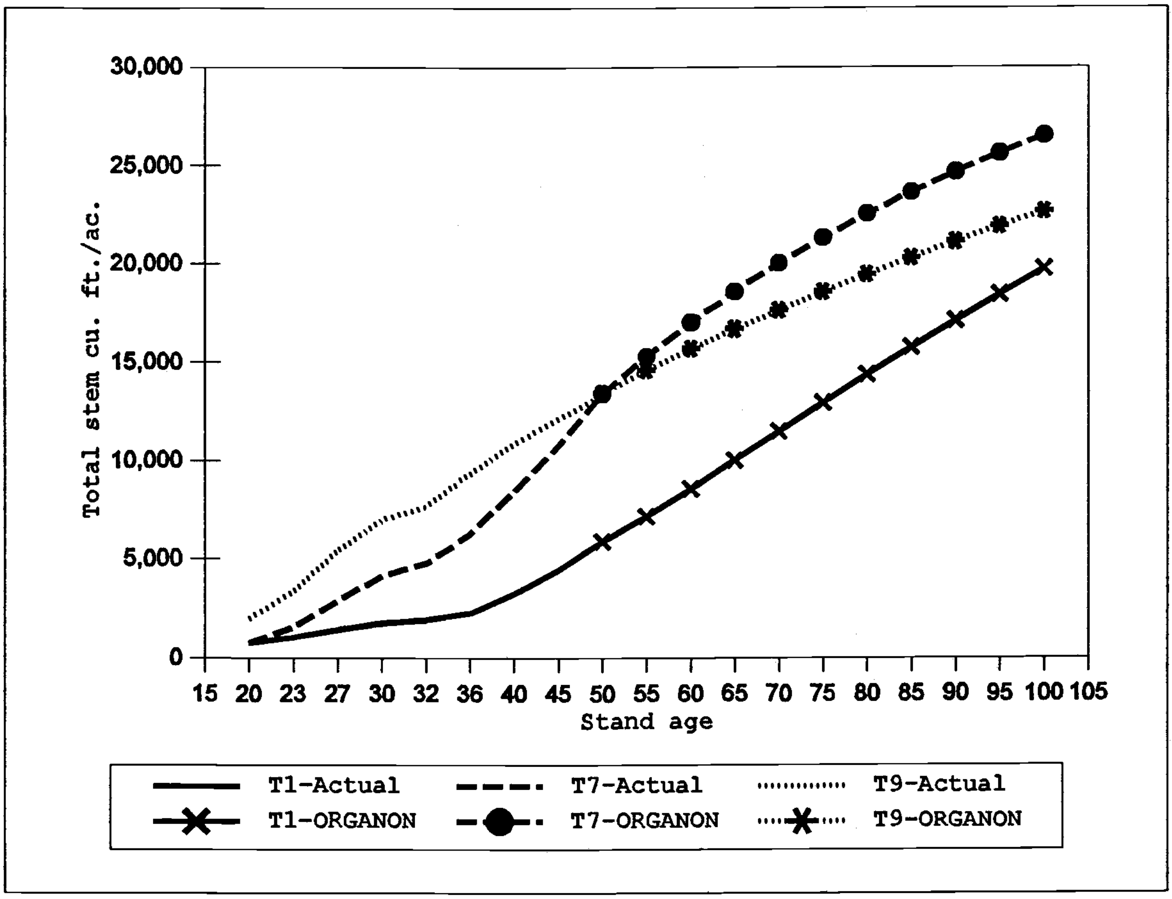

Figure A-3. Actual and ORGANON projected total stem cubic foot volume per acre development for treatments 1 (T1), 7 (T7), and the control (T9).

Appendix B Taper Equation Validation

The taper equation developed by Walters and Hann (1986) was tested for validity at Hoskins from data collected on 232 felled trees. A total of 3,175 measurements were made along the stem and compared to taper equation predicted diameters. Measured trees came only from the thinning treatments. Felled trees had a mean DBH of 8.9 inches (ranged from 2.4 to 18.9 inches), a mean height of 59.8 feet (ranged from 28.9 to 94.8 feet), and a mean crown ratio of 0.59 (ranged from 0.23 to 0.81). Table B-1 presents a summary and comparison results.

Table B-1. Results from taper equation validation measurements at Hoskins[3].

Mid-Class h/HT[1]	N Obs.	Mean Diff. (in.)	St. Dev. Diff.	T-Value Ho: Diff.= 0	Mean. % Diff.
0.05	448	0.97	1.13	18.06	7.77
0.15	335	0.39	0.61	11.5	1.78
0.25	342	0.46	0.29	29.13	5.71
0.35	350	0.37	0.31	22.45	5.19
0.45	343	0.26	0.34	14.03	3.78
0.55	352	0.11	0.34	6.15	1.81
0.65	344	-0.04	0.33	-2.21	-1.35
0.75	337	-0.19	0.31	-11.6	-7.14
0.85	364	-0.27	0.29	-15.14	-16.04
0.95	60	-0.24	0.19	-10.01	-24.56
All Data:	3175	0.26			0.38

[1]Height on the stem (h)/total tree height(HT).

[3] Personal communication. 1996. David D. Marshall, Assistant Professor, Department of Forest Resources, Oregon State University, Corvallis, OR., 97331.

Appendix C Branch Equation Validation

To test the validity of the branch equation for second-growth Douglas-fir by Johnston et al. (draft) comparisons of actual and predicted branch diameters were made. A total of 51 branch diameters were measured and evaluated for differences. Branches were selected for measurement by finding all whorls that had an actual branch measurement and a projected measurement at the exact same height where live crown begins. Of all trees measured on all treatments only 51 trees met this criteria. Measuring branch diameter differences at the base of live crown was selected because at this point the prediction equation should exactly match the actual measurement.

Because the log grading rules use 0.5 inch diameter breaks for limbs, it was assumed that the equation would be valid if a branch diameter could be estimated to the nearest 0.25 inch. Results indicate that the equation is valid with a absolute mean difference of 0.205 inches (standard deviation of 0.14 inches). Table C-1 presents the differences between actual and estimated diameters.

Table C-1. Results from branch equation validation where whorl height (hgt.), difference (diff.), and absolute difference (abs. diff.) are examined.

Obs.	Hgt. (ft.)	Diff. (in.)	Abs. Diff. (in.)	Obs.	Hgt. (ft.)	Diff. (in.)	Abs. Diff. (in.)
1	22.0	-0.515	0.515	27	8.0	-0.036	0.036
2	40.0	0.155	0.155	28	10.0	0.021	0.021
3	10.0	-0.16	0.16	29	14.0	0.003	0.003
4	27.0	0.111	0.111	30	7.0	-0.247	0.247
5	40.0	-0.459	0.459	31	8.0	0.205	0.205
6	37.0	-0.369	0.369	32	7.0	0.181	0.181
7	7.0	0.275	0.275	33	8.0	0.405	0.405
8	9.0	-0.242	0.242	34	30.0	-0.029	0.029
9	8.0	0.023	0.023	35	8.0	0.288	0.288
10	8.0	0.093	0.093	36	8.0	0.204	0.204
11	35.0	-0.78	0.78	37	8.0	0.21	0.21
12	35.0	-0.213	0.213	38	9.0	-0.201	0.201
13	8.0	-0.243	0.243	39	9.0	0.071	0.071
14	9.0	0.357	0.357	40	9.0	-0.161	0.161
15	8.0	0.286	0.286	41	40.0	-0.218	0.218
16	9.0	0.019	0.019	42	34.8	0.122	0.122
17	10.0	-0.179	0.179	43	9.0	-0.113	0.113
18	8.0	0.132	0.132	44	8.0	-0.283	0.283
19	8.0	-0.323	0.323	45	26.4	0.686	0.686
20	26.0	-0.301	0.301	46	10.9	0.359	0.359
21	9.0	-0.073	0.073	47	22.5	-0.275	0.275
22	9.0	0.367	0.367	48	10.0	0.002	0.002
23	6.0	-0.271	0.271	49	10.0	0.032	0.032
24	7.0	0.244	0.244	50	8.0	0.217	0.217
25	6.0	0.016	0.016	51	9.0	0.251	0.251
26	8.0	-0.162	0.162		**Mean:**	0.0036	0.2056

Appendix D Tables of Analysis Results

Table D-1. Board foot volume (A) and dollar value (B) per acre removed for all thinnings by treatment in domestic log grades.

(A) Bf./ac.	Treatment			
Grade	1	3	5	7
SM	0.00	0.00	0.00	0.00
2 Saw	0.00	0.00	0.00	0.00
3 SM	1228.00	787.00	733.00	340.00
3 Saw	1243.00	1379.00	1483.00	554.00
4 Saw	5464.00	4756.00	3738.00	2600.00
Total:	7935.00	6922.00	5954.00	3494.00

(B) $/ac.	Treatment			
Grade	1	3	5	7
SM	0.00	0.00	0.00	0.00
2 Saw	0.00	0.00	0.00	0.00
3 SM	834.00	534.00	498.00	231.00
3 Saw	796.00	882.00	949.00	355.00
4 Saw	3339.00	2906.00	2284.00	1589.00
Total:	4969.00	4322.00	3731.00	2175.00

Table D-2. Board foot volume (A) and dollar value (B) per acre removed for all thinnings by treatment in export log grades.

(A) Bf./ac.	Treatment			
Grade	1	3	5	7
Japan 12"	0.00	0.00	0.00	0.00
China	0.00	0.00	0.00	0.00
Japan 8"	0.00	0.00	0.00	0.00
Korea	1228.00	787.00	733.00	340.00
3 Saw	1243.00	1379.00	1483.00	554.00
4 Saw	5464.00	4756.00	3738.00	2600.00
Total:	7935.00	6922.00	5954.00	3494.00

(B) $/ac.	Treatment			
Grade	1	3	5	7
Japan 12"	0.00	0.00	0.00	0.00
China	0.00	0.00	0.00	0.00
Japan 8"	0.00	0.00	0.00	0.00
Korea	967.00	620.00	578.00	268.00
3 Saw	796.00	882.00	949.00	355.00
4 Saw	3339.00	2906.00	2284.00	1589.00
Total:	5102.00	4408.00	3811.00	2212.00

Table D-3. Board foot volume (A) and dollar value (B) per acre by treatment in domestic log grades at stand age 30.

(A) Bf./ac.	Treatment				
Grade	1	3	5	7	Control
SM	0.00	0.00	0.00	0.00	0.00
2 Saw	0.00	0.00	0.00	0.00	0.00
3 SM	0.00	0.00	0.00	0.00	340.00
3 Saw	1825.00	2783.00	1915.00	3380.00	2709.00
4 Saw	2263.00	3752.00	6595.00	7611.00	15636.00
Total:	4088.00	6535.00	8510.00	10991.00	18685.00

(B) $/ac.	Treatment				
Grade	1	3	5	7	Control
SM	0.00	0.00	0.00	0.00	0.00
2 Saw	0.00	0.00	0.00	0.00	0.00
3 SM	0.00	0.00	0.00	0.00	231.00
3 Saw	1168.00	1781.00	1225.00	2163.00	1734.00
4 Saw	1383.00	2293.00	4029.00	4650.00	9554.00
Total:	2551.00	4074.00	5254.00	6813.00	11519.00

Table D-4. Board foot volume (A) and dollar value (B) per acre by treatment in export log grades at stand age 30.

(A) Bf./ac.	Treatment				
Grade	1	3	5	7	Control
Japan 12"	0.00	0.00	0.00	0.00	0.00
China	0.00	0.00	0.00	0.00	0.00
Japan 8"	0.00	0.00	0.00	0.00	0.00
Korea	0.00	0.00	0.00	0.00	340.00
3 Saw	1825.00	2783.00	1915.00	3380.00	2709.00
4 Saw	2263.00	3752.00	6595.00	7611.00	15636.00
Total:	4088.00	6535.00	8510.00	10991.00	18685.00

(B) $/ac.	Treatment				
Grade	1	3	5	7	Control
Japan 12"	0.00	0.00	0.00	0.00	0.00
China	0.00	0.00	0.00	0.00	0.00
Japan 8"	0.00	0.00	0.00	0.00	0.00
Korea	0.00	0.00	0.00	0.00	268.00
3 Saw	1168.00	1781.00	1225.00	2163.00	1734.00
4 Saw	1383.00	2293.00	4029.00	4650.00	9554.00
Total:	2551.00	4074.00	5254.00	6813.00	11556.00

Table D-5. Board foot volume (A) and dollar value (B) per acre by treatment in domestic log grades at stand age 50.

(A) Bf./ac.	Treatment				
Grade	1	3	5	7	Control
SM	0.00	0.00	0.00	0.00	0.00
2 Saw	16869.00	21613.00	21970.00	24704.00	9106.00
3 SM	4533.00	9000.00	15756.00	20799.00	24916.00
3 Saw	1371.00	2765.00	4001.00	6681.00	12431.00
4 Saw	988.00	1946.00	3215.00	4277.00	11193.00
Total:	23761.00	35324.00	44942.00	56461.00	57646.00

(B) $/ac.	Treatment				
Grade	1	3	5	7	Control
SM	0.00	0.00	0.00	0.00	0.00
2 Saw	12112.00	15518.00	15775.00	17737.00	6538.00
3 SM	3078.00	6111.00	10698.00	14123.00	16918.00
3 Saw	878.00	1769.00	2560.00	4276.00	7956.00
4 Saw	604.00	1189.00	1965.00	2613.00	6839.00
Total:	16672.00	24587.00	30998.00	38749.00	38251.00

Table D-6. Board foot volume (A) and dollar value (B) per acre by treatment in export log grades at stand age 50.

(A) Bf./ac.	Treatment				
Grade	1	3	5	7	Control
Japan 12"	0.00	0.00	0.00	0.00	327.00
China	17536.00	22205.00	21970.00	25031.00	8779.00
Japan 8"	0.00	193.00	3415.00	4862.00	11412.00
Korea	3236.00	8552.00	12341.00	15937.00	13503.00
Domestic	2989.00	4373.00	7216.00	10632.00	23624.00
Total:	23761.00	35323.00	44942.00	56462.00	57645.00

(B) $/ac.	Treatment				
Grade	1	3	5	7	Control
Japan 12"	0.00	0.00	0.00	0.00	381.00
China	15642.00	19807.00	19598.00	22327.00	7831.00
Japan 8"	0.00	170.00	3077.00	4381.00	10470.00
Korea	2550.00	6739.00	9724.00	12558.00	10641.00
Domestic	1885.00	2742.00	4525.00	6680.00	14795.00
Total:	20077.00	29458.00	36924.00	45946.00	44118.00

Table D-7. Board foot volume (A) and dollar value (B) per acre by treatment in domestic log grades at stand age 100.

(A) Bf./ac.	Treatment				
Grade	1	3	5	7	Control
SM	26009.00	50394.00	64582.00	66225.00	49824.00
2 Saw	79022.00	74309.00	60513.00	62039.00	45956.00
3 SM	394.00	2866.00	6672.00	7653.00	16225.00
3 Saw	1904.00	2699.00	2567.00	2868.00	3002.00
4 Saw	749.00	1522.00	2293.00	2854.00	3638.00
Total:	108078.00	131790.00	136627.00	141639.00	118645.00

(B) $/ac.	Treatment				
Grade	1	3	5	7	Control
SM	21275.00	41222.00	52828.00	54172.00	40756.00
2 Saw	56738.00	53354.00	43449.00	44544.00	32996.00
3 SM	268.00	1946.00	4530.00	5196.00	11017.00
3 Saw	1219.00	1727.00	1643.00	1836.00	1921.00
4 Saw	457.00	930.00	1401.00	1744.00	2223.00
Total:	79957.00	99179.00	103851.00	107492.00	88913.00

Table D-8. Board foot volume (A) and dollar value (B) per acre by treatment in export log grades at stand age 100.

(A) Bf./ac.	Treatment				
Grade	1	3	5	7	Control
Japan 12"	70219.00	112595.00	121456.00	125860.00	95120.00
China	34811.00	12108.00	3639.00	2404.00	660.00
Japan 8"	0.00	313.00	972.00	1992.00	7643.00
Korea	394.00	2553.00	5699.00	5662.00	8581.00
Domestic	2653.00	4221.00	4860.00	5722.00	6640.00
Total:	108077.00	131790.00	136626.00	141640.00	118644.00

(B) $/ac.	Treatment				
Grade	1	3	5	7	Control
Japan 12"	83597.00	137491.00	148702.00	155598.00	118062.00
China	31051.00	10800.00	3246.00	2144.00	589.00
Japan 8"	0.00	292.00	905.00	1854.00	7116.00
Korea	311.00	2012.00	4491.00	4461.00	6762.00
Domestic	1676.00	2657.00	3044.00	3580.00	4144.00
Total:	116635.00	153252.00	160388.00	167637.00	136673.00

Table D-9. Total board foot volume (A) and dollar value (B) per acre removed in all thinnings by treatment in lumber grades.

(A) Bf./ac.	Treatment			
Grade	1	3	5	7
D Selects & better	0.00	0.00	0.00	0.00
Select	1317.40	1295.50	987.50	627.70
No. 1	2030.20	1996.10	1635.90	1067.30
No. 2	4407.00	3698.20	3010.10	1974.70
Utility	1134.60	818.00	647.10	424.60
Economy	428.90	308.40	240.80	157.70
Total:	9318.10	8116.20	6521.40	4252.00

(B) $/ac.	Treatment			
Grade	1	3	5	7
D Selects & better	0.00	0.00	0.00	0.00
Select	587.56	577.79	440.43	279.95
No. 1	760.59	747.82	612.87	399.85
No. 2	1485.16	1246.29	1014.40	665.47
Utility	257.55	185.69	146.89	96.38
Economy	48.47	34.85	27.21	17.82
Total:	3139.33	2792.44	2241.80	1459.47

Table D-10. Board foot volume (A) and dollar value (B) per acre by treatment in lumber grades at stand age 30.

(A) Bf./ac.	Treatment				
Grade	1	3	5	7	Control
D Selects & better	0.00	0.00	0.00	0.00	0.00
Select	655.80	1095.90	1448.40	1762.90	3095.10
No. 1	1198.90	1971.60	2519.50	3209.90	4699.30
No. 2	3125.40	4371.50	5510.10	6980.40	8602.60
Utility	899.60	1107.60	1363.80	1715.80	1852.60
Economy	339.80	413.10	507.10	637.70	696.90
Total:	6219.50	8959.70	11348.90	14306.70	18946.50

(B) $/ac.	Treatment				
Grade	1	3	5	7	Control
D Selects & better	0.00	0.00	0.00	0.00	0.00
Select	292.49	488.77	645.99	786.25	1380.41
No. 1	449.16	738.64	943.91	1202.56	1760.55
No. 2	1053.26	1473.20	1856.90	2352.39	2899.08
Utility	204.21	251.43	309.58	389.49	420.54
Economy	38.40	46.68	57.30	72.06	78.75
Total:	2037.52	2998.72	3813.68	4802.75	6539.33

Table D-11. Board foot volume (A) and dollar value (B) per acre by treatment in lumber grades at stand age 50.

(A) Bf./ac.	Treatment				
Grade	1	3	5	7	Control
D Selects & better	0.00	0.00	0.00	0.00	0.00
Select	3696.90	5902.30	7086.90	8284.10	7814.80
No. 1	5715.60	8654.00	11063.30	13713.20	13588.40
No. 2	15049.00	21397.30	26719.70	33121.90	30138.10
Utility	4354.40	5844.70	7085.00	8748.80	7478.40
Economy	1662.20	2204.00	2652.00	3254.90	2766.60
Total:	30478.10	44002.30	54606.90	67122.90	61786.30

(B) $/ac.	Treatment				
Grade	1	3	5	7	Control
D Selects & better	0.00	0.00	0.00	0.00	0.00
Select	1648.82	2632.43	3160.76	3694.71	3485.40
No. 1	2141.29	3242.13	4144.75	5137.51	5090.76
No. 2	5071.51	7210.89	9004.54	11162.08	10156.54
Utility	988.45	1326.75	1608.30	1985.98	1697.60
Economy	187.83	249.05	299.68	367.80	312.63
Total:	10037.90	14661.25	18218.03	22348.08	20742.93

Table D-12. Board foot volume (A) and dollar value (B) per acre by treatment in lumber grades at stand age 100.

(A) Bf./ac.	Treatment				
Grade	1	3	5	7	Control
D Selects & better	0.00	0.00	0.00	0.00	0.00
Select	18301.40	26189.60	29800.80	33887.30	27525.70
No. 1	27082.40	37147.50	42592.00	48738.90	43673.10
No. 2	57264.60	71989.80	80545.10	90765.30	83155.20
Utility	14002.50	16326.40	17813.80	19736.50	18301.40
Economy	5268.10	6139.70	6688.90	7402.10	6809.70
Total:	121919.00	157793.00	177440.60	200530.10	179465.10

(B) $/ac.	Treatment				
Grade	1	3	5	7	Control
D Selects & better	0.00	0.00	0.00	0.00	0.00
Select	8162.42	11680.56	13291.16	15113.74	12276.46
No. 1	10146.15	13916.94	15956.67	18259.54	16361.69
No. 2	19298.17	24260.56	27143.70	30587.91	28023.30
Utility	3178.57	3706.09	4043.73	4480.19	4154.42
Economy	595.30	693.79	755.85	836.44	769.50
Total:	41380.61	54257.94	61191.11	69277.82	61585.37

Table D-13. Board foot volume (A) and dollar value (B) per acre by treatment in domestic log grades at stand age 100 without branch self-pruning.

(A) Bf./ac.	Treatment				
Grade	1	3	5	7	Control
SM	4112.00	2124.00	12038.00	560.00	0.00
2 Saw	98439.00	120320.00	113057.00	127349.00	94869.00
3 SM	394.00	2866.00	6672.00	7653.00	16225.00
3 Saw	4384.00	4958.00	2567.00	3223.00	3002.00
4 Saw	749.00	1522.00	2293.00	2854.00	4549.00
Total:	108078.00	131790.00	136627.00	141639.00	118645.00

(B) $/ac.	Treatment				
Grade	1	3	5	7	Control
SM	3363.00	1738.00	9847.00	458.00	0.00
2 Saw	70679.00	86390.00	81175.00	91437.00	68116.00
3 SM	268.00	1946.00	4530.00	5196.00	11016.00
3 Saw	2806.00	3173.00	1643.00	2063.00	1921.00
4 Saw	457.00	930.00	1401.00	1744.00	2780.00
Total:	77573.00	94177.00	98596.00	100898.00	83833.00

Table D-14. Board foot volume (A) and dollar value (B) per acre by treatment in export log grades at stand age 100 without branch self-pruning.

(A) Bf./ac.	Treatment				
Grade	1	3	5	7	Control
Japan 12"	55671.00	106544.00	110689.00	114884.00	88663.00
China	49359.00	18159.00	14405.00	13381.00	6205.00
Japan 8"	0.00	178.00	691.00	600.00	2788.00
Korea	394.00	2688.00	5981.00	7053.00	13437.00
Domestic	2653.00	4221.00	4860.00	5722.00	7551.00
Total:	108077.00	131790.00	136626.00	141640.00	118644.00

(B) $/ac.	Treatment				
Grade	1	3	5	7	Control
Japan 12"	66485.00	130249.00	135650.00	142101.00	110229.00
China	44028.00	16198.00	12849.00	11936.00	5535.00
Japan 8"	0.00	166.00	640.00	558.00	2595.00
Korea	311.00	2118.00	4713.00	5558.00	10588.00
Domestic	1676.00	2657.00	3044.00	3580.00	4701.00
Total:	112500.00	151388.00	156896.00	163733.00	133648.00

Appendix E. Log Count and Mean Scaling Diameter

Table E-1. Log count per acre and Mean Scaling Diameter from all thinnings and at stand ages 30, 50, and 100.

	Treatment				
	1	3	5	7	Control
Total thinnings					
Logs/ac.	235	195	167	92	n/a
Diam. (in.)	5.47	5.38	5.37	5.27	n/a
Stand age 30					
Logs/ac.	83	142	202	252	507
Diam. (in.)	5.40	5.35	5.16	5.22	5.12
Stand age 50					
Logs/ac.	145	272	392	538	758
Diam. (in.)	9.68	8.85	8.40	8.14	6.87
Stand age 100					
Logs/ac.	189	313	391	446	508
Diam. (in.)	16.57	14.48	13.40	12.80	9.60